

## REVIEW

# Ultrasound elastography in the head and neck. Part I. Basic principles and practical aspects

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### Abstract

Ultrasound elastography (USE) is a rapidly developing field of imaging that measures and displays tissue elasticity or stiffness properties using ultrasound. In recent years, real-time USE modes have appeared on commercially available clinical ultrasound machines, stimulating an explosion of research into potential oncologic and non-oncologic clinical applications of USE. Preliminary evidence suggests that USE can differentiate benign and malignant conditions accurately in several different tissues. This article presents an overview of the basic principles of different USE technologies that are currently under investigation in the head and neck region. In addition, more practical aspects pertaining to the optimal performance of USE at this site are discussed.

**Keywords:** *Ultrasound; elastography; acoustic radiation force impulse; shear wave elastography; thyroid; lymph nodes; salivary glands; neck.*

### Introduction

Elasticity imaging quantifies and displays tissue stiffness properties non-invasively by measuring their displacement in response to mechanical stimulation. The word elastography, first coined by Ophir et al. in 1991<sup>[1]</sup>, has become an umbrella term for any elasticity imaging technique. Using the same physical basis as clinical palpation, elastography has clinical usefulness because pathologic processes including cancer and fibrosis alter tissue elasticity (stiffness). Elasticity corresponds to a quantifiable biomechanical parameter called Young's elastic modulus, which can 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 explosion of research into ultrasound elastography (USE), which has been fuelled by its appearance on modern clinical ultrasound (US) machines. USE has been most extensively investigated in the breast where evidence suggests that it can improve the specificity of conventional US for breast malignancy without appreciably lowering its sensitivity<sup>[2]</sup>. USE has been evaluated for almost every tissue amenable

to transcutaneous or endoscopic US interrogation. At the time of writing, over 50 pilot studies have been published for USE in the head and neck region including the thyroid gland, cervical lymph nodes, salivary glands and miscellaneous neck masses. This article outlines the basic principles of USE and summarizes the published evidence regarding the accuracy of USE for malignancy in the head and neck.

### Basic principles

USE can be divided broadly into 2 groups depending on the type of tissue displacement that is tracked in tissues that have been subjected to a deforming force. Strain elastography measures tissue displacements occurring along the axis of an applied force, which are termed longitudinal, bulk or compression waves. An analogy of this type of displacement is that of an elastic spring that is compressed or relaxed along its length. Shear wave elastography measures a different type of wave that is also produced when tissues are mechanically stimulated. Shear waves are comparatively weak waves that are

generated by tangential sliding of tissue particles, which travel perpendicular to the direction of the applied force.

## Strain elastography

Strain elastography was the first technique to appear on clinical US systems because it could be performed using conventional US hardware with software modifications, and currently is the most widely published. Transducer positioning is similar to that of conventional US, with identification of the tissue of interest in the gray-scale image. Then either gentle intermittent freehand compression is applied via the transducer along the axis of the US beam (axial), or the transducer is held stationary and endogenous stimuli such as arterial pulsations or other physiologic motions are used to displace tissues. From the radiofrequency (RF) data received, tissue displacements along the beam axis (axial) are determined by comparison of successive image frames using software cross-correlation methods, and tissue strain (change in length/original length) is calculated for each spatial location. The resultant strain data are displayed graphically as a two-dimensional map of relative tissue strain, called an elastogram (Fig. 1). Elastograms are usually displayed as a semi-transparent overlay onto gray-scale images using a colour-coded scale that can vary between US systems. Nowadays, all commercial strain USE systems display strain elastograms dynamically, giving rise to the term real-time elastography (RTE).

Stiff lesions deform less than soft lesions for a given stress, and thus have lower strain.

