The EFSUMB Guidelines and Recommendations for the Clinical Practice of Elastography in Non-Hepatic Applications: Update 2018

Die EFSUMB-Leitlinien und Empfehlungen für die klinische Praxis der Elastografie bei nichthepatischen Anwendungen: Update 2018

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ABSTRACT

This manuscript describes the use of ultrasound elastography, with the exception of liver applications, and represents an update of the 2013 EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) Guidelines and Recommendations on the clinical use of elastography.

ZUSAMMENFASSUNG

Diese Arbeit beschreibt den Einsatz der Ultraschall-Elastografie mit Ausnahme der Leberanwendungen und ist eine Aktualisierung der Leitlinien und Empfehlungen der EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) von 2013 zum klinischen Einsatz der Elastografie.

ABBREVIATIONS

SE	strain elastography
SWE	shear wave elastography
pSWE	point shear wave elastography
TE	transient elastography
IQR	interquartile range
IQR/M	interquartile range/median
ARFI	acoustic radiation force impulse
BIRADS	Breast Imaging Reporting and Data System
TIRADS	Thyroid Imaging Reporting and Data System
TI	thermal index
MI	mechanical index
SR	strain ratio
SH	strain histogram
EFSUMB	European Federation of Societies for Ultrasound in Medicine and Biology
ECMUS	European Committee of Medical Ultrasound Safety
WFUMB	World Federation for Ultrasound in Medicine and Biology
LoE	levels of evidence
GoR	grades of recommendation

1. Introduction

This manuscript describes the use of ultrasound elastography, with the exception of liver applications, and represents an update of the 2013 EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) Guidelines and Recommendations on the clinical use of elastography. A taskforce comprising 32 EFSUMB members was established in 2017 to draft a manuscript derived and updated from the previous EFSUMB guidelines on elastography: part 1 (Basic Principles and Technology) and part 2 (Clinical Applications) [1, 2]. For each recommendation levels of evidence (LoE) and grades of recommendation (GoR) were also included to show the clinical role and value of elastography in various non-liver applications. These were assigned according to the Oxford Centre for Evidence-based Medicine criteria (http://www.cebm.net/oxford-centre-evidencebased-medicine-levels-evidence-march-2009/). A consensus opinion was established by vote as follows: strong consensus (> 95 %), broad consensus (> 80 %), with approval, disapproval or abstaining from each participant. The manuscript was prepared initially by e-mail communication and was discussed in a consensus meeting in Frankfurt am Main, Germany, during February 2018.

2. Training

EFSUMB maintains a policy to attain high quality in all aspects of ultrasound education and to promote excellent professional standards in the practice of elastography. EFSUMB has defined three levels of competence, defined in the document on minimal training requirements [3], and these training levels also apply to the application of elastography. To ensure high-quality scanning and the lowest possible intra-operator variability, EFSUMB recommends that ultrasound elastography should be performed by operators that have passed competence Level 1. This is particularly relevant to the evaluation of focal lesions present in various

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organs as these lesions must be first assessed by B-mode and Doppler ultrasound [4]. However, it is possible to train dedicated personnel to selectively perform elastography, e. g. for the thyroid gland [5]. Nevertheless, there has to be an appreciation of the difference between acquisition and interpretation of elastography, as the latter also requires knowledge of the patient's clinical history, hematological and biochemical parameters, and other comparative imaging findings. Furthermore, experience in ultrasonography is important as this influences the ability to perform shear wave measurements, particularly in obese patients [6]. For all ultrasound operators it is important to follow international guidelines, obtain adequate knowledge and training, and to perform elastography in accordance with national medico-legal regulations.

> **RECOMMENDATION 1**
> The operator should obtain adequate knowledge and training in ultrasonography and elastographic methods and perform the examination within the medico-legal framework of the specific country (LoE 5, GoR C) (For 20, Abstain 0, Against 0).

3. Terminology

Terminology of ultrasound elastography has been widely accepted [1, 7]. In the following, we briefly refer to the distinction between strain elastography (SE) and shear wave elastography (SWE), which includes acoustic radiation force impulse (ARFI) based techniques and transient elastography (TE). All available ultrasound elastography methods employ ultrasound to measure the internal tissue shear deformations resulting from an applied force but the type of force is important. If the force varies slowly relative to the shear propagation time to the depth of interest, as is the case for transducer palpation or physiological motion, it is considered quasi-static. The signal processing within the scanner for all current commercial ultrasound elastography methods begins with the measurement of tissue displacement as a function of spatial position and time, which is performed using cross-correlation tracking, Doppler, or other signal processing. The various elastography methods differ importantly according to what they do with these displacement data, to create an elastogram or elasticity measurement.

According to the EFSUMB guidelines, there are two options for the property displayed [8, 9]:

- Display tissue strain or strain rate, calculated from the spatial gradient of displacement or velocity respectively, as in SE. SE is a type of quasistatic elastography, because the applied force varies slowly, while the acquired images are qualitative for tissue properties.
- Display shear wave speed, calculated by using the time varying displacement data to measure the arrival time of a shear wave at various locations. There are a number of such methods, which are grouped under the heading SWE, and include transient elastography (TE), point shear wave elastography (pSWE)

and multidimensional SWE (2D-SWE and 3D-SWE). These are based on either a transient shear deformation induced by a controlled applied force (TE) or by quantification of tissue displacement induced by acoustic radiation force impulse (ARFI) [8, 9].

Most SE ultrasound systems do have an indicator (quality index) displayed in real time, indicating that the degree of compressions/decompressions is appropriate to generate repeatable and reproducible SE images [7 – 11]. The pressure and direction of compressions can be changed by the examiner, especially for external ultrasound procedures, with the compressions/decompressions needed by most systems being less than 2 %. Quality factors for the shear wave speed estimate are available also for the 2D-SWE techniques. For ARFI-based techniques, an approach similar to that of TE has been employed to assess the quality of the measurement, including the interquartile range (IQR) values (i. e. the difference between the 75th and 25th percentile) and IQR/median. Assessment is considered reliable when the IQR is less than 30 % of the median [8, 9]. The values obtained for SWE vary between different machines and are not interchangeable.

For more terminology and quality assurance details, refer to the EFSUMB and WFUMB guidelines on the use of elastography [1, 2, 7 – 11].

4. Safety

Elastography needs a "push" to the organ of interest that can be produced either mechanically or acoustically and may be quasi-static or dynamic. Different techniques are commercially available for the measurement of elastic values for an increasingly wide range of clinical applications. It is essential to know the principle of each of the techniques and how it is applied to understand the implications for patient safety [1 – 3]. A possible risk depends on the technology or type of elastography used and its anatomical application.

4.1 Methods

Techniques which utilize a mechanically induced force to generate SE, strain rate imaging, TE and time harmonic elastography (which uses external vibrations at multiple frequencies to create compound shear wave speed maps) share the same output issues as conventional B-mode ultrasound examination [1]. Therefore, applications of TE measuring quantitative stiffness data were demonstrated to be feasible for children to assess not only liver stiffness data [12, 13] but also spleen stiffness measurement [14] with no increased risk. Also, there is new evidence that patients with cardiac pacemakers or implantable cardioverter defibrillators, have a low potential to be harmed by TE applications [15, 16].

Acoustically induced techniques which require push pulses (known as ARFI imaging, ARFI quantification, pSWE, SWE [2]) on the other hand operate with higher output (higher TI and MI values) [17, 18]. The safety profile is comparable with pulse-wave Doppler mode and the acoustic output will depend on the applied sequence and repetition of pushing and tracking pulses.

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A certain amount of energy is required to displace the tissue, even a few microns, using acoustic radiation force to generate shear waves within the tissue (longer pulses of up to 1000 μs are needed, as compared to short pulses up to 2 μs for diagnostic ultrasound) [8, 9]. The number of push pulses and repetitions during the measurement determine the amount of energy deposited in the tissue. Simulations have revealed a possible temperature rise of about 5 degrees Celsius if bone is present or sensitive tissues such as the eye and a fetus are involved with the temperature maximum at the focus [19 – 21]. Also, tracking beams, repeated with high frequencies, use pulse pressures close to the upper Food and Drug Administration limit (MI ≤ 1.9) to ensure a sufficient signal-to-noise ratio for reliable detection [22]. During ARFI imaging, the displayed indices (MI and TI) may be underestimated.

> ### RECOMMENDATION 2
> To comply with safety, the ALARA (as low as reasonably achievable) principle should be applied when using ultrasound elastography (LoE 2b, GoR B) (For 18, Abstain 2, Against 0).

> ### RECOMMENDATION 3
> Caution is recommended for shear wave elastography using long pulse sequences, particularly when exposing sensitive tissues (LoE 2b, GoR B) (For 19, Abstain 1, Against 0).

5. Breast

5.1 Background

Breast elastography is used for differentiating benign focal lesions from suspicious focal lesions – benign lesions have low stiffness, while malignant lesions have high stiffness. Both strain and shear wave methods have been evaluated for improving the generally high sensitivity and specificity of the Breast Imaging Reporting and Data System (BIRADS) and it is recommended that they are used as add-ons to the regular B-mode examination.

5.2 Methods

5.2.1 Strain elastography

SE images in breast ultrasound may be evaluated visually using the Tsukuba score (also known as the Itoh or Ueno score) [23], semi-quantitatively using strain ratio (SR) or strain histograms (SH) [24] or by the lesion size on elastography divided by the lesion size on B-mode ultrasound (E/B ratio) [25]. An optimal elastogram includes the glandular tissue, the surrounding fat, and the lesion [11].

The Tsukuba score is a five-point visual scale, where the lesion is scored according to the extent of stiff tissue. A lesion not stiffer than the surrounding tissue is designated as 1, a value of 2 or 3 is assigned to lesions with increasing proportions of stiff tissue, a value of 4 is assigned to a lesion that is stiffer throughout, and 5 indicates that the stiffness extends beyond the margins of the mass seen on B-mode. The best cut-off point for discriminating benign from suspicious masses has been shown to be a score between 3 and 4 [26 – 28]. It has been shown that SE, in addition to B-mode ultrasound, increases the specificity of the examination (up to 97 %) and helps to avoid unnecessary biopsies [29].

Anechoic lesions with liquid content show a typical three-layered echo-pattern in SE, called the Blue Green Red (BGR) sign.

5.2.2 Shear wave elastography

For SWE, findings are measured in m/s but may also be reported in kPa depending on the system used. As for SE the optimal image should include the lesion, fat and the glandular tissue. Malignant tumors tend to be more heterogeneous and stiffer than benign tumors. Often the stiffness seems to be most marked at the periphery of the mass and may demonstrate such high values that the system is unable to record a measurement.

5.3 Clinical Applications

5.3.1 Evaluation of breast masses

An early study using SR in 99 nonpalpable benign and malignant breast masses established an optimal cut-off of 2.24 and stated that the higher the SR, the higher the risk of malignancy [30]. The cut-off for SR has since been evaluated in several studies with different systems and is incomparable between different vendors, as seen in other organ applications. In a recent meta-analysis [31], the accuracy of SR was evaluated based on 9 studies (2087 tumors) with a sensitivity of 0.88 and a specificity of 0.83. The E/B ratio (ratio of the lesion size with SE to the lesion size with B-mode ultrasound) increases with increasing tumor grading, with low grade tumors having a ratio close to 1 [11].

In the BE1 multicenter study SWE results were studied retrospectively and several parameters were examined. One finding of the study was that the addition of SWE resulted in some BIRADS 3 lesions appearing stiffer and potentially allowed for an upgrade to a 4a mass, requiring a biopsy. If SWE had been included and used in this way, the overall sensitivity and specificity would have increased to 98.6 % and 78.5 % versus 97.2 % and 61.1 % for B-mode ultrasound alone [32]. Increasing stiffness has also been shown to correlate with increasing tumor grading [33 – 36].

In cysts with pure liquid, no signals are obtained from the shear waves and the lesion is seen as black. However, in cysts with a higher viscosity shear wave signals may be obtained depicting the cyst as having a low stiffness.

5.3.2 Evaluation of axillary lymph nodes

Both SWE and SE have been used in the evaluation of axillary lymph nodes, with one study reporting a sensitivity and specificity of 82.8 % and 69.6 %, respectively, using SWE to distinguish between benign and malignant lymph nodes using a cut-off of 1.44 m/s [37]. Using SE, the sensitivity was 60 % and the specificity was 79.6 % for the diagnosis of malignancy [38]. Another study

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compared the AUROC for elastography with the AUROC for conventional B-mode ultrasound. The values were 62% and 92%, respectively, and no significant improvement was shown when elastography was added to B-mode ultrasound (AUC: 93%) [39].

5.3.3 Prognosis

The key factors for prognostic information are provided by histological and pathological analysis, based on cancer sub-typing and also immuno-histochemical analysis. Univariate analysis has demonstrated a significant correlation between stiffness of a breast cancer and prognostic factors. For SWE, studies reported an increased stiffness for cancer grading of more malignant tumors, larger lesion size, tumor and lympho-vascular invasion in invasive breast cancer. Triple-negative carcinomas (testing negative for oestrogen, progesterone and HER2 receptors), which are often evaluated with BIRADS 3 on B-mode ultrasound, are quite difficult to assess in clinical practice. SWE is reported to show increased stiffness in these cases and can lead to the correct assessment [33 – 35, 40].

A study reporting the analysis of 396 breast cancers showed that SWE is an independent predictor of lymph node metastasis when using E-mean (mean elasticity values for a defined region of interest) as a descriptor. When the breast cancer had E-mean < 50 kPa, only 7% of the lymph nodes were metastatic, whereas 41% of the lymph nodes were positive when E-mean was higher than 150 kPa [41].

5.3.4 Efficacy of neoadjuvant therapy

The tumor response to neoadjuvant chemotherapy may be evaluated with different imaging modalities. In a study with a small sample size of 15 patients, the possibility of predicting response to neoadjuvant chemotherapy with SE was reported [42]. However, larger studies for SE using commercially available systems are not available. A significant correlation between response to treatment and the decrease in heterogeneity and tumor stiffness has been reported [43, 44]. Currently, imaging methods other than elastography should be used in the evaluation of tumor response to neoadjuvant chemotherapy.

5.4 Limitations and artifacts

Pre-compression with the transducer should be avoided as this increases the stiffness of all tissues. Normal fatty tissue has E-mean values ranging from 5 – 10 kPa (using SWE) if the scale is from 0 – 180, although the color scale may be changed. If the color changes according to these values, the pre-compression should be adjusted [45].

> **RECOMMENDATION 4**
> Ultrasound elastography could be used to increase diagnostic confidence in the characterization of a breast lesion (LoE 2a, GoR B) (For 20, Abstain 0, Against 0).

> **RECOMMENDATION 5**
> A BIRADS 3 lesion appearing stiffer on breast ultrasound elastography should be considered for biopsy (LoE 2a, GoR b) (For 20, Abstain 0, Against 0).

6. Prostate

6.1 Background

The screening standard for prostate abnormalities has been the combination of digital rectal examination and the serum prostate specific antigen (PSA) level. However, PSA screening leads to a substantial number of unnecessary biopsies in patients with no or indolent cancer who do not need immediate treatment [46] and has a high false-negative rate (17 – 21%) [47]. Saturation biopsy (up to 40 cores) can rule out prostate cancer, but has many limitations, including cost and morbidity, and over-diagnosis of microscopic tumor foci [48]. SE and SWE assessment and identification of stiff prostatic tissue with a transrectal ultrasound approach can be useful as described in previous elastography guidelines [1].

6.2 Methods

6.2.1 Strain elastography

Hypoechoic stiff lesions of the prostate are suspicious for malignancy [49]. Slight compressions are induced using the transrectal transducer. The use of an inflatable balloon has been suggested to improve the standardization of compressions. The elastography box should cover the entire gland and the surrounding tissues, but avoid the bladder. Semi-quantitative information can be derived by measuring the SR between two regions of interest.

Using stepwise scanning of the prostate from base to apex, SE allows detection of stiff regions and provides stiffness comparisons between lesions and the adjacent prostatic tissue. Most studies report a significant improvement in prostate cancer identification with SE, including guidance for targeted biopsies [50 – 53]. However, there are still controversies and one recent study reported the inability to differentiate prostate cancer from chronic prostatitis [54]. The sensitivity, specificity, negative predictive value, positive predictive value, and accuracy for identifying cancer index lesions for focal therapy were 58.8%, 43.3%, 54.1%, 48.1%, and 51.6%, respectively [55]. Though improvement in biopsy guidance is reported in many studies [53, 56, 57], others did not confirm this result [58].

6.2.2 Shear wave elastography

Unlike SE, SWE requires no compression on the rectal wall [59]. Optimized settings include maximizing penetration and setting up an appropriate scale. The image can cover the entire gland in the transverse section when the prostate is not markedly enlarged. Otherwise, each side of the prostate is imaged separately from base to apex for review and measurements of elastography values. For each plane, the transducer is maintained in a steady

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position until the image stabilizes. Hypoechoic stiff lesions are suspicious for malignancy. The ratio between the mean elasticity values of two regions can be calculated.

In young healthy subjects the entire prostate exhibits a uniform low stiffness appearance with low elasticity values [60, 61]. In benign prostate hyperplasia, the peripheral zone remains homogeneous with low stiffness, while the central and transition zones become heterogeneous and stiff, particularly when there are calcifications. Typical benign peripheral lesions have a similar stiffness as the surrounding normal parenchyma, while cancers are stiff [60, 61]. The best cut-off stiffness value to maximize the negative predictive value for malignant lesions was found to be 35 and 37 kPa in two studies with 2D-SWE [57, 58] with a sensitivity, specificity, PPV and NPV of 63 %, 91 %, 69.4 %, and 91 %, respectively. The SWE ratio provided additional information as it considers the increased stiffness of the peripheral zone from calcification and chronic prostatitis. The ratio showing the best accuracy to differentiate between the nodule and the adjacent peripheral gland for benign and malignant lesions was 1.5 ± 0.9 and 4.0 ± 1.9, respectively (p < 0.002) [61].

6.3 Clinical applications

Several studies indicate that elastography provides useful additional information to conventional transrectal ultrasound for prostate cancer detection. Applications that have been more extensively investigated include the characterization of abnormal areas, the detection of lesions not seen with any previous imaging technique and biopsy targeting. Additionally, elastography could be combined with other imaging techniques in the same examination to address the heterogeneous growth pattern of prostate cancer. Improvement in detection and prediction of cancer was seen during multiparametric ultrasound when elastography is used as a triage test followed by contrast-enhanced ultrasound or as an adjunct during image fusion of magnetic resonance imaging and transrectal ultrasound [62 – 65].

