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Ultrasound Elastography: The State of Art and Its Perspective

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Abstract
Ultrasound elastography is a modern imaging modality that is used to study the mechanical properties of tissues such as hardness and elasticity in a non-invasive and real-time mode. Elastography was first created to identify liver fibrosis, but lately, this method was willingly transferred to many other areas. This paper presents the recent advancements in ultrasound elastography and stresses on strain elastography and shear wave elastography (SWE). In particular, we address promising image analysis methods based on artificial intelligence and dosed and non-dosed wearable elastography systems that increase diagnostic performance and automate clinic operations. New uses in neurology, cardiology, and oncology research for elastography further prove the technique's usefulness in diagnosis and assessment of many disorders. In addition, this paper reviews the issues & limitations related to its clinical use such as operator dependence, tissue composition and variability, normalization, etc. Needs for further research are especially addressed to possible elastography-induced treatment techniques and combining elastography with other imaging techniques. Efforts are in place to ensure that with time elastography becomes a key player in imaging and diagnosing diseases across all age groups.

Keywords: Ultrasound elastography, mechanical imaging, ultrasound liver fibrosis elastography, strain elastrography, artificial intelligence in imaging, non-invasive imaging, stiffness of tissue abdomen, imaging of cardiovascular elastography, scintimammography, therapeutic ultrasound.

Introduction

Ultrasound elastography is a type of imaging used to quantitatively determine the stiffness and elasticity of the biological tissues. It has attracted considerable interest recently due to its diagnostic capabilities with regard to human tissues' pathologies without resorting to intrusion. The technology is based on the fact that, for example, a tumor or a scar feels 'harder' than normal tissue, which is why this imaging technique has found its application in the diagnosis of various diseases, including cancer, liver pathology, and cardiovascular disorders [1].

Elastography is a relatively novel imaging technique, which first appeared in the early 1990s when the ultrasound began to be used for imaging of TMUs that were differentiated by their hardness. This technique has made a long and impressive journey from only using qualitative-strain image techniques to presently using more advanced imaging techniques such as shear wave elastography, which gives an insight to quantitative measures of stiffness of the tissue. With the increasing accuracy and the possibility of performing elastography in real-time, it has been widely used for a variety of indications in clinical practice, from liver fibrosis assessment to the detection of breast or thyroid cancer [2]. However, as the technology evolved, different problems such as the musculoskeletal system, the prostate, or the cardiovascular system, – where tissue stiffness may be a marker of pathology, have been reported [3].

Progressing and rapid use of the ultrasound elastography, however, has difficulty or problems as an application. The challenges for wider application include clinical factors such as how the operator performs ultrasound examinations, different nature of tissues, and the need to establish standardization of the protocols. Additionally, the quick development of elastography practice particularly with respect to the advances in equipment and applications, it is critical to constantly validate and contrive elastography practice in concurrence to specific diagnostic methods [4]. However, the future of elastography seems promising, most especially with regard to new trends like as artificial intelligence (AI) and machine learning that are going to help improve the accuracy of diagnosing and automate the analysis of images.

There is a need to formulate the purpose of this paper and its structure ratherFull Contents. This article strives to do a review of ultrasound elastography with special attention directed towards its recent clinical usage and possible development in future. Considering recent developments in technology and clinical practice as well as new studies, this research demonstrates that elastography future is revolutionary in the field of medical care. Furthermore, it will consider what aspects need tackling for the technology to be utilized to its fullest and integrated in everyday work [5].

Basics of Ultrasound elastography

The reasoning behind ultrasound elastography is that soft tissue components also exhibit modified physical properties such as elasticity and stiffness in the states coming with illness. Elastography, by applying stress to tissues, makes it possible to measure their deformation or shear wave propagation, which contributes to stiffness estimation, such or those stated earlier. Routine ultrasound imaging gives only structural data, while the functional elastography gives an added value of differentiating tissues based on their biomechanical properties [1]. The primary and essential techniques of ultrasound elastography are strain elastography and shear wave elastography with particular merits and indication [2].