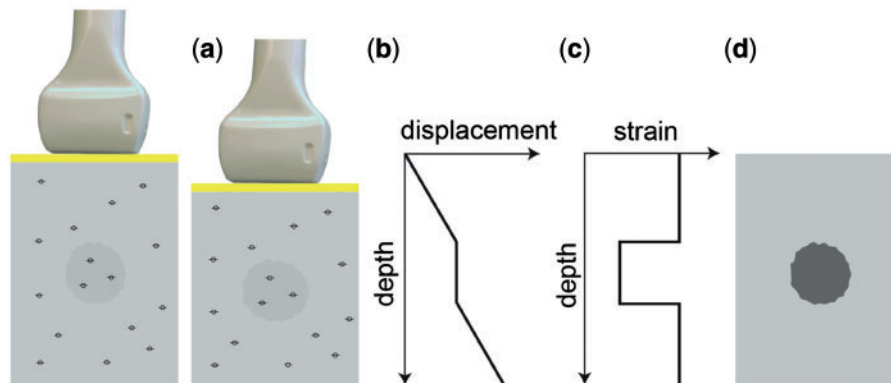
Strain (no units) = change in length/original length

Stress (kPa) = force/area

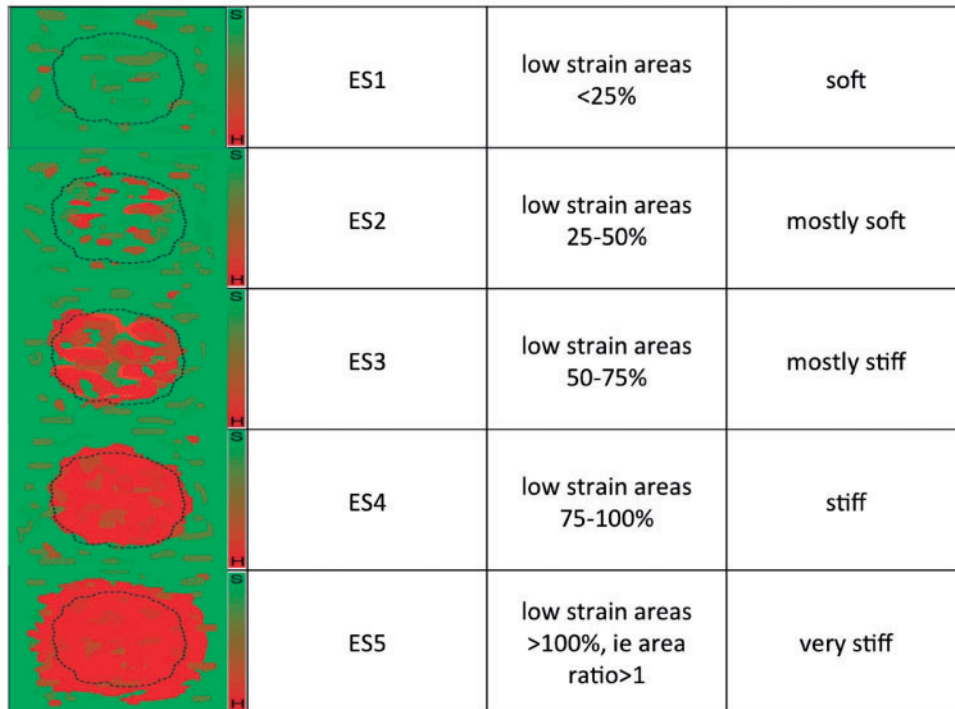
Stiffness  $\cong$  Young's elastic modulus (kPa) = stress/strain  
(Hooke's law)

Strain elastography is optimally performed using minimal strains ( $\sim 1\%$ ) as higher strains can alter tissue stiffness, resulting in misleading elastograms. Young's modulus cannot be calculated from strain elastograms because it is not possible to determine stress reliably for each spatial location due to factors that cause inhomogeneity in the stress field, such as boundary conditions and stress decay<sup>[3]</sup>.

