**Title-** Ultrasound Elastography- A Novel Tool in the Assessment of Temporomandibular Disorders

Running title- USG elastography in TMDs

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Abstract

Ultrasound is an essential modality within medical imaging, predominantly for assessing soft tissues. Ultrasound elastography has become commercially available in recent years for further assessment of tissues, in addition to the standard B-mode and Doppler imaging. Elastography provides a different form of tissue assessment and possibly showing pathology before it can be detected on B mode imaging. This may be of particular use in the musculoskeletal system where there is a wide spectrum of tissue specialisation. Elastography is a novel diagnostic tool and helps in evaluating the muscle stiffness both qualitatively in the form of an elastogram and quantitatively in terms of muscle elasticity index. Elastography assesses the strain (stiffness) of these tissues in response to stress, through a variety of different methods. Strain wave and Shear wave are the two techniques used in USG elastography to assess stiffness of tissues.Elastography has been used widely in musculoskeletal imaging. Temporomandibular disorders are associated with masticatory muscle pain. Till date palpation is the only subjective tool to to assess muscle pain. With the advent of elastography, it has helped in early disease detection and differential diagnosis as it reflects qualitative alterations even if morphological alterations are not noticeable. This chapter highlights the application of ultrasound elastography for various Temporomandibular disorders

Key words: Ultrasonography, Strain wave elastography, Shear wave elastography, Temporomandibular disorders, Myofascial pain, Masseter

**Introduction**

Ultrasound is an essential modality within medical imaging, predominantly for assessing soft tissues. While a variety of technique such as CT, MRI, and PET are being put to practical use for diagnostic imaging of morphology and function, a technique for objectively assessing tissue stiffness was only recently made widely available with the commercial introduction of ultrasound elastography. Recently, the additional tool of ultrasound elastography has become commercially available for further assessment of tissues, in addition to the standard B-mode and Doppler imaging. The elastic properties of tissues are different from the acoustic impedance used to create B mode imaging and the flow properties used within Doppler imaging, hence elastography provides a different form of tissue assessment and possibly showing pathology before it can be detected on B mode imaging. This may be of particular use in the musculoskeletal system where there is a wide spectrum of tissue specialisation. Elastography assesses the strain (stiffness) of these tissues in response to stress, through a variety of different methods.1

The term elastography was described by Ophir *et al*2 as a method of portraying the strain properties of biological tissue. In strain, or compression elastography, a force (*i.e.*, stress) is applied from the transducer by repetitive manual pressure and the displacement (strain) is calculated from the return velocities of the tissues with respect to time. Measuring the displacement (strain) of the tissues secondary to an applied force (stress) gives a qualitative

map of the elastic modulus distribution, termed an elastogram. This elastogram is colour-coded and often super-imposed on a grey-scale B mode image for anatomical localisation. True quantitative measures cannot be taken from this elastogram, as the applied force is unknown. A semi-quantitative evaluation, however, can be determined from the ratio of the displacement of the tissue of interest and an adjacent structure, such as subcutaneous fat. This is measured in terms of Muscle elasticity index.3,4

The Temporomandibular disorders are prevalent in among 60% to 70% of the normal pop­ulation and only around 15% exhibit the TMD symptoms.5 Myofascial pain, one of the most common findings in TMD, is diagnosed on the basis of the presence of pain and tenderness by palpation. Myofascial pain is often associated with regional pain in tender areas, known as trigger points, which are expressed in taut bands of skeletal muscle and tendon. Clinically, the masticatory muscle associated with myofascial pain is hard and stiff on palpation.

Myofascial pain is a common condition, but the underlying mechanisms are still not fully understood. The pain associated with the TMDs causes masticatory dysfunction, affects activities of dai­ly life and, in particular, leads to psychological problems. Clinicians highlight the role of addressing increased stiffness and tonus of the masseter muscle as part of the conservative treatment of TMD. Efforts to prevent or ameliorate TMD may therefore improve patient quality of life.6

The diagnosis depends on a subjective assessment by patients and clinicians; therefore, it is difficult to assess the disease objectively. However, this is a subjective finding by practised clinicians well-experienced in palpation. A clear objective assessment of masticatory muscle stiffness in patients with myofascial pain has yet to be made. Therefore, it is necessary to establish an effective method to objectively evaluate the severity of masticatory muscle stiffness and the effect of treatment on myofascial pain.