Strain Elastography

Strain elastography is the older method of ultrasound elastography where a compressive force is applied to the tissue and the strain or deformation is measured. Under this method, ultrasound is utilized to monitor the internal movement of tissues caused by external forces and relative changes in the amount of stiffness in the tissues are assessed qualitatively. Tumor tissues in the majority are harder than the benign or normal tissues, therefore, strain elastography can be applied in breast cancer screening, thyroid nodule assessment, and liver fibrosis evaluation [3]. However, strain elastography relies upon the ability of the operator to consistently apply the required pressure and as a result, it suffers more from inter-operator variability than other types of elastography [4]. Despite these shortcomings, strain elastography has been clinically applicable in practice, especially in developing countries where other sophisticated medical equipment may not be accessible [5].

Shear Wave Elastography

This investigation further shows that SI is well corrected and not negatively influenced by undue stress due to pushing motions in si based behavioral assessments. Shear wave elastography (SWE) quantifies the stiffness of biological tissues by generating and propagating shear waves under the tissue. Because tension in the tissue also affects the mechanical elasticity of tissues, there is a direct proportionality in the speed of shear wave propagating within the tissue. A common application of SWE is that an ultrasound system is used to generate a concentrated push pulse which causes displacement of the tissues in the form of shear wave propagating in the direction normal to that of the push pulse [6]. This allows for real-time assessment of tissue stiffness within the US imaging system, with imaging of the cocked speed of these tissues reviewed. It has also been successfully validated for the diagnosis of liver fibrosis where it serves as a noninvasive alternative to liver biopsy and is more reproducible than strain elastography [7].

The strength of SWE arises from the quantitative and reproducible results provided in this case which are less influenced by individual variability or the operator. Studies to some extent have validated some of these claims such as the ski that SWE can totally replace some of the classical diagnostic tools like the ability to tell whether a liver lesion is malignant or not or in detecting significant fibrosis in a chronic liver disease patient [8]. The cost of additional technology enhances the accuracy which may be required for SWE, whereas this imaging technique is relatively cheaper than the strain elastography imaging technique due to less advance ultrasound machine and imaging performed within the machine [9].

Developments in Ultrasound Elastography Technology.

Quality improvements and functional enhancement in hardware and software characterize medical ultrasound elastography in the past ten years. These innovations enhance diagnostic accuracy and speed, increase the number of clinical applications and make new ones possible. Evolution of elastography from strain imaging to shear wave technique indicates the dynamic nature of the elastography field. In the past years erecting new algorithms and having advanced imaging systems have paved the way for elastography in noninvasive tissue characterization and in particular in diagnosing liver fibrotic changes, breast cancer and thyroid nodules [1].