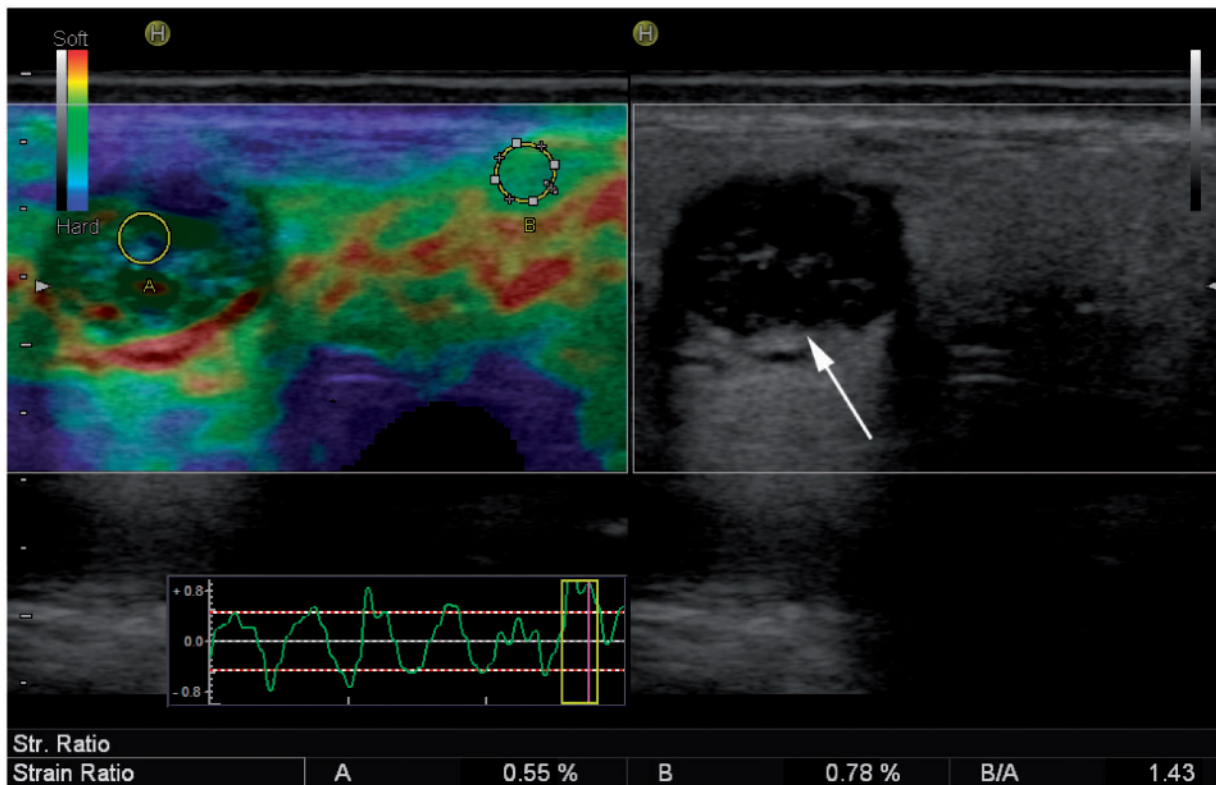
The earliest commercially available strain USE systems were only capable of producing elastograms, thus interpretation was by necessity qualitative. However, these have been superseded by second-generation systems that produce semi-quantitative output as strain ratios (SRs). There is no standardized method of interpreting elastograms qualitatively in the head and neck although many classification systems use a framework that was first described for breast elastography<sup>[4,5]</sup>. These assess lesion stiffness visually using a 4- to 6-point elastographic scale (ES) according to the relative proportion of low strain (high stiffness) areas within the lesion; stiffer lesions are assigned higher ES scores (Fig. 2). Other criteria such as margin regularity, distribution of stiff areas (e.g. peripheral rim versus central) and area ratios may also be included. Area ratio refers to the area of the lesion displaying low strain divided by the area of lesion visible on the corresponding gray-scale image. In the breast, high area ratios ( $>1$ ) are predictive of malignancy, which may reflect the presence of a peritumoural desmoplastic response<sup>[6-9]</sup>. For SR estimation, the ultrasonographer selects an electronic region of interest (ROI) in the tissue of interest and a reference tissue, and the ratio of strain between these is computed (Fig. 3). SRs are normally displayed such that values  $>1$  indicate the target lesion has lower strain (higher stiffness) than the reference tissue<sup>[10]</sup>.



