How to perform shear wave elastography. Part I

Giovanna Ferraioli[1], Richard G Barr[2], André Farrokh[3], Maija Radzina[4], Xin Wu Cui[5], Yi Dong[6], Laurence Rocher[7], Vito Cantisani[8], Eleonora Polito[8], Mirko D'Onofrio[9], Davide Roccarina[10,11], Yasunobu Yamashita[12], Manjiri K. Dighe[13], Daniela Fodor[14], Christoph F Dietrich[15]

[1]Department of Clinical, Surgical, Diagnostic and Pediatric Sciences, Medical School University of Pavia, Pavia, Italy, [2]Northeastern Ohio Medical University, Rootstown, Ohio, USA, [3]University Hospital Schleswig-Holstein, Campus Kiel, Department of Gynecology and Obstetrics, Germany, [4]Diagnostic Radiology Institute, Paula Stradins Clinical University Hospital, Riga, Latvia, [5]Sino-German Tongji-Caritas Research Center of Ultrasound in Medicine, Department of Medical Ultrasound, Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China, [6]Department of Ultrasound, Zhongshan Hospital, Fudan University, Shanghai, China, [7]Service de Radiologie, APHP Hôpitaux Paris Saclay, Hôpital Antoine Béclère, Clamart, France. Université Paris Saclay, Le Kremlin-Bicêtre, France, [8]Department of Radiology, Oncology, Anatomo-Pathology, Sapienza-University of Rome, Rome, Italy, [9]Department of Radiology, University Hospital G.B. Rossi, University of Verona, Italy, [10]Sheila Sherlock Liver Unit and UCL Institute for Liver and Digestive Health, Royal Free Hospital, London, UK, [11]SOD Medicina Interna ed Epatologia, Azienda Ospedaliero-Universitaria Careggi, Florence, Italy, [12]Second Department of Internal Medicine, Wakayama Medical University, Wakayama, Japan, [13]Department of Radiology, University of Washington, Seattle, USA, [14]2nd Internal Medicine Department, "Iuliu Hatieganu" University of Medicine and Pharmacy, Cluj-Napoca, Romania, [15]Department Allgemeine Innere Medizin (DAIM), Kliniken Hirslanden Beau Site, Salem und Permancence, Bern, Switzerland

Abstract

We recently introduced a series of papers describing how to do certain techniques. This article is the first part of a review of shear wave elastography (SWE). It reports the principles and interpretation of the technique and describes how to optimize it. Normal values, pitfalls and artefacts for the examination of liver, breast. thyroid and salivary gland with shear wave elastography are presented. The manuscript provides specific tips for applying SWE as part of a diagnostic US examination.

Keywords: ultrasound; elastography; elastometry; technique

Introduction

Ultrasound (US) elastography is a method to determine tissue stiffness. It is similar to palpation used in the physical examination. According to the current EFSUMB [1-5] and WFUMB guidelines [6-9] two types of US elastography can be defined: strain elastography (SE) and shear wave elastography (SWE). Strain uses an ap-

plied force either by palpation or an Acoustic Radiation Force Impulse (ARFI) method to create and receive information about tissue displacement associated with the elastic restoring forces in the tissue that act against shear deformation as a function of time and space to display biomechanical properties. This method has been previously described in detail [10,11].

Aim

Two articles on "how to perform strain imaging techniques" have been recently published using conventional [10] and endoscopic US elastography [11]. This article is the first part of a review of SWE applied to several organs. It describes how to optimize the examination technique, discussing normal values, pitfalls and artefacts for the examination of the liver, breast. thyroid and salivary glands. The manuscript provides more specific tips for applying SWE as part of a diagnostic US examination.

Shear wave based elastography – how does it work?

SWE techniques include vibration controlled transient elastography (VCTE) and ARFI based techniques. The shear waves are generated by a body-surface vibration, as in VCTE, or by the push-pulse of a focused US beam, as in ARFI techniques. In VCTE, a body-surface vibration creates a shear wave, which then travels to the organ of interest. The frequency of the vibration is controlled (50 Hz), as are its shape and amplitude. VCTE is implemented on the Fibroscan®, which is a dedicated device that does not display an anatomical image. In ARFI-based techniques, the shear waves are generated directly in the tissue. A convex or linear transducer transmits focused US pulses (also known as a push pulses or ARFI) that generate shear waves. The pulses are repeated several times over a short period of time, and the shear waves generated travel at a much slower rate than US. B-mode tracking pulses are used to detect the propagation velocity of the shear wave [12] by measuring the difference in arrival time (time lag) between two points at known distances apart from each other [1,6,13]. Such push pulses generate much slower shear waves off-axis [14]. ARFI-based techniques include point shear-wave elastography (pSWE) and multidimensional SWE (2D-SWE, 3D-SWE). pSWE measures the stiffness at the focal ($\sim$1cm^3) point in the tissue whereas with 2D-SWE the stiffness is measured over a much larger area and a color-coded image of the qualitative elastic properties is displayed on the monitor of the US system [3,4].

Shear wave speed

The shear wave speed (SWS) is almost one thousand times lower than the velocity of US in soft tissues, the shear waves attenuate very rapidly and some do not propagate in the simple fluids [14]. The shear wave propagates faster in stiffer tissue than in softer tissue. The expected SWS in the liver in normal and pathologic states is typically in the range 0.7 to 5.0 m/s (1.5 kPa to 75 kPa). For breast cancers it can be up to 10 m/s (300 kPa) and even higher for normal tendons. Pathology in any tissue often creates changes in tissue stiffness making elastography a method to characterize pathological changes. SWS values may vary depending on the vendor; therefore, vendor specific cut-off values may be necessary.

Differences of equipment

Different equipment may give different values of stiffness within the same tissue in the same patient. This is because the measured values of SWS will vary with a number of system factors, in particular shear-wave vibration mean frequency and bandwidth. In addition, measurement bias may occur due to the algorithm employed to calculate relative shear wave arrival time and speed.

kPa or can they change to m/s?

The propagating speed [12] of the generated shear wave is reported in meters per second (m/s) but can also be converted to Young's modulus values in kilopascals (kPa) by applying the formula $E=3\rho Vs^2$, where E is tissue elasticity, Vs is the shear wave speed, and ρ is the density of tissue in kg/m^3, and making some assumptions [1-3,6]. One main reason why it is preferable to report results in units of ms^{-1} rather than kPa is the fact that the SWS is measured by the scanner in ms^{-1}. However, mainly for liver application, the units of the Young's modulus are largely used, as many clinicians are familiar with them.

Angle of insonation

The angle of insonation has a significant influence on the measurement, which is of importance when a curved transducer is used [15]. The shear waves are generated perpendicular to the ARFI push pulse therefore the B-mode tracking must be in the same angle to accurately estimate the SWS.

Region of interest

The ROI should be positioned so that the push pulse is generated perpendicular to the center of the transducer surface. For more information about the technology we also refer to the recently published guidelines on elastography [1,7,15,16].

Does the size and/or the shape of the ROI influences measurements?

The size of the ROI depends on the tissue being evaluated. Even though a larger ROI would give SWE information over a larger amount of tissue, it risks the inclusion of artifacts particularly in heterogeneous masses. By using two different 2D-SWE US systems, it has been shown that, for the assessment of breast lesions, a small round ROI (approximately 2 mm in diameter) placed over the stiffest area of the lesion was more accurate than a larger ROI manually drawn along the margin of the lesion [17]. In another study that assessed the influence on the accuracy of 2D-SWE in evaluating breast lesions by using three different ROI size (1, 2 and 3 mm), the diagnostic accuracy was not affected by changing the ROI size [18]. In general, malignant lesions are heterogeneous in stiffness and using the area of highest stiffness is more accurate in characterizing the lesion. However, for homogenous tissue like liver, a larger ROI can average the stiffness over a larger area of tissue.

In ex vivo study involving porcine muscle, a significant increase of SWS (*p<0.001*) was observed for larger ROI widths. In this animal model, the SWS was also influenced by several other factors, including probe frequency, applied pressure, muscle orientation, different machine settings, and placement depth [19].

Artefacts

SWE images are reconstructed using time-of-flight based images. In heterogeneous tissues these algorithms might introduce a variety of artifacts. One of them is SWE under- and overestimation from reflections at stiffness interfaces. Reflected waves violate the assumption of a single direction of propagation, leading to artifacts in SWE images [20]. To avoid this, directional filters had been applied [20,21]. By separating the forward and backward components, it is possible to almost entirely remove the reflected wave [21]. It is highly recommended in transient shear wave applications to avoid reflection artifacts. For liver assessment, common artifacts include reverberation from the liver capsule, respiratory/cardiac motion and vessel pulsation/loss of the SWE signal (fig 1). The penetration of the US beam can also generate artifacts since consistent elasticity estimates cannot be obtained in the far field due to attenuation of the ARFI pulse. The most consistent estimates are generally obtained near the focus zone of the ARFI pulse, where the largest displacements is generated by the push pulses [22]. A detailed analysis of all the artifacts is out of the scope of this review article and can be found elsewhere [22-24].
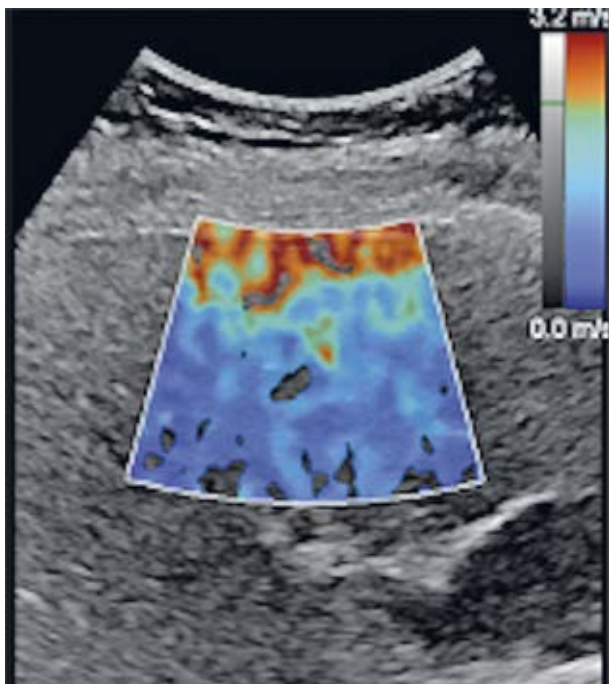
Fig 1. Example of the reverberation artifact from the liver capsule in SWE. The red and teal areas are the artifacts; the blue areas are the accurate stiffness measurements. Note that in p-SWE a color map is not provided, so it is critical to place the ROI box 1.5-2 cm below the liver capsule. Whereas in 2D-SWE the artifact can be identified on the color map and be avoided.

Liver

Main objective, clinical value

The liver is an important target organ for the use of elastography; stiffness correlates with the degree of fibrosis and indirectly with portal hypertension and the risk of developing hepatocellular carcinoma. Due to the large overlap between stiffness values, guidelines do not recommend the use of SWE to differentiate benign and malignant focal liver lesions [15,25-28].

The most important clinical management may be summarized as follows:
1. SWE values within the normal range can rule out compensated advanced chronic liver disease (cA-CLD) when in agreement with the clinical and laboratory data.
2. SWE technologies perform best to rule out cirrhosis.
3. SWE technologies can be used as first line assessment for the severity of liver fibrosis but are much less reliable in differentiating intermediate stages of fibrosis.
4. An interquartile range/median (IQR/M) ≤30% with measurements taken in kPa or <15% when taken in m/s is the most important reliability criterion [29].

"Knobology"
Prerequisites

The user should always refer to the manufacturer's recommendations for a good quality measurement. The parameters that should be taken into account vary from one manufacturer to another and include judgment of the signal-to-noise ratio or the stability of the signal over time (2D-SWE acquisitions). Several manufacturers have developed quality criteria for either pSWE or 2D-SWE techniques. The users must always refer to them when they are available.

Transient elastography: probe selection

In transient elastography (TE) three different probes are available (S, M and XL probes). The S probe is used in children with a thoracic belt <75 cm whereas the XL probe is dedicated to overweight/obese subjects with more reliable results as compared with the M probe. The XL probe must be used when the skin-to-liver capsule distance is higher than 25 mm. Limiting factors for the XL probe are a skin-to-liver capsule distance >3.4 cm and extreme obesity (BMI >40 kg/m²) [3,4,28]. Values obtained with XL probe are usually lower than with the M probe, therefore no recommendation on the cut-offs to be used can be given.

ARFI-based techniques: transducer (frequency) selection

In adults, the convex transducer is used for performing the elastography studies, whereas in children the choice of the probe, either the linear or the curvilinear one, depends on the body habitus and age. Generally, the

same rule used for the choice between the two probes for the B-mode image of the liver applies also to the assessment of liver stiffness (LS) in children. However, it should be kept in mind that the difference in frequency between the two probes gives different readings in the same subject. In phantom studies, it has been shown that the readings with the higher frequency of the linear transducer are higher than those obtained with the convex transducer. Moreover, in children the acquisition could be more challenging due to the lack of cooperation and this could affect the feasibility of the technique [30,31].

Description of (other) parameters

The strength of the push-pulse is higher in the center of the transducer, thus the sampling should be done in the central area of the image, whereas the sampling at the edge should be avoided.

The influence of depth on the estimation of the elastic properties is not negligible [32]. The acoustic push pulse is progressively attenuated as it traverses the tissue. The results with the lowest variability are obtained at a depth of 4-5 cm from the skin surface [33]. The attenuation is higher in stiffer liver, thus in cirrhotic or steatotic patients, measurements are more variable [15]. The ROI box should be perpendicular to the transducer.

Region of interest (ROI) size, shape, others

The region of interest should be in between 2-6 cm below the liver capsule.

In pSWE the size of the region of interest (ROI) is small and fixed by the manufacturer because the technique assesses the stiffness at a single location by using a sequence of push-pulses, generally up to five.

In 2D-SWE the size of the ROI is user-adjustable and can theoretically be as large as the ARFI FOV image. However, the larger the ROI the higher the risk of including artifacts. Thus, generally the ROI's size in SWE technique may influence the quality of the elastogram. Following EFSUMB guidelines and recommendations, we suggest using an ROI of 2.5x2.5 cm in size [3,4]. Many vendors have quality or confidence maps, which help to identify and avoid artifacts [15].

Position of the transducer

The measurements should be performed through the intercostal space rather than the subcostal approach yielding the highest intra- and interobserver agreement [15,34-36].

Description of quality parameters

The most important criterion for a measurement of good quality seems an IQR/M ≤30% when the results are reported in Young's modulus [29]. This ratio, in fact, is a measure of the variability between consecutive acquisitions, and studies have reported a decrease in accuracy when this criterion is not fulfilled [37-41]. For measure-

ment reported in m/s the IQR/M should be ≤15% because the conversion between the two is not linear [29].

Pre-compression

Pre-compression should be avoided.

How many measurements?

Based on literature data, for the pSWE technique the EFSUMB and WFUMB guidelines have recommended to use the median value of 10 acquisitions [3,4,9]. However, some studies have shown that the accuracy does not decrease when fewer acquisitions (up to five) are obtained [38-40,42]. For 2D-SWE, the EFSUMB updated guidelines have recommended to obtain at least three acquisitions [3,4]. The updated WFUMB and SRU guidelines are more cautious and have suggested five acquisitions when a quality factor is available [9,43]. The higher number of acquisitions suggested by the WFUMB updated guidelines may give a better estimation of the variability assessed through the calculation of the IQR/M ratio.

Reproducibility

The intra-observer reproducibility of VCTE [44-46], pSWE [34,36,47-49] and 2D-SWE [50-52] for LS assessment is excellent with ICC above 0.90.

How to use shear wave elastography

The transducer should be positioned in an intercostal space; perpendicular to the liver in both superior/inferior and right/left planes, avoiding the ribs or the lung artifacts. As the SWS is calculated based on B-mode, the quality of the B-mode US image affects the quality of the SWE acquisitions. The most common limitations encountered with US, i.e. poor acoustic window, limited penetration, and rib or lung shadowing, may influence both the feasibility and the performance of the SWE techniques. Some of these limitations can be avoided, thus the operator should obtain an optimal scan of the liver before launching the acquisition. The perpendicular position of the transducer can be assessed by looking at the liver capsule that appears as a sharp white line, parallel to the transducer's line (fig 2). Motion of the probe or of the patient affects the quality of the measurement as well. The patient should breathe normally while the operator is searching for the best acoustic window and for the best area of liver parenchyma where the sample box will be positioned. This area should be homogeneous, i.e., free of vessels or ligaments. Before launching the acquisition, the operator asks the patient to hold the breath in a neutral position without performing a Valsalva's maneuver for the few seconds needed for the acquisition [15]. Special applications in pediatric patients are discussed elsewhere [30,31,53].

Tips and tricks

Depth as assessed by the skin-to-liver capsule distance may influence the SWS values assessed by all
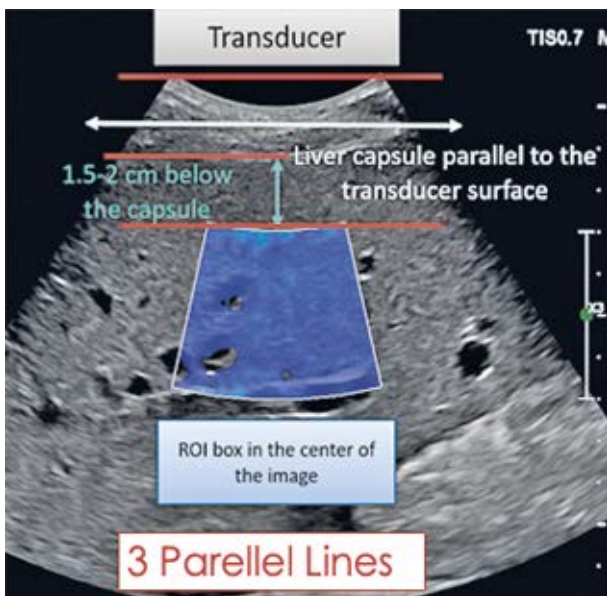
Fig 2. Figure demonstrating the positioning of the liver capsule and FOV box in liver stiffness assessment. The transducer, liver capsule and top of the FOV box should be parallel lines. The liver capsule should be a sharp echogenic line.

SWE-techniques. Due to the attenuation of the US beam, the depth for reliable measurements is up to 7 cm in most systems; measurements performed deeper have a lower signal/noise ratio. Using a deep abdominal probe may allow for measurements at a greater depth in high BMI patients. In ARFI techniques, the US beam that generates the shear waves is also attenuated by the interaction with the tissue that it traverses thus, its strength is inversely related to the depth; this attenuation is higher in cases of liver steatosis or severe fibrosis. Due to these factors, measurements in patients with significant liver steatosis or severe fibrosis could have a higher rate of unreliable results or failures. This is also true in obese patients with thick subcutaneous tissue due to higher attenuation of the US beam in the near field. In staging liver fibrosis, Metavir-derived cutoff values are system-specific and could not be applied interchangeably across different US systems. A recent study has shown that the agreement between LS measurements obtained with different US systems is good to excellent; however, the difference between values was higher than two kPa, assigning the patient to different stages of liver fibrosis [54]. Because the overlap of LS values between METAVIR-derived scores is as large if not larger than the difference between vendors, the updated SRU consensus advises that separate cut-off values for each vendor are not required when determining the likelihood for cACLD [29]. The SWE values might be overestimated in certain diseases, e.g. sinusoidal obstruction syndrome due to congestion [55].

Normal reference values

For all equipment, a SWE measurement within the normal range, in a subject without other clinical or laboratory evidence of liver disease, may exclude significant liver fibrosis with a high degree of certainty. For both VCTE and ARFI-based techniques, there is consensus in considering that values ≤5 kPa (1.3 m/s) have high probability of being normal [29,56].

What to avoid?

Confounding factors that may lead to an increase of LS independently from liver fibrosis have been listed elsewhere [57-59]. Briefly, eating may increase the stiffness of the liver, thus measurements are performed in the fasting status of at least 4 hours. LS does not necessarily reflect liver fibrosis, but can reflect many other physiological or pathological conditions including hepatic inflammation (elevated transaminase level) [60-63], obstructive cholestasis [64], neoplastic and other infiltration of the liver and hepatic congestion [65,66]. Recently, it has been reported that portal vein thrombosis is also a confounder [67]. On the other hand, SWE can play a role in cases of liver congestion due to right-sided heart failure, congenital heart diseases or valvular diseases as well as in the hepatic sinusoidal obstruction syndrome or in the Budd-Chiari syndrome [31,68].

Specific artifacts

Measurements should be performed at least 1-2 cm below the liver capsule to avoid reverberation artifacts. However, when using 2D-SWE with a quality map the measurement can be taken closer to the liver capsule as the artifact can be visualized and avoided. This is helpful in high BMI or steatotic patients since the reverberation artifact in these patients can be as small as 5mm and visualizing the artifact on 2D-SWE may help with placing the ROI closer to the liver surface and still avoid the reverberation artifact.

Breast

Main objective, clinical value

Various studies have shown that malignant and benign breast tumours differ significantly in their elasticity [7,69-75]. Benign alterations tend to be softer than malignant lesions. This fact forms the basis for the use of elastography to differentiate between different breast tumors. SWE is a new method introduced in 2009 and, unlike strain elastography, allows quantitative measurement of tissue stiffness. SWE is not only capable of the differentiation between benign and malignant tumours, but can also be used for therapy monitoring under neoadjuvant chemotherapy [76-79]. Recently, the fifth edition of the ACR BI-RADS Atlas 2013 incorporated elasticity

assessment of breast lesions as one of the associated features of ultrasound [80].

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Transducer (frequency) selection

A standard 5 cm wide linear transducer is very well suited to perform SWE of breast lesions. Depending on vendor, transducers of 9 MHz to 18 MHz are SWE enabled. Before the elastography mode is activated, a high-quality B-mode image must first be set, because the elastogram is derived from it. It is recommended to use higher US frequencies in the assessment of superficial breast lesions and lower frequencies for better depth penetration for lesions located deep inside the breast. The operator must be aware that lower frequencies result in a lower spatial resolution. The US probe must be placed perpendicular on the skin of breast directly above the lesion with enough contact to the breast tissue to obtain a good B-mode image while avoiding excessive pre-compression. Pre-compression can be recognized when fatty tissue that should normally appear blue (soft) on the color map has a different color (fig 3). The examiner must not move the US probe while the elastogram is being obtained.

Region of interest (ROI) size

There are several approaches in setting the ROI size. One way is to use a small ROI placed at the site of the stiffest area within the mass or within 3 cm surrounding the mass. Another way is to use larger ROIs that cover the entire lesion. No general standard is given within published guidelines. A recent paper evaluating 154 breast lesions came to the conclusion that a small ROI measuring the mean or maximum stiffness value is superior to medium sized or large sized ROI in distinguishing between benign and malignant lesions [17]. Regardless of the size of the ROI, it has been shown that minimum stiffness value is the least significant and should therefore not be used.

Description of quality parameters

Some vendors provide a quality map, which is a color-coded map that can be superimposed on the B-mode US image and provides information of the quality of the shear wave propagation and the image quality. Even green distributions indicate a high quality elastogram, whereas yellow or red areas should not be used for assessment [81].

Pre-compression

Pre-compression is an important factor of influence changing the appearance of a lesion in the elastogram. If too much pre-compression were applied, the lesion would appear stiffer than it really is [82]. Therefore, the recommendation is to apply a large amount of gel and then place the US transducer on the breast. The subcutaneous fatty tissue should appear in dark blue. If it appears
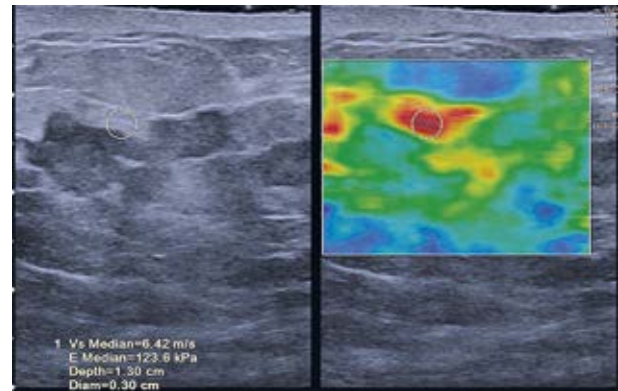
Fig 3. 2D-SWE of an invasive ductal cancer. The irregular hypoechoic lesion is the malignancy. Note that the skin surface is parallel to the transducer, there is a small amount of coupling gel between the transducer and skin confirming minimal precompression and that the area of highest stiffness is just adjacent to the lesion.

in green or even red than too much pre-compression is used and needs to be corrected.

Checking reproducibility

To assess the quality and reproducibility of the elastography image, place the probe and hold it still while the elastogram builds superimposed on the B-mode image. Wait 5-10 seconds until the elastograms shows a consistent and permanent color pattern. Also check that the fatty tissue is displayed soft, which indicates that not too much pre-compression is applied. Then freeze the picture and proceed with the measurements within the elastogram.

How to use shear wave elastography

The basic recommendations about performing SWE as described above also apply to the use in breast tumours. SWE should be used as a lesion-based adjunct to conventional B-mode imaging using all ACR BI-RADS criteria giving the examiner more information in order to make a final assessment. It should not be used as a screening tool without a lesion. However, if a palpable lesion is present with no B-mode findings elastography may identify an isoechoic lesion. A quantitative assessment using the mean or maximum stiffness values can be used. Alternatively, the color pattern of the elastogram can be analyzed by using different color pattern scores [83,84].

Artifacts

There is a well-documented artifact with SWE in malignant lesions. They may appear as soft lesions even though they are very stiff. This artifact is not infrequent and can be recognized by evaluating the quality map. In these false negative cases the quality map usually will confirm that there are poor shear wave and the results should not be used. These cases of false negative lesions on SWE are always true positives on SE. Therefore, the

combination of SE and SWE will improve diagnostic accuracy [71,72,85].

Tips and tricks

- Use ultrasound frequency according to lesion localization (depth);
- Use small ROI and mean or maximum stiffness values for assessment;
- Change the clinical procedure for BI-RADS 4a and BI-RADS 3 lesions according to SWE measurements;
- If the stiff rim sign occurs measure within the stiff rim and not inside the uncolored lesions center.

Normal reference values

Normal fatty tissue: mean stiffness values 5-10 kPa (1.3-1.8 m/s); breast parenchyma: mean stiffness values 30-50 kPa (3.1-4.1 m/s) [86].

Differentiating between benign and malignant lesions the following cut-off values are reported: maximum stiffness values 33.3-80 kPa, (3.3-5.0 m/s); mean stiffness values 46.7-93.8 kPa, (4.0-5.6 m/s).

What to avoid?

During examination it should be avoided the precompression by checking the stiffness of fatty tissue which should be in the normal range, the use of minimum stiffness values for the differentiation between benign and malignant breast lesions and measurements in areas of poor quality on the quality map.

Thyroid

Main objective, clinical value

Despite fine needle aspiration (FNA) being the gold standard in the diagnosis of thyroid neoplasms, US has a paramount role in the diagnostic process. Thyroid nodules are indeed present in almost 50% of the population and so performing cytology on one or multiple targets on each patient is not feasible; the detection of certain suspect features on B-mode US is then fundamental in deciding which nodules should be assessed with FNA [87,88]. SWE is a quick, readily available tool, and effective in increasing US sensitivity in the detection of thyroid neoplasms [89].

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Prerequisites

It is recommended to verify the manufacturer's instructions about quality parameters. No patient preparation is required; patient has to lie down in supine position with a pillow or a towel used to extend the patient's neck [2].

Select an appropriate transducer and frequency selection

Select a high-end linear transducer, usually 7 to 18 MHz [90].
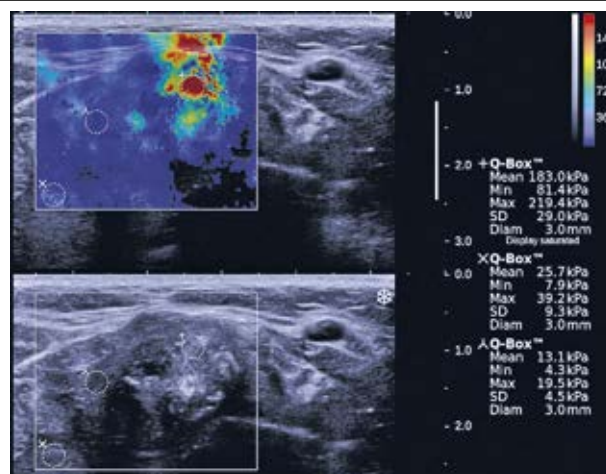
Fig 4. SWE examination of a thyroid with several nodules. The ROI is placed in each nodule to avoid including normal thyroid or other structures. In this case the more central nodule with a mean stiffness value of 183 kPa was a papillary carcinoma. The other two nodules were benign.

Region of interest (ROI) size, shape, others

The sample box features depend on the SWE method being used. In pSWE the small fixed-size ROI should be completely included within the nodule. In 2D-SWE the box should be large enough to include the whole nodule, avoiding nearby vessels or gland areas with cystic or fibrotic changes (fig 4) [5,91].

Description of quality parameters

For pSWE 3 to 10 measurements should be acquired at the same location and the average of these should be calculated. For 2D-SWE at least three measurements must be performed [5,91].

Pre-compression

An abundant quantity of gel should be used to avoid pre-compression, since it may alter tissue elastic modulus thus causing artifacts. The operator places the transducer perpendicular to the target nodule without pressure, maintaining only slight contact with the skin. A manufacturer quality control tool should be used if available [92].