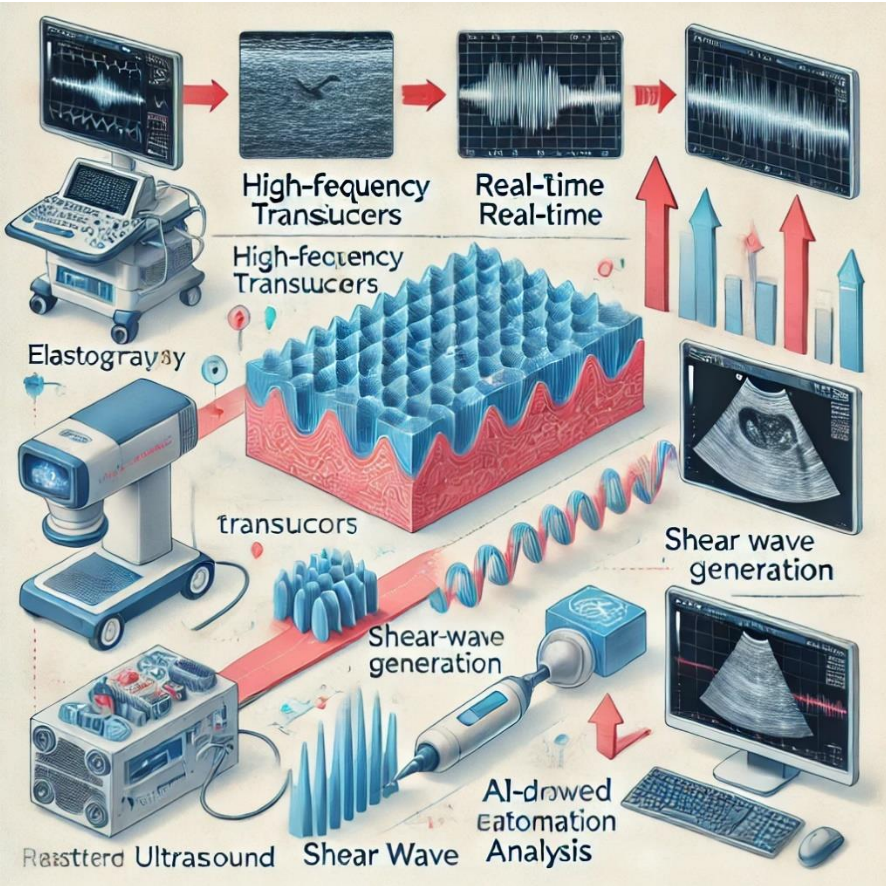

Figure 1 Developments in Ultrasound Elastography Technology.

Hardware Improvements

High frequency ultrasound transducers are one of the most pronounced improvements in elastography technology. High frequency ultrasound transducers have high sensitivity and resolution compared to the previous lower frequency transducers. These transducers enable clinicians to get better images of superficially placed organs such as the breast, prostate and thyroid region enhancing diagnostic confidence [2]. In the same way […] in the further development of ultrasound systems theвЂ¦ the time required for the acquisition of images or the real time off-line imaging capabilities were altering to allow more efficient performance of imaging elastography in everyday clinical practice. Additionally, portable and point-of-care ultrasound devices have entered the market making the application of elastography in disadvantaged areas and in emergency medicine more feasible [3].

The clinical application of elastography has benefitted a lot from the combination of real time elastography with conventional ultrasound machines. Such systems are becoming more sophisticated as they integrate other imaging modes, for instance, compound imaging and harmonic imaging. This has enhanced the contrast and reduced artifacts, thus allowing for a more accurate measurement of elasticity [4]. Advancements in the transducer technology have also made it possible to carry out a 3D elastography that offers volumetric data that can be used in complicated conditions like cancer staging and surgical strategy design [5].

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Software Innovations and Advanced Algorithms

Improvements in soft ware used in ultrasound elastography have probably improved imaging, processing and analysis in use over time. Today, advanced algorithms are employed to undertake a direct measurement of tissue stiffness, hence less operator dependence which was a draw back in the initial techniques of elastography [6]. These algorithms have shown to possess the potential of measuring and quantifying the stiffness of tissues with high precision hence minimizing the usage of traditional B modality ultrasound interpretation whose interpretation is highly subjective in nature.

Apart from automatic stiffness quantification, artificial intelligence and machine learning have also commenced being used in the analysis of elastography subsections. Tools based on artificial intelligence can help doctors with the assessment of elastography images in real time, which might enhance the accuracy of diagnostics and streamline clinical workflow. Algorithms built into machine learning models can effectively sift through even the most complicated data sets, looking for and finding things that may not be common knowledge or easy to notice with most people's eyes. This has paved way for the use of AI to coordinate disease diagnosis especially in chronic diseases like liver cirrhosis that require early and effective intervention.

Besides, the application of combined imaging approaches such as ultrasound applied with contrast agents and MR with elastography has produced combined imaging procedures with enhanced diagnostic performance. Thanks to these multimodal methods, clinicians can now explain the tissue elasticity changes in relation to vascularization and other imaging modalities, improving the accuracy of elastography for some specific diseases.