Various tools have been used to assess the stiffness in myofascial pain like Myotonometry, muscle hardness meter but its use in TMDs is limited. Although alterations in masseter muscles have been evaluated by EMG, this method has limitations, as the electrical signal is easily affected by the experimental environment.7,8

Ultrasonography (US) may be an alternative which can noninvasively depict the morphology and thickness of the masseter and other muscles situated superficial to the bone structures in the head and neck region. Elastography is a novel diagnostic tool and helps in evaluating the muscle stiffness both qualitatively in the form of an elastogram and quantitatively in terms of muscle elasticity index. Elastographic studies performed in other organs like thyroid, trapezius and fibromyalgia have proven to be statistically significant.3,4This chapter highlights the application of ultrasound elastography for various Temporomandibular disorders.

**USG Elastography for Musculoskeletal imaging**

In recent years, the number of publications on USE has increased significantly, primarily due to its widespread availability on commercial US systems. 9Based on a literature review of USE of Musculo skeletal applications, (MSK) the European Society of Skeletal Radiology published a group consensus asserting that USE has a low level of indication in clinical practise, but that it is a promising technique for soft tissue masses and nerve entrapment.10

Several USE methods are available, contingent upon the method of force application and data processing. Strain wave elastography (StWE) and shear wave elastography (SWE) are the most frequently used techniques in the field of MSK radiology.9

**Techniques for elastography**

Strain imaging and shear wave speed measurement/imaging are the two primary categories of techniques currently utilised in commercially available equipment. The various kinds of Elastography differs in both the method used to exert the force (stress) and the measurement of the subsequent tissue displacement (strain), but they may be complementary due to their distinct physical properties, artefacts, limitations, and clinical applications for which they are best suited.

Principles of Strain Elastography

Strain elastography is based on the principle that tissue compression produces displacement, or strain. In stiffer tissue, strain is minimal, whereas strain is greater in softened tissue. Using a hand-held ultrasound transducer, tissue displacement is computed based on repeated manual compression. Using the transducer to apply repetitively minimal pressure to the tissues generates strain images. Strain is determined by calculating the axial gradient of the succeeding tissue displacement between pairs of RF echo frames. A stiff region experiences less strain (deformation) than adjacent soft tissue under the same amount of stress. Using a colour map to represent various strain magnitudes, a two-dimensional strain image can be superimposed translucently on a conventional B-mode image, facilitating the evaluation of the spatial relationship between the ultrasound image and the elastography data. The distribution of displacement is depicted in an elastogram, which is typically displayed as a color-coded image superimposed on the B-mode image. Typically, red is used to depict gentler tissue, blue to depict harder tissue, and yellow or green to depict tissue with intermediate elasticity. (Figure 1-3) Given that the colour signifies the relative rigidity of the tissues, the colour coding can be modified. Due to nonlinear changes in tissue elasticity, excessively heavy or light compression can distort elastograms, posing a further challenge to StrWE reliability.9,11

Most vendors display the quantity of manual compression as an on-screen indicator.7 For instance, a "quality factor" greater than 60 indicates the optimal compression force, whereas a "strain indicator" indicates whether displacement is adequate to compute local strains within the region of interest (ROI).12 Certain systems provide semiquantitative tools for analysing image characteristics as a strain ratio.9 This is an index of relative elasticity between the target region of interest and the reference region of interest (typically the subcutaneous fat layer).3,7As the local degree of stress is unknown, it is impossible to derive kPa-based quantitative elasticity measurements. Consequently, strain elastography is a qualitative technique that displays relative stiffness differences in sonified tissue.13

**Shear Wave Elastography**

In the past decade, SWE, also known as dynamic elastography, has been used to evaluate various musculoskeletal tissues in research and clinical contexts, allowing for both qualitative and quantitative measurements of tissue elasticity. In musculoskeletal imaging, this technique is rapidly developing novel applications and clinical utility. By quantifying the mechanical and elastic properties of tissue, SWE supplements the diagnosis acquired from grayscale (B-mode) ultrasound and power and colour Doppler ultrasound.

The shear wave is a transverse wave that propagates through an elastic medium subjected to a periodic shear force. Shear is defined as a change in the shape of a substance layer without a change in volume, resulting from a pair of equal forces acting in opposing directions along the two sides of the layer. After the shear interaction, the initial layer (tissue) will return to its original shape, while the adjacent layers endure shear, and the shear wave, which propagates as a transverse shear wave, will undergo further shifting. 14

**Principles of Shear Wave Elastography**

In the first step, shear waves are generated using focused acoustic radiation force from a linear US array, which generates a local stress and local displacement in the tissue.