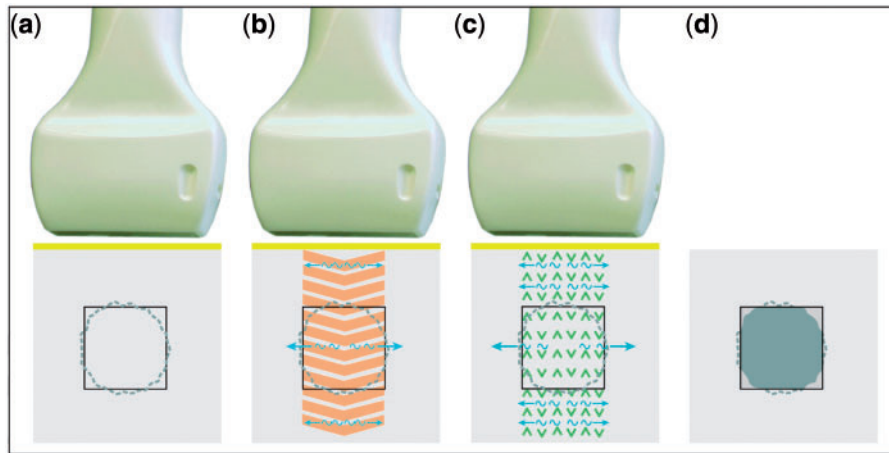
**Figure 1** Strain imaging schematic. A tissue containing a stiff lesion is compressed longitudinally by a transducer while performing US (a). Returning US signals are analysed to measure tissue displacements for different depths (b), which are converted to strain data (displacement/original length) (c). The graphs represent data from a single scan line through the middle of the lesion. The lesion shows minimal displacement and low strain compared with the reference tissue. The resulting strain data for multiple scan lines is displayed graphically as an elastogram corresponding to relative strain (d). This lesion is conspicuous on the elastogram due to its difference in strain compared with the surrounding tissue.



**Figure 2** Diagram showing a qualitative scoring system for lesions assessed using strain elastography. The lesion's margin on the corresponding B mode image is shown by the dotted line. Lesions are visually graded from ES1 to ES5 based on the relative proportion of low strain (red) and high strain (green) areas. Low and high ES scores suggest a soft and stiff lesion compared with the surrounding tissue, respectively.



**Figure 3** Strain elastogram with the corresponding gray-scale US image of a benign hyperplastic thyroid nodule (white arrow) showing a colour-coded map and ROIs placed to calculate the strain ratio. An ROI is placed in the nodule and the surrounding parenchyma. The SR was 1.43, which indicates a stiffer lesion than the normal parenchyma.



**Figure 4** Schematic illustration of shear wave imaging. (a) An elastography ROI (black box) is placed over a mass on the gray-scale US image. (b) High-intensity acoustic impulses (orange arrows) are transmitted into the tissue, which induce shear waves (blue). (c) Diagnostic impulses (green arrows) track shear wave propagation. In this example, shear waves travel faster in the mass than the background parenchyma. (d) The SWE map displays the mass on the basis of its stiffness contrast compared with the adjacent parenchyma.

### Shear wave elastography

Recently, quantitative USE systems utilizing shear wave elastography (SWE) have appeared. In SWE systems, a specially modified transducer produces focused impulses of high-intensity acoustic radiation (ultrasound), termed push pulses, at specific locations within the tissue of interest. This induces shear waves, whose velocities are tracked by a series of normal intensity impulses using ultrasound correlation methods<sup>[11]</sup> (Fig. 4). Shear waves propagate in solids but not true liquids, and travel with a velocity proportional to the square root of the tissue stiffness, according to the following formula:

$$E = 3\rho c^2$$

where  $E$  is stiffness, i.e. Young's elastic modulus (kPa),  $c$  is the shear wave velocity (m/s), and  $\rho$  is the density (kg/m<sup>3</sup>). For most soft tissues,  $\rho$  approximates the density of water (1000 kg/m<sup>3</sup>).

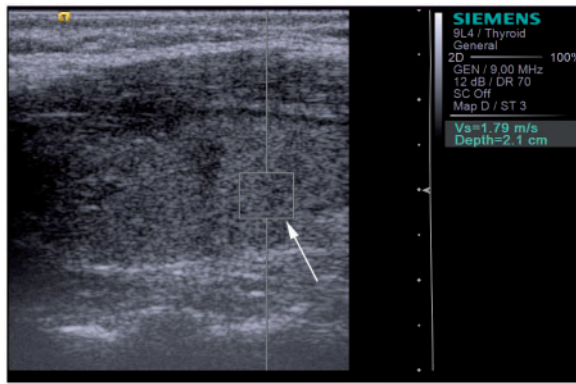
The precise implementation of SWE technology differs between US system manufacturers, and are given different descriptions including ARFI (acoustic radiation force impulse) imaging and SSI (supersonic shear imaging). In ARFI systems, the ultrasonographer positions a fixed size ROI (typically a  $5 \times 5$  mm box) over the tissue of interest on the gray-scale image, triggers the ARFI capture mode, and shortly afterwards an estimate of the mean shear wave velocity value of the ROI is displayed (Fig. 5). Real-time elastograms are not generated by current ARFI systems and although this method is quantitative in terms of displaying an estimate of the shear wave velocity, the elastic modulus is not calculated. However, another US system manufacturer uses proprietary technology termed SSI, in which a relatively large field of view is interrogated using supersonic speed push pulses

that induce and amplify shear waves, and the induced shear waves are tracked throughout the entire window using ultrafast ultrasound tracking impulses and computationally demanding software post-processing<sup>[12]</sup>. This system displays real-time colour-coded elastograms of shear wave velocity (m/s) or elastic modulus (kPa), and quantitative elastic modulus measurements can be obtained for ROIs placed within static elastograms (Fig. 6).

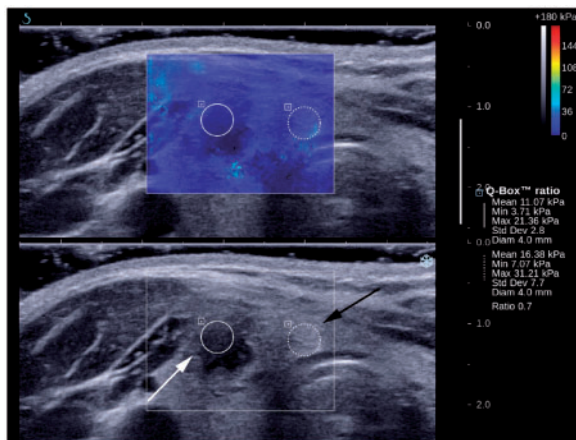
### General comments regarding USE

USE is quick to perform and well tolerated by patients, adding only a few minutes per lesion to conventional sonographic examinations. There are several caveats when performing USE. As USE requires returning RF signals to generate a signal, it is unsuitable for lesions that are obscured (e.g. by rim calcifications) or contain too few acoustic reflectors (markedly hypoechoic/anecchoic lesions). Strain elastography requires a reference tissue in the elastogram because it displays relative strain. By contrast, SWE is an absolute quantitative method and thus can be performed for lesions that are larger than the elastographic window. Both strain elastography and SWE are unreliable for tissues more than a few centimetres deep to the skin surface using currently available linear transducers due to progressive decay of the stress field at increasing distances away from the stimulus. Strain elastography is also unreliable for lesions that are partially cystic because the liquid component may dissipate the applied stress rather than transmit it to the adjacent solid component, which may result in solid components appearing artefactually stiff<sup>[13]</sup>. Assessment of very superficial lesions may be hindered by the presence of artefacts in the near field caused by



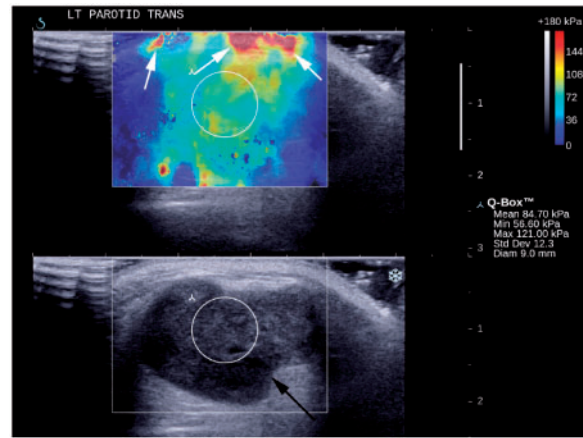


**Figure 5** Longitudinal US image of a thyroid lobe in a patient with multinodular goitre showing ARFI measurement in a region of normal thyroid parenchyma (white arrow). The ROI for ARFI measurement is a square box of fixed dimensions ( $\sim 5 \times 5$  mm). The mean ARFI velocity for the ROI is 1.79 m/s. This system does not generate elastograms. Image provided courtesy of Dr Chander Lulia, Ria Clinic, Mumbai.



**Figure 6** Transverse gray-scale US image with corresponding shear wave elastogram of a hypoechoic thyroid nodule (white arrow), which was confirmed to be a benign hyperplastic degenerative nodule. ROIs are placed in the nodule and adjacent parenchyma (black arrow). The mean SWE stiffness of the nodule is 11.1 kPa and of the parenchyma is 16.4 kPa.

stress concentration that occurs when a transducer is applied onto the skin (Fig. 7). Furthermore, the boundary of structures with very different stiffnesses can produce localized distortions of the stress field, resulting in artefacts. Several other types of artefact have been described in the head and neck for RTE<sup>[14]</sup> and SWE<sup>[15–17]</sup>. These artefacts must be recognized by the ultrasonographer to prevent misinterpretation of elastograms.



**Figure 7** Transverse gray-scale US image with corresponding shear wave elastogram of a hypoechoic parotid nodule (black arrow), which was confirmed to be a pleomorphic adenoma. There is focal stress concentration in the superficial tissues overlying the nodule, seen here as regions of red colour on the elastogram (white arrows). Some of the high stiffness areas appear to extend into the superficial aspect of the nodule. Stress concentration may be problematic for assessing superficial head and neck lesions that produce a marked convex bulge of the skin.

Both strain elastography and SWE are operator dependent, requiring careful attention to practical technique. Minimal pressure should be applied with the transducer on the skin during acquisitions because tissue elastic modulus varies according to the amount of resting pressure applied, termed precompression. In this regard, excessive precompression increases the stiffness of tissues globally while lowering relative stiffness contrast between different tissues, which can produce misleading elastograms<sup>[18]</sup>. Strain elastography using freehand compression is highly dependent on compression technique for 2 reasons. First; as described above, excessive compression alters tissue stiffness, and second; non-axial displacements (i.e. displacements occurring laterally or out of the imaging plane) can degrade the accuracy of software correlation algorithms, resulting in decorrelation artefacts and suboptimal elastograms. Applying an appropriate level of axial compression appears straightforward but can be challenging in the neck. This is due to the varying mobility of different structures in the neck, which can slide non-axially under compression, and the competing effects of other physiologic motions such as adjacent arterial pulsations and breathing. More recent commercial strain elastography systems can monitor and feed back information regarding compression quality in the form of visual scales and graphs, which operators can view in real time to optimize their compression technique. Because SWE does not require freehand compressions, it may be less operator dependent than strain imaging. Nevertheless, USE using either technique can

be problematic if there is a focal convex bulge of the skin overlying the tissue of interest because, under these circumstances, it may not be possible to apply a linear transducer without producing focal stress concentration within the tissue of interest, resulting in spuriously stiff elastograms (Fig. 7).

USE elastogram interpretation is also operator dependent for several reasons. First, dynamic elastograms can appear unstable due to software processing artefacts as well as genuine tissue displacements being detected within the imaging window. Although elastograms can be stabilized to a variable degree by software temporal and spatial averaging techniques, bulk tissue motions occurring during compression–relaxation cycles or other subtle tissue movements means that selecting a representative static image from a dynamic series remains challenging in clinical practice. Second, qualitative interpretation of elastograms is inherently subjective. Third, selecting representative ROIs for SR or SWE measurements is subjective and complicated by the fact that many tissues are spatially heterogeneous on USE.

Given the multiplicity of factors that can produce variations in USE, its reproducibility should be determined, although surprisingly this issue has been addressed in a relatively small number of studies on the head and neck. An early study of qualitative strain elastography of thyroid nodules using a first-generation USE system documented poor interobserver agreement<sup>[19]</sup>, whereas a few more recent studies using second-generation USE systems have reported good to excellent interobserver agreement<sup>[20–22]</sup>. The discrepancy in results may have several explanations although it is possible that a major contributing factor was the inclusion of compression quality feedback scales in the more recent studies, which may have enabled ultrasonographers to optimize and standardize their freehand compression techniques and select only high-quality elastograms for analysis. Some investigators have evaluated thyroid USE using intrinsic carotid pulsations instead of freehand compression, and have documented highly reproducible results<sup>[23]</sup>. For SWE, reproducibility data from individual studies indicate fair to excellent interobserver agreement<sup>[24–26]</sup>. However, absolute values of stiffness obtained using SWE for benign and malignant thyroid nodules have differed appreciably between publications, raising questions regarding its reproducibility<sup>[15,24,27]</sup>. The reproducibility of USE for other sites in the head and neck has been investigated in only a couple of studies<sup>[26,28]</sup>. A recent study of quantitative SWE in the head and neck documented fair to excellent interobserver agreements for all head and neck sites, although agreement was higher for thyroid lesions compared with other neck masses, and for benign compared with malignant lesions<sup>[26]</sup>. Further research is required to determine precisely how and to what extent specific tissue characteristics influence the reliability of USE in the head and neck.

## Conflict of interest

The authors have no conflicts of interest to declare.

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## References

- [1] Ophir J, Cespedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: a quantitative method for imaging the elasticity of biological tissues. *Ultrason Imaging* 1991; 13: 111–134. PMID:1858217.
- [2] Berg WA, Cosgrove DO, Dore CJ, et al. Shear-wave elastography improves the specificity of breast US: The BE1 multinational study of 939 masses. *Radiology* 2012; 262: 435–449. doi:10.1148/radiol.11110640. PMID:22282182.
- [3] Garra BS. Imaging and estimation of tissue elasticity by ultrasound. *Ultrasound Q* 2007; 23: 255–268. doi:10.1097/ruq.0b013e31815b7ed6. PMID:18090836.
- [4] Itoh A, Ueno E, Tohno E, et al. Breast disease: clinical application of US elastography for diagnosis. *Radiology* 2006; 239: 341–350. doi:10.1148/radiol.2391041676. PMID:16484352.
- [5] Ueno E, Ito A. Diagnosis of breast cancer by elasticity imaging. *Eizo Joho Medical* 2004; 36: 2–6.
- [6] Lyshchik A, Higashi T, Asato R, et al. Elastic moduli of thyroid tissues under compression. *Ultrason Imaging* 2005; 27: 101–110. doi:10.1177/016173460502700204. PMID:16231839.
- [7] Hall TJ, Zhu Y, Spalding CS. In vivo real-time freehand palpation imaging. *Ultrasound Med Biol* 2003; 29: 427–435. doi:10.1016/S0301-5629(02)00733-0. PMID:12706194.
- [8] Regner DM, Hesley GK, Hangiandreou NJ, et al. Breast lesions: evaluation with US strain imaging—clinical experience of multiple observers. *Radiology* 2006; 238: 425–437. doi:10.1148/radiol.2381041336. PMID:16436810.
- [9] Barr RG, Destounis S, Lackey LB, 2nd, Svensson WE, Balleyguier C, Smith C. Evaluation of breast lesions using sonographic elasticity imaging: a multicenter trial. *J Ultrasound Med* 2012; 31: 281–287. PMID:22298872.
- [10] Luo S, Lim DJ, Kim Y. Objective ultrasound elastography scoring of thyroid nodules using spatiotemporal strain information. *Med Phys* 2012; 39: 1182–1189. doi:10.1118/1.3679857. PMID:22380349.
- [11] Palmeri ML, Nightingale KR. Acoustic radiation force-based elasticity imaging methods. *Interface Focus* 2011; 1: 553–564. doi:10.1098/rsfs.2011.0023. PMID:22419986.
- [12] Bercoff J, Tanter M, Fink M. Supersonic shear imaging: a new technique for soft tissue elasticity mapping. *IEEE Trans Ultrason Ferroelectr Freq Control* 2004; 51: 396–409. doi:10.1109/TUFFC.2004.1295425. PMID:15139541.
- [13] Azizi G, Keller J, Lewis Pa M, Puett DW, Rivenbark K, Malchoff CD. Performance of elastography for the evaluation of thyroid nodules: a prospective study. *Thyroid* 2012; Nov 8. [Epub ahead of print].
- [14] Bhatia KS, Rasalkar DP, Lee YP, et al. Cystic change in thyroid nodules: a confounding factor for real-time qualitative thyroid ultrasound elastography. *Clin Radiol* 2011; 66: 799–807. doi:10.1016/j.crad.2011.03.011. PMID:21530955.
- [15] Bhatia KS, Tong CS, Cho CC, Yuen EH, Lee YY, Ahuja AT. Shear wave elastography of thyroid nodules in routine clinical practice: preliminary observations and utility for detecting malignancy. *Eur Radiol* 2012; 22: 2397–2406. doi:10.1007/s00330-012-2495-1. PMID:22645042.

- [16] Bhatia KS, Cho CC, Tong CS, Lee YY, Yuen EH, Ahuja AT. Shear wave elastography of focal salivary gland lesions: preliminary experience in a routine head and neck US clinic. *Eur Radiol* 2012; 22: 957–965. doi:10.1007/s00330-011-2364-3. PMID: 22200901.
- [17] Slapa RZ, Piwowonski A, Jakubowski WS, et al. Shear wave elastography may add a new dimension to ultrasound evaluation of thyroid nodules: case series with comparative evaluation. *J Thyroid Res* 2012; 657147. PMID:22685685.
- [18] Barr RG, Zhang Z. Effects of precompression on elasticity imaging of the breast: development of a clinically useful semiquantitative method of precompression assessment. *J Ultrasound Med* 2012; 31: 895–902. PMID:22644686.
- [19] Park SH, Kim SJ, Kim EK, Kim MJ, Son EJ, Kwak JY. Interobserver agreement in assessing the sonographic and elastographic features of malignant thyroid nodules. *AJR Am J Roentgenol* 2009; 193: W416–W423. doi:10.2214/AJR.09.2541. PMID:19843721.
- [20] Ragazzoni F, Deandrea M, Mormile A, et al. High diagnostic accuracy and interobserver reliability of real-time elastography in the evaluation of thyroid nodules. *Ultrasound Med Biol* 2012; 38: 1154–1162. doi:10.1016/j.ultrasmedbio.2012.02.025. PMID:22542262.
- [21] Merino S, Arrazola J, Cardenas A, et al. Utility and interobserver agreement of ultrasound elastography in the detection of malignant thyroid nodules in clinical care. *AJNR Am J Neuroradiol* 2011; 32: 2142–2148. doi:10.3174/ajnr.A2716. PMID:22051809.
- [22] Kim JK, Baek JH, Lee JH, et al. Ultrasound elastography for thyroid nodules: a reliable study? *Ultrasound Med Biol* 2012; 38: 1508–1513. doi:10.1016/j.ultrasmedbio.2012.05.017. PMID: 22766122.
- [23] Lim DJ, Luo S, Kim MH, Ko SH, Kim Y. Interobserver agreement and intraobserver reproducibility in thyroid ultrasound elastography. *AJR Am J Roentgenol* 2012; 198: 896–901. doi:10.2214/AJR.11.7009. PMID:22451558.
- [24] Veyrieres JB, Albarel F, Lombard JV, et al. A threshold value in Shear Wave elastography to rule out malignant thyroid nodules: a reality? *Eur J Radiol* 2012; 81: 3965–3972. doi:10.1016/j.ejrad.2012.09.002. PMID:23031543.
- [25] Zhang YF, Xu HX, He Y, et al. Virtual touch tissue quantification of acoustic radiation force impulse: a new ultrasound elastic imaging in the diagnosis of thyroid nodules. *PLoS One* 2012; 7: e49094. doi:10.1371/journal.pone.0049094. PMID:23152855.
- [26] Bhatia K, Tong CS, Cho CC, Yuen EH, Lee J, Ahuja AT. Reliability of Shear Wave ultrasound elastography for neck lesions identified in routine clinical practice. *Ultraschall Med* 2012; Sep 21. [Epub ahead of print].
- [27] Sebag F, Vaillant-Lombard J, Berbis J, et al. Shear wave elastography: a new ultrasound imaging mode for the differential diagnosis of benign and malignant thyroid nodules. *J Clin Endocrinol Metab* 2010; 95: 5281–5288. doi:10.1210/jc.2010-0766. PMID:20881263.
- [28] Bhatia KS, Cho CC, Yuen YH, Rasalkar DD, King AD, Ahuja AT. Real-time qualitative ultrasound elastography of cervical lymph nodes in routine clinical practice: interobserver agreement and correlation with malignancy. *Ultrasound Med Biol* 2010; 36: 1990–1997. doi:10.1016/j.ultrasmedbio.2010.08.016. PMID:20950927.