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Ultrasound elastography in the evaluation of thyroid pathology. Current status

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ABSTRACT

Thyroid pathology including thyroid nodules and diffuse thyroid diseases represents often a diagnosing challenge for clinicians. US, although highly accurate in identifying thyroid nodules and diffuse thyroid diseases, is still not sufficiently accurate to evaluate them. US-elastography has been introduced in order to further increase US accuracy in many fields and eventually for thyroid disease. The aim of the present paper it to provide an update of the literature on different available techniques and the results reported both for thyroid nodules differentiation and for diffuse thyroid disease evaluation. Advantages and limitations of elastography are also discussed.

1. Introduction

Reported by Hippocrates, palpation is an ancient diagnostic technique used in several fields and especially for thyroid clinical evaluation. A firm or hard nodule consistency is associated with an increased risk of malignancy. A novel, evolving and fast expanding technology – elastography, based on the premise that pathologic processes such as cancer, alter the tissue stiffness, evaluates the mechanical features of tissue elasticity. By assessing hardness as indicator of malignancy, elastography has recently become an additional tool for thyroid nodule differentiation, in combination with conventional ultrasound (US) and fine-needle aspiration cytology (FNAC).

The current status of thyroid elastography, with regard to the techniques, applications, performance and limitations, are discussed in the present paper. We also briefly describe histologic notes of normal thyroid and its pathology, in correlation with their reported stiffness characteristics.

2. Examination technique

Elastography being a stiffness imaging modality, acquires information on the movement of tissue in response to a small applied pressure. In softer tissues, applied pressure causes the tissue to compress more whereas hard tissues compress less. This compressibility property is known as strain and it is displayed as an image (elastogram) or measured, using dedicated software [1,2].

Techniques of elastography applied to thyroid use two different types of compression force: the free-hand compression with the probe, quasi-static that uses the compression of the carotid artery pulsations or strain elastography (SE), with its qualitative and semi-quantitative variants, and the quantitative approach with compression induced by an acoustic pulse of the transducer, shear wave elastography (SWE).

2.1. Free hand quasi-static or strain elastography (SE)

SE is the most widely available method in commercial units. With the compression of the probe, it measures the

Abbreviations: ARFI, acoustic radiation force impulse; ECI, elasticity contrast index; FNAB, fine needle aspiration biopsy; NPV, negative predictive value; PPV, positive predictive value; ROI, region of interest; RTE, real time elastography; SE, strain elastography; SR, strain ratio; SWE, shear wave elastography; US, ultrasound.

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shape-deformation, providing a value of lesion stiffness compared to that of surrounding tissue. The induced displacements are estimated by tracking the echo delays acquired before and after the quasi-static compression and assessed by a dedicated software. SE is an add-on module that can be incorporated in standard ultrasound devices, with conventional ultrasound transducers, permitting the direct visualization of thyroid while performing stiffness evaluation. The strain is dependable on the compression, therefore in order to select optimal compressions and discard non-uniform ones, the quality of the operator's pressure, is displayed in real-time on the screen.

This technique allows a qualitative and a semi-quantitative assessment of elasticity [1,2].

2.1.1. Qualitative approach – real time elastography (RTE)

In RTE stiffness is displayed by an elastic image or elastogram as an elasticity color map superimposed on the B-mode images, similar to color-Doppler. During the ultrasound examination, using the same ultrasound machine and the same transducer, the operator exerts light repetitive pressure with the probe after setting for elastography acquisition [1,2]. In a region-of-interest (ROI) the stiffest structures, usually malignancies, (with lowest elastic strain or no strain) are displayed in blue or red, while the soft, most deformed tissues (with greatest elastic strain) in red or green or blue (according to the manufacturer) [1,2], while B-mode US and elastograms are displayed side-by-side on the screen.

Scoring systems with 4–5 scales, based on the predominant color pattern of the lesion, are an attempt for RTE systematization [2,3]. The subjectively determined score, combined with the operator-dependent free-hand compression, may contribute to interobserver variability [4,5].

2.1.2. Semi-quantitative approach – strain ratio elastography

Second-generation SE devices perform a semi-quantitative analysis: two ROIs are drawn over the lesion and the reference normal thyroid, and a strain ratio is generated in the device or off-line [6–8]. This evaluation does not directly represent the elasticity (i.e. Young's modulus), due to an array of technical reasons, mainly the difficulty of measuring the amount of the applied stress with the free hand.