In step 1, the generated shear waves propagate through the adjacent tissues in the transverse plane, perpendicular to the primary wave that generates the acoustic radiation force, at a significantly slowed velocity, causing shear displacements in tissue.

In step 2, fast plane wave excitation is employed to monitor tissue displacement and shear wave velocities as shear waves propagate. Calculating tissue displacement using a speckle tracking algorithm. In step 3, tissue displacement maps are utilised to determine shear-wave velocity (cs), which is typically expressed in metres per second. The distribution of shear-wave velocities at each pixel is directly proportional to the shear modulus G, which is determined by a simple mathematical equation and expresses the tissue stiffness and elasticity in pressure units—typically kilopascals. The shear modulus is defined as the ratio of stress to strain, which is given by the equation G = rcs2, where r is the density of the material. E = 3G is the definition of the Young modulus (E [or ]) for isotropic media. The material density for soft tissue is typically estimated based on values published in the literature for the type of tissue being examined, or approximating the density of water (1 g/cm3) (36,37). There is a direct relationship between the shear and Young moduli, as reported in some investigations as E = 2G(1+ ), where represents the Poisson ratio. Because it is commonly assumed that soft tissues with modest deformations (i.e., quasi-static displacements) are incompressible (i.e., = 0.5), the simple equation E = 3G is sometimes used to convert G to E for incompressible media (39). Consequently, despite the fact that some studies refer to shear-wave values or G, others report E based on this relationship.

On the US screen, quantitative shear modulus maps are displayed in a color-coded elasto-gram that displays shear-wave velocities in metres per second (Figs 2, 5–20) or tissue elasticity in kilopascals. Typically, red elastograms indicate a firm consistency, blue indicates a soft consistency, and green and yellow indicate an intermediate stiffness.15,16(Figure 4)

The propagation of tissue shear deformation as a shearwave is one of the principles utilised in SWE.SWE is a form of dynamic elastography based on the measurement of the tissue propagation velocity distribution of the directional shear wave generated by an ultrasound pulse. SWE can quantify the absolute elasticity value of an imaged structure, in addition to qualitatively depicting it with elastograms. Shear waves travel quicker through denser tissue. The quantitative measurement can be expressed as shear wave velocity in metres per second (m/sec) or as tissue elasticity based on the calculation of the shear modulus in kilopascals (kPa).4

**Discussion**

Several studies have been conducted to assess the stiffness of masstter muscle with strain and shear wave elastography. **Ariji Y *et al.,***17investigated the relationship between the masseter muscle elasticity index (MEI) ratio obtained by sonographic elastography and the hardness measured by a hardness meter in healthy volunteers, and to clarify the characteristics of the masseter muscle hardness in temporomandibular disorder (TMD) patients with myofascial pain.Sonographic elastography images were obtained using a LOGIQ E9 (GE Healthcare), and the MEI ratios were calculated using Elasto Q software. The relationship between the MEI ratio and the masseter muscle hardness measured using a hardness meter was examined in 35 healthy volunteers. The MEI ratio in 8 TMD patients with myofascial pain was compared with that of the healthy volunteers. The MEI ratio was significantly correlated with the masseter muscle hardness. There was a significant difference between the MEI ratios of the symptomatic and asymptomatic sides in the TMD patients with myofascial pain. The MEI ratio of the symptomatic side in the TMD patients was larger than that on the right side of the healthy volunteers. The authors concluded that Sonographic elastography can be used to express the muscle hardness. It can be selected as a modality for showing the features of muscles with pain.

**Ariji Y *et al.,***18 investigated the intramuscular changes on sonographic elastography (SE) after low-level static contraction of the masseter muscle, to clarify the relationship with the total hardness and edematous change. Ten healthy volunteers performed sustained bilateral biting at 20% of maximal voluntary contraction for 10 min. The SE and magnetic resonance (MR) scans of the masseter muscles were performed before, immediately after, and 10 min after exercise. The masseter muscle elasticity index (MEI) ratio, muscle thickness, and intramuscular soft and hard areas distribution were evaluated on SE images. The signal to noise ratio (SNR), indicating the water content, was measured on MR images. The soft area ratio showed significant correlations with the water content expressed as SNR. The hard area ratio

showed significant correlations with the total muscle hardness expressed as the MEI ratio. The authors concluded that Intramuscular soft and hard areas could be used both clinically and experimentally,

Nakayama M et al., 19 verified the use of a single coupling agent as a reference to obtain the elasticity index (EI) ratios and to investigate the EI ratios of the masseter muscles of healthy volunteers. Muscle phantoms with known elasticity (20, 40 and 60 kPa in the Young's modulus) were examined by strain-type sonoelastography using a coupling agent as the reference. The correlation coefficients were determined between the EI ratio and Young's modulus of muscle phantoms. Strong correlations were found between the EI ratios and Young's modulus for both soft and hard references. The variations of the EI ratios were larger with soft coupling agents than those with hard coupling agents, and they increased in phantoms with 60 kPa elasticity. There were no differences in the EI ratios of the masseter muscle at rest between males and females or between the right and left sides. The ratio increased during clenching. **The authors concluded that the** hard reference coupling agent was suitable for obtaining EI ratio of the masseter muscle.

A study was conducted by Habibi et al20 to provide the normative quantitative elasticity values of disc and masseter muscle which could be a reference point for upcoming studies. Mean stiffness values of the disc were 37.02 ± 23.75 kPa and 3.28 ± 1.09 m/s in the anterior part, 30.47 ± 18.89 kPa and 2.97 ± 1.04 m/s in the intermediate part, 22.61 ± 13.97 kPa and 2.55 ± 0.88 m/s in the posterior part. Stiffness values showed significant decrease in the posterior part compared to the rest of the disc both in males and females. No significant differences in mean stiffness values of masseter muscle related to mouth position, age or gender. This study provided the normative quantitative elasticity values of disc and masseter muscle which could be a reference point for upcoming studies. Disc elasticity values are higher in women than men. Maybe this is one of the reason why TMD is more common in women. TMJ disc stiffness was significantly lower in the posterior part. SWE is a useful imaging method that can be used with routine ultrasonography in evaluation of the TMJ disc and masticatory muscles.

Paluch et al21 studied the usefulness of shear wave elastography in n determining the temporomandibular disc stiffness in patients with a temporomandibular disorders (TMDs). The study included 37 patients with confirmed TMDs and 208 healthy volunteers. Patients presented with significantly greater stiffness of the intermediate zone of the disc (region of interest [ROI] 1) and significantly lower stiffness of its anteriorly displaced portion (ROI 3). A receiver operating characteristics analysis indicated that a decrease in the stiffness in ROI 3 less than 8.667 KPa provided 100% sensitivity, 97.3% specificity, 100% positive predictive value (PPV) and 99.5% negative predictive value (NPV) in distinguishing between patients with TMDs and without. Whereas an increase in ROI 1 stiffness to at least 54.33 KPa provided high specificity and NPV, both the sensitivity and the PPV of this predictor equaled zero. Findings suggest that a decrease in anteriorly dislocated disc stiffness less than 8.667 kPa can accurately identify patients with TMDs. The articular discs in patients with TMDs might gradually lose their elasticity, and this parameter, as determined by means of SWE, could serve as a marker of pathologic processes in TMJs.

Olchowy et al22 conducted a prospective study among 35 patients with masticatory muscle disorders. The study lasted for eight weeks. The patients were treated with manual therapy and stabilization occlusal splint and evaluated using shear wave elastography of the masseter muscles and patient-reported outcome measures to assess pain, anxiety, quality of sleep, satisfaction with life and perceived stress. After the treatment, the stiffness of both masseter muscles decreased significantly (by 4.21 kPa). The patients reported a significant reduction in pain. At baseline, the median scores ranged from 5 to 8; after treatment, theyranged from 0 to 1 (p < 0.0001). The patients also reported significant improvement in terms of all patient-reported outcome measures. The authors concluded that shear wave elastography has the potential for broad application in clinical practice to monitor masticatory muscle disorders treatment effects due to its objectivity and non-invasive character.

Toker et al23 conducted a study to evaluate the use of Shear wave elastography in bruxism. SWE was performed on the left and right masseter muscles under three conditions: relaxed jaw, 50% of the subjective maximal bite force, and maximal jaw opening. SWE was significantly increased during relaxed jaw (bruxism 1.92 m/s± 0.44; controls 1.66 m/s± 0.24). The results of the study suggested that SWE in bruxism is feasible and could be of potential use for diagnostics and monitoring of the condition.

The above studies substantiate the use of USG elastography in early disease detection and differential diagnosis because it may reflect qualitative alterations even if morphological alterations are not noticeable. Shear wave elastography is superior to strain wave elastography as it gives quantitative evaluation of muscle and disc stiffness and is not operator dependant.

**Applications of USG elastography in TMDs**

1. Assessing the stiffness of masseter muscles in conditions of Myofascial pain in TMDs
2. Assessing the normal values of stiffness of masseter muscles in healthy adults and children
3. Assessing the normal values of stiffness of articular disc of temporomandibular joint in patients with internal disc derangement and healthy adults.
4. Used as diagnostic tool to assess the decrease in muscle stiffness before and after treatment in patients with myofascial pain
5. Can be used a potential tool to assess patients with bruxism and as a follow up modality after treatment in these patients.

**Conclusion**

USG Elastography is a cost- effective diagnostic tool and has an added advantage of using non-ionising radiation. It’s a real time imaging modality and the results are available rapidly in a short period of time. As discussed in the above studies, USG Elastography is a promising tool for the assessment of the masseter muscle and temporomandibular joint disc stiffness, but the evidence is insufficient. Studies on larger groups are needed to determine the accuracy of elastography to characterize temporomandibular disorders.

Conflict of interest -NIL

Funds- Nil

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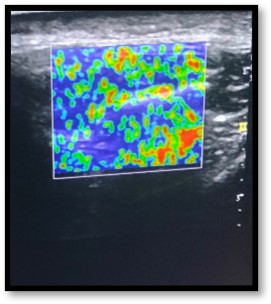


Figure 1- Color coded elastogram -blue areas depicting areas of muscle hardness

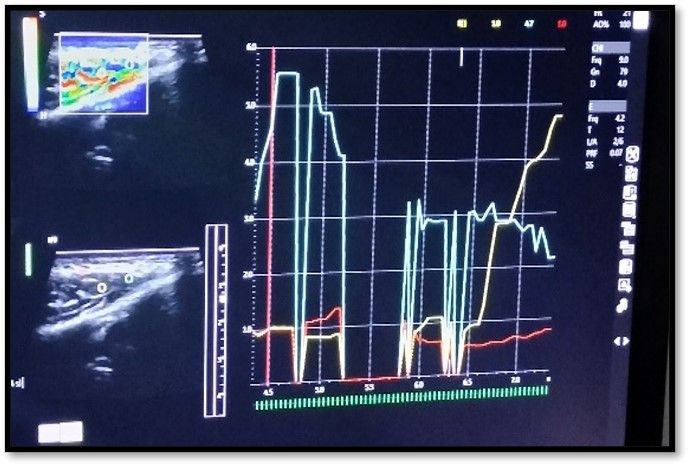


Figure 2- Masseter muscle elasticity index Ratio of elasticity index of muscle to subcutaneous tissue in patients with myofascial pain

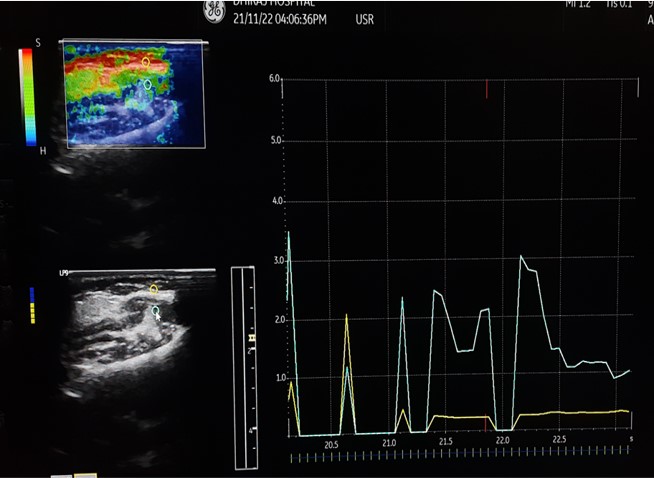


Figure 3- Masseter muscle elasticity index Ratio of elasticity index of muscle to subcutaneous tissue in healthy patients



Figure 4- Shear wave elastogram of Masseter.The region of interest iss set on the masseter

muscle, and Young’s modulus of the masseter muscle was measured (56.23 kPa)