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Elastography -A new boon in oral and maxillofacial imaging

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Abstract

Elastography is a recent imaging modality used to assess the mechanical properties of tissues, mainly for the evaluation of tissue stiffness of superficial organs .The underlying principle is application of stress and detection of tissue displacement using ultrasonography. It is a non-invasive method for differentiating benign & malignant lymph nodes and to detect metastatic cervical lymph nodes. It is also used in the diagnosis of salivary gland disorders, superficial neck masses and assessment of muscular pathologies as well as disc disorders of TMJ.. It is widely used as it is inexpensive, easy to use, and has minimal adverse effects compared to other imaging methods. This paper provides an overview about the principles and implications of elastography in the head and neck region.

Keywords: Ultrasonography; Elastogram; Elasticity

Introduction

From the era of Hippocrates, physicians have gained insight into tissue biology through diagnostic palpation, the physical examination technique by which mechanical tissue property changes are detected. It has been long known that tissue stiffness can be considered as a biomarker of tissue pathology [1] .This has paved way for

the development of a new noninvasive advanced ultrasound technique termed as Ultrasound Elastography (USE). This imaging modality quantifies and displays tissue stiffness properties by measuring their displacement in response to mechanical stimulation and assess changes in tissue mechanics in common disease processes such as fibrosis, inflammation and neovascularization[2].Thus this rapidly developing field of imaging measures tissue elasticity using ultrasound. As real time USE modes are available in commercial clinical ultrasound machines, many researches are under progress in potential oncologic and non-oncologic clinical applications of USE.

The word elastography was first coined by Ophir et al. in 1991[3].The technique uses the concept of diagnostic clinical palpation as many pathologic processes such as cancer and fibrosis alter tissue elasticity (stiffness). Elasticity is measured as a quantifiable biomechanical parameter called Young's coefficient of elasticity, which may be up to 10 times higher in malignant tissue compared with benign tissue. Elastography can be performed using different imaging modalities although in the last few years there has been an evolution of research into ultrasound elastography (USE).

Principles of ultrasound elastography

The main principle which defines elastography is tissue compression. It produces strain (displacement) within the tissue and this strain is lower in harder tissues than in softer tissues. Thus tissue hardness is estimated by measuring tissue strain induced by compression. Tissue elasticity resulting from compression is displayed as an image called elastogram, in which hard areas appear blue in color and soft areas red. Because malignant tissue is usually harder than normal surrounding tissue, elastography might provide clinical information that allows observation of tissue stiffness, which might be a helpful addition to findings on palpation [4].

Mechanics

Elastography allows assessment of the elastic properties of tissues, and therefore the images obtained are compared before and after compression. Elasticity varies in several tissues (fat, collagen, etc.) and within the same tissue during different pathologic states (inflammatory, malignancy). Tissue stiffness tends to change (usually increase) with disease and can be imaged by measuring the tissue distortion under an applied stress [5]. The resulting high contrast images can cause early detection of disease processes. The data are then compared employing a cross correlation technique to work out the quantity of displacement each small region of tissue undergoes in response to the compression applied by the ultrasound transducer [6].

The development of elastography has been the result of an interdisciplinary research. When stress (or displacement) is applied, a resulting level of longitudinal strain is experienced at all points in the elastic medium. The greatest effect is observed in components along the axis of compression. The longitudinal (axial and lateral) strains are estimated by the analysis of ultrasonic signals obtained from standard diagnostic ultrasound equipment. Initially, a set of digitized radiofrequency echo lines are obtained from the tissues and then a second set of post-compression echo lines are recorded from the same region of interest by compressing the tissue to a small amount with an ultrasonic transducer along the axis of ultrasonic radiation [7]. The data from these two echo lines undergo processing, and an elastographic image (elastogram) ultimately appears on the monitor.

There are two types of elastograms: Gray scale elastograms and Color elastograms. The hard and soft areas (Areas of high and low elasticity, respectively) appear in the gray-scale elastogram as dark and bright, respectively. In color elastogram of a general device,

increasing tissue hardness appears, in ascending order, as red, yellow, green, and blue These colors represent the relative hardness of the tissues in the elastogram as shown in figure 1 [8].

