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Elastography: A novel diagnostic method

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Abstract

Various imaging diagnostic methods have emerged in past few decades for the detection of pathological lesions in our body. Palpation was the earliest and most common method of assessing a lesion based on its hardness. Ultrasound elasticity imaging is an extension of the ancient art of palpation. Elastography is the method for assessing tissue hardness by imaging the tissue strain with an underlying principle that, tissue compression produces strain within the tissue which is lower in hard tissue than in soft tissue and this change in strain pattern is imaged as bright and dark respectively. The major clinical applications of elastography in maxillofacial region are differentiating benign from malignant lesions, differentiating reactive and malignant lymph node, to assess masseter stiffness, to evaluate focal lesions in major salivary glands. This review highlights a new non-invasive diagnostic method elastography, its principles of action and clinical applications and advantages over conventional ultrasonography.

Keywords: Elastography, Ultrasonography, Lymph Node.

Introduction

The estimation of tissue hardness is a very ancient diagnostic tool in medicine.(1) Palpation was the earliest and most common method practiced by the physicians ever since the age of Hippocrates to detect the differences in tissue stiffness. The relationship of tissue elasticity and hardness to palpation follows the basic principle that, to be palpable the object must have change in consistency compared to the surrounding tissues. The pressure receptors at various points on the skin covering the fingers sense the local stress over the region of interest during palpation.(2) Ultrasonographic imaging is a dynamic, non-invasive, easily available and patient friendly technique that is particularly useful in the examination of superficial structures(3) and has wide range of application in maxillofacial imaging. (Table 1)

Table 1

Indication of ultrasound in maxillofacial region(4)
1. Assessment of lymph nodes
2. Assessment of salivary gland and thyroid gland
3. Assessment of soft tissue cysts
4. Ultrasound guided biopsy
5. Assessment of tumour thickness

During past few decades ultrasound has been revolutionised from conventional grey scale imaging to colour and power Doppler imaging and recently to a new method of elasticity imaging. Elastography is a novel imaging method described by Ophir et al in 1991 that measures the characteristics of tissue compliance and evaluates tissue stiffness.(5) The aim of this review is to highlight this new imaging modality, its principle of action, clinical applications and advantages over conventional ultrasonography.

Theory of elastography

Elastography, which is based on principal of physical elasticity, consists of applying a pressure on the examined medium and in estimating the induced strain distribution by tracking the tissue motion. It is based on the theory of Young's modulus (E) describing longitudinal deformation in terms of strain (fractional change in length) in response to longitudinal stress (force per unit area), the shear modulus (G) related to the transverse strain to transverse stress and describing the shear wave propagation in the isotropic homogenous media and the Bulk Modulus (K) of elasticity, describes the change in volume of a material to external stress. Young's modulus and the shear modulus of tissue are related by a scaling factor of three, that is, $E=3G$. The high water content in the biological tissues means that they change shape easily when compressed but the volume is conserved.

Mechanism of elastography

Elastrography allows assessing the elastic properties of various tissues, and the images obtained are compared to before and after compression.(7) Elasticity varies in different tissues, like fat, collagen etc., and in the same tissue during different pathologic states, like inflammatory, malignancy.(8) Tissue stiffness tends to change (usually increase) with the disease and can be imaged by measuring the tissue distortion under an applied stress.(9) The resulting high contrast images can lead to early detection of the disease processes. The data are then compared using a cross-correlation technique to determine the amount of displacement each small region of tissue undergoes in response to the compression applied by the ultrasound transducer.(10)

The development of elastography has been the result of interdisciplinary research. Upon application of a stress (or displacement), all points in the elastic medium experience a resulting level of longitudinal strain, although the greatest effect is observed in components which are along the axis of compression. If one or more of the tissues has different stiffness parameters than the others, the level of strain will be higher or lower, and a stiffer tissue element will generally experience less strain than the one that is less stiff. The longitudinal (axis or lateral) strains are estimated from the analysis of ultrasonic signals obtained from standard diagnostic ultrasound equipment.(11) This is accomplished by acquiring a set of digitized radio-frequency echo lines from the tissue, compressing the tissue by a small amount with the ultrasonic transducer along the axis of ultrasonic radiation, and acquiring a second, post-compression, set of echo lines from the same region of interest.(8,9)