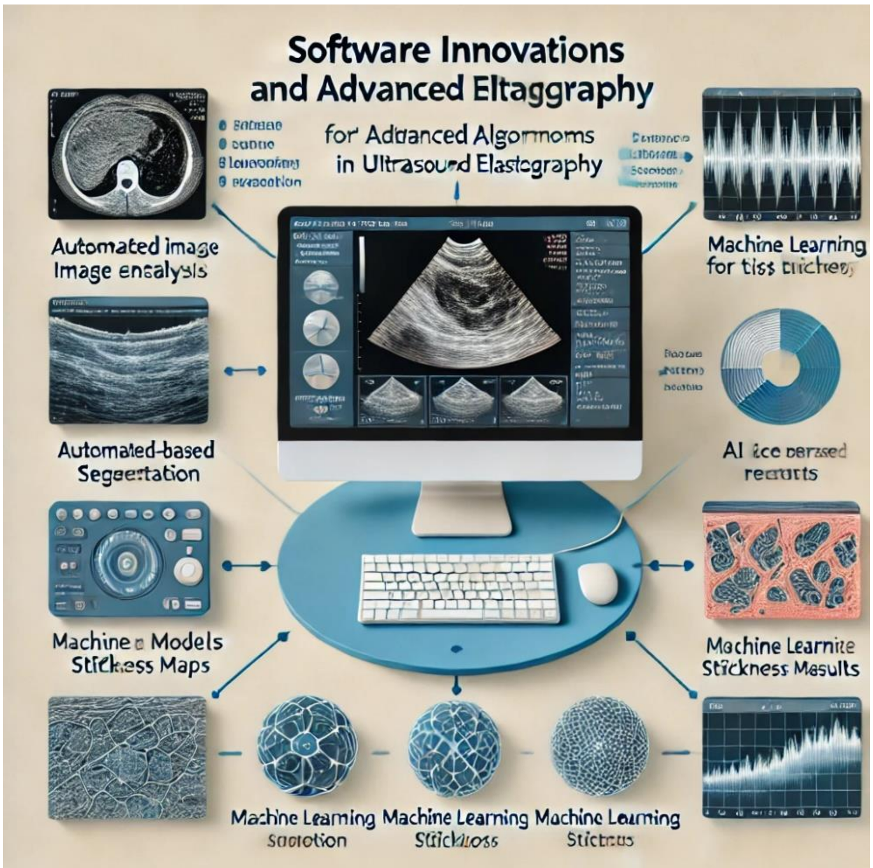

Figure 2 Software Innovations and Advanced Algorithms

There are Relative Studies and their Validation

A number of comparative studies have shown that SWE technology has advantages over classical methods such as strain elastography or other investigation techniques. In liver fibrosis, for example, shear wave elastography has been shown to provide more accurate and reproducible findings as compared to liver biopsy, which although considered the gold standard is an invasive procedure that is not free from complications [10]. Clinical trials have confirmed the clinical effectiveness of SWE for detecting hepatic fibrosis at sensitivity and specificity rates over 90% with some studies [11].

In the application of elastography to breast cancer diagnosis, differentiating between benign and malignant breast lesions has been effective. It has been found that using elastography, it is possible to increase the specificity of conventional ultrasound and avoid unnecessary biopsies [12]. In the same way, elastography in the assessment of thyroid nodules has demonstrated improvement in the ultrasound diagnostic performance in terms of benign versus malignant nodules discrimination [13]. These studies have strengthened the application of elastography in clinical practice and even more so in situations where non-invasive methods are preferred [14].

3. Current State of Ultrasound Elastography

Elastography has cut out a niche for itself in numerous medical practices and is positively advancing in the field because it enables the assessment of tissue stiffness in a quick, totally non-invasive and relatively inexpensive way. This range of elasticity includes mainly the liver pathology and oncology, but the number of studies becoming more focused and standardized grows. This part will evaluate clinical studies justifying the use of elastography, existing limitations of elastography as well as problems related to the standardization of elastography numbers.

Clinical Evidence and Validation

Among the most common fields where ultrasound elastography is used and of which a number of researches have been well documented is liver fibrosis wherein it has been an advantageous alternative to performing a biopsy of the liver. The most frequently applied techniques for measuring liver stiffness include Shear wave elastography (SWE) and transitory elastography (TE), which gives a numeric level of measurement that corresponds to the level of fibrillation [15]. The Application of elastography in clinical settings has shown that indeed it is possible to stage liver fibrosis and this may have sensitivity and specificity greater than 90% with regards to significant fibrosis and end-stage liver cirrhosis. For example, SWE compared unfavorably with liver biopsy in a large multicenter study, since a strong correlation was found between SWE levels and histological grade of fibrosis making it an important tool for the management of chronic liver disease including hepatitis B and C [16].