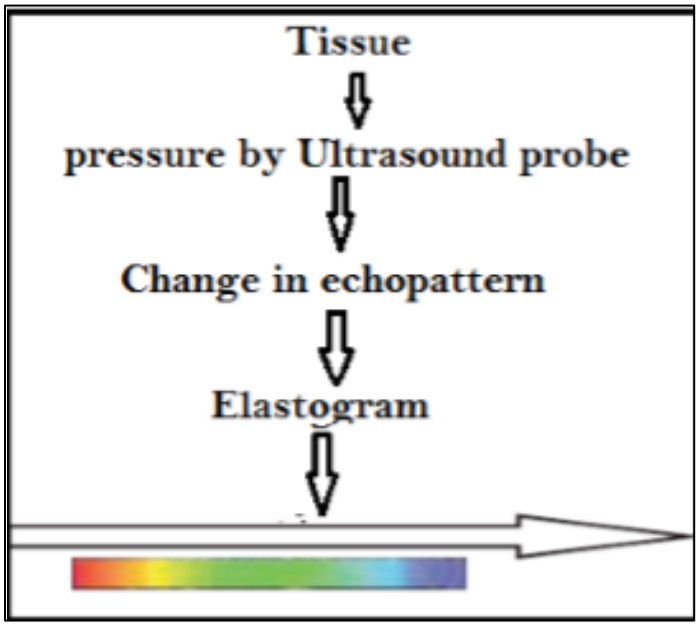

Figure 1: Increasing tissue hardness appears in ascending order as red, yellow, green & blue

Clinical applications

Assessment of salivary gland neoplasms

Sonography is the first-choice of imaging for evaluation of salivary gland neoplasms. There are many studies that reported features of the salivary gland tumors using sonographic elastography. Margin irregularity is considered to be the main sonographic feature of malignancy but has limited sensitivity and specificity Klintworth et al[2012] qualitatively evaluated strain pattern distribution on strain elastography for parotid tumors, and documented that a pattern of heterogeneous reticular distribution was more frequent in malignant tumors than in benign tumors[8] and the stiffness of the malignant tumors was higher than that of the benign neoplasms and that of pleomorphic adenoma[PAs] was higher than that of Warthin tumors[WTs]. Margin irregularity is the main sonographic feature of malignancy but has limited sensitivity and specificity. To date, seven studies have evaluated USE using real time elastography [RTE] or shear wave elastography [SWE] for characterization of focal lesions within the major salivary glands. Dumitriu et al [2011] evaluated 74 salivary tumours (18 malignancies) using qualitative RTE and documented higher strain indices in malignant neoplasms compared with benign tumours but no difference was noticed between malignant neoplasms and PAs, or between PAs and WTs [9]. Mansour et al [2012] performed qualitative RTE and Acoustic Radiation Force Impulse Imaging [ARFI] of 33 parotid lesions (4 malignancies) and documented similar strain patterns and ARFI velocities for malignant lesions, WTs, and other benign tumours except for PAs [19]. Bhatia et al [2013] evaluated 60 focal salivary lesions (5 malignancies) using supersonic imaging [SSI] and stated an overlap in elastic moduli between benign pathologies and malignant neoplasms such that there was no clinically useful cut-off [11]. However, the discriminatory performances for detection of malignancy were found to be poor in all studies, as an appreciable overlap was detected between stiffness of pleomorphic adenomas and malignant neoplasms. Figure 2 shows the elastogram of a parotid gland with a hypo echoic mass.