Technique of Elastography

Elastography techniques have been developed for both ultrasound and MR imaging.(12) US elastography also called as sonoelastography depends on reproducible differences in the back scattered ultrasound signals that result from compression of tissues of varying stiffness.(12) Image representation of tissue hardness can be obtained using a conventional sonography machine with special software and a conventional ultrasound probe.(5)

The steps involved in production of an elastogram (image produced with elastography) are(10):

1. Elastography receives digitised radiofrequency echo lines from the tissue.
2. Slight compression is given by the transducer along the radiation axis to make some displacement.
3. Post compression digitised radiofrequency echo is received from the same tissue.
4. Data undergoes processing and ultimately an elastogram appears on the monitor.

There are two types of elastograms, gray scale and colour. The hard and soft areas appear in the gray scale elastogram as dark and bright respectively. In the colour elastogram, increasing tissue hardness appears in the ascending order as red, yellow, green and blue. These colours represent the relative hardness of the tissues in the elastogram.(13)

MR elastography is a quantitative method that relies on shear pressure waves and elastic displacement of tissue.(12) It obtains information about the stiffness of tissue by assessing the propogation of mechanical waves through the tissue with a special MRI technique, which essentially involves the 3 steps(16):

1. Generating shear waves in the tissue.
2. Acquiring MR images depicting the propagation of the induced shear waves.
3. Processing the images of the shear waves to generate quantitative maps of tissue stiffness, called elastograms.

Applications of Elastography

A wide number of organs and diseases are potential candidates for elastographic evaluation. These include superficial organs such as breast, scrotum, neck, thyroid and superficial masses in other organs. Deeper organs that are accessible to pressure from an intracavitary transducer such as uterus, ovaries and prostate gland and structures subject to physiological displacements like arterial walls, liver and brain are also good candidates.

Specific applications of elastography in the above organs are gradually being explored in various studied and have shown satisfactory results.(1,12,17,18,19)

Elastography in Maxillofacial region

Elastography is a good diagnostic adjunct for pathologies involving maxillofacial region. It is useful in the following aspects:

1. Assessment of cervical lymph nodes – to differentiate between reactive and malignant nodes
2. Differentiate benign and malignant lesions
3. Measure muscle stiffness in MPDS
4. Evaluate focal lesions in major salivary glands

Cervical lymph nodes

Lymph nodes in the maxillofacial region are well-defined fusiform, kidney bean shape with an intermediate or low reflectivity, homogenous cortex, and a highly reflective central hilus. The length of the node is not considered as important as the dimension of the short axis, which should not normally exceed 10mm. A width to length ratio greater than 0.5 implies a rounded abnormal node, and the more rounded a node, the more likely it is to contain metastatic disease. Notably the submandibular and submental regions normal nodes tend to be more rounded, so shape alone should not be used as an isolated predictor of malignancy.(3)

Cervical lymph nodes are said to be well positioned for elastographic examination as they are easily accessible and can be efficiently compressed against underlying structures with the use of an ultrasound probe. Information on lymph node stiffness would likely be clinically useful for guidance of percutaneous biopsy and/ or nodal dissection which helps in early detection of cancer recurrence.(13)

For assessment of cervical lymph node, qualitative criteria is used, called the gray scale criterion, stating- lymph node visibility, relative brightness, margin regularity, and margin definition- as well as the quantitative criterion strain index, which was obtained by comparing the absolute values of lymph node strain with the absolute values of surrounding muscle strain. Using a strain index of greater than 1.5 as a threshold for diagnosing tumor resulted in a sensitivity of 85% and a specificity of 98%- considerably better than the best gray scale criterion.(21) The combination of B-mode US, US elastography, and positron emission tomography-computed tomography (CT) could prove to be a powerful set of tools for assessment of nodal metastasis.(21)