Lately, elastic imaging has been popular in breast imaging to supplement conventional ultrasound examination. It is possible to differentiate stiffer tissues characteristic of malignant lesions, from such mass, as benign ones. There have been reports validating the use of elastography for breast cancer screening, showing that it enhances the performance of the diagnosis and decreases the number of needless biopsies performed. One reported that the additional use of elastography with the B-mode proporcionately increased positive cancer detection for axial ultrasound imaging, especially among patients with high breast density where standard modalities frequently fail.

Elastography techniques in the recent past have been widely applied in assessing thyroid nodules for malignant changes. Ultrasound elastography (particularly strain imaging elastography) is reported to improve the accuracy of diagnosing thyroid nodules and reduces the need for biopsy for diagnosis. In a meta-analysis done on several studies, the overall MP was found to be high due to elastography for malignant nodules and is therefore a useful adjunct to the ultrasound practice.

Limitations and Challenges

Compared to many advantages, ultrasound elastography even has a few limitations. For instance, inter observer variability is complicated by the operator dependency in strain elastography, where the extent of compression while scanning has an influence on the outcomes. This can often results in measurement more especially when more than one institution or operator is involved [21]. Instead, for the time being, work is still focused on improving surfaces and advanced algorithms that are intended reducing operator dependence too, namely in shear wave elastography which is otherwise not this severe [22].

Spa and Khanna further state that another limitation with elastography is tissue inhomogeneity which can lead to inaccuracies. For example some homogeneous regions like the liver or breast could harbor some regional stiff and soft tissues which aunty it out such that the fibroscan will capture different readings within the same area. More serious difficulties concerning such measurements might also be induced by voluntary or involuntary patient's body movements, respiratory and heartbeat velocities, invasions by ascites or edema [23]. As previously stated, very few studies have been published on the utility of elastography in diagnosing neoplasia in the pancreas and kidney thus further studies are required to support this information [24].

Standardization Efforts

It is necessary to standardize elastography protocols because it assures uniformity and dependability in clinical environment. Thus, professional bodies like the World Federation for Ultrasound in Medicine and Biology (WFUMB) and the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) have issued recommendations on the clinical application of ultrasound elastography in several anatomical regions: liver, breast, and thyroid, to name a few [25]. Such details provide guidance regarding appropriate best practices for the purchase and interpretation elastography, strain as well as shear wave techniques and the significance of stiffness values defined within a range of diseases.

Along with clinical recommendations, reference values for the stiffness of tissues within various organs are also being constructed. These reference values are essential in the interpretation of elastographic data because they permit the relative assessment of the patient data against these normal values. Thus, while there is substantive documentation of stiffness values for liver fibrosis, other parameters like that of the pancreas or kidneys are still growing, as their reference values have not been determined [26]. The availability of these reference standards will enhance the elastography application in other clinical areas outside the liver.

The table below presents volumetric ultimate crushing loads exerted on selected organs in percentage values relative to that for femur of average adult, based on the available science and practices used by rheumatologists. Such values are used to help distinguish normal and abnormal tissue rigidity in various settings.

Table 1: Typical Tissue Stiffness Values for Various Organs

Organ	Stiffness Range (kPa)	Clinical Use
Liver	2.5 – 75	Fibrosis and cirrhosis assessment
Breast	10 – 200	Differentiation of benign and malignant lesions
Thyroid	20 – 50	Evaluation of thyroid nodules
Prostate	10 – 150	Prostate cancer detection
Pancreas	1.5 – 3.5	Emerging use, under validation

Table 1: Adapted from multiple studies, including [27], [28], [29].

Emerging Applications and Future Perspectives

Elastography is undergoing further development beyond its current applications, with new prospects for development in such areas as neurology, cardiology, or oncology, and in imaging methodologies related to the use of artificial intelligence. These new techniques will enhance the scope of the application of elastography to additional areas of clinical practice and make it even more useful in diagnostics. In this section, these new applications are expanding in elastography, the role of the future AI technology in elastography, competition with other modalities, and the changes that may take place in this imaging technology in the near future.

Emerging Applications in Neurology and Cardiovascular Health

What makes elastography even more exciting is its use in neuroscience especially its application on the stiffness of the brain tissue. Very few studies suggest that there might be probably some correlation between brain stiffness and neurodegenerative diseases such as Alzheimer’s disease or Parkinson’s disease where pathological changes in the brain affect the mechanical properties of the brain tissue [30]. Brain stiffness measurement using magnetic resonance elastography (MRE) has been already practiced for some time in studies but ultrasound elastography gets ready to market sooner in life. So far research on transcranial elastography which measures the stiffness of the brain tissue through the skull is in its early stage but has potential for use in the assessment of neurology in a non-invasive way [31].

In the same sphere, non-contrast cardiac MR elastography is a newly developing area that concentrates on the evaluation of arterial stiffness, an important cardiovascular risk factor. Stiffness of arteries is most often a feature of diseases such as atherosclerosis, high blood pressure and congestive heart disease, and such a parameter can be assessed with the use of ultrasound elastography. Researchers have demonstrated the accuracy of arterial stiffness assessment applying shear wave elastography, which offered the new dimension to the assessment of vascular health and risk of events [32]. Although still mostly in research phase, this technique holds a real promise of becoming a peripheral device within a cardiologist's office most especially in the management of early vascular changes and therapeutic progress [33].

Oncology: Expanding Horizons

Elastography has already demonstrated its usefulness in the diagnosis of breast, liver and prostate cancers in the field of oncology. New applications would be the further levels of exploration and extending of its use towards other types of technology. For example, it is being studied how elastography can be used for the early detection of pancreatic cancer which has a poor prognosis since it is often diagnosed too late due to its deep location and vague symptoms. In initial studies, it has been observed that pancreatic tumors are much stiffer than the surrounding tissues, and this suggests possibilities in elastography for early diagnosis of the aggressive cancer [34].

T Ferreira An equally important challenge is in the area of monitoring treatment response and staging the tumor. Elastography can assess the stiffness of a tumor in real time and this measurement could alter with the tumor treatment. By way of instance, literature has indicated that malignancies that are responding favorably to treatment with chemotherapy or radiation might gradually become less stiff as time goes on, hence elastography could be used as an assessment tool in treatment [35]. This technique may permit a comprehensive assessment of tumor evolution over time during therapy thus limiting the need for repeated biopsies.

Artificial Intelligence and Automation in Elastography

The emerging technology of AI is altering the perception of elastography whereby clinicians no longer have exclusive control over the interpretation of elastography studies because the use of AI does help. It is particularly those algorithms that rely on machine or deep learning that can be effective in automating the segmentation and analysis of elastography images and hence save time that would have been used in manual interpretation and increase the diagnosed accuracy [36]. It is envisaged that these tools will also work with en masse data of images obtained following elastography in which cases various variants would be considered.

For instance, there are already AI algorithms that can automatically determine the stage of liver fibrosis appearing in elastography and their accuracy is nearly as good as that of expert radiologists. Also, AI can reduce the operator dependency of elastography, a known limitation of the technique in the past since different clinicians and practices would interpret the imaging differently rather than providing an interpretation guideline [37]. In its following stages of development, artificial intelligence is assumed to be more beneficial for elastography, allowing support for clinical decisions in an operating room and enhancing the performance of elastography in more intricate diagnosis.

Wearable Ultrasound Elastography

Another interesting area regarding elastography technology is the creation of wearable devices, which allow the dynamics of tissue stiffness to be assessed on a continuous basis. There is an effort to further pursue the miniaturization of elastography transducers and create elasto-patches or other portable is ultrasound systems which would allow the real-time monitoring of fibrosis and other muscular or cardiovascular disorders [38]. Such wearable systems would further enable monitoring of disease and recovery from treatment, hence providing returning patient data to the clinician without the going back for clinical visits.

Even if it remains within a conceptual framework, the monitored treatment of chronic conditions with the use of wearable elastography devices may change the paradigm of clinical practice. Because effective stiffness monitoring would have enabled such patients to properly tune their therapy from the very early stages of the disease advancement.

Therapeutic Ultrasound and Elastography

Effective in diagnosis, elastography is being reported also as an imaging modality used for guidance of therapeutic procedures with one specific area of interest being focused ultrasound therapy. Focused ultrasound is a non-invasive treatment option, which uses high intensity focused ultrasound waves to selectively ablate the pathological tissue like tumour, fibrotic lesions etc. without any surgical intervention. The elastography may be utilized to navigate through these endeavours by enabling the assessment of targeted abnormal stiffness for treatment precision during the procedure; thus, enabling real-time observations on the treatment effects in clinical practice.

For example, in the management of liver tumors, focused ultrasound therapy assisted by elastography may assist doctors in understanding the most rigid parts of the tumor where high-intensity ultrasound needs to be implemented. This means that there are possibilities for enhancing focused ultrasound therapy by accurately targeting the region to be ultrasonically treated hence maintaining a minimum effect on the surrounding healthy tissues which improves healing outcomes on the part of the patient [41]. In as much as therapeutic ultrasound seems to be evolving, there is a high probability that elastography will be employed in navigating and supervising such procedures.

Future Trends in Elastography

In regard to the above described expansion of elastography, it will be aided by continued increase of the ultrasound devices according to the type of surgery practiced, advancement of transducers and increase of AI technology. The combination of elastography with other imaging methods such as MRI and CT scan would benefit in creating better diagnostic methods by exploiting the combined benefits of these methods for better tissue health assessment [42].

One of the most exciting trends these days is the possibility of incorporating elastography as a routine health monitoring method in primary care, which could be used for identifying diseases such as liver pathology or cardiovascular diseases at an earlier stage. In time, as the cost of elastography systems decreases and their usability improves, it is likely that such devices will be included in general physical examinations, and will allow rapid non-invasive measurements of tissue stiffness for the evaluation of pathology prior to overt disease.[43]

Conclusion

Ultrasound elastography represents a quantum leap as far as the imaging is concerned as it allows the clinician to assess the stiffness of tissues in a non-invasively real-time fashion. This technology was primarily used in abdominal imaging hepatologists to find liver fibrosis, but has gradually found its way to other areas such as breast, thyroid and prostate cancer detection, with possible further developments in neurology and cardiovascular diseases. Both strain elastography and shear wave elastography (SWE), which is a recently developed technology seem to have earned their spots into clinical practice by increasing the accuracy of the definitive diagnosis, lowering the number of surgical interventions and hence, allowing a more timely disease detection.

The reasons for rapid development of elastography skills included technology evolution. The development of ultrasound transducer along with a number of powerful image processing algorithms and real time imaging has increased the accuracy and reproducibility of elastography measurements. With this technology, the process of interpretation of elastography results has been thus simplified through integration of artificial intelligence (AI) and machine learning, which is believed, would contribute towards the efficacy of the heart and neck diseases diagnosis by enhancing the clinical workflow while decreasing operator over-dependency.

Nevertheless, there is an ongoing struggle everywhere. Operator variability, tissue heterogeneity, and the need for standardization of protocols are among the common factors hampering outreach activities. Organizations such as the World Federation for Ultrasound in Medicine and Biology (WFUMB) and the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) are taking steps to address these shortcomings in an effort to provide guidance on the correct acquisition of images and interpretation of elastography data. As well as this, there are studies that look at extending the use of elastography to other organs and pathological conditions such as the brain, pancreas and heart.

The future of ultrasound elastography is bright, as the field undergoes several important changes in the near future. New promising directions such as elastography for the diagnosis of neurological and cardiovascular diseases, development of 'smart' devices with easy to use features, automation of the process using artificial intelligence are ready to change the game even more than before. Moreover, the combination of elastography with therapeutic ultrasound has a promise of enabling monitoring and guidance of afflictive procedures, for example, focused ultrasound in the treatment of cancers, in real time.

Overall, it is fortunate that a negation in any one aspect of aging health has strongly improved with ultrasound elastography. Indeed, ultrasound elastography has developed into a versatile and powerful imaging tool for numerous areas of practice when crossing the boundaries of medicine. It is especially useful in providing quantitative assessment of the tissue biomechanics in a dynamic manner which is crucial in the early diagnosis, assessment and management of diseases. With the meaningful logical validation and advancement of imaging technologies, the existing standing of the surface ultrasound elastography in modern diagnosis of disease will be upgraded tremendously.

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