Normal reference values

Normal values may vary depending on the manufacturer; however, guidelines suggest that benign nodules show a mean elasticity of 15.3-28 kPa [5]. Recent studies state that the optimal cut-off between benign and malignant nodules is 34.5-37.5 kPa [93,94].

What to avoid?

As stated before, it is important to avoid compression artifacts, which may jeopardize measurement's accuracy and reliability. Certain neck morphologies may be challenging when correctly placing the probe perpendicular to the target nodule; previous neck surgery and subsequent fibrosis may as well represent an obstacle [2].

Salivary glands

Main objective, clinical value

Salivary glands are readily accessible to high resolution US, which is the initial imaging modality when clinically indicated. SWE is useful for the assessment of diffuse diseases, such as Sjögren syndrome, parotitis in pediatric patients or damage due to irradiation [95-97]. As for the evaluation of focal lesions, a substantial overlap of stiffness values has been reported [94]. A multiparametric approach to allow a better differentiation between benign and malignant lesions has been suggested [90].

"Knobology"

Prerequisites

Before starting shear wave measurement, it is recommended to verify the quality of the shear wave generation by referring to the manufacturer's quality parameters.

Transducer (frequency) selection

SWE is performed with a high-frequency linear transducer, typically 7 to 12 MHz, with patient lying in the supine position with a pillow or a towel used to extend the patient's neck [90,98].

Region of interest (ROI) size, shape, others

The sample box should be positioned in a region of the gland free of vessels or cystic or fibrotic transformation, and between 1 to 2 cm from the anterior glandular contour.

Description of quality parameters

For pSWE, the fixed ROI should be placed at the point of interest. Three to 10 measurements should be acquired and the median value calculated. For 2D-SWE, because a larger FOV is available, at least three measurements must be performed [5].

Pre-compression

Pre-compression should be avoided.

Tips and tricks

For obtaining a prompt and reliable SWE acquisition, it is recommended to hold the transducer perpendicular to the plane being explored, avoiding any movement of the transducer or of the patient when the acquisition has been launched. A sufficient quantity of gel has to be used and minimal pressure should be applied to avoid pre-compression because it can alter tissue elastic modules and produce artifacts. False negative cases do occur and if the B-mode findings are suggestive of a malignancy a biopsy should not be cancelled based on elastography. When there are several similar nodules, SWE can be used to select the stiffest lesion for sampling.

Normal reference values

Literature data suggest that the mean stiffness of the salivary glands is quite uniform (approximately 11±3 kPa) (fig 5) [99].
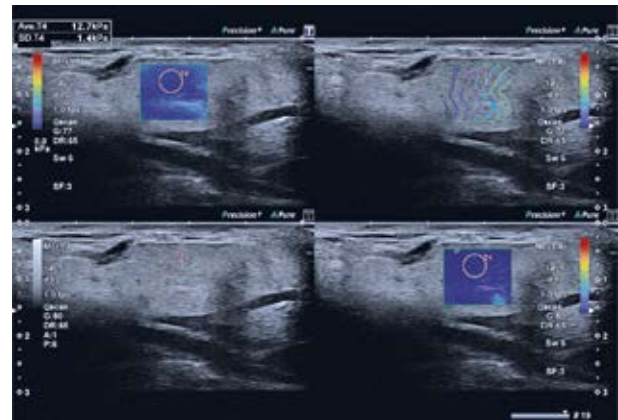

Fig 5. 2D-SWE of a normal parotid gland.

What to avoid

As explained for other organs, artifacts should be limited for a prompt and reliable elastography acquisition. The interpretation of a 2D-SWE elastogram is operator dependent and the choice of an adequate ROI is challenging due to the multiplicity and complexity of the structures in the neck region.

Specific artifacts

The reliability of the measurement may be affected by some artifacts that may arise in the region of the neck, generally due to the proximity to the skin, to the osseous plane (ramus of mandible) or to the eventual presence of focal convex bulge of the skin, which generates local inhomogeneity and falsify the real elasticity of the tissue. Some very stiff cancers show a circular stiff area in the surroundings of the actual lesion. This artifact is called the "stiff rim sign". In 3D SWE there is a similar sign in the c-plane called the "crater sign" [100]. The reason for these artifacts is still under discussion but it may indicate a very low shear wave amplitude within the cancer due to attenuation of US energy resulting in no colour coded information in the elastogram [101]. Furthermore, the "stiff ring sign" and the "crater sign" can be used as predictors of malignancy [102].

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