Lyshchik et al[13] studied the accuracy of sonoelastography in differentiating benign and metastatic cervical lymph nodes in patients suspected with thyroid cancer. Histological findings were used are standard reference for comparison. They found most benign nodes have the same brightness as surrounding anatomic tissues and were not clear on US elastograms. In contrast, most malignant nodes appeared darker with better marginal delineation. In another study, Alam et al[17] evaluated the diagnostic performance of sonoelastography and B mode sonography of enlarged lymph nodes and found that elastography significantly improved sonography in diagnosis of enlarged metastatic cervical lymph nodes.

Salivary Glands

Salivary gland masses are mostly superficial and it is notoriously difficult to determine the pathologic type by use of any imaging technique.[20] Elastography helped in differentiating benign salivary gland masses from malignancy and thus assisted the surgeons in deciding the type of surgical procedure.

Dana Dumitriu et al[21] studied the efficacy of real time sonoelastography in differential diagnosis of salivary gland tumours. Histopathological confirmation was taken as standard for comparison. Although this study revealed a difference in elastographic score between benign and malignant tumours, detailed analysis did not prove consistent results. Sonoelastography was proved to be a limited technique in differentiating benign and malignant salivary gland masses.

Muscle stiffness

Estimation of individual muscle force could provide considerable insight into neuromuscular physiology, motor control, biomechanics, and robotics. It can also contribute to improved diagnosis and management of both neurological and orthopaedic diseases.[22] Classically, muscle activity level is evaluated by surface electromyography (EMG), but several limitations inherent to this technique can preclude an accurate estimation of muscle force.[23] Muscle stress is linked to its elastic modulus.[24] Consequently, muscle stiffness could provide an estimation of muscle force during contraction which can be assessed with elastography. Various muscle pathologies which can be evaluated are: myospam, myosistis, myositis ossificans, hematoma and tumours of muscles.

Masseter muscle stiffness can be evaluated using elastography. It is known that the hardness of muscle in men is higher than in women.[25] Ariji et al[26] conducted a study with sonoelastography to assess the stiffness of masseter muscle for investigating the correlation of muscle stiffness with most comfortable massage pressure in MPDS patients.

Elastography is a valid support in the study of skeletal muscle pathology, because not only it gives appraisal of the entity of the lesion, but also shows the state of the peri lesional area indispensable in the clinical and therapeutic follow up of muscular lesions, allowing thus a more correct evaluation of the functional recovery in relation to the actual condition of muscular fibres involved in the repair process.[27]

Advantages

1. Finer definition of tissue components with better margin delineation
2. Differentiation of benign from malignant lesions
3. Can complement B mode US images with more diagnostic information
4. Clinically useful guide for percutaneous biopsy or nodal dissection
5. Early detection of cancer recurrence

Limitations[4]

1. Inability to control the extent of tissue compression by the transducer
2. Some strain images of large lymph nodes can be suboptimal due to inadequate probe contact over the large area
3. Artefacts can be caused by movement of surrounding tissues and vessels

Recent advances in Elastography

A recent development in the elastographic technique, shear wave elastography,[12] uses focused beams of ultrasound energy from conventional transducers to produce movement on the order of several microns at depth of up to 6cm beneath the transducer. The speed of shear wave propagation is directly proportional to tissue elasticity with faster speed in stiffer tissues. This method has the advantage of being quantitative, reproducible and operator independent and is suitable for monitoring changes over time. ARFI imaging technique has been introduced to overcome the inability to control the extent of tissue compression.[29] It uses radiation impulses to induce localised displacement of tissue and then monitor the dynamic response to individual tissue displacement.[30] To equalise the pressure over the tissue, balloon systems indicating the force of compression has been integrated into the probes.[30]

Conclusion

Elasticity imaging has received considerable attention due to its intuitive source of mechanical contrast and the significant diagnostic potential. We have every reason to believe that with continued development, elastography will become a more objective, non invasive diagnostic tool in the future and its prospective promises to be valuable in every bit.

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