2.1.3. Semi-quantitative approach – in vivo SE using carotid artery pulsation

The thyroid vibrates because of carotid artery pulsations, while the operator holds the probe gently and motionless, US signals in pre and post compression are tracked and strain images are generated [9,10]. A semi-quantitative evaluation with a ratio: the strain near carotid artery (high strain area) divided by the thyroid nodule strain, is termed thyroid stiffness index – TSI, or elasticity contrast index – ECI in other equipment [9–11].

2.2. Shear-wave measurement approach – the shear-wave elastography (SWE)

SE with free hand or carotid artery method, has shown some limitations, as strain acquisition is a parameter of relative stiffness and depends on the dynamics of the particular compression (strain changes with the applied compression). Instead, shear wave elastography (SWE) [12], using acoustic pressure from the probe, a standardization of compression, is a new technique, not available in all US systems, which is designed to provide quantitative elastic information in "real time". The transverse component of displacement of particles (the shear-wave) induced by an acoustic pulse of the linear US probe is measured. Shear waves are rapidly attenuated, and in order to assess them, immediately after generation, an ultrafast echographic sequence is emitted to track this lateral movement. Based on Young's modulus formula, the assessment of tissue elasticity can be derived from shear wave propagation speed. Quantitative information in the studied area is also delivered in m/s or in kPa (kilo-Pascal) depending on the type of SWE.

The quantitative nature of SWE, unlike the subjective elastogram evaluation at RTE, and the fact that, not the operator's hand with its variability, but the acoustic pulse moves the tissue, should improve consistency.

Literature reports two SWE methods used in thyroid: the Acoustic Radiation Force Impulse (ARFI) and the Supersonic Shear Wave.

2.2.1. SWE – acoustic radiation force impulse (ARFI)

ARFI uses short-duration (usually around 262 μs) acoustic pulses, to mechanically excite tissue within ROI, generating localized displacements that induce a lateral shear-waves. Though the amplitude of these shear waves is minute, they can be detected with multiple laterally positioned ultrasound "tracking" beams and analysing algorithms reconstruct the shear wave velocity by measurement of the time to peak [13,14]. The shear wave propagation velocity is proportional to the square root of tissue elasticity. The stiffer the tissue the faster the shear wave propagates. Results are expressed in m/s. ARFI, like free-hand elastography, is an add-on module that can be embedded in standard ultrasound devices, and uses the conventional linear transducer. Tissue stiffness measurements acquired by ARFI, are not used for generating color-coded elastograms as in the other methods.

Two ARFI methods involve qualitative and quantitative stiffness assessment: Virtual Touch tissue imaging (VTI) and Virtual Touch tissue quantification (VTQ); (Siemens Medical Solutions, Mountain View, CA) [13,14]. 10 measurements are generally used by some authors, for obtaining a reliable value [14].

2.2.2. SWE – the supersonic shear wave

SWE has features similar to ARFI technology, and uses focused ultrasonic beams, the so-called "pushing beams", with a patented technology called "Sonic Touch." Several pushing beams at increasing depths are transmitted to generate a quasi-plane shear wave frame that propagates throughout the whole imaging area. The measurement of the displacement induced, is used by Young's modulus formula for the measurement of elasticity in kPa (kilo Pascal) or in m/s. A color-coded superimposed image is displayed with blue for soft and red for hard, confusingly the opposite of color-coding of RTE, in which the color-coded scale is linked to the values in kPa ranging from 0 to 240 kPa [12,15,16]. Thus the technique permits a quantitative mapping of thyroid tissue viscoelasticity. A precise (kPa or m/s) evaluation is possible designing one or more ROI over the color-coded image.

3. Clinical applications

3.1. Normal thyroid

Elasticity of the gland depends on the structural properties of the matrix of tissues (cells, membranes, extravascular matrix, microvessels, etc.) whereas in conventional US, it is the microscopic structure that determines reflectivity. This means that in elastography, there is an image contrast based on histologic tissue structure, enabling the differentiation of normal gland from nodules and parenchymal diseases.

At RTE the normal thyroid has a soft appearance, homogeneously green with score 1, at times with green/red/yellow with score 2. A variability in elastography appearance of the normal gland could be an expression of the normal balance between parenchymal hyperplasia and involution, producing deviations from the usual histologic pattern [17].