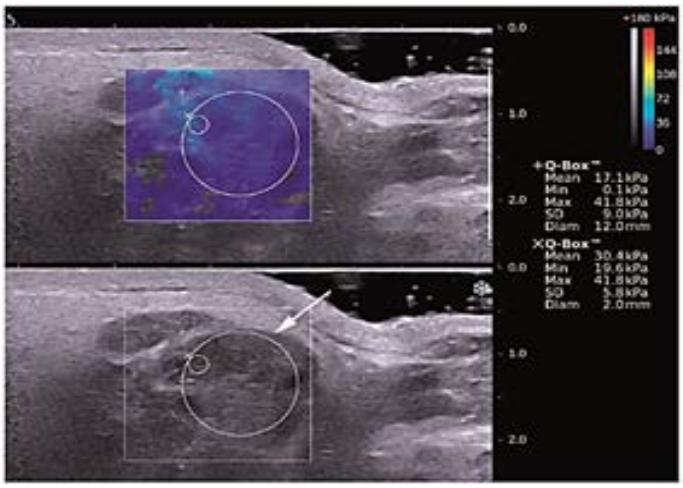

Figure 2: Elastogram of a parotid gland showing hypo

echoic mass [arrows] that appears homogenous with high stiffness

Assessment of thyroid nodules

Thyroid nodules are extremely common, and only a small proportion is considered to be malignant. The limitations of US guided fine-needle aspiration cytology in evaluation of thyroid nodules are inadequate, non-representative, or indeterminate specimens leading to suboptimal sensitivity for malignancy. A meta-analysis of eight USE studies performed between 2005 and 2009 (639 thyroid nodules, 24% malignancies) calculated a pooled sensitivity and specificity of 92% and 90%, respectively [12].There are several sonographic criteria that have a predictive value for malignancy such as

- Irregular margin
- Punctate micro calcifications,
- Hypo echogenicity
- Taller than wide shape

But no single criterion or combination of criteria achieves a balanced high sensitivity and specificity. Thyroid strain elastographic studies have excluded large or coalescent thyroid nodules, and in some cases nodules within a background thyroiditis, due to the shortage of sufficient normal thyroid parenchyma in the elastogram for reference. Many real time strain elastography (RTE) studies have also excluded nodules containing coarse calcifications or large cystic foci because evidence indicates that these factors can genuinely increase nodule stiffness and thus may reduce the accuracy of RTE for malignancy [13]. It is worth highlighting that all RTE studies have used freehand compression to generate elastograms although there are several reports of off-line thyroid USE using intrinsic compressions from the carotid artery as the only compressive source [14]. Most USE reports document higher stiffness indices for thyroid cancers compared with benign nodules. These findings are also supported by very limited biomechanical stiffness data from thyroidectomy specimens. In this respect, if nodules are subjected to identical test loads, the elastic modulus of malignant nodules is significantly higher than that of benign nodules and normal thyroid parenchyma [15].Figure 3 shows elastogram of a thyroid nodule.

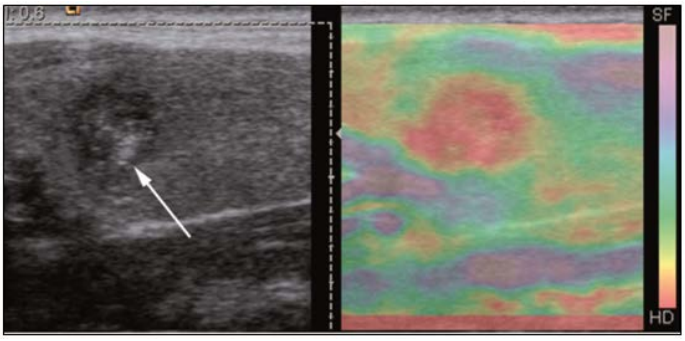

Figure 3: Elastogram of an irregular hypo echoic thyroid nodule appearing red in colour

Assessment of benign and malignant lymph nodes

The most important prognostic factor in patients with head and neck cancer is lymph node status. Neck lymph nodes are well positioned for the elastographic examination as they are easily accessible and can be efficiently compressed against underlying anatomic structures with the use of an ultrasound probe [16].Inflammatory or reactive lymph nodes that do not contain metastatic deposits, have the same USE appearance as the soft tissues of the neck and are rarely visible as distinct entities on USE images. They do not contain blue areas, or blue areas occupy <45% of the node surface.. Blue areas depicting rigid, hard tissue occupy more than 45% of the lymph node area. Red, yellow, and green are not encountered in malignant deposit areas, whereas stiff tissue is depicted only in turquoise and blue. Margin delineation was also better on elastograms, as the margins of metastatic lymph nodes were more regular and distinct than those of benign lymph nodes [16]. This finding corresponds to differences of elasticity properties between malignant lymph nodes and surrounding tissue or a desmoplastic reaction that

creates a stiff rim around malignant lymph nodes. Yellow, green, and turquoise in color USE had sensitivity of 93.8% and specificity of 89.5% in the differentiating benign and malignant cervical lymph nodes. In a systematic review, it was reported that results of a study of 141 peripheral neck lymph nodes which were evaluated using strain elastography showed a sensitivity, specificity, and accuracy of 85%, 98%, and 92%,respectively; while the best gray scale criterion achieved 75% sensitivity, 81% specificity, and 79% accuracy. For strain elastography, lymph nodes are evaluated using either the loose connective tissue surrounding the lymph node or the sternocleidomastoid muscle as reference. In general, metastatic nodes display color patterns, strain ratios, or shear wave indices equating to higher stiffness than benign nodes [17]. Alam et al[2008] evaluated 53 metastatic and 32 reactive lymph nodes using a modified classification and reported a sensitivity, specificity, and accuracy of 83%, 100%, and 89% for elastography, 98%, 59%, and 84% for gray scale US, and 92%, 94%, and 93% for combined assessment[18].Figure 4 shows elastogram of a reactive lymph node .Figure 5 shows elastographic patterns of lymph nodes.

To summarize, the preliminary evidence suggests that USE may be useful to differentiate benign and malignant cervical lymph nodes although further research is required. Ideally, future studies should be sufficiently large and detailed to enable stratification of USE accuracy results according to nodal histology and determine the accuracies of USE for both unselected and selected populations.

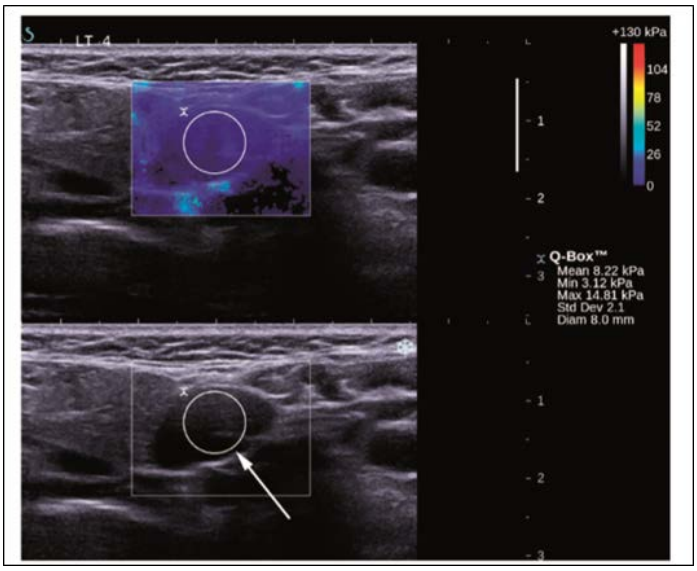

Figure 4: Elastogram showing a reactive lymph node which appears blue in colour

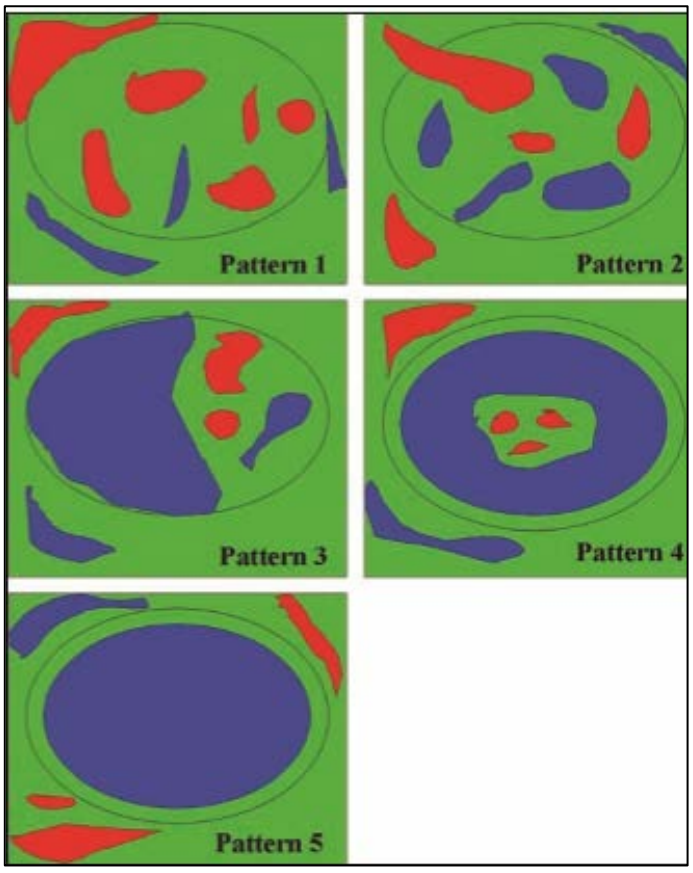

Figure 5:Elastographic patterns of lymph nodes showing hard & soft areas

Assessment of masseter stiffness

The impression of increased muscle hardness in painful muscles is usually reported within the clinical practice but

is difficult to assess and diagnose. Mechanical devices and ultrasound imaging (strain and shear wave elastography) methods are consistently used to measure masticatory muscle hardness, but an undisputable reference standard is yet to be determined.

Strain elastography has identified greater masseter hardness of the symptomatic side in patients with unilateral myofascial TMD pain in comparison to the contralateral side and healthy controls (HC). Likewise, shear wave elastography has shown greater masseter elasticity modulus in patients with myofascial TMD pain in comparison to HC, which can be a sign of muscle hardness. Figure 6 shows strain elastogram of a non-painful masseter muscle and displays less blue coloured areas[hard areas] when compared to figure 7 which is the strain elastogram of a painful masseter muscle. Although assessment bias could partly explain these preliminary findings, future randomized controlled trials are encouraged to investigate this relationship [19].

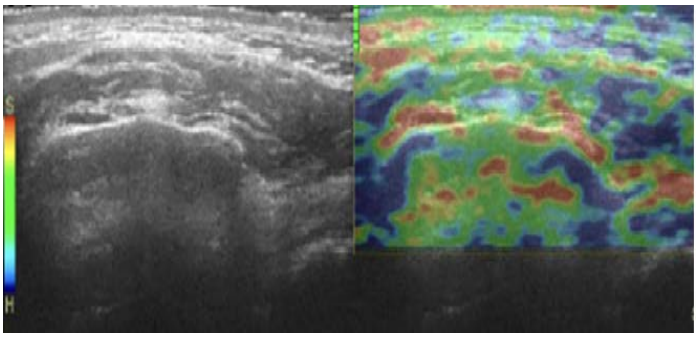

Figure 6: Strain elastogram of a non-painful masseter muscle

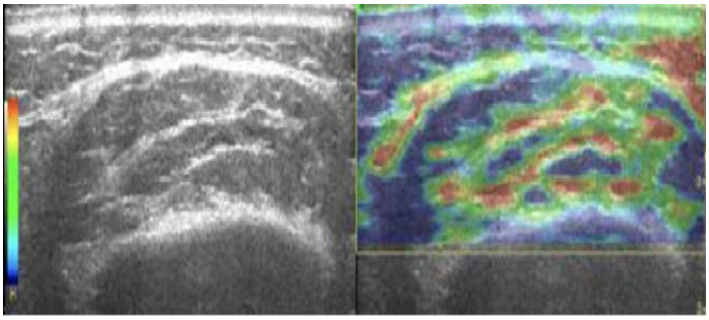

Figure 7: Strain elastogram of a painful masseter muscle

Assessment of skin fibrosis in scleroderma

Scleroderma or systemic sclerosis [SSc] may be a rare systemic autoimmune disorder , predominantly affecting young females, characterized by excessive collagen deposition and fibrosis within the skin, lungs, alimentary canal , and other internal organs of the body. The resultant skin tightening is the hallmark of this disease and causes significant morbidity with limitation of finger movements, mouth opening, and restriction of chest expansion[20]. Clinical quantification of skin tightening is usually done by the Modified Rodnan Skin Score (MRSS), which grades skin tightening from 0 to 3 in seventeen areas of the body (fingers, hands, forearms, arms, face and neck, chest, abdomen, thighs, legs, feet) with a maximum score of 51[21]. Even though MRSS is extensively validated and used in clinical trials, it is limited by the requirement of a trained and experienced assessor to accurately assess the extent of skin involvement. Clinically, evident skin fibrosis is thought to be a sign of advanced disease. Hence, there has been an emerging trend in recent times to detect early, subclinical skin involvement to assess the extent of skin fibrosis using objective techniques like ultrasound. Skin fibrosis is often assessed ultrasonographically by determining dermal thickness; however, this again may be a marker of established disease. Hence, techniques such as ultrasonographic shear wave elastography (SWE), which assess quantitatively the extent of skin fibrosis, have gained attention. SWE assesses the elasticity of skin utilizing ultrasound, with a decrease in elasticity suggesting skin fibrosis. This technique not only objectively assesses extent of cutaneous involvement but also detects subclinical fibrosis which may be more vulnerable to therapeutic modulation than established, clinically evident, skin thickening [22]. Di Geso et al [2011] studied 22 patients with SSc in whom they assessed the dermal thickness in the second digit of

the dominant hand using gray scale ultrasound and ultrasound elastography. They concluded that dermal thickness assessed using ultrasound elastosonography was more accurate than that using gray scale ultrasound alone [23]. Accurate objective assessment of skin tightness or skin fibrosis is important not only to distinguish involved skin from healthy skin in scleroderma but also to detect skin involvement before it is clinically detectable. Hence, utilization of SWE as a tool to detect subclinical disease may help identify early scleroderma, which can be more amenable to immunosuppressive therapy to retard progression to clinical disease or arrest the disease at an early stage of fibrosis. Another importance is that SWE could also be useful within the setting of clinical trials to assess the efficacy of anti-fibrotic therapies. Figure 8 shows elastogram of skin of forearm of a patient.

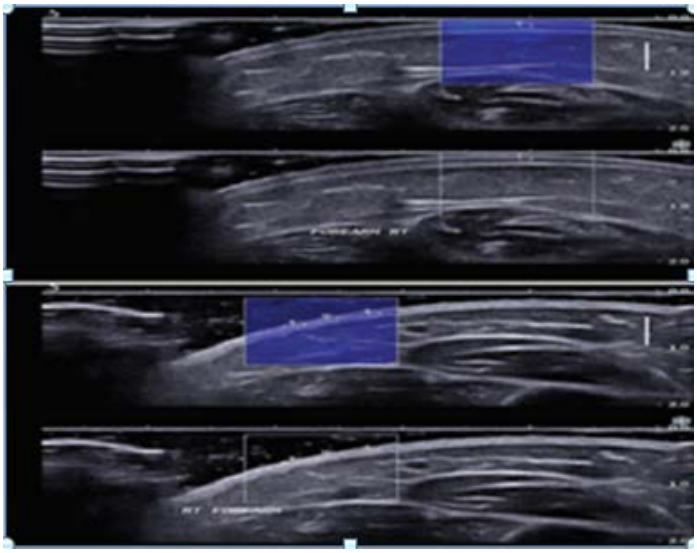

Figure 8: Elastogram of skin of forearm of a patient with scleroderma

Conclusion

Ultrasound elastography with its high sensitivity and specificity can be used as a screening tool for the assessment of superficial head and neck masses for which biopsies has to be performed. A lot of research remains needed to completely understand the numerous appearances of diseases and to standardize its application. Consequently, a task for elastography in routine sonographic evaluation of the head and neck is unclear at the present, although the preliminary evidence provides ample justification for further research during this field. Given the predominantly encouraging results for elastography within the head and neck, and therefore the incontrovertible fact that elastographic technologies are still emerging and continually improving, it's possible that a combination of elastographic and sonographic criteria will become a part of routine diagnostic head and neck sonography within the near future

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