6.4 Limitations and artifacts

Both techniques suffer from intrinsic limitations: not all cancers are stiff and not all stiff lesions are cancers (particularly in the presence of calcifications and fibrosis). The transrectal technique carries an intrinsic risk of inadvertently applying excess pre-compression because of the end fire arrangement of the transducer.

Limitations of SE include the non-uniform force over the gland and intra- and inter-operator dependency. 2D-SWE has additional limitations such as a slower frame rate and the small elasticity box which only allows examination of half the gland at a time.

RECOMMENDATION 6

Transrectal ultrasound elastography of the prostate could be used to identify suspicious target regions for biopsy in order to increase the diagnostic yield of biopsy (LoE 2b, GoR b) (For 20, Abstain 0, Against 0).

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7. Thyroid

7.1 Background

Chronic thyroiditis and malignant tumors increase diffuse or focal thyroid stiffness [66]. Elastography is emerging as a potential indicator for these abnormalities and may provide additional information to support clinical decision-making.

7.2 Classification systems – TIRADS

Accurate estimation of the malignancy risk by ultrasound could help to select thyroid nodules with a high risk of cancer for fine needle aspiration and biopsy (FNAB). More recently, an assessment concept called "grading system" or "reporting system" termed "Thyroid Imaging Reporting and Data System" or TIRADS has emerged, allowing thyroid nodules to be classified into categories related to their ultrasound patterns [66 – 74].

7.3 Methods

SE is the initial method which has been implemented on most commercially available ultrasound systems, thus evidence is quite consolidated on this topic, with a number of studies and meta-analyses being published [75 – 81]. More recently, SWE has become available for thyroid evaluation with multiple studies reported [82 – 85].

7.4 Clinical applications

7.4.1 Strain elastography

Two different methods of assessing SE outcome have been reported, namely semi-quantitative scoring systems involving five, four, or two color patterns respectively [86 – 88] and SR, which compares the strain values of the nodule to those of the surrounding thyroid parenchyma (parenchyma-to-nodule ratio) or the surrounding muscles (muscle-to-nodule ratio) [4, 89]. Although no consensus has been reached about the cut-off values to use for SR (as low as 1.5 for benign nodules and as high as 5 for malignant nodules have been suggested), it has been shown that the SR has a lower inter-observer variability and is more easily learned than simple color patterns [4]. Importantly, most studies on SE were performed in selected populations with a high prevalence of malignant nodules. It has been shown that SE has a lower sensitivity and specificity in a low-risk population [4, 90]. Furthermore, tumors other than papillary carcinomas may have an unexpectedly low stiffness [4, 91, 92]. In patients with coexistent diffuse thyroid disease, the role of SE in detecting malignant nodules has still not been validated [4]. The most recent meta-analysis [81] included 13 studies on SE performed from 2007 to 2016, with sensitivities ranging from 48 % [93] to 97 % [94] and specificities ranging from 64 % [95] to 100 % [94]. The pooled sensitivity and specificity of the meta-analysis was 84 % (95 % CI, 76 % – 90 %) and 90 % (95 % CI, 85 % – 94 %), respectively, with pooled accuracy of 94 % (95 % CI, 91 % – 96 %).

7.4.2 SWE

The mean SW elasticity for malignant thyroid nodules is 19.60 – 52.18 kPa with a reported cut-off value of 26.6 – 65 kPa [96 –

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104]. For benign nodules the mean elasticity is lower at 15.3 – 28 kPa [96 – 104]. Studies included nodules from 2 – 71 mm and most were papillary carcinomas. Therefore, cut-off values have a wide range and a single threshold cannot be established [82, 83, 85]. The sensitivity for SWE has been reported as 63.8 – 93.8 %, and the specificity as 50 – 88.2 % [96, 97, 100, 102, 104 – 106]. The most recent meta-analysis [82] included 14 studies and 2851 thyroid nodules with cut-off values ranging from 26.6 to 85.2 kPa. It concluded that 2D-SWE has a fairly good diagnostic accuracy although the sensitivity and specificity are average. Studies using ARFI indicated that it enables the evaluation of tissue stiffness and the mean SWE velocity for malignant nodules is 3.13 – 3.9 m/s [96, 107 – 111] with a cut-off value 2.15 – 3.77 m/s [96, 107 – 111]. Interestingly, a recent meta-analysis [81] showed that SE and SWE are not significantly different in terms of sensitivity (SWE pooled sensitivity = 79 % [95 % CI, 73 % – 84 %]) but SE is superior to SWE in terms of specificity (SWE pooled specificity = 87 % [95 % CI, 79 % – 92 %]) and accuracy (SWE pooled accuracy = 83 % [95 % CI, 80 % – 86 %]).

7.5 Limitations and artifacts

The thyroid is among the most extensively investigated non-liver application after the breast. Nevertheless, the relevance in the malignant/benign differential diagnosis remains unclear. Recent American Thyroid Association and Korean guidelines do not consider stiffness as an indicator of malignancy. However, elastography was recently mentioned by both the French TIRADS and the EU-TIRADS as a complementary imaging tool [70, 112]. Thus, elastography should not replace B-mode US assessment but should be used as a complementary tool for assessing nodules for fine-needle aspiration, especially due to its high negative predictive value (only 3 % false-positive results) [70].

> **RECOMMENDATION 7**
> Ultrasound elastography of the thyroid could be used as part of nodule characterization, particularly with use of semi-quantitative methods (LoE 2A, GoR A) (For 17, Abstain 3, Against 0).

8. Pancreas

8.1 Background

Elastographic properties of the pancreas may be studied with a transabdominal approach, as well as with an endoscopic or intraoperative ultrasound approach. Pancreatic transabdominal ultrasound elastography requires clear visualization of the gland (which is not always possible with external ultrasound), whereas endoscopic ultrasound (EUS) is a minimally invasive technique that provides high-resolution images of the pancreas, with the close vicinity of the transducer and the pancreas avoiding artifacts (fat, gas, etc.).

8.2 Methods

For the elastographic assessment of the pancreatic parenchyma and focal pancreatic lesions, SWE [7, 113 – 133] as well as SE [7, 119, 120, 123, 124, 131, 134 – 177] may be used. Transabdominal elastography can be performed both by using SE with qualitative and semiquantitative information, and SWE with qualitative and quantitative data. EUS can be performed currently only with SE techniques with qualitative and semi-quantitative evaluation [178]. For the semi-quantitative approach, both SR and SH can be used in order to obtain an estimate of the elasticity [153].

The normal pancreas has a uniform intermediate stiffness throughout the head, body, and tail [123, 124, 129, 130, 132]. Embryologically, the pancreas develops from two primordia, a dorsal and a ventral part. With SE, elasticity properties seem to be almost similar in the two parts of a healthy pancreas with a homogeneous low stiffness appearance [158]. Studies in normal volunteers affirmed that the mean wave velocity value obtained in a healthy pancreas with the ARFI technique is approximately 1.40 m/s [114].

8.3 Clinical applications

8.3.1 Effect of aging, gender, anatomical segment, and other variables

With advancing age, pancreatic elasticity may decrease as has been shown consistently for SE [134] and SWE [121, 129, 131]. Data on the influence of gender, body mass index (BMI), and pancreatic echogenicity are not consistent, with most studies demonstrating no significant influence of these variables on shear wave velocity [113, 116, 121, 129, 131]. One study using SE with SH analysis showed lower mean strain values in patients with a hyperechoic pancreas and higher BMI [134]. In another study shear wave velocity was significantly lower in men compared to women [129].

8.3.2 Acute pancreatitis

The consistency of the pancreatic parenchyma usually becomes stiffer in acute pancreatitis as compared to the healthy pancreas, which is identifiable with SE and SWE, including ARFI [116]. Necrosis is identified as a low stiffness area. However, studies using elastographic techniques in patients with acute pancreatitis are conflicting [116, 130, 179, 180]. One prospective study failed to find significant differences in pancreatic shear wave velocities between patients with acute pancreatitis and healthy volunteers [130]. Three other studies showed significantly higher pancreatic shear wave velocities in patients with acute pancreatitis compared to persons with a normal pancreas [116, 179, 180]. In one of these studies, shear wave velocities of patients with acute pancreatitis were higher than in chronic pancreatitis patients [179]. Another prospective study compared transabdominal ARFI imaging with B-mode ultrasound and computed tomography (CT) at hospital admission for the diagnosis of acute pancreatitis. SWE was more accurate (100 %) for the diagnosis of acute pancreatitis than CT (76 %) and B-mode ultrasound (53.4 %). The authors were able to identify segmental involvement of the pancreas as well as parenchymal necrosis [180].

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8.3.3 Chronic pancreatitis

Qualitative SE displays the pancreatic parenchyma in chronic pancreatitis with a heterogeneous colored (honeycombed) pattern, with predominantly stiffer strands. Nevertheless, differential diagnosis between chronic pancreatitis and pancreatic tumor can be challenging during elastography because both diseases have a similar stiffness. Therefore, elastography alone is not able to distinguish chronic pancreatitis from malignant tumors [164].

Both SWE and SE may be used to assess pancreatic fibrosis and chronic pancreatitis and in particular to grade the severity of fibrosis (based on simple scoring systems with 4 grades) and chronic pancreatitis [115 – 117, 122 – 124, 127, 131, 136, 138, 142, 146, 151, 164, 167, 169, 170, 179, 181 – 185]. In patients with chronic pancreatitis, pancreatic shear wave velocities [116, 124, 127, 131, 186], SR [148] and SH [146] are significantly higher than in healthy volunteers or patients with a normal pancreatic parenchyma. Several studies have shown a significant correlation between SWE [117, 123, 184] and semi-quantitative SE [138, 167, 169, 185] and histological pancreatic fibrosis stage. Moreover, SWE [122, 124, 169] and SR [141] are significantly correlated with stages of chronic pancreatitis derived from EUS-based criteria for the diagnosis of chronic pancreatitis. Another recent study showed significantly higher pancreatic SWE velocities in patients with clinical markers of severe disease (disease duration > 10 years, chronic analgesic treatment, lower body weight) [127]. A direct relationship between the SR of pancreatic parenchyma and low stiffness peripancreatic tissue and the probability of pancreatic exocrine insufficiency was shown in a study using EUS-SE [136]. Another study reported an inverse correlation between preoperative SW velocity and postoperative exocrine function in patients undergoing pancreatic resection [117].

EUS elastography might be helpful in identifying patients with autoimmune pancreatitis, due to the unique appearance of diffuse stiff tissue with an elastographic pattern visible both in the mass lesion and in the adjacent pancreatic parenchyma, with mainly stiff color signals that were evenly spread over the head and the body of the pancreas [161, 187].

8.3.4 Preoperative indications

Recently, elastography has been used prior to pancreatic surgery to examine the gland stiffness in order to assess the risk of surgical complications. Evaluation of pancreatic stiffness might be an objective index to estimate pancreatic fibrosis and predict the risk of postoperative pancreatic fistula. Data from several studies suggest that SWE [115, 117, 184, 188] and SE [138, 170, 185] may be used for this purpose. In particular, a pancreatic parenchyma with a low stiffness as determined by semi-quantitative SE [138, 170] or SWE [117] proved to be an independent predictor of postoperative pancreatic fistula.

8.3.5 Pancreatic ductal adenocarcinoma and other solid pancreatic neoplasms

In pancreatic ductal adenocarcinoma (PDAC), shear wave velocities are significantly higher than in normal pancreatic parenchyma

obtained in healthy subjects [116, 125, 133] as well as in pancreatic parenchyma surrounding the tumor [125]. Shear wave velocities measured in PDAC usually exceed 3 m/s [116, 125, 126, 133]. However, there is a significant overlap of SWE velocities between malignant solid lesions, benign solid lesions, and chronic pancreatitis [116, 126]. One study demonstrated a significantly higher difference between the SWE velocities of malignant lesions and surrounding pancreatic parenchyma compared to the difference values between benign lesions and surrounding parenchyma [126]. No large prospective comparative studies evaluating the accuracy of SWE for the characterization of solid pancreatic lesions are available.

More evidence is available on the clinical value of EUS-SE for the differential diagnosis of solid pancreatic lesions [172, 189 – 192]. An early study described EUS elastography patterns in healthy subjects, in diffuse chronic pancreatitis and in focal pancreatic lesions [139]. All malignant pancreatic tumors and serous cystadenomas showed a honeycomb pattern of medium stiffness, and were well delineated against healthy parenchyma. However, this pattern was also observed in half of the chronic pancreatitis patients, so that the specificity of the method was reported at only about 60 %, attributed to fibrotic structures producing similar mechanical properties in cancer and chronic pancreatitis [139, 164]. Therefore, elastography is not sufficient to contribute to the early diagnosis of pancreatic carcinoma in chronic pancreatitis [139, 164].

Qualitative [137, 139, 163, 164, 193 – 195] and semi-quantitative SE approaches (SR, SH analysis) [135, 142 – 144, 149, 150, 152 – 156, 175, 177, 196 – 199] have been used for the differential diagnosis of benign and malignant focal pancreatic masses, with both showing high overall accuracy. Computer-aided diagnosis techniques might improve the accuracy for the differential diagnosis of focal pancreatic masses, with artificial neural networks being used most often [154, 156]. Several multicenter studies [155, 156, 194] and other prospective studies [135, 149, 150, 152, 177, 197, 198] consistently showed a very high sensitivity (over 90 %), but considerably lower specificity and negative predictive values for the diagnosis of benign versus malignant focal pancreatic masses. These findings have been summarized in meta-analyses, affirming the very high sensitivity (95 % – 99 %) and negative predictive value of EUS-SE, but limited specificity (64 % – 76 %) and positive predictive value to diagnose pancreatic malignancy [172, 189 – 192]. Significant differences in favor of qualitative or semi-quantitative assessment techniques have not been observed in meta-analyses. Therefore, there is expert consensus that SE cannot replace a cytopathological diagnosis of focal pancreatic disease [162, 200, 201]. Combining several EUS-based advanced tools of tissue characterization may provide the best results in differential diagnosis of focal pancreatic lesions [135, 143, 144, 149, 202 – 205]. Nevertheless, when EUS-guided sampling is negative or inconclusive, suspicious findings with elastography and contrast-enhanced techniques will influence further clinical decisions by indicating repeat sampling or direct referral to surgery. On the other hand, the finding of a solid pancreatic lesion with elastographic properties of low stiffness and without hypo-enhancement in contrast-enhanced EUS is nearly always predictive for the benign nature of the lesion. Since the negative

predictive value of EUS-FNA for the diagnosis of a malignant solid pancreatic lesion is only 72 % [203 – 207], such a finding may prevent potentially nondiagnostic or risky procedures [195, 207].

8.3.6 Cystic pancreatic tumors

Elastography can have a role in pancreatic cystic lesions, both with SE and with SWE, in particular with ARFI. SWE has been shown to be accurate for the differentiation between serous and mucinous cystic pancreatic lesions [133, 208 – 212]. Serous cystadenomas are filled with serous fluid exhibiting similar physical properties as water, while numerous and dense septa together with a fibrous scar can be present in a mucinous cystadenoma. Therefore, the microcystic serous cystadenoma appears as a very stiff lesion with EUS-SE [139, 164, 196]. With ARFI, shear wave velocity in serous cystadenoma is infinitely high and numerical values cannot be obtained. Due to the more complex fluid content, shear wave velocities in mucinous cystic lesions are very high, but numerical values may be obtained in most cases [133, 208 – 212].

8.4 Limitations and artifacts

EUS-elastography suffers from technical limitations and artifacts. Some issues are common with transabdominal ultrasound, such as the need to obtain a close proximity to the target and to avoid anatomical planes allowing slip movements anterior to or within the imaged region [1]. In particular, large vessels in the imaged area represent the main reason for shear stress damping. Issues peculiar to EUS are essentially caused by the small size of the transducer providing a limited stress source to image the region of interest. In addition, it is very difficult to standardize the pressure exerted by the echoendoscope tip to the gastrointestinal wall, resulting in variability of the color mapping. Lastly, respiration and heartbeat-induced movements of the target lesion may cause a complete lack of color signal within the region of interest. As far as the color mapping of EUS elastography is concerned, disadvantages include subjective differences in color vision and image categories that may not correspond well to pathology [194]. The selection of frames for the SR or SH measurements is user-dependent. In addition, unrepresentative elastograms or reference tissues with a different distance to the stress source may result in method bias [213]. For these reasons, finding an optimal cut-off for differentiating pancreatic tumors from benign disease has been challenging.

> **RECOMMENDATION 8**
> Transabdominal and endoscopic ultrasound elastography may be used as additional imaging tools for the diagnosis and grading of chronic pancreatitis (LoE 2b, GoR B) (For 20, Abstain 0, Against 0).

> **RECOMMENDATION 9**
> Endoscopic ultrasound elastography could be used as a complementary imaging tool for the characterization of solid pancreatic lesions. However, it cannot decisively differentiate focal pancreatitis from pancreatic carcinoma (LoE 2a, GoR B) (For 20, Abstain 0, Against 0).

> **RECOMMENDATION 10**
> When a combination of endoscopic ultrasound elastography with contrast studies suggests pancreatic cancer despite a negative or inconclusive biopsy, repeated sampling or surgery should be considered (LoE 2b, GoR B) (For 12, Abstain 7, Against 1).

9. GastroIntestinal Tract

9.1 Background

The gastrointestinal tract wall may be visualized by ultrasound as a layered structure consisting of typically 5 layers [214, 215]. When examining the intestine, it is preferable to use frequencies above 7.5 MHz to enable optimal visualization of wall layers, thickened bowel wall and focal lesions. This also applies for SE and SWE.

9.2 Methods

SE and SWE are the methods used for elasticity imaging and measurements in bowel examinations. Studies investigating elastography of bowel wall lesions are predominantly based on SE.

9.2.1 Image interpretation and evaluation

Pathological lesions that increase wall thickness are most relevant for SE and SWE. This is because the bowel wall is a thin structure on ultrasound imaging that has natural peristalsis and allows considerable movement on both the serosa and the luminal sides. This tends to add artifacts to strain imaging and makes a targeted SWE or SE measurement more difficult and user-dependent. The bowel wall may become thickened in both neoplastic and inflammatory disease, predominantly in Crohn's disease (CD). In particular, SE has been applied in order to clinically distinguish fibrotic from inflammatory lesions in CD and to distinguish rectal adenoma from adenocarcinoma.

9.3 Clinical applications

9.3.1 Distinction between fibrous and inflammatory strictures in Crohn's disease

Several studies on CD in animal models and human specimens conclude that stiffness is associated with the presence of fibrotic strictures. Some studies indicate that SE and SWE elastography can differentiate fibrosis from inflammatory lesions [216 – 218]. A study compared SE in terminal ileum stenosis in CD reporting a higher visual score of tissue stiffness in fibrosis using magnetic resonance (MR) enterography as a reference [219]. Another ex-vivo study on bowel specimens from CD and neoplastic lesions

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also showed that higher stiffness was present in both CD lesions and in adenocarcinoma, but not in adenomas [220].

The results from seven small series were included in a systematic review of 154 CD lesions in 129 patients [221], suggesting that stiffness was significantly higher in fibrotic stenosis. Nevertheless, the systematic review mentions "inhomogeneous and scarcely comparable" endpoints, as authors used either absolute strain values or a strain ratio with various anatomic structures for comparison (mesenteric fat surrounding the bowel wall or abdominal wall muscles). In a study of ten patients, SE using the mean strain in the bowel wall of affected and unaffected bowel segments pre-, intra- and postoperatively found significant differences in strain values in affected and unaffected segments which correlated well with the histological distribution of connective tissue and collagen content [222]. Also, the strain measurements had an acceptable intraclass correlation coefficient (ICC) in the three examinations. A study of 23 consecutive patients undergoing surgery for CD [223] found excellent differentiation of patients with severe ileal fibrosis by histology but also by using SR (including an excellent inter-rater agreement). Conflicting findings are reported in a prospective study on SE in 26 patients undergoing surgery for stricturing CD. On preoperative ultrasound, the SR did not correlate with histological scoring of fibrosis or inflammation [224]. Strain imaging of bowel lesions in CD may predict the response to anti-inflammatory treatment. In a prospective study of 30 patients with CD, the five patients who needed surgery had significantly higher SR measurements at baseline and there was a significant negative correlation between the SR at baseline and wall thickness following 52 weeks of anti-tumor necrosis factor (TNF) therapy [225]. SWE should not be used as a method to distinguish fibrotic from inflammatory lesions in CD based on current evidence.

9.3.2 Characterization and staging of rectal tumors

The differentiation and staging of rectal tumors can be performed using SE as an add-on to B-mode endoscopic rectal ultrasound (ERUS). Thus, SE may improve the staging of rectal cancer and differentiate adenoma from adenocarcinoma, when compared to ERUS alone and with MR imaging (with high interobserver agreement of recorded videos and images) [226 – 228]. Another group found good correlation between diffusion-weighted MR imaging which is associated with fibrosis, and SWE of malignant rectal tumors [229]. Another study assessed the performance of ERUS for rectal tumors using SWE using an 8 MHz endorectal transducer, finding that the tumor stiffness measurements corresponded accurately to the pathological tumor T-stage and diagnostic accuracy of tumor staging improved from 76.7 % to 93.3 % [230].

RECOMMENDATION 11

Ultrasound strain elastography can be used to characterize bowel wall lesions in Crohn's disease (LoE 3b, GoRC) (For 19, Abstain 1, Against 0).

RECOMMENDATION 12

Ultrasound elastography may improve the staging of rectal cancer when used as an add-on to endoscopic rectal ultrasound and magnetic resonance imaging (LoE 2b, GoRC) (For 17, Abstain 3, Against 0).

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10. Spleen

10.1 Background

Spleen stiffness measurement is an elastography technique used to assess the severity of chronic liver disease, mainly in conjunction with liver stiffness measurements for the evaluation of liver fibrosis or portal hypertension-related complications. Various SWE techniques have been investigated to predict the presence of clinically significant portal hypertension, esophageal varices or to predict long-term prognosis.

10.2 Methodology

Spleen elastography should be performed after at least 3 hours of fasting and after at least 10 minutes of rest [231, 232], with the patient in dorsal decubitus and with the left arm in maximal adduction [233]. The transducer should be placed between the left intercostal spaces in an area with a good ultrasound window needed for TE [234], or at least 2 cm below the capsule for non-TE techniques [235, 236], with the measurement preferably being performed at the inferior pole [237].

10.3. Clinical applications

a) Assessment of liver fibrosis

Using spleen stiffness as a surrogate marker for staging liver fibrosis, two studies [238, 239] demonstrated a pooled sensitivity and specificity for detecting significant fibrosis (F2) and cirrhosis (F4) of 0.70 and 0.87 and 0.77 and 0.82, respectively with an AUROC of 0.88 and 0.85, respectively [22].

b) Assessment of clinically significant portal hypertension

Spleen stiffness correlates well with the hepatic vein portal gradient and has an excellent diagnostic accuracy (AUROC = 0.92) for clinically significant portal hypertension, irrespective of the technique used [240], with TE showing a better correlation with the hepatic vein portal gradient than measuring liver stiffness [234]. For values ≥ 46 kPa, the AUROC for clinically significant portal hypertension varies from 0.846 to 0.966, with good sensitivity (0.77 – 0.88) and specificity (0.79 – 0.91) [234, 241].

For pSWE, the overall correlation with the hepatic vein portal gradient is similar and better than for liver stiffness measurements [242], but for values > 10 mmHg, the association is weaker [242, 243]. However, for pSWE, the plotted sensitivity is higher than for other techniques (0.98 vs. 0.62 – 0.83), while the specificity is lower (0.78 vs. 0.89 – 0.93), thus raising the possibility of the heterogeneity and variability of this technique [240, 244].

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As for 2D-SWE, the diagnostic accuracy varied significantly, as AUROC analysis shows: 0.63 (for a cut-off value of 34 kPa) [245], 0.725 [235] or 0.84 [237]. Despite the fact that the last two studies recommend different cut-off values to rule-in (≥ 40 or 35.6 kPa) or out (≤ 22.7 or 21.7 kPa) clinically significant portal hypertension, the diagnostic accuracy remains low for the study by Procopet et al. [235] (12/40 correctly classified), but satisfactory for the study by Jansen et al. [237] (66/111 patients correctly classified). However, if a combined approach is used (both spleen and liver stiffness measured), only 11/109 patients (89.9 % accuracy) are misclassified [237].

c) Assessment of oesophageal varices

TE of splenic stiffness has a good accuracy to detect the presence of oesophageal varices (80.4 %), but it is unable to differentiate the grade [233]. Values ≤ 40kPa were proposed to rule-out esophageal varices, while values ≥ 55kPa were suggested to rule them in [234]. In a meta-analysis, the pooled sensitivity and specificity to detect varices was satisfactory (0.76 and 0.78, respectively), while the sensitivity is better (0.86 vs. 0.69) for the detection of varices needing treatment [246]. A modified calculation algorithm for TE was proposed, so that values > 75 kPa could be measured, which proved to be the sole independent predictor of the need to treat [247]. Therefore, a dedicated transducer and calculation algorithm were developed, showing better performance compared with the original algorithm and with liver stiffness [248].

For pSWE, the sensitivity and specificity for detecting oesophageal varices varies from 0.31 and 0.79 [249] up to 0.95 and 0.92 [243]. However, the pooled performance for detecting the need to treat appears to be lower than for TE [246], although the analysis did not take into account a report which showed very good positive and negative predictive values: 0.97 and 0.89, respectively [243].

With 2D-SWE, [245] there is no discrimination between patients with and without varices needing treatment. In a much larger cohort, however, the AUROC for detecting oesophageal varices of any grade was 0.8, while the probability is only 10 % for patients with compensated cirrhosis if the spleen stiffness is lower than 25.6 kPa (10). If 2D-SWE SSM (</≥ 38 kPa) is used in a step-wise approach alongside liver stiffness (</≥ 19 kPa) and platelet count (≤/> 100x10³), the oesophageal varices can be ruled-out with 83 % accuracy and 74 % of unnecessary endoscopies could be eliminated [248].

d) Assessment of prognosis and response to therapy

Spleen stiffness can also predict liver-related complications, as the only independent predictor of decompensation besides the MELD score (if higher than 54 kPa), in a cohort of compensated hepatitis C virus (HCV) cirrhosis, during a 2-year follow-up period [250]. No data is available regarding the role of spleen stiffness in monitoring the response to non-selective beta-blockers. Spleen stiffness (assessed by pSWE) seems to decrease after TIPS placement [251, 252], suggesting that spleen stiffness could be an additional tool to evaluate TIPS efficiency.

Small series also suggest that successful antiviral therapy of HCV cirrhosis induces a small reduction of spleen stiffness during follow-up, which is not always significant and it is not as important or as persistent as liver stiffness reduction [253, 254], reflecting more likely a reduction of hepatic inflammation.

e) Miscellaneous

Spleen stiffness was also used to assess patients with non-cirrhotic portal hypertension. In extrahepatic portal vein obstruction, spleen stiffness increases and is higher in patients with a history of bleeding [255]. In patients with idiopathic portal sinusoidal disease, spleen stiffness is markedly increased, in contrast to quasi-normal liver stiffness values [256, 257]. Furthermore, a combination could be used in children with biliary atresia before or after Kasai portoenterostomy to predict outcome or to monitor subsequent liver disease and portal hypertension [258, 259]. Spleen stiffness by TE was also positively correlated with the grade of bone-marrow fibrosis in patients with primary myelofibrosis, suggesting that this could be a simple noninvasive method to monitor disease progression [260].

10.4 Limitations and artifacts

TE can be performed in only 85 – 90 % of cases, mainly because of high BMI, presence of ascites, lung or colonic gas interposition, or transverse spleen diameter < 4 cm [233, 234, 247]. An additional 12 – 21 % of patients reach the maximum value (75 kPa) measured by the conventional machine [233, 247], hence the applicability of TE is approximately 70 %. The applicability of 2D-SWE is similar and appears to be related to a higher BMI and smaller spleen size [261]. As for pSWE, the applicability is higher (up to 97 %) [242], but the reproducibility is influenced by small spleen size and central obesity [244].

> **RECOMMENDATION 13**
> Ultrasound elastography of the spleen can be used as an additional noninvasive method to assess portal hypertension (LoE 2b, GoR B) (For 20, Abstain 0, Against 0).

11. Kidney

11.1 Background

Renal elastography has been used for the noninvasive assessment of chronic kidney disease (CKD), particularly for the early stages when renal function is not yet significantly affected, or for disease monitoring [262]. The hypothesis that the development of glomerular and interstitial fibrosis should lead to stiffness changes is supported by experimental findings in a rat model of CKD [263].

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11.2 Methods & confounding factors

11.2.1 Strain elastography

SE can only be used for superficial kidneys, usually renal transplants, mainly a qualitative technique that supposes uniform deformation of the tissue of interest, with a limited role due to the depth of the organ, the difficulty to apply reproducible homogeneous external deformation and the inability to achieve absolute stiffness measurements [264].

11.2.2 Shear wave elastography

TE allows quantitative evaluation of the tissue stiffness and has been widely used for liver fibrosis estimation [2, 265], but the volume of tissue involved in the measurement is at a fixed depth and has a length of 40 mm, making this technique unsuitable for renal stiffness estimation.

The inter-operator agreement of pSWE used in transplanted kidneys obtained in different studies was fair or moderate with the ICC ranging between 0.31 [268] and 0.47 [269]. In studies performed in native kidneys, the reproducibility of the method was strong, with ICCs between 0.60 [270] and 0.71 [271]. The inter-operator agreement obtained in the elastographic assessment of the kidneys (native and transplant) was lower compared to studies of liver stiffness (ICCs are over 0.80), because of confounding factors. Currently, there are few studies available using 2D SWE techniques in the assessment of the kidneys [272, 273].

11.3 Clinical applications

11.3.1 Normal kidney stiffness

A limited number of studies (most of them using pSWE) report normal kidney stiffness, and are different depending on the type of pSWE device used. In adult native kidneys, normal cortical stiffness values range from 2.15 to 2.54 m/s with one system [114, 270, 271, 277 – 279] compared to 1.23 to 1.54 m/s with a different system [280]. In 9 – 16-year-old children, higher pSWE stiffness values were found, ranging from 3.00 to 3.33 m/sec (mean 3.13 ± 0.09 m/s, corresponding approximately to 29.4 kPa). In a study performed in healthy people aged 18 – 30, 31 – 50, 51 – 65, and above 65 years, pSWE was 2.94 ± 0.60, 2.26 ± 0.82, 2.48 ± 0.8 and 1.82 ± 0.63 m/s, respectively [277]. In the same study, a statistically significant difference was found between women and men. Surprisingly, normal kidney stiffness was found to exhibit an inverse, statistically significant relationship with patient age (p = 0.0003). Using pSWE, similar values were found in a small series of normal volunteers with superficial kidneys, with a cortical average stiffness of 15.4 ± 2.5 kPa [281]. The stiffness of the renal medulla was found to be lower than the cortical stiffness [272], except for in one study using pSWE [278].

11.3.2 Kidney stiffness for the assessment of renal pathology

In renal transplantation, serum creatinine levels and estimated Glomerular Filtration Rate (eGFR) are poor predictors of the severity of histological lesions. A noninvasive test that could provide diagnosis and/or prognosis early on to avoid repeated biopsies and to allow early targeted therapeutic intervention could improve pa-

tient management. Several studies report a correlation between renal stiffness and fibrosis or renal function. In experimental models of glomerulosclerosis, the cortical stiffness was correlated to the degree of renal dysfunction [263]. In humans, this correlation remains highly variable in both native and transplanted kidneys. Some authors reported a correlation between renal stiffness and fibrosis or renal function with several techniques [270, 278, 282 – 285].

In other studies, the correlation between CKD stages and kidney stiffness was negative, as shear wave velocity was found to decrease with increasing stages of CKD [270, 286] or decreasing eGFR [287, 288]. The cut-off values of renal stiffness proposed by different studies could only predict advanced stages of CKD. In the remaining studies, no correlation was found between renal stiffness and the degree of CKD or interstitial fibrosis and tubular atrophy, even in diabetic CKD [270, 272, 278, 288 – 294]. The renal perfusion changes might impact renal stiffness and explain some discrepancies between results [284], as intrarenal blood flow is decreased with the progression of fibrosis. Thus, renal blood flow decrease could be the cause of the decrease of stiffness with the progression of CKD, and could have a bigger influence on stiffness compared to renal fibrosis.

Additional preliminary applications include stiffness assessment in the case of reflux nephropathy and tumor. In a study of 28 children, CKD degree increased SWE values mainly in the kidney involved with vesicoureteral reflux (6.57 ± 0.96 m/s) but also in the contralateral kidney (4.09 ± 0.97 m/s) while the normal value in the pediatric population without renal disease was 3.13 ± 0.09 m/s [295]. The increased stiffness even in the contralateral kidney may result from increased glomerular filtration and minimal fibrosis. Renal elastography might also play a role in the detection and characterization of renal masses, improving the identification of ill-defined lesions and providing information about tumor stiffness [296].

11.4 Limitations and artifacts

Anatomical confounding factors include renal anisotropy, blood perfusion and hydronephrosis. The effect of anisotropy has been demonstrated in muscle and kidney elastography due to their spatial organization [275, 276]. When shear wave propagation is parallel to the renal tubules and interlobular arteries (and the ultrasound beam is perpendicular to these structures), the velocity of the shear waves is increased [262]. Elasticity measurements performed in the perpendicular direction to the long axis of the pyramids exhibit higher values for all renal compartments. Renal perfusion strongly affects renal elastography, with a drop in the medulla ranging from 44 % to 72.7 % in renal artery occlusion, and an increase over 500 % in renal vein thrombosis [276]. Hydronephrosis also results in a renal elasticity increase, with a correlation between urinary tract pressure and cortical stiffness varying from 119 % to 137 % between 5 and 40 mmHg [276]. Additional confounding factors include the type of technology and effect of transmit frequency, attenuation of transmit pulse (deteriorating signal-to-noise ratio). Using ARFI, the shear wave velocity was reduced by 27 % when the depth increased from 2 – 3 cm to 6 – 7 cm (2.95 ± 0.41 m/s and 2.16 ± 0.61 m/s, respectively) [277].

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Measurement depth influences the reproducibility of the method, a lower reproducibility being found in patients with deep kidneys, either native kidneys at a depth more than 4 cm or transplanted kidneys.

12. Lymph nodes

12.1 Background

Noninvasive discrimination of malignant and benign lymph nodes is important for further diagnostic and clinical decision-making. Whereas contrast-enhanced ultrasound is not recommended for the assessment of lymph nodes [297], elastography has a better diagnostic performance [298], with evidence for the examination of superficial lymph nodes and mediastinal lymph nodes. Superficial lymph nodes have been investigated by percutaneous US using SE and SWE. Mediastinal lymph nodes have been investigated by endoscopic ultrasound using only SE.

12.2 Methods

SE is the method most frequently described, as the technique is more widely available on most commercial systems, with more consolidated evidence with a number of single research studies and two meta-analyses published. More recently, SWE has been evaluated with one meta-analysis published.

12.3 Clinical applications

12.3.1 Differential diagnosis of lymphadenopathy

Assessment of superficial lymph nodes using SE presents conflicting data. Two recent meta-analyses demonstrated a high accuracy in differentiating between benign and malignant lymph nodes. The first meta-analysis included 578 patients with 936 lymph nodes with a sensitivity of the scoring and SR measurements of 76 % and 83 %, respectively [299]. The second meta-analysis included 545 patients with 835 lymph nodes and indicated a sensitivity of the elasticity scoring and SR measurements of 74 % and 88 %, with a specificity of 88 % and 91 %, respectively [300].

A meta-analysis including 481 patients with 647 lymph nodes evaluated the role of SWE in superficial lymph nodes. SWE for the discrimination of malignant and benign lymph nodes achieved a sensitivity of 81 % and specificity of 85 % [301]. The latest meta-analysis regarding the value of EUS elastography for the differentiation of malignant and benign lymph nodes included 6 studies with 368 patients and 431 lymph node, with SE demonstrating a sensitivity of 88 %, and a specificity of 85 % [302]. Newer studies including patients investigated by endobronchial ultrasound (EBUS) had similar performance [303, 304].

12.3.2 Preoperative Assessment of Lymph Nodes in Patients with Known Primary Cancer

With preoperative lymph node assessment for metastatic involvement, no systematic review is available. Two studies investigated SWE in the prediction of metastatic involvement from thyroid cancer. A retrospective analysis [305] found that using the Mean Elastic Modulus with a cut-off set to 29 kPa led to 66.67 % sensitivity and 72.62 % specificity, 78 % PPV, 64.71 % NPV and 0.748 AUC, whereas the combination with B-mode ultrasound lead to 98.04 % sensitivity, 45.45 % specificity, 73.53 % PPV, 93.75 % NPV and 0.811 AUROC. Other authors found that the best SWE parameter for predicting metastatic involvement was the maximum value of elasticity with the cut-off set to 40 kPa, leading to 80 % sensitivity, 93.1 % specificity and 0.918 AUC [306].

12.4 Limitations and artifacts

Elastography is unlikely to be suitable for a differential diagnosis, but is more likely to be useful for targeting malignant lymph nodes for fine needle aspiration if multiple lymph nodes are present [307]. It cannot be assumed that the entire lymph node is involved in malignancy, but may range from a few undetectable cells to involvement of a small area. Only a limited number of studies with small sample sizes are available and invariably have a selection bias [308, 309]. Some malignant lymph nodes cannot be discriminated by tissue stiffness alone, as is the case with the lymph nodes of lymphoma [310]. There is no standardization of the technique particularly in SE, making study comparisons difficult [311]. Often with lymph node imaging in EUS, there is a relative depletion of surrounding tissue as a normal reference for SR calculation, including the gastrointestinal wall advocated as the standard comparison for tissue reference [309].

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13. MusculoSkeletal

13.1 Background

In comparison with the previous guidelines, there has been an increase in studies regarding musculoskeletal (MSK) elastography [2].

13.2 Methods

Published data concerning the use of SE, ARFI imaging, and SWE for elastographic evaluation of the MSK structures, especially for tendons, muscles and nerves, are available.

13.3 Clinical applications

13.3.1 Tendons

In SE the healthy Achilles tendon is mostly rigid (86.7 – 93 % of the tendon has high stiffness) [312, 313] and there is an increase in stiffness with age [314]. Using SWE, different values of shear wave velocity or elastic modulus were obtained depending on the machine used, tendon position, or plane of imaging [113, 315, 316]. In Achilles tendinopathy the SR (comparing tendon with Kager's fat) is higher and the tendon becomes less stiff [317]. SE proved to be superior to B-mode ultrasound (sensitivity 99 %, specificity 78 %, accuracy 95 %) [318], underlining the ability of SE to detect pathology before the appearance of the B-mode ultrasound morphologic changes [319, 320]. No differences between athletes and controls nor between the dominant and non-dominant leg were found in SE evaluation of the patellar tendon [321]. With age, a significant decrease in shear wave velocity values was detected, with SWE having the capacity to detect aging tendons before morphologic abnormalities were observed on B-mode ultrasound [322, 323].

For lateral epicondylitis the addition of SE to B-mode ultrasound findings improves the sensitivity for detecting tendon pathology [324, 325]. Using B-mode ultrasound in combination with SE resulted in a better correlation with histologic results. In the rotator cuff, SE can detect small partial tears of the supraspinatus tendon [326]. In patients with tendinopathy, a significant decrease in the shear wave velocity of the supraspinatus muscle was observed [327]. Currently, no observations monitoring tendon healing are available in longitudinal studies.

13.3.2 Muscle

Using SE, the normal relaxed muscle appears as an inhomogeneous mosaic of intermediate or increased stiffness with scattered less stiff and stiffer areas, especially at the boundaries of the muscle [328, 329]. In SWE the normal relaxed muscle has a lower shear wave velocity (which increases during contraction) and the boundary fascia or aponeurosis show intermediate shear wave velocity [330].

Physiological factors (age, sex, muscle performance, fatigue, or training) and pathological changes (trauma, degeneration, or neuromuscular disease) influence muscle elasticity [331 – 337]. Normal and abnormal ranges of shear wave velocity of various

muscles are available [327, 333, 336, 338] but the results are limited, without establishing any reference values.

SWE for the evaluation of muscle stiffness in various neurologic conditions (Parkinson disease, chronic stroke, cerebral palsy, multiple sclerosis or Duchenne dystrophy) is a reliable quantitative imaging technique for diagnosis, treatment decisions and follow-up and may be an alternative to electromyography [333, 338 – 342].

In inflammatory myopathies SE demonstrated that the involved muscles become stiffer, and significant correlations with histological findings were obtained [328, 343]. Acute muscle and fascial tears show a lower shear wave velocity [330], but no prospective studies have been published.

13.3.3 Ligaments and fascia

Using SWE in patients with adhesive capsulitis, the coracohumeral ligament proved to be stiffer in the symptomatic shoulder [344]. The increased stiffness of the transverse carpal ligament evaluated on SE may be one of the causes for carpal tunnel syndrome [345]. The plantar fascia becomes less stiff with age and in subjects with plantar fasciitis abnormality is seen when using ARFI imaging (pixel intensity), SE or SWE even in the absence of pathological findings on B-ode ultrasound examination [346 – 350], suggesting a role of elastography in the diagnosis of early stages of plantar fasciitis.

13.3.4 Nerves

Median nerve strain is significantly lower in patients with carpal tunnel syndrome than in controls [351], and the perineural area surrounding the median nerve is stiffer than in healthy volunteers [352]. The SE can be used to follow up the median nerve recovering after carpal tunnel release [353] or after local corticosteroid injection [354] but does not have the capability to categorize the severity. The combined use of B-mode ultrasound and SE has been suggested [355].

Using pSWE the shear wave velocity of the median nerve was 3.857 m/s in patients with carpal tunnel syndrome and 2.542 m/s in the control group (p < 0.05) [356]. Using 2D-SWE the mean shear modulus of the median nerve was 66.7 kPa in patients and 32.0 kPa in the control group (p < 0.001) [357]. Both methods have high sensitivity and specificity for carpal tunnel syndrome diagnosis and are highly reproducible. The increased stiffness was attributed to nerve fibrosis or edema.

The elasticity of the tibial nerve in diabetic patients is reduced compared with a control group and decreased further after developing diabetic peripheral neuropathy [358 – 360].

The joints and limb position and the patients' age should be taken into consideration during a nerve ultrasound examination [361].

13.4 Practical points

SE is an operator-dependent technique, with a recommendation to record several (at least 3) compression-relaxation cycles as cine-loops and then select the best elastograms for evaluation. The examination transducer should be perpendicular to the tissue

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to avoid anisotropy, as the B-mode ultrasound appearance influences the quality of the elastogram.

The use of standoff devices for SE of the superficial structures does not influence the elastogram (a minimum 3 mm distance between transducer and lesion being necessary) [362], but the inclusion of gel within the region of interest should be avoided (may mask minimal differences in tendon stiffness) [329].

The SWE examination of muscles and tendons should be performed with the lightest transducer pressure. The dimension of the region of interest does not influence the mean elastic modulus [363].

The transducer must be oriented longitudinally to the muscle fibers in order to achieve accurate and reliable SWE measurements. The shear waves propagate faster in contracted tendons and muscles and along the long axis of tendons [330]. The ligaments should be examined in the same position as the corresponding joints [344].

13.5 Limitations and artifacts

When a solid structure is delimited by an incompressible shell, SE analysis of the internal structure is limited (the eggshell effect) [364]. Cystic masses characteristically have a mosaic of all levels of stiffness. Low stiffness lines may appear at the interfaces between tissues (due to tissue shifting), around calcifications, behind bone or at the superficial edge of a homogeneous lesion. Fluctuant changes at the borders of the Achilles tendon in an axial elastogram can be seen due to varying contact with the skin [365].

A limitation of SWE is depth of penetration. Superficial structures may be better visualized by applying a 5 mm layer of coupling ultrasound gel as standoff. SWE examination is influenced by the transducer pressure and angle, and the shear modulus depends on the orientation of the transducer relative to the examined structures [330, 366].

> **RECOMMENDATION 18**
>
> Ultrasound elastography can be used as a supplementary tool to increase confidence in diagnosing tendinopathy, particularly for Achilles tendinopathy, for evaluating muscle stiffness and for plantar fasciitis (LoE 2b GoR B) (For 19, Abstain 1, Against 0).

> **RECOMMENDATION 19**
>
> Ultrasound elastography can be used for the diagnosis and follow-up of carpal tunnel syndrome and diabetic peripheral neuropathy (LoE 2b, GoR B) (For 19, Abstain 1, Against 0).

14. Testis

14.1 Background

Traditionally the presence of a focal lesion in the testis was addressed by removing the testis for histological examination, on the premise that nearly all of these lesions are malignant. However, access to modern ultrasound technology has rendered this approach obsolete, and as many as 80 % of incidentally discovered lesions are benign [367]. The use of newer contrast-enhanced ultrasound and elastography techniques [368], combined as multiparametric ultrasound [369], has resulted in a more cautious approach to incidental focal testicular lesions [370]. The use of elastography to assess the stiffness of abnormal areas of the testis to ascertain stiffness as a sign of underlying malignancy is an attractive proposition to add to the overall multiparametric assessment.

14.2 Methods

14.2.1 Strain elastography

SE has been the most employed technique for the assessment of testicular lesions [371 – 375]. Early studies, predominantly retrospective, have commented on the possibility of differentiating malignant from benign lesions with certainty using SE and SR. However, these findings have not been confirmed in recent studies, with specificities between 25.0 % and 37.5 % in differentiating benign from malignant lesions [375 – 377]. A number of case series detailing the use of SE and SR (some in combination with contrast-enhanced ultrasound) have described the findings in Leydig cell tumors [378], epidermoid cysts, hematoma, lymphoma, focal infarction, capillary hemangioma, adrenal rest cells [379 – 384] and in extra-testicular lesions [385], without comparison between the findings of these different lesions.

14.2.2 SWE

There is limited information regarding the use of SWE in the evaluation of testicular lesions. Investigation of the role of SWE in the overall assessment of background parenchyma has suggested that values may be elevated in the case of testicular microlithiasis [386], infertility [387], undescended testis [388]. It also has the potential to differentiate seminomas from non-seminomatous lesions [389] and has been evaluated in burnt-out tumors [390]. No prospective study reporting the differences in SWE in focal testicular lesions has been published.

14.3 Clinical applications

The use of all forms of elastography in the assessment of focal testicular lesions is promising, with tissue stiffness confirmed with both SE and SWE techniques, but with overlap in findings between benign and malignant neoplasms. The current status would allow elastography to be an adjunct to the overall ultrasound examination rather than a standalone technique.

14.4 Limitations and artifacts

For testicular lesions, the values obtained for SWE vary between different machines and are not interchangeable [391]. The prob-

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lems associated with the areas of fibrosis adjacent to the tunica albuginea hamper the assessment of focal lesions adjacent to this region [392]. Measurements using SWE between the center and peripheral zones differ and the point of measurement requires standardization [393, 394].

> **RECOMMENDATION 20**
> Ultrasound elastography for the evaluation of focal testicular lesions can only be recommended in conjunction with other ultrasound techniques, as there is overlap between benign and malignant neoplasms (LoE 3A GoR B) (For 19, Abstain 1, Against 0).

15. Vascular

15.1 Background

It is well established that ageing and atherosclerotic disease increases arterial stiffness [395]. Elastography biomarkers are emerging as potential indicators for diseases such as stroke, hypertension, diabetes mellitus and cardiovascular disease, and may provide additional information to support clinical decision-making.

15.2 Methods

The majority of studies are based on SE. Early studies used intravascular ultrasound and more recent studies have focused on noninvasive techniques including SWE. These techniques have been compared with alternative imaging techniques, histology, clinical outcome measures and/or in experimental phantoms and simulations.

15.3 Clinical applications

15.3.1 Strain elastography

Plaque characterization is a challenging, clinically important application for which evidence of clinical benefit is growing [396]. Evidence from animal and human studies [397 – 403] typically associates vulnerable plaque with regions of high strain. The potential to detect and age thrombus has been demonstrated in animal models [404, 405]. A clinical application to differentiate acute from chronic deep vein thrombosis (DVT) has been demonstrated in humans [406 – 408], and a systematic review concluded that elastography imaging is a feasible adjunct to current first-line imaging for DVT [409]. However, at least one recent study was not able to differentiate acute DVT from subacute DVT [410]. Other potential vascular applications include cardiac, abdominal aorta and the use of elastography biomarkers for disease [411 – 414].

15.3.2 SWE

The feasibility of quantifying Young's modulus in arteries has been demonstrated in human [415], ex-vivo animal [416, 417] and phantom [418 – 420] studies. Identification of the vulnerable car-

otid plaque is emerging as a promising clinical application. Phantom studies have demonstrated the feasibility of Young's modulus estimates but highlight errors due to the requirement for a different wave propagation model than used by current commercial systems [418 – 421]. Nevertheless, human studies show good reproducibility and potential clinical benefit [422 – 426], with evidence that Young's modulus of carotid plaque correlates with qualitative (Gray-Weale scale) appearance [422, 425, 426] and quantitative (grayscale median) B-mode ultrasound measurements [422, 426], and helps to provide improved diagnostic performance of carotid plaque vulnerability [422, 426]. Studies found a lower mean Young's modulus for vulnerable plaque, although values differ (50 kPa vs. 79 kPa [426]; 62 kPa vs. 88 kPa [422]; 81 kPa vs. 115 kPa [425]). Evidence is limited for other vascular applications such as cardiac [427 – 429] and DVT [430, 431].

15.4 Limitations and artifacts

Vascular imaging is challenging due to the small heterogeneous tissue size, the dynamic environment resulting from pulsatile blood flow, thin vessel walls, non-linear tissue elasticity and shear wave propagation model assumptions which may not be valid due to the potential for Lamb wave propagation in vessel walls [415, 418]. Studies should report the shear wave velocity or calculation used to convert velocity to Young's modulus as future scanners may implement different models of wave propagation. Vascular applications are promising, especially for the assessment of carotid plaque, where larger, multicenter studies are required to validate initial findings, establish cut-off values and optimize methodologies.

> **RECOMMENDATION 21**
> Vascular ultrasound elastography is an area of active research. However, it cannot currently be recommended for clinical decision-making (LoE 5, GoR C) (For 20, Abstain 0, Against 0).

16. Intraoperative

16.1 Background

All surgical disciplines make use of preoperative imaging to visualize a pathology for improved surgical planning.

16.2 Methods

Improved ultrasound technology has resulted in high-frequency small transducers with better resolution including 3 D ultrasound, contrast-enhanced ultrasound and elastography.

16.3 Clinical applications

The utility of intraoperative ultrasound is less obvious. The advantages include intraoperative navigation without ionizing radiation exposure or relevant workflow interruption, assessment of the extent of resection, and organ shift monitoring and compensation (most important for the brain). Disadvantages for ultrasound elas-

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tography include organ deformity intraoperatively due to a number of factors including tumor resection sequelae and post-interventional swelling. The use of intraoperative elastography has been reported for the liver [8, 9, 432 – 435], brain [436 – 443], pancreas [115, 185], prostate [444], lung [445] and other organs [446].

RECOMMENDATION 22

Intraoperative ultrasound elastography is an area of active research. However, it cannot be currently recommended for clinical decision-making (LoE 5, GoR C) (For 20, Abstain 0, Against 0).

Conflict of interest

Odd Helge Gilja: Advisory Board/Consultant fee from: AbbVie, Bracco, GE Healthcare, Samsung, and Takeda
Paul S. Sidhu: Speaker honoraria, Bracco, Siemens, Samsung, Hiatchi, GE and Philips
Christoph F. Dietrich: Speaker honoraria, Bracco, Hitachi, GE, Mindray, Supersonic, Pentax, Olympus, Fuji, Boston Scientific, AbbVie, Falk Foundation, Novartis, Roche; Advisory, Board Member, Hitachi, Mindray, Siemens; Research grant, GE, Mindray, SuperSonic
Vito Cantisani: Speaker honoraria, Canon/Toshiba, Bracco, Samsung
Dominique Amy: Speaker honoraria, Hitachi, Supersonic, EpiSonica
Marco Brock: Speaker honoraria, Hitachi
Fabrizio Calliada: Speaker honoraria, Bracco, Hitachi, Shenshen Mindray
Dirk Andre Clevert: Speaker honoraria, Siemens, Samsung, GE, Bracco, Philips; Advisory Board, Siemens, Samsung, Bracco, Philips
Jean-Michel Correas: Speaker honoraria, Hitachi-Aloka, Canon/Toshiba, Philips, Supersonic, Bracco, Guerbet; Research collaboration, Bracco Sonocap, Guerbet NsSafe and Secure protocols
Mirko D'Onofrio: Speaker honoraria, Siemens, Bracco, Hitachi; Advisory Board Siemens, Bracco
Andre Farrokh: Speaker honoraria, Hitachi
Pietro Fusaroli: Speaker honoraria, Olympus
Roald Flesland Havre: Speaker honoraria, GE Healthcare, Conference participation support from Pharmacosmos, Ultrasound equipment from Samsung Medison
André Ignee: Speaker honoraria: Siemens, Canon/Toshiba, Hitachi, Boston Scientific, Bracco, Supersonic, Abbvie
Christian Jenssen: Speaker honoraria, Bracco, Hitachi, Canon/Toshiba, Falk Foundation, Covidien; Research grant, Novartis
Maija Radzina: Speaker honoraria, Bracco, Canon/Toshiba
Luca Sconfienza: Travel grants from Bracco Imaging Italia Srl, Esaote SPA, Abiogen SPA, Fidia Middle East. Speaker honoraria from Fidia Middle East
Ioan Sporea: Speaker honoraria, Philips, GE, Canon/Toshiba; Advisory Board Member, Siemens; Congress participation support, Siemens
Mickael Tanter: Speaker honoraria, Supersonic; Co Founder and shareholder, Supersonic; Research collaboration, Supersonic
Peter Vilmann: Speaker honoraria, Pentax, Norgine; Advisory Board, Boston Scientific; Consultancy MediGlobe
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References

[1] Bamber J, Cosgrove D, Dietrich CF et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Ultrasound Elastography. Part 1: Basic Principles and Technology. Ultraschall in Der Medizin 2013; 34: 169–184

[2] Cosgrove D, Piscaglia F, Bamber J et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Ultrasound Elastography. Part 2: Clinical Applications. Ultraschall in Der Medizin 2013; 34: 238–253

[3] Education and Practical Standards Committee ErFoSfUiMaB. Minimum training recommendations for the practice of medical ultrasound. Ultraschall in Med 2006; 27: 79–105

[4] Cosgrove D, Barr R, Bojunga J et al. WFUMB Guidelines and Recommendations on the Clinical Use of Ultrasound Elastography: Part 4. Thyroid. Ultrasound Med Biol 2017; 43: 4–26

[5] Tatar IG, Kurt A, Yilmaz KB et al. The learning curve of real time elasto-sonography: a preliminary study conducted for the assessment of malignancy risk in thyroid nodules. Med Ultrason 2013; 15: 278–284

[6] Grădinaru-Taşcău O, Sporea I, Bota S et al. Does experience play a role in the ability to perform liver stiffness measurements by means of supersonic shear imaging (SSI)? Med Ultrason 2013; 15: 180–183

[7] Shiina T, Nightingale KR, Palmeri ML et al. WFUMB guidelines and recommendations for clinical use of ultrasound elastography: Part 1: basic principles and terminology. Ultrasound Med Biol 2015; 41: 1126–1147

[8] Dietrich CF, Bamber J, Berzigotti A et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Liver Ultrasound Elastography, Update 2017 (Long Version). Ultraschall in Der Medizin 2017; 38: E16–E47

[9] Dietrich CF, Bamber J, Berzigotti A et al. EFSUMB Guidelines and Recommendations on the Clinical Use of Liver Ultrasound Elastography, Update 2017 (Short Version). Ultraschall in Der Medizin 2017; 38: 377–394

[10] Ferraioli G, Filice C, Castera L et al. WFUMB guidelines and recommendations for clinical use of ultrasound elastography: Part 3: liver. Ultrasound Med Biol 2015; 41: 1161–1179

[11] Barr RG, Nakashima K, Amy D et al. WFUMB guidelines and recommendations for clinical use of ultrasound elastography: Part 2: breast. Ultrasound Med Biol 2015; 41: 1148–1160

[12] Stenzel M, Mentzel HJ. Ultrasound elastography and contrast-enhanced ultrasound in infants, children and adolescents. Eur J Radiol 2014; 83: 1560–1569

[13] Goldschmidt I, Streckenbach C, Dingemann C et al. Application and limitations of transient liver elastography in children. J Pediatr Gastroenterol Nutr 2013; 57: 109–113

[14] Goldschmidt I, Brauch C, Poynard T et al. Spleen stiffness measurement by transient elastography to diagnose portal hypertension in children. J Pediatr Gastroenterol Nutr 2014; 59: 197–203

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

441

[15] Peralta L, Molina FS, Melchor J et al. Transient Elastography to Assess the Cervical Ripening during Pregnancy: A Preliminary Study. Ultraschall in Med 2017; 38: 395–402

[16] Friedrich-Rust M, Schoelzel F, Linzbach S et al. Safety of transient elastography in patients with implanted cardiac rhythm devices. Dig Liver Dis 2017; 49: 314–316

[17] Tabaru M, Yoshikawa H, Azuma T et al. Experimental study on temperature rise of acoustic radiation force elastography. J Med Ultrason (2001) 2012; 39: 137–146

[18] Herman BA, Harris GR. Models and regulatory considerations for transient temperature rise during diagnostic ultrasound pulses. Ultrasound Med Biol 2002; 28: 1217–1224

[19] Liu Y, Herman BA, Soneson JE et al. Thermal safety simulations of transient temperature rise during acoustic radiation force-based ultrasound elastography. Ultrasound Med Biol 2014; 40: 1001–1014

[20] Palmeri ML, Nightingale KR. On the thermal effects associated with radiation force imaging of soft tissue. IEEE Trans Ultrason Ferroelectr Freq Control 2004; 51: 551–565

[21] Skurczynski MJ, Duck FA, Shipley JA et al. Evaluation of experimental methods for assessing safety for ultrasound radiation force elastography. Br J Radiol 2009; 82: 666–674

[22] Deng Y, Palmeri ML, Rouze NC et al. Evaluating the Benefit of Elevated Acoustic Output in Harmonic Motion Estimation in Ultrasonic Shear Wave Elasticity Imaging. Ultrasound Med Biol 2018; 44: 303–310

[23] Itoh A, Ueno E, Tohno E et al. Breast disease: clinical application of US elastography for diagnosis. Radiology 2006; 239: 341–350

[24] Carlsen JF, Ewertsen C, Sletting S et al. Strain histograms are equal to strain ratios in predicting malignancy in breast tumours. PLoS One 2017; 12: e0186230

[25] Grajo JR, Barr RG. Strain elastography for prediction of breast cancer tumour grades. J Ultrasound Med 2014; 33: 129–134

[26] Hatzung G, Grunwald S, Zygmunt M et al. Sonoelastography in the diagnosis of malignant and benign breast lesions: initial clinical experiences. Ultraschall in Med 2010; 31: 596–603

[27] Cho N, Jang M, Lyou CY et al. Distinguishing benign from malignant masses at breast US: combined US elastography and color doppler US-influence on radiologist accuracy. Radiology 2012; 262: 80–90

[28] Wojcinski S, Farrokh A, Weber S et al. Multicenter study of ultrasound real-time tissue elastography in 779 cases for the assessment of breast lesions: improved diagnostic performance by combining the BI-RADS®-US classification system with sonoelastography. Ultraschall in Med 2010; 31: 484–491

[29] Sadigh G, Carlos RC, Neal CH et al. Ultrasonographic differentiation of malignant from benign breast lesions: a meta-analytic comparison of elasticity and BIRADS scoring. Breast Cancer Res Treat 2012; 133: 23–35

[30] Cho N, Moon WK, Kim HY et al. Sonoelastographic strain index for differentiation of benign and malignant nonpalpable breast masses. J Ultrasound Med 2010; 29: 1–7

[31] Sadigh G, Carlos RC, Neal CH et al. Accuracy of quantitative ultrasound elastography for differentiation of malignant and benign breast abnormalities: a meta-analysis. Breast Cancer Res Treat 2012; 134: 923–931

[32] Berg WA, Cosgrove DO, Doré CJ et al. Shear-wave elastography improves the specificity of breast US: the BE1 multinational study of 939 masses. Radiology 2012; 262: 435–449

[33] Evans A, Whelehan P, Thomson K et al. Invasive breast cancer: relationship between shear-wave elastographic findings and histologic prognostic factors. Radiology 2012; 263: 673–677

[34] Chang JM, Park IA, Lee SH et al. Stiffness of tumours measured by shear-wave elastography correlated with subtypes of breast cancer. Eur Radiol 2013; 23: 2450–2458

[35] Choi WJ, Kim HH, Cha JH et al. Predicting prognostic factors of breast cancer using shear wave elastography. Ultrasound Med Biol 2014; 40: 269–274

[36] Berg WA, Mendelson EB, Cosgrove DO et al. Quantitative Maximum Shear-Wave Stiffness of Breast Masses as a Predictor of Histopathologic Severity. Am J Roentgenol 2015; 205: 448–455

[37] Tamaki K, Tamaki N, Kamada Y et al. Non-invasive evaluation of axillary lymph node status in breast cancer patients using shear wave elastography. Tohoku J Exp Med 2013; 231: 211–216

[38] Wojcinski S, Dupont J, Schmidt W et al. Real-time ultrasound elastography in 180 axillary lymph nodes: elasticity distribution in healthy lymph nodes and prediction of breast cancer metastases. BMC Med Imaging 2012; 12: 35

[39] Park YM, Fornage BD, Benveniste AP et al. Strain elastography of abnormal axillary nodes in breast cancer patients does not improve diagnostic accuracy compared with conventional ultrasound alone. Am J Roentgenol 2014; 203: 1371–1378

[40] Youk JH, Gweon HM, Son EJ et al. Shear-wave elastography of invasive breast cancer: correlation between quantitative mean elasticity value and immunohistochemical profile. Breast Cancer Res Treat 2013; 138: 119–126

[41] Evans A, Rauchhaus P, Whelehan P et al. Does shear wave ultrasound independently predict axillary lymph node metastasis in women with invasive breast cancer? Breast Cancer Res Treat 2014; 143: 153–157

[42] Falou O, Sadeghi-Naini A, Prematilake S et al. Evaluation of neoadjuvant chemotherapy response in women with locally advanced breast cancer using ultrasound elastography. Transl Oncol 2013; 6: 17–24

[43] Evans A, Armstrong S, Whelehan P et al. Can shear-wave elastography predict response to neoadjuvant chemotherapy in women with invasive breast cancer? Br J Cancer 2013; 109: 2798–2802

[44] Lee SH, Chang JM, Han W et al. Shear-Wave Elastography for the Detection of Residual Breast Cancer After Neoadjuvant Chemotherapy. Ann Surg Oncol 2015; 22 (Suppl. 3): S376–S384

[45] Tanter M, Bercoff J, Athanasiou A et al. Quantitative assessment of breast lesion viscoelasticity: initial clinical results using supersonic shear imaging. Ultrasound Med Biol 2008; 34: 1373–1386

[46] Kelloff GJ, Choyke P, Coffey DS et al. Challenges in clinical prostate cancer: role of imaging. Am J Roentgenol 2009; 192: 1455–1470

[47] Singh H, Canto EI, Shariat SF et al. Predictors of prostate cancer after initial negative systematic 12 core biopsy. J Urol 2004; 171: 1850–1854

[48] Ashley RA, Inman BA, Routh JC et al. Reassessing the diagnostic yield of saturation biopsy of the prostate. Eur Urol 2008; 53: 976–981

[49] Onur R, Littrup PJ, Pontes JE et al. Contemporary impact of transrectal ultrasound lesions for prostate cancer detection. J Urol 2004; 172: 512–514

[50] Pallwein L, Mitterberger M, Struve P et al. Real-time elastography for detecting prostate cancer: preliminary experience. BJU Int 2007; 100: 42–46

[51] Salomon G, Köllerman J, Thederan I et al. Evaluation of prostate cancer detection with ultrasound real-time elastography: a comparison with step section pathological analysis after radical prostatectomy. Eur Urol 2008; 54: 1354–1362

[52] Brock M, von Bodman C, Sommerer F et al. Comparison of real-time elastography with grey-scale ultrasonography for detection of organ-confined prostate cancer and extra capsular extension: a prospective analysis using whole mount sections after radical prostatectomy. BJU Int 2011; 108: E217–222

[53] Brock M, von Bodman C, Palisaar RJ et al. The impact of real-time elastography guiding a systematic prostate biopsy to improve cancer detection rate: a prospective study of 353 patients. J Urol 2012; 187: 2039–2043

442

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

[54] Kapoor A, Mahajan G, Sidhu BS. Real-time elastography in the detection of prostate cancer in patients with raised PSA level. Ultrasound Med Biol 2011; 37: 1374–1381

[55] Walz J, Marcy M, Pianna JT et al. Identification of the prostate cancer index lesion by real-time elastography: considerations for focal therapy of prostate cancer. World J Urol 2011; 29: 589–594

[56] Aigner F, Pallwein L, Junker D et al. Value of real-time elastography targeted biopsy for prostate cancer detection in men with prostate specific antigen 1.25 ng/ml or greater and 4.00 ng/ml or less. J Urol 2010; 184: 913–917

[57] Aboumarzouk OM, Ogston S, Huang Z et al. Diagnostic accuracy of transrectal elastosonography (TRES) imaging for the diagnosis of prostate cancer: a systematic review and meta-analysis. BJU Int 2012; 110: 1414–1423; discussion 1423

[58] Kamoi K, Okihara K, Ochiai A et al. The utility of transrectal real-time elastography in the diagnosis of prostate cancer. Ultrasound Med Biol 2008; 34: 1025–1032

[59] Bercoff J, Tanter M, Muller M et al. The role of viscosity in the impulse diffraction field of elastic waves induced by the acoustic radiation force. IEEE Trans Ultrason Ferroelectr Freq Control 2004; 51: 1523–1536

[60] Barr RG, Memo R, Schaub CR. Shear wave ultrasound elastography of the prostate: initial results. Ultrasound Q 2012; 28: 13–20

[61] Correas JM, Tissier AM, Khairoune A et al. Ultrasound elastography of the prostate: state of the art. Diagn Interv Imaging 2013; 94: 551–560

[62] Aigner F, Schäfer G, Steiner E et al. Value of enhanced transrectal ultrasound targeted biopsy for prostate cancer diagnosis: a retrospective data analysis. World J Urol 2012; 30: 341–346

[63] Brock M, Eggert T, Löppenberg B et al. Value of real-time elastography to guide the systematic prostate biopsy in men with normal digital rectal exam. Aktuelle Urol 2013; 44: 40–44

[64] Brock M, Löppenberg B, Roghmann F et al. Impact of real-time elastography on magnetic resonance imaging/ultrasound fusion guided biopsy in patients with prior negative prostate biopsies. J Urol 2015; 193: 1191–1197

[65] Brock M, Roghmann F, Sonntag C et al. Fusion of Magnetic Resonance Imaging and Real-Time Elastography to Visualize Prostate Cancer: A Prospective Analysis using Whole Mount Sections after Radical Prostatectomy. Ultraschall in Med 2015; 36: 355–361

[66] Friedrich-Rust M, Meyer G, Dauth N et al. Interobserver agreement of Thyroid Imaging Reporting and Data System (TIRADS) and strain elastography for the assessment of thyroid nodules. PLoS One 2013; 8: e77927

[67] Ito Y, Amino N, Yokozawa T et al. Ultrasonographic evaluation of thyroid nodules in 900 patients: comparison among ultrasonographical, cytological, and histological findings. Thyroid 2007; 17: 1269–1276

[68] Tae HJ, Lim DJ, Baek KH et al. Diagnostic value of ultrasonography to distinguish between benign and malignant lesions in the management of thyroid nodules. Thyroid 2007; 17: 461–466

[69] Haugen BR, Alexander EK, Bible KC et al. 2015 American Thyroid Association Management Guidelines for Adult Patients with Thyroid Nodules and Differentiated Thyroid Cancer: The American Thyroid Association Guidelines Task Force on Thyroid Nodules and Differentiated Thyroid Cancer. Thyroid 2016; 26: 1–133

[70] Russ G, Bonnema SJ, Erdogan MF et al. European Thyroid Association Guidelines for Ultrasound Malignancy Risk Stratification of Thyroid Nodules in Adults: The EU-TIRADS. Eur Thyroid J 2017; 6: 225–237

[71] Kwak JY, Han KH, Yoon JH et al. Thyroid imaging reporting and data system for US features of nodules: a step in establishing better stratification of cancer risk. Radiology 2011; 260: 892–899

[72] Horvath E, Majlis S, Rossi R et al. An ultrasonogram reporting system for thyroid nodules stratifying cancer risk for clinical management. J Clin Endocrinol Metab 2009; 94: 1748–1751

[73] Park JY, Lee HJ, Jang HW et al. A proposal for a thyroid imaging reporting and data system for ultrasound features of thyroid carcinoma. Thyroid 2009; 19: 1257–1264

[74] Yoon JH, Lee HS, Kim EK et al. Malignancy Risk Stratification of Thyroid Nodules: Comparison between the Thyroid Imaging Reporting and Data System and the 2014 American Thyroid Association Management Guidelines. Radiology 2016; 278: 917–924

[75] Cantisani V, Grazhdani H, Drakonaki E et al. Strain US Elastography for the Characterization of Thyroid Nodules: Advantages and Limitation. Int J Endocrinol 2015; 2015: 908575

[76] Cantisani V, Maceroni P, D'Andrea V et al. Strain ratio ultrasound elastography increases the accuracy of colour-Doppler ultrasound in the evaluation of Thy-3 nodules. A bi-centre university experience. Eur Radiol 2016; 26: 1441–1449

[77] Cantisani V, Grazhdani H, Ricci P et al. Q-elastosonography of solid thyroid nodules: assessment of diagnostic efficacy and interobserver variability in a large patient cohort. Eur Radiol 2014; 24: 143–150

[78] Ghajarzadeh M, Sodagari F, Shakiba M. Diagnostic accuracy of sonoelastography in detecting malignant thyroid nodules: a systematic review and meta-analysis. Am J Roentgenol 2014; 202: W379–W389

[79] Razavi SA, Hadduck TA, Sadigh G et al. Comparative effectiveness of elastographic and B-mode ultrasound criteria for diagnostic discrimination of thyroid nodules: a meta-analysis. Am J Roentgenol 2013; 200: 1317–1326

[80] Sun J, Cai J, Wang X. Real-time ultrasound elastography for differentiation of benign and malignant thyroid nodules: a meta-analysis. J Ultrasound Med 2014; 33: 495–502

[81] Hu X, Liu Y, Qian L. Diagnostic potential of real-time elastography (RTE) and shear wave elastography (SWE) to differentiate benign and malignant thyroid nodules: A systematic review and meta-analysis. Medicine (Baltimore) 2017; 96: e8282

[82] Nattabi HA, Sharif NM, Yahya N et al. Is Diagnostic Performance of Quantitative 2D-Shear Wave Elastography Optimal for Clinical Classification of Benign and Malignant Thyroid Nodules?: A Systematic Review and Meta-analysis. Acad Radiol 2017. (Epub ahead of print)

[83] Tian W, Hao S, Gao B et al. Comparing the Diagnostic Accuracy of RTE and SWE in Differentiating Malignant Thyroid Nodules from Benign Ones: a Meta-Analysis. Cell Physiol Biochem 2016; 39: 2451–2463

[84] Lin P, Chen M, Liu B et al. Diagnostic performance of shear wave elastography in the identification of malignant thyroid nodules: a meta-analysis. Eur Radiol 2014; 24: 2729–2738

[85] Zhan J, Jin JM, Diao XH et al. Acoustic radiation force impulse imaging (ARFI) for differentiation of benign and malignant thyroid nodules – A meta-analysis. Eur J Radiol 2015; 84: 2181–2186

[86] Rago T, Vitti P. Role of thyroid ultrasound in the diagnostic evaluation of thyroid nodules. Best Pract Res Clin Endocrinol Metab 2008; 22: 913–928

[87] Rago T, Vitti P. Potential value of elastosonography in the diagnosis of malignancy in thyroid nodules. Q J Nucl Med Mol Imaging 2009; 53: 455–464

[88] Rago T, Scutari M, Santini F et al. Real-time elastosonography: useful tool for refining the presurgical diagnosis in thyroid nodules with indeterminate or nondiagnostic cytology. J Clin Endocrinol Metab 2010; 95: 5274–5280

[89] Ciledag N, Arda K, Aribas BK et al. The utility of ultrasound elastography and MicroPure imaging in the differentiation of benign and malignant thyroid nodules. Am J Roentgenol 2012; 198: W244–W249

[90] Vidal-Casariego A, López-González L, Jiménez-Pérez A et al. Accuracy of ultrasound elastography in the diagnosis of thyroid cancer in a low-risk population. Exp Clin Endocrinol Diabetes 2012; 120: 635–638

[91] Hong Y, Liu X, Li Z et al. Real-time ultrasound elastography in the differential diagnosis of benign and malignant thyroid nodules. J Ultrasound Med 2009; 28: 861–867

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

443

[92] Unlütürk U, Erdoğan MF, Demir O et al. Ultrasound elastography is not superior to grayscale ultrasound in predicting malignancy in thyroid nodules. Thyroid 2012; 22: 1031–1038

[93] Zhan J, Diao XH, Chai QL et al. Comparative study of acoustic radiation force impulse imaging with real-time elastography in differential diagnosis of thyroid nodules. Ultrasound Med Biol 2013; 39: 2217–2225

[94] Rago T, Santini F, Scutari M et al. Elastography: new developments in ultrasound for predicting malignancy in thyroid nodules. J Clin Endocrinol Metab 2007; 92: 2917–2922

[95] Kagoya R, Monobe H, Tojima H. Utility of elastography for differential diagnosis of benign and malignant thyroid nodules. Otolaryngol Head Neck Surg 2010; 143: 230–234

[96] He YP, Xu HX, Li XL et al. Comparison of Virtual Touch Tissue Imaging & Quantification (VTIQ) and Toshiba shear wave elastography (T-SWE) in diagnosis of thyroid nodules: Initial experience. Clin Hemorheol Microcirc 2017; 66: 15–26

[97] Wang F, Chang C, Gao Y et al. Does Shear Wave Elastography Provide Additional Value in the Evaluation of Thyroid Nodules That Are Suspicious for Malignancy? J Ultrasound Med 2016; 35: 2397–2404

[98] Swan KZ, Nielsen VE, Bibby BM et al. Is the reproducibility of shear wave elastography of thyroid nodules high enough for clinical use? A methodological study. Clin Endocrinol (Oxf) 2017; 86: 606–613

[99] Bardet S, Ciappuccini R, Pellot-Barakat C et al. Shear Wave Elastography in Thyroid Nodules with Indeterminate Cytology: Results of a Prospective Bicentric Study. Thyroid 2017; 27: 1441–1449

[100] Liu Z, Jing H, Han X et al. Shear wave elastography combined with the thyroid imaging reporting and data system for malignancy risk stratification in thyroid nodules. Oncotarget 2017; 8: 43406–43416

[101] Dobruch-Sobczak K, Gumińska A, Bakuła-Zalewska E et al. Shear wave elastography in medullary thyroid carcinoma diagnostics. J Ultrason 2015; 15: 358–367

[102] Dobruch-Sobczak K, Zalewska EB, Gumińska A et al. Diagnostic Performance of Shear Wave Elastography Parameters Alone and in Combination with Conventional B-Mode Ultrasound Parameters for the Characterization of Thyroid Nodules: A Prospective, Dual-Center Study. Ultrasound Med Biol 2016; 42: 2803–2811

[103] Wang D, He YP, Zhang YF et al. The diagnostic performance of shear wave speed (SWS) imaging for thyroid nodules with elasticity modulus and SWS measurement. Oncotarget 2017; 8: 13387–13399

[104] Duan SB, Yu J, Li X et al. Diagnostic value of two-dimensional shear wave elastography in papillary thyroid microcarcinoma. Onco Targets Ther 2016; 9: 1311–1317

[105] Liu MJ, Men YM, Zhang YL et al. Improvement of diagnostic efficiency in distinguishing the benign and malignant thyroid nodules via conventional ultrasound combined with ultrasound contrast and elastography. Oncol Lett 2017; 14: 867–871

[106] Wang F, Chang C, Chen M et al. Does Lesion Size Affect the Value of Shear Wave Elastography for Differentiating Between Benign and Malignant Thyroid Nodules? J Ultrasound Med 2018; 37: 601–609

[107] Liu BJ, Lu F, Xu HX et al. The diagnosis value of acoustic radiation force impulse (ARFI) elastography for thyroid malignancy without highly suspicious features on conventional ultrasound. Int J Clin Exp Med 2015; 8: 15362–15372

[108] Liu BJ, Zhao CK, Xu HX et al. Quality measurement on shear wave speed imaging: diagnostic value in differentiation of thyroid malignancy and the associated factors. Oncotarget 2017; 8: 4848–4959

[109] Zhou H, Yue WW, Du LY et al. A Modified Thyroid Imaging Reporting and Data System (mTI-RADS) For Thyroid Nodules in Coexisting Hashimoto's Thyroiditis. Sci Rep 2016; 6: 26410

[110] Pandey NN, Pradhan GS, Manchanda A et al. Diagnostic Value of Acoustic Radiation Force Impulse Quantification in the Differentiation of Benign and Malignant Thyroid Nodules. Ultrason Imaging 2017; 39: 326–336

[111] Liu BJ, Li DD, Xu HX et al. Quantitative Shear Wave Velocity Measurement on Acoustic Radiation Force Impulse Elastography for Differential Diagnosis between Benign and Malignant Thyroid Nodules: A Meta-analysis. Ultrasound Med Biol 2015; 41: 3035–3043

[112] Russ G. Risk stratification of thyroid nodules on ultrasonography with the French TI-RADS: description and reflections. Ultrasonography 2016; 35: 25–38

[113] Arda K, Ciledag N, Aktas E et al. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. Am J Roentgenol 2011; 197: 532–536

[114] Gallotti A, D'Onofrio M, Pozzi Mucelli R. Acoustic Radiation Force Impulse (ARFI) technique in ultrasound with Virtual Touch tissue quantification of the upper abdomen. Radiol Med 2010; 115: 889–897

[115] D'Onofrio M, Tremolada G, De Robertis R et al. Prevent Pancreatic Fistula after Pancreatoduodenectomy: Possible Role of Ultrasound Elastography. Dig Surg 2018; 35: 164–170

[116] Goertz RS, Schuderer J, Strobel D et al. Acoustic radiation force impulse shear wave elastography (ARFI) of acute and chronic pancreatitis and pancreatic tumour. Eur J Radiol 2016; 85: 2211–2216

[117] Harada N, Ishizawa T, Inoue Y et al. Acoustic radiation force impulse imaging of the pancreas for estimation of pathologic fibrosis and risk of postoperative pancreatic fistula. J Am Coll Surg 2014; 219: 887–894. e885

[118] He Y, Wang H, Li XP et al. Pancreatic Elastography From Acoustic Radiation Force Impulse Imaging for Evaluation of Diabetic Microangiopathy. Am J Roentgenol 2017; 209: 775–780

[119] Hirooka Y, Kuwahara T, Irisawa A et al. JSUM ultrasound elastography practice guidelines: pancreas. J Med Ultrason (2001) 2015; 42: 151–174

[120] Kawada N, Tanaka S. Elastography for the pancreas: Current status and future perspective. World J Gastroenterol 2016; 22: 3712–3724

[121] Kawada N, Tanaka S, Uehara H et al. Potential use of point shear wave elastography for the pancreas: a single center prospective study. Eur J Radiol 2014; 83: 620–624

[122] Kuwahara T, Hirooka Y, Kawashima H et al. Usefulness of shear wave elastography as a quantitative diagnosis of chronic pancreatitis. J Gastroenterol Hepatol 2018; 33: 756–761

[123] Kuwahara T, Hirooka Y, Kawashima H et al. Quantitative evaluation of pancreatic tumour fibrosis using shear wave elastography. Pancreatology 2016; 16: 1063–1068

[124] Llamoza-Torres CJ, Fuentes-Pardo M, Álvarez-Higueras FJ et al. Usefulness of percutaneous elastography by acoustic radiation force impulse for the non-invasive diagnosis of chronic pancreatitis. Rev Esp Enferm Dig 2016; 108: 450–456

[125] Onoyama T, Koda M, Fujise Y et al. Utility of virtual touch quantification in the diagnosis of pancreatic ductal adenocarcinoma. Clin Imaging 2017; 42: 64–67

[126] Park MK, Jo J, Kwon H et al. Usefulness of acoustic radiation force impulse elastography in the differential diagnosis of benign and malignant solid pancreatic lesions. Ultrasonography 2014; 33: 26–33

[127] Pozzi R, Parzanese I, Baccarin A et al. Point shear-wave elastography in chronic pancreatitis: A promising tool for staging disease severity. Pancreatology 2017; 17: 905–910

[128] Sağlam D, Bilgici MC, Kara C et al. Acoustic Radiation Force Impulse Elastography in Determining the Effects of Type 1 Diabetes on Pancreas and Kidney Elasticity in Children. Am J Roentgenol 2017; 209: 1143–1149

[129] Stumpf S, Jaeger H, Graeter T et al. Influence of age, sex, body mass index, alcohol, and smoking on shear wave velocity (p-SWE) of the pancreas. Abdom Radiol (NY) 2016; 41: 1310–1316

[130] Xie J, Zou L, Yao M et al. A Preliminary Investigation of Normal Pancreas and Acute Pancreatitis Elasticity Using Virtual Touch Tissue Quantification (VTQ) Imaging. Med Sci Monit 2015; 21: 1693–1699

[131] Yashima Y, Sasahira N, Isayama H et al. Acoustic radiation force impulse elastography for noninvasive assessment of chronic pancreatitis. J Gastroenterol 2012; 47: 427–432

[132] Zaro R, Lupsor-Platon M, Cheviet A et al. The pursuit of normal reference values of pancreas stiffness by using Acoustic Radiation Force Impulse (ARFI) elastography. Med Ultrason 2016; 18: 425–430

[133] D'Onofrio M, De Robertis R, Crosara S et al. Acoustic radiation force impulse with shear wave speed quantification of pancreatic masses: A prospective study. Pancreatology 2016; 16: 106–109

[134] Chantarojanasiri T, Hirooka Y, Kawashima H et al. Age-related changes in pancreatic elasticity: When should we be concerned about their effect on strain elastography? Ultrasonics 2016; 69: 90–96

[135] Chantarojanasiri T, Hirooka Y, Kawashima H et al. Endoscopic ultrasound in diagnosis of solid pancreatic lesions: Elastography or contrast-enhanced harmonic alone versus the combination. Endosc Int Open 2017; 5: E1136–E1143

[136] Dominguez-Muñoz JE, Iglesias-Garcia J, Castiñeira Alvariño M et al. EUS elastography to predict pancreatic exocrine insufficiency in patients with chronic pancreatitis. Gastrointest Endosc 2015; 81: 136–142

[137] Dyrla P, Gil J, Florek M et al. Elastography in pancreatic solid tumours diagnoses. Prz Gastroenterol 2015; 10: 41–46

[138] Harada N, Yoshizumi T, Maeda T et al. Preoperative Pancreatic Stiffness by Real-time Tissue Elastography to Predict Pancreatic Fistula After Pancreaticoduodenectomy. Anticancer Res 2017; 37: 1909–1915

[139] Hirche TO, Ignee A, Barreiros AP et al. Indications and limitations of endoscopic ultrasound elastography for evaluation of focal pancreatic lesions. Endoscopy 2008; 40: 910–917

[140] Iglesias García JJ, Lariño Noia J, Alvarez Castro A et al. Second-generation endoscopic ultrasound elastography in the differential diagnosis of solid pancreatic masses. Pancreatic cancer vs. inflammatory mass in chronic pancreatitis. Rev Esp Enferm Dig 2009; 101: 723–730

[141] Iglesias-Garcia J, Domínguez-Muñoz JE, Castiñeira-Alvariño M et al. Quantitative elastography associated with endoscopic ultrasound for the diagnosis of chronic pancreatitis. Endoscopy 2013; 45: 781–788

[142] Iglesias-Garcia J, Larino-Noia J, Abdulkader I et al. Quantitative endoscopic ultrasound elastography: an accurate method for the differentiation of solid pancreatic masses. Gastroenterology 2010; 139: 1172–1180

[143] Iglesias-Garcia J, Lindkvist B, Lariño-Noia J et al. Differential diagnosis of solid pancreatic masses: contrast-enhanced harmonic (CEH-EUS), quantitative-elastography (QE-EUS), or both? United European Gastroenterol J 2017; 5: 236–246

[144] Iordache S, Costache MI, Popescu CF et al. Clinical impact of EUS elastography followed by contrast-enhanced EUS in patients with focal pancreatic masses and negative EUSguided FNA. Medical Ultrasonography 2016; 18: 18–24

[145] Itokawa F, Itoi T, Sofuni A et al. EUS elastography combined with the strain ratio of tissue elasticity for diagnosis of solid pancreatic masses. J Gastroenterol 2011; 46: 843–853

[146] Janssen J, Papavassiliou I. Effect of aging and diffuse chronic pancreatitis on pancreas elasticity evaluated using semiquantitative EUS elastography. Ultraschall in Med 2014; 35: 253–258

[147] Kawada N, Tanaka S, Uehara H et al. Alteration of strain ratio evaluated by transabdominal ultrasound elastography may predict the efficacy of preoperative chemoradiation performed for pancreatic ductal carcinoma: preliminary results. Hepatogastroenterology 2014; 61: 480–483

[148] Kim SY, Cho JH, Kim YJ et al. Diagnostic efficacy of quantitative endoscopic ultrasound elastography for differentiating pancreatic disease. J Gastroenterol Hepatol 2017; 32: 1115–1122

[149] Kongkam P, Lakananurak N, Navicharern P et al. Combination of EUS-FNA and elastography (strain ratio) to exclude malignant solid pancreatic lesions: A prospective single-blinded study. J Gastroenterol Hepatol 2015; 30: 1683–1689

[150] Opačić D, Rustemović N, Kalauz M et al. Endoscopic ultrasound elastography strain histograms in the evaluation of patients with pancreatic masses. World J Gastroenterol 2015; 21: 4014–4019

[151] Rana SS, Dambalkar A, Chhabra P et al. Is pancreatic exocrine insufficiency in celiac disease related to structural alterations in pancreatic parenchyma? Ann Gastroenterol 2016; 29: 363–366

[152] Rustemović N, Kalauz M, Grubelić Ravić K et al. Differentiation of Pancreatic Masses via Endoscopic Ultrasound Strain Ratio Elastography Using Adjacent Pancreatic Tissue as the Reference. Pancreas 2017; 46: 347–351

[153] Săftoiu A, Vilmann P. Differential diagnosis of focal pancreatic masses by semiquantitative EUS elastography: between strain ratios and strain histograms. Gastrointest Endosc 2013; 78: 188–189

[154] Săftoiu A, Vilmann P, Gorunescu F et al. Neural network analysis of dynamic sequences of EUS elastography used for the differential diagnosis of chronic pancreatitis and pancreatic cancer. Gastrointest Endosc 2008; 68: 1086–1094

[155] Săftoiu A, Vilmann P, Gorunescu F et al. Accuracy of endoscopic ultrasound elastography used for differential diagnosis of focal pancreatic masses: a multicenter study. Endoscopy 2011; 43: 596–603

[156] Saftoiu A, Vilmann P, Gorunescu F et al. Efficacy of an Artificial Neural Network- Based Approach to Endoscopic Ultrasound Elastography in Diagnosis of Focal Pancreatic Masses. Clinical Gastroenterology and Hepatology 2012; 10: U84–U167

[157] Cui XW, Chang JM, Kan QC et al. Endoscopic ultrasound elastography: Current status and future perspectives. World J Gastroenterol 2015; 21: 13212–13224

[158] Dietrich CF. Elastography, the new dimension in ultrasonography. Praxis (Bern 1994) 2011; 100: 1533–1542

[159] Dietrich CF, Barr RG, Farrokh A et al. Strain Elastography – How To Do It? Ultrasound Int Open 2017; 3: E137–E149

[160] Dietrich CF, Cantisani V. Current status and perspectives of elastography. Eur J Radiol 2014; 83: 403–404

[161] Dietrich CF, Hirche TO, Ott M et al. Real-time tissue elastography in the diagnosis of autoimmune pancreatitis. Endoscopy 2009; 41: 718–720

[162] Dietrich CF, Săftoiu A, Jenssen C. Real time elastography endoscopic ultrasound (RTE-EUS), a comprehensive review. Eur J Radiol 2014; 83: 405–414

[163] Hocke M, Ignee A, Dietrich CF. Advanced endosonographic diagnostic tools for discrimination of focal chronic pancreatitis and pancreatic carcinoma–elastography, contrast enhanced high mechanical index (CEHMI) and low mechanical index (CELMI) endosonography in direct comparison. Z Gastroenterol 2012; 50: 199–203

[164] Janssen J, Schlörer E, Greiner L. EUS elastography of the pancreas: feasibility and pattern description of the normal pancreas, chronic pancreatitis, and focal pancreatic lesions. Gastrointest Endosc 2007; 65: 971–978

[165] Azemoto N, Kumagi T, Koizumi M et al. Diagnostic Challenge in Pancreatic Sarcoidosis using Endoscopic Ultrasonography. Intern Med 2018; 57: 231–235

[166] Chantarojanasiri T, Hirooka Y, Kawashima H et al. Endoscopic ultrasound in the diagnosis of acinar cell carcinoma of the pancreas: contrast-enhanced endoscopic ultrasound, endoscopic ultrasound elastography, and pathological correlation. Endosc Int Open 2016; 4: E1223–E1226

[167] Itoh Y, Itoh A, Kawashima H et al. Quantitative analysis of diagnosing pancreatic fibrosis using EUS-elastography (comparison with surgical specimens). J Gastroenterol 2014; 49: 1183–1192

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

445

[168] Jafri M, Sachdev AH, Khanna L et al. The Role of Real Time Endoscopic Ultrasound Guided Elastography for Targeting EUS-FNA of Suspicious Pancreatic Masses: A Review of the Literature and A Single Center Experience. JOP 2016; 17: 516 – 524

[169] Kuwahara T, Hirooka Y, Kawashima H et al. Quantitative diagnosis of chronic pancreatitis using EUS elastography. J Gastroenterol 2017; 52: 868 – 874

[170] Kuwahara T, Hirooka Y, Kawashima H et al. Usefulness of endoscopic ultrasonography-elastography as a predictive tool for the occurrence of pancreatic fistula after pancreatoduodenectomy. J Hepatobiliary Pancreat Sci 2017; 24: 649 – 656

[171] Lee TH, Cho YD, Cha SW et al. Endoscopic ultrasound elastography for the pancreas in Korea: a preliminary single center study. Clin Endosc 2013; 46: 172 – 177

[172] Pei Q, Zou X, Zhang X et al. Diagnostic value of EUS elastography in differentiation of benign and malignant solid pancreatic masses: a meta-analysis. Pancreatology 2012; 12: 402 – 408

[173] Popescu A, Ciocalteu AM, Gheonea DI et al. Utility of endoscopic ultrasound multimodal examination with fine needle aspiration for the diagnosis of pancreatic insulinoma – a case report. Current health sciences journal 2012; 38: 36 – 40

[174] Rana SS, Sharma R, Guleria S et al. Endoscopic ultrasound (EUS) elastography and contrast enhanced EUS in groove pancreatitis. Indian J Gastroenterol 2018; 37: 70 – 71

[175] Schrader H, Wiese M, Ellrichmann M et al. Diagnostic value of quantitative EUS elastography for malignant pancreatic tumours: relationship with pancreatic fibrosis. Ultraschall in Med 2012; 33: E196 – E201

[176] Soares JB, Iglesias-Garcia J, Goncalves B et al. Interobserver agreement of EUS elastography in the evaluation of solid pancreatic lesions. Endosc Ultrasound 2015; 4: 244 – 249

[177] Rustemovic N, Opacic D, Ostojic Z et al. Comparison of elastography methods in patients with pancreatic masses. Endosc Ultrasound 2014; 3: S4

[178] Saftoiu A, Vilman P. Endoscopic ultrasound elastography – a new imaging technique for the visualization of tissue elasticity distribution. J Gastrointestin Liver Dis 2006; 15: 161 – 165

[179] Mateen MA, Muheet KA, Mohan RJ et al. Evaluation of ultrasound based acoustic radiation force impulse (ARFI) and eSie touch sonoelastography for diagnosis of inflammatory pancreatic diseases. JOP 2012; 13: 36 – 44

[180] Goya C, Hamidi C, Hattapoglu S et al. Use of acoustic radiation force impulse elastography to diagnose acute pancreatitis at hospital admission: comparison with sonography and computed tomography. J Ultrasound Med 2014; 33: 1453 – 1460

[181] Domínguez-Muñoz JE. Predicting Pancreatic Exocrine Insufficiency With EUS Elastography. Gastroenterol Hepatol (N Y) 2016; 12: 511 – 512

[182] Uchida H, Hirooka Y, Itoh A et al. Feasibility of tissue elastography using transcutaneous ultrasonography for the diagnosis of pancreatic diseases. Pancreas 2009; 38: 17 – 22

[183] Friedrich-Rust M, Schlueter N, Smaczny C et al. Non-invasive measurement of liver and pancreas fibrosis in patients with cystic fibrosis. J Cyst Fibros 2013; 12: 431 – 439

[184] Sugimoto M, Takahashi S, Kojima M et al. What is the nature of pancreatic consistency? Assessment of the elastic modulus of the pancreas and comparison with tactile sensation, histology, and occurrence of postoperative pancreatic fistula after pancreaticoduodenectomy. Surgery 2014; 156: 1204 – 1211

[185] Hatano M, Watanabe J, Kushihata F et al. Quantification of pancreatic stiffness on intraoperative ultrasound elastography and evaluation of its relationship with postoperative pancreatic fistula. Int Surg 2015; 100: 497 – 502

[186] D'Onofrio M, Crosara S, De Robertis R et al. Elastography of the pancreas. Eur J Radiol 2014; 83: 415 – 419

[187] Dong Y, D'Onofrio M, Hocke M et al. Autoimmune pancreatitis: Imaging features. Endosc Ultrasound 2018; 7: 196 – 203

[188] Lee TK, Kang CM, Park MS et al. Prediction of postoperative pancreatic fistulas after pancreatectomy: assessment with acoustic radiation force impulse elastography. J Ultrasound Med 2014; 33: 781 – 786

[189] Hu DM, Gong TT, Zhu Q. Endoscopic ultrasound elastography for differential diagnosis of pancreatic masses: a meta-analysis. Dig Dis Sci 2013; 58: 1125 – 1131

[190] Mei M, Ni J, Liu D et al. EUS elastography for diagnosis of solid pancreatic masses: a meta-analysis. Gastrointest Endosc 2013; 77: 578 – 589

[191] Li X, Xu W, Shi J et al. Endoscopic ultrasound elastography for differentiating between pancreatic adenocarcinoma and inflammatory masses: a meta-analysis. World J Gastroenterol 2013; 19: 6284 – 6291

[192] Ying L, Lin X, Xie ZL et al. Clinical utility of endoscopic ultrasound elastography for identification of malignant pancreatic masses: a meta-analysis. J Gastroenterol Hepatol 2013; 28: 1434 – 1443

[193] Iglesias-Garcia J, Larino-Noia J, Abdulkader I et al. EUS elastography for the characterization of solid pancreatic masses. Gastrointest Endosc 2009; 70: 1101 – 1108

[194] Giovannini M, Thomas B, Erwan B et al. Endoscopic ultrasound elastography for evaluation of lymph nodes and pancreatic masses: A multi-center study. World Journal of Gastroenterology 2009; 15: 1587 – 1593

[195] Ignee A, Jenssen C, Hocke M et al. Contrast-enhanced (endoscopic) ultrasound and endoscopic ultrasound elastography in gastrointestinal stromal tumours. Endoscopic Ultrasound 2017; 6: 55 – 60

[196] Havre RF, Ødegaard S, Gilja OH et al. Characterization of solid focal pancreatic lesions using endoscopic ultrasonography with real-time elastography. Scand J Gastroenterol 2014; 49: 742 – 751

[197] Dawwas MF, Taha H, Leeds JS et al. Diagnostic accuracy of quantitative EUS elastography for discriminating malignant from benign solid pancreatic masses: a prospective, single-center study. Gastrointest Endosc 2012; 76: 953 – 961

[198] Mayerle J, Beyer G, Simon P et al. Prospective cohort study comparing transient EUS guided elastography to EUS-FNA for the diagnosis of solid pancreatic mass lesions. Pancreatology 2016; 16: 110 – 114

[199] Figueiredo FA, da Silva PM, Monges G et al. Yield of Contrast-Enhanced Power Doppler Endoscopic Ultrasonography and Strain Ratio Obtained by EUS-Elastography in the Diagnosis of Focal Pancreatic Solid Lesions. Endosc Ultrasound 2012; 1: 143 – 149

[200] Popescu A, Ciocalteu AM, Gheonea DI et al. Utility of endoscopic ultrasound multimodal examination with fine needle aspiration for the diagnosis of pancreatic insulinoma – a case report. Curr Health Sci J 2012; 38: 36 – 40

[201] Deprez PH. EUS elastography: is it replacing or supplementing tissue acquisition? Gastrointest Endosc 2013; 77: 590 – 592

[202] Săftoiu A, Iordache SA, Gheonea DI et al. Combined contrast-enhanced power Doppler and real-time sonoelastography performed during EUS, used in the differential diagnosis of focal pancreatic masses (with videos). Gastrointest Endosc 2010; 72: 739 – 747

[203] Dumonceau JM, Deprez PH, Jenssen C et al. Indications, results, and clinical impact of endoscopic ultrasound (EUS)-guided sampling in gastroenterology: European Society of Gastrointestinal Endoscopy (ESGE) Clinical Guideline – Updated January 2017. Endoscopy 2017; 49: 695 – 714

[204] Jenssen C, Hocke M, Fusaroli P et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part IV – EUS-guided interventions: General Aspects and EUS-guided Sampling (Short Version). Ultraschall in Med 2016; 37: 157 – 169

[205] Jenssen C, Hocke M, Fusaroli P et al. EFSUMB Guidelines on Interventional Ultrasound (INVUS), Part IV – EUS-guided Interventions: General

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Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

aspects and EUS-guided sampling (Long Version). Ultraschall in Med 2016; 37: E33 – E76

[206] Hewitt MJ, McPhail MJ, Possamai L et al. EUS-guided FNA for diagnosis of solid pancreatic neoplasms: a meta-analysis. Gastrointest Endosc 2012; 75: 319 – 331

[207] Dietrich C, Sahai A, D'Onofrio M et al. Differential diagnosis of small solid pancreatic lesions. Gastrointestinal Endoscopy 2016; 84: 933 – 940

[208] D'Onofrio M, Crosara S, Canestrini S et al. Virtual analysis of pancreatic cystic lesion fluid content by ultrasound acoustic radiation force impulse quantification. J Ultrasound Med 2013; 32: 647 – 651

[209] D'Onofrio M, Gallotti A, Falconi M et al. Acoustic radiation force impulse ultrasound imaging of pancreatic cystic lesions: preliminary results. Pancreas 2010; 39: 939 – 940

[210] D'Onofrio M, Gallotti A, Martone E et al. Solid appearance of pancreatic serous cystadenoma diagnosed as cystic at ultrasound acoustic radiation force impulse imaging. JOP 2009; 10: 543 – 546

[211] D'Onofrio M, Gallotti A, Mucelli RP. Pancreatic mucinous cystadenoma at ultrasound acoustic radiation force impulse (ARFI) imaging. Pancreas 2010; 39: 684 – 685

[212] D'Onofrio M, Gallotti A, Salvia R et al. Acoustic radiation force impulse (ARFI) ultrasound imaging of pancreatic cystic lesions. Eur J Radiol 2011; 80: 241 – 244

[213] Havre RF, Waage JR, Gilja OH et al. Real-Time Elastography: Strain Ratio Measurements Are Influenced by the Position of the Reference Area. Ultraschall in Med 2011. (Epub ahead of print)

[214] Nylund K, Ødegaard S, Hausken T et al. Sonography of the small intestine. World J Gastroenterol 2009; 15: 1319 – 1330

[215] Nylund K, Maconi G, Hollerweger A et al. EFSUMB Recommendations and Guidelines for Gastrointestinal Ultrasound Part 1: Examination Techniques and Normal Findings (Long version). Ultraschall in Der Medizin 2017; 38: E1 – E15

[216] Kim K, Johnson LA, Jia C et al. Noninvasive ultrasound elasticity imaging (UEI) of Crohn's disease: animal model. Ultrasound Med Biol 2008; 34: 902 – 912

[217] Stidham RW, Higgins PD. Imaging of intestinal fibrosis: current challenges and future methods. United European Gastroenterol J 2016; 4: 515 – 522

[218] Dillman JR, Stidham RW, Higgins PD et al. US elastography-derived shear wave velocity helps distinguish acutely inflamed from fibrotic bowel in a Crohn disease animal model. Radiology 2013; 267: 757 – 766

[219] Sconfienza LM, Cavallaro F, Colombi V et al. In-vivo Axial-strain Sonoelastography Helps Distinguish Acutely-inflamed from Fibrotic Terminal Ileum Strictures in Patients with Crohn's Disease: Preliminary Results. Ultrasound Med Biol 2016; 42: 855 – 863

[220] Havre RF, Leh S, Gilja OH et al. Strain assessment in surgically resected inflammatory and neoplastic bowel lesions. Ultraschall in Med 2014; 35: 149 – 158

[221] Pescatori LC, Mauri G, Savarino E et al. Bowel Sonoelastography in Patients with Crohn's Disease: A Systematic Review. Ultrasound Med Biol 2018; 44: 297 – 302

[222] Baumgart DC, Müller HP, Grittner U et al. US-based Real-time Elastography for the Detection of Fibrotic Gut Tissue in Patients with Stricturing Crohn Disease. Radiology 2015; 275: 889 – 899

[223] Fraquelli M, Branchi F, Cribiù FM et al. The Role of Ultrasound Elasticity Imaging in Predicting Ileal Fibrosis in Crohn's Disease Patients. Inflamm Bowel Dis 2015; 21: 2605 – 2612

[224] Serra C, Rizzello F, Pratico' C et al. Real-time elastography for the detection of fibrotic and inflammatory tissue in patients with stricturing Crohn's disease. J Ultrasound 2017; 20: 273 – 284

[225] Orlando S, Fraquelli M, Coletta M et al. Ultrasound Elasticity Imaging predicts therapeutic outcomes of patients with Crohn's disease treated with anti-tumour necrosis factor antibodies. J Crohns Colitis 2018; 12: 63 – 70

[226] Waage JE, Bach SP, Pfeffer F et al. Combined endorectal ultrasonography and strain elastography for the staging of early rectal cancer. Colorectal Dis 2015; 17: 50 – 56

[227] Waage JE, Leh S, Røsler C et al. Endorectal ultrasonography, strain elastography and MRI differentiation of rectal adenomas and adeno-carcinomas. Colorectal Dis 2015; 17: 124 – 131

[228] Waage JE, Rafaelsen SR, Borley NR et al. Strain Elastography Evaluation of Rectal Tumours: Inter- and Intraobserver Reproducibility. Ultraschall in Med 2015; 36: 611 – 617

[229] Rafaelsen SR, Vagn-Hansen C, Sørensen T et al. Elastography and diffusion-weighted MRI in patients with rectal cancer. Br J Radiol 2015; 88: 20150294

[230] Chen LD, Wang W, Xu JB et al. Assessment of Rectal Tumours with Shear-Wave Elastography before Surgery: Comparison with Endorectal US. Radiology 2017; 285: 279 – 292

[231] Arena U, Lupsor Platon M, Stasi C et al. Liver stiffness is influenced by a standardized meal in patients with chronic hepatitis C virus at different stages of fibrotic evolution. Hepatology 2013; 58: 65 – 72

[232] Berzigotti A, De Gottardi A, Vukotic R et al. Effect of meal ingestion on liver stiffness in patients with cirrhosis and portal hypertension. PLoS One 2013; 8: e58742

[233] Ştefănescu H, Grigorescu M, Lupşor M et al. Spleen stiffness measurement using Fibroscan for the noninvasive assessment of esophageal varices in liver cirrhosis patients. J Gastroenterol Hepatol 2011; 26: 164 – 170

[234] Colecchia A, Montrone L, Scaioli E et al. Measurement of spleen stiffness to evaluate portal hypertension and the presence of esophageal varices in patients with HCV-related cirrhosis. Gastroenterology 2012; 143: 646 – 654

[235] Procopet B, Berzigotti A, Abraldes JG et al. Real-time shear-wave elastography: applicability, reliability and accuracy for clinically significant portal hypertension. J Hepatol 2015; 62: 1068 – 1075

[236] Karlas T, Lindner F, Tröltzsch M et al. Assessment of spleen stiffness using acoustic radiation force impulse imaging (ARFI): definition of examination standards and impact of breathing maneuvers. Ultraschall in Med 2014; 35: 38 – 43

[237] Jansen C, Bogs C, Verlinden W et al. Shear-wave elastography of the liver and spleen identifies clinically significant portal hypertension: A prospective multicentre study. Liver Int 2017; 37: 396 – 405

[238] Samir AE, Dhyani M, Vij A et al. Shear-wave elastography for the estimation of liver fibrosis in chronic liver disease: determining accuracy and ideal site for measurement. Radiology 2015; 274: 888 – 896

[239] Grgurevic I, Puljiz Z, Brnic D et al. Liver and spleen stiffness and their ratio assessed by real-time two dimensional-shear wave elastography in patients with liver fibrosis and cirrhosis due to chronic viral hepatitis. Eur Radiol 2015; 25: 3214 – 3221

[240] Song J, Huang J, Huang H et al. Performance of spleen stiffness measurement in prediction of clinical significant portal hypertension: A meta-analysis. Clin Res Hepatol Gastroenterol 2018; 42: 216 – 226

[241] Zykus R, Jonaitis L, Petrenkienė V et al. Liver and spleen transient elastography predicts portal hypertension in patients with chronic liver disease: a prospective cohort study. BMC Gastroenterol 2015; 15: 183

[242] Takuma Y, Nouso K, Morimoto Y et al. Portal Hypertension in Patients with Liver Cirrhosis: Diagnostic Accuracy of Spleen Stiffness. Radiology 2016; 279: 609 – 619

[243] Attia D, Schoenemeier B, Rodt T et al. Evaluation of Liver and Spleen Stiffness with Acoustic Radiation Force Impulse Quantification Elastography for Diagnosing Clinically Significant Portal Hypertension. Ultraschall in Med 2015; 36: 603 – 610

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

447

[244] Balakrishnan M, Souza F, Muñoz C et al. Liver and Spleen Stiffness Measurements by Point Shear Wave Elastography via Acoustic Radiation Force Impulse: Intraobserver and Interobserver Variability and Predictors of Variability in a US Population. J Ultrasound Med 2016; 35: 2373 – 2380

[245] Elkrief L, Rautou PE, Ronot M et al. Prospective comparison of spleen and liver stiffness by using shear-wave and transient elastography for detection of portal hypertension in cirrhosis. Radiology 2015; 275: 589 – 598

[246] Singh S, Eaton JE, Murad MH et al. Accuracy of spleen stiffness measurement in detection of esophageal varices in patients with chronic liver disease: systematic review and meta-analysis. Clin Gastroenterol Hepatol 2014; 12: 935 – 945.e934

[247] Calvaruso V, Bronte F, Conte E et al. Modified spleen stiffness measurement by transient elastography is associated with presence of large oesophageal varices in patients with compensated hepatitis C virus cirrhosis. J Viral Hepat 2013; 20: 867 – 874

[248] Stefanescu H, Allegretti G, Salvatore V et al. Bidimensional shear wave ultrasound elastography with supersonic imaging to predict presence of oesophageal varices in cirrhosis. Liver Int 2017; 37: 1405

[249] Bota S, Sporea I, Sirli R et al. Can ARFI elastography predict the presence of significant esophageal varices in newly diagnosed cirrhotic patients? Ann Hepatol 2012; 11: 519 – 525

[250] Colecchia A, Colli A, Casazza G et al. Spleen stiffness measurement can predict clinical complications in compensated HCV-related cirrhosis: a prospective study. J Hepatol 2014; 60: 1158 – 1164

[251] Gao J, Ran HT, Ye XP et al. The stiffness of the liver and spleen on ARFI Imaging pre and post TIPS placement: a preliminary observation. Clin Imaging 2012; 36: 135 – 141

[252] Novelli PM, Cho K, Rubin JM. Sonographic assessment of spleen stiffness before and after transjugular intrahepatic portosystemic shunt placement with or without concurrent embolization of portal systemic collateral veins in patients with cirrhosis and portal hypertension: a feasibility study. J Ultrasound Med 2015; 34: 443 – 449

[253] Verlinden W, Bourgeois S, Gigase P et al. Liver Fibrosis Evaluation Using Real-time Shear Wave Elastography in Hepatitis C-Monoinfected and Human Immunodeficiency Virus/Hepatitis C-Coinfected Patients. J Ultrasound Med 2016; 35: 1299 – 1308

[254] Pons M, Simón-Talero M, Millán L et al. Basal values and changes of liver stiffness predict the risk of disease progression in compensated advanced chronic liver disease. Dig Liver Dis 2016; 48: 1214 – 1219

[255] Sharma P, Mishra SR, Kumar M et al. Liver and spleen stiffness in patients with extrahepatic portal vein obstruction. Radiology 2012; 263: 893 – 899

[256] Furuichi Y, Moriyasu F, Taira J et al. Noninvasive diagnostic method for idiopathic portal hypertension based on measurements of liver and spleen stiffness by ARFI elastography. J Gastroenterol 2013; 48: 1061 – 1068

[257] Seijo S, Reverter E, Miquel R et al. Role of hepatic vein catheterisation and transient elastography in the diagnosis of idiopathic portal hypertension. Dig Liver Dis 2012; 44: 855 – 860

[258] Uchida H, Sakamoto S, Kobayashi M et al. The degree of spleen stiffness measured on acoustic radiation force impulse elastography predicts the severity of portal hypertension in patients with biliary atresia after portoenterostomy. J Pediatr Surg 2015; 50: 559 – 564

[259] Colecchia A, Marasco G, Festi D. Are Noninvasive Methods Clinically Useful in Advanced, Decompensated Liver Cirrhosis When "Les Jeux Sont Faits"? Radiology 2016; 278: 304 – 305

[260] Iurlo A, Cattaneo D, Giunta M et al. Transient elastography spleen stiffness measurements in primary myelofibrosis patients: a pilot study in a single centre. Br J Haematol 2015; 170: 890 – 892

[261] Cassinotto C, Charrie A, Mouries A et al. Liver and spleen elastography using supersonic shear imaging for the non-invasive diagnosis of cir-

rhosis severity and oesophageal varices. Dig Liver Dis 2015; 47: 695 – 701

[262] Correas JM, Anglicheau D, Joly D et al. Ultrasound-based imaging methods of the kidney-recent developments. Kidney Int 2016; 90: 1199 – 1210

[263] Derieppe M, Delmas Y, Gennisson JL et al. Detection of intrarenal microstructural changes with supersonic shear wave elastography in rats. Eur Radiol 2012; 22: 243 – 250

[264] Franchi-Abella S, Elie C, Correas JM. Ultrasound elastography: advantages, limitations and artefacts of the different techniques from a study on a phantom. Diagn Interv Imaging 2013; 94: 497 – 501

[265] Ferraioli G, Tinelli C, Malfitano A et al. Performance of real-time strain elastography, transient elastography, and aspartate-to-platelet ratio index in the assessment of fibrosis in chronic hepatitis C. Am J Roentgenol 2012; 199: 19 – 25

[266] Nightingale K, Bentley R, Trahey G. Observations of tissue response to acoustic radiation force: opportunities for imaging. Ultrason Imaging 2002; 24: 129 – 138

[267] Sarvazyan AP, Rudenko OV, Nyborg WL. Biomedical applications of radiation force of ultrasound: historical roots and physical basis. Ultrasound Med Biol 2010; 36: 1379 – 1394

[268] Syversveen T, Brabrand K, Midtvedt K et al. Assessment of renal allograft fibrosis by acoustic radiation force impulse quantification–a pilot study. Transpl Int 2011; 24: 100 – 105

[269] Ozkan F, Yavuz YC, Inci MF et al. Interobserver variability of ultrasound elastography in transplant kidneys: correlations with clinical-Doppler parameters. Ultrasound Med Biol 2013; 39: 4 – 9

[270] Guo LH, Xu HX, Fu HJ et al. Acoustic radiation force impulse imaging for noninvasive evaluation of renal parenchyma elasticity: preliminary findings. PLoS One 2013; 8: e68925

[271] Bob F, Bota S, Sporea I et al. Kidney shear wave speed values in subjects with and without renal pathology and inter-operator reproducibility of acoustic radiation force impulse elastography (ARFI)–preliminary results. PLoS One 2014; 9: e113761

[272] Grenier N, Poulain S, Lepreux S et al. Quantitative elastography of renal transplants using supersonic shear imaging: a pilot study. Eur Radiol 2012; 22: 2138 – 2146

[273] Samir AE, Allegretti AS, Zhu Q et al. Shear wave elastography in chronic kidney disease: a pilot experience in native kidneys. BMC Nephrol 2015; 16: 119

[274] Gennisson JL, Rénier M, Catheline S et al. Acoustoelasticity in soft solids: assessment of the nonlinear shear modulus with the acoustic radiation force. J Acoust Soc Am 2007; 122: 3211 – 3219

[275] Gennisson JL, Deffieux T, Macé E et al. Viscoelastic and anisotropic mechanical properties of in vivo muscle tissue assessed by supersonic shear imaging. Ultrasound Med Biol 2010; 36: 789 – 801

[276] Gennisson JL, Grenier N, Combe C et al. Supersonic shear wave elastography of in vivo pig kidney: influence of blood pressure, urinary pressure and tissue anisotropy. Ultrasound Med Biol 2012; 38: 1559 – 1567

[277] Bota S, Bob F, Sporea I et al. Factors that influence kidney shear wave speed assessed by acoustic radiation force impulse elastography in patients without kidney pathology. Ultrasound Med Biol 2015; 41: 1 – 6

[278] Asano K, Ogata A, Tanaka K et al. Acoustic radiation force impulse elastography of the kidneys: is shear wave velocity affected by tissue fibrosis or renal blood flow? J Ultrasound Med 2014; 33: 793 – 801

[279] Bob F, Bota S, Sporea I et al. Relationship between the estimated glomerular filtration rate and kidney shear wave speed values assessed by acoustic radiation force impulse elastography: a pilot study. J Ultrasound Med 2015; 34: 649 – 654

[280] Singh H, Panta OB, Khanal U et al. Renal Cortical Elastography: Normal Values and Variations. J Med Ultrasound 2017; 25: 215 – 220

[281] Grenier N, Gennisson JL, Cornelis F et al. Renal ultrasound elastography. Diagn Interv Imaging 2013; 94: 545 – 550

[282] Arndt R, Schmidt S, Loddenkemper C et al. Noninvasive evaluation of renal allograft fibrosis by transient elastography–a pilot study. Transpl Int 2010; 23: 871 – 877

[283] Stock KF, Klein BS, Cong MT et al. ARFI-based tissue elasticity quantification and kidney graft dysfunction: first clinical experiences. Clin Hemorheol Microcirc 2011; 49: 527 – 535

[284] Marticorena GarciaSR, Guo J, Dürr M et al. Comparison of ultrasound shear wave elastography with magnetic resonance elastography and renal microvascular flow in the assessment of chronic renal allograft dysfunction. Acta Radiol 2018; 59: 1139 – 1145

[285] Grass L, Szekely N, Alrajab A et al. Point shear wave elastography (pSWE) using Acoustic Radiation Force Impulse (ARFI) imaging: a feasibility study and norm values for renal parenchymal stiffness in healthy children and adolescents. Med Ultrason 2017; 19: 366 – 373

[286] Sasaki Y, Hirooka Y, Kawashima H et al. Measurements of renal shear wave velocities in chronic kidney disease patients. Acta Radiol 2018; 59: 884 – 890

[287] He WY, Jin YJ, Wang WP et al. Tissue elasticity quantification by acoustic radiation force impulse for the assessment of renal allograft function. Ultrasound Med Biol 2014; 40: 322 – 329

[288] Bob F, Grosu I, Sporea I et al. Ultrasound-Based Shear Wave Elastography in the Assessment of Patients with Diabetic Kidney Disease. Ultrasound Med Biol 2017; 43: 2159 – 2166

[289] Syversveen T, Midtvedt K, Berstad AE et al. Tissue elasticity estimated by acoustic radiation force impulse quantification depends on the applied transducer force: an experimental study in kidney transplant patients. Eur Radiol 2012; 22: 2130 – 2137

[290] Wang L, Xia P, Lv K et al. Assessment of renal tissue elasticity by acoustic radiation force impulse quantification with histopathological correlation: preliminary experience in chronic kidney disease. Eur Radiol 2014; 24: 1694 – 1699

[291] Lee J, Oh YT, Joo DJ et al. Acoustic Radiation Force Impulse Measurement in Renal Transplantation: A Prospective, Longitudinal Study With Protocol Biopsies. Medicine (Baltimore) 2015; 94: e1590

[292] Bob F, Grosu I, Sporea I et al. Is there a correlation between kidney shear wave velocity measured with VTQ and histological parameters in patients with chronic glomerulonephritis? A pilot study. Med Ultrason 2018; 1: 27 – 31

[293] Early HM, Cheang EC, Aguilera JM et al. Utility of Shear Wave Elastography for Assessing Allograft Fibrosis in Renal Transplant Recipients: A Pilot Study. J Ultrasound Med 2018; 37: 1455 – 1465

[294] Yoo MG, Jung DC, Oh YT et al. Usefulness of Multiparametric Ultrasound for Evaluating Structural Abnormality of Transplanted Kidney: Can We Predict Histologic Abnormality on Renal Biopsy in Advance? Am J Roentgenol 2017; 209: W139 – W144

[295] Bruno C, Caliari G, Zaffanello M et al. Acoustic radiation force impulse (ARFI) in the evaluation of the renal parenchymal stiffness in paediatric patients with vesicoureteral reflux: preliminary results. Eur Radiol 2013; 23: 3477 – 3484

[296] Clevert DA, Stock K, Klein B et al. Evaluation of Acoustic Radiation Force Impulse (ARFI) imaging and contrast-enhanced ultrasound in renal tumours of unknown etiology in comparison to histological findings. Clin Hemorheol Microcirc 2009; 43: 95 – 107

[297] Sidhu PS. Ultrasound Collaboration across Europe: An EFSUMB success story in politically troubled times? Ultraschall in Med 2016; 37: 451 – 452

[298] Tan S, Miao LY, Cui LG et al. Value of Shear Wave Elastography Versus Contrast-Enhanced Sonography for Differentiating Benign and Malignant Superficial Lymphadenopathy Unexplained by Conventional Sonography. J Ultrasound Med 2017; 36: 189 – 199

[299] Ghajarzadeh M, Mohammadifar M, Azarkhish K et al. Sono-elastography for Differentiating Benign and Malignant Cervical Lymph Nodes: A Systematic Review and Meta-Analysis. Int J Prev Med 2014; 5: 1521 – 1528

[300] Ying L, Hou Y, Zheng HM et al. Real-time elastography for the differentiation of benign and malignant superficial lymph nodes: a meta-analysis. Eur J Radiol 2012; 81: 2576 – 2584

[301] Suh CH, Choi YJ, Baek JH et al. The diagnostic performance of shear wave elastography for malignant cervical lymph nodes: A systematic review and meta-analysis. Eur Radiol 2017; 27: 222 – 230

[302] Xu W, Shi J, Zeng X et al. EUS elastography for the differentiation of benign and malignant lymph nodes: a meta-analysis. Gastrointest Endosc 2011; 74: 1001 – 1009; quiz 1115.e1001–1004

[303] Mao XW, Yang JY, Zheng XX et al. Comparison of two quantitative methods of endobronchial ultrasound real-time elastography for evaluating intrathoracic lymph nodes. Zhonghua Jie He He Hu Xi Za Zhi 2017; 40: 431 – 434

[304] Sun J, Zheng X, Mao X et al. Endobronchial Ultrasound Elastography for Evaluation of Intrathoracic Lymph Nodes: A Pilot Study. Respiration 2017; 93: 327 – 338

[305] Jung WS, Kim JA, Son EJ et al. Shear wave elastography in evaluation of cervical lymph node metastasis of papillary thyroid carcinoma: elasticity index as a prognostic implication. Ann Surg Oncol 2015; 22: 111 – 116

[306] You J, Chen J, Xiang F et al. The value of quantitative shear wave elastography in differentiating the cervical lymph nodes in patients with thyroid nodules. J Med Ultrason (2001) 2018; 45: 251 – 259

[307] Janssen J, Dietrich CF, Will U et al. Endosonographic elastography in the diagnosis of mediastinal lymph nodes. Endoscopy 2007; 39: 952 – 957

[308] Bhatia KS, Lee YY, Yuen EH et al. Ultrasound elastography in the head and neck. Part II. Accuracy for malignancy. Cancer Imaging 2013; 13: 260 – 276

[309] Larsen MH, Fristrup C, Hansen TP et al. Endoscopic ultrasound, endoscopic sonoelastography, and strain ratio evaluation of lymph nodes with histology as gold standard. Endoscopy 2012; 44: 759 – 766

[310] Łasecki M, Olchowy C, Sokołowska-Dąbek D et al. Modified sonoelastographic scale score for lymph node assessment in lymphoma – a preliminary report. J Ultrason 2015; 15: 45 – 55

[311] Dudea SM, Botar-Jid C, Dumitriu D et al. Differentiating benign from malignant superficial lymph nodes with sonoelastography. Med Ultrason 2013; 15: 132 – 139

[312] De Zordo T, Chhem R, Smekal V et al. Real-time sonoelastography: findings in patients with symptomatic achilles tendons and comparison to healthy volunteers. Ultraschall in Med 2010; 31: 394 – 400

[313] De Zordo T, Fink C, Feuchtner GM et al. Real-time sonoelastography findings in healthy Achilles tendons. Am J Roentgenol 2009; 193: W134 – W138

[314] Turan A, Teber MA, Yakut ZI et al. Sonoelastographıc assessment of the age-related changes of the Achilles tendon. Med Ultrason 2015; 17: 58 – 61

[315] Aubry S, Risson JR, Kastler A et al. Biomechanical properties of the calcaneal tendon in vivo assessed by transient shear wave elastography. Skeletal Radiol 2013; 42: 1143 – 1150

[316] Chen XM, Cui LG, He P et al. Shear wave elastographic characterization of normal and torn achilles tendons: a pilot study. J Ultrasound Med 2013; 32: 449 – 455

[317] Ooi CC, Schneider ME, Malliaras P et al. Diagnostic performance of axial-strain sonoelastography in confirming clinically diagnosed Achilles tendinopathy: comparison with B-mode ultrasound and color Doppler imaging. Ultrasound Med Biol 2015; 41: 15 – 25

[318] Klauser AS, Miyamoto H, Tamegger M et al. Achilles tendon assessed with sonoelastography: histologic agreement. Radiology 2013; 267: 837 – 842

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

449

[319] Balaban M, Idilman IS, Ipek A et al. Elastographic Findings of Achilles Tendons in Asymptomatic Professional Male Volleyball Players. J Ultrasound Med 2016; 35: 2623 – 2628

[320] Ooi CC, Schneider ME, Malliaras P et al. Prevalence of morphological and mechanical stiffness alterations of mid Achilles tendons in asymptomatic marathon runners before and after a competition. Skeletal Radiol 2015; 44: 1119 – 1127

[321] Ozcan AN, Tan S, Tangal NG et al. Real-time sonoelastography of the patellar and quadriceps tendons: pattern description in professional athletes and healthy volunteers. Med Ultrason 2016; 18: 299 – 304

[322] Klauser AS, Pamminger M, Halpern EJ et al. Extensor tendinopathy of the elbow assessed with sonoelastography: histologic correlation. Eur Radiol 2017; 27: 3460 – 3466

[323] De Zordo T, Lill SR, Fink C et al. Real-time sonoelastography of lateral epicondylitis: comparison of findings between patients and healthy volunteers. Am J Roentgenol 2009; 193: 180 – 185

[324] Lacourpaille L, Nordez A, Hug F et al. Time-course effect of exercise-induced muscle damage on localized muscle mechanical properties assessed using elastography. Acta Physiol (Oxf) 2014; 211: 135 – 146

[325] Klauser AS, Pamminger MJ, Halpern EJ et al. Sonoelastography of the Common Flexor Tendon of the Elbow with Histologic Agreement: A Cadaveric Study. Radiology 2017; 283: 486 – 491

[326] Tudisco C, Bisicchia S, Stefanini M et al. Tendon quality in small unilateral supraspinatus tendon tears. Real-time sonoelastography correlates with clinical findings. Knee Surg Sports Traumatol Arthrosc 2015; 23: 393 – 398

[327] Rosskopf AB, Ehrmann C, Buck FM et al. Quantitative Shear-Wave US Elastography of the Supraspinatus Muscle: Reliability of the Method and Relation to Tendon Integrity and Muscle Quality. Radiology 2016; 278: 465 – 474

[328] Botar-Jid C, Damian L, Dudea SM et al. The contribution of ultrasonography and sonoelastography in assessment of myositis. Med Ultrason 2010; 12: 120 – 126

[329] Drakonaki E. Ultrasound elastography for imaging tendons and muscles. J Ultrason 2012; 12: 214 – 225

[330] Taljanovic MS, Gimber LH, Becker GW et al. Shear-Wave Elastography: Basic Physics and Musculoskeletal Applications. Radiographics 2017; 37: 855 – 870

[331] Akagi R, Kusama S. Comparison Between Neck and Shoulder Stiffness Determined by Shear Wave Ultrasound Elastography and a Muscle Hardness Meter. Ultrasound Med Biol 2015; 41: 2266 – 2271

[332] Andonian P, Viallon M, Le Goff C et al. Shear-Wave Elastography Assessments of Quadriceps Stiffness Changes prior to, during and after Prolonged Exercise: A Longitudinal Study during an Extreme Mountain Ultra-Marathon. PLoS One 2016; 11: e0161855

[333] Brandenburg JE, Eby SF, Song P et al. Quantifying passive muscle stiffness in children with and without cerebral palsy using ultrasound shear wave elastography. Dev Med Child Neurol 2016; 58: 1288 – 1294

[334] Dubois G, Kheireddine W, Vergari C et al. Reliable protocol for shear wave elastography of lower limb muscles at rest and during passive stretching. Ultrasound Med Biol 2015; 41: 2284 – 2291

[335] Eby SF, Cloud BA, Brandenburg JE et al. Shear wave elastography of passive skeletal muscle stiffness: influences of sex and age throughout adulthood. Clin Biomech (Bristol, Avon) 2015; 30: 22 – 27

[336] Koo TK, Guo JY, Cohen JH et al. Quantifying the passive stretching response of human tibialis anterior muscle using shear wave elastography. Clin Biomech (Bristol, Avon) 2014; 29: 33 – 39

[337] Nakamura M, Hasegawa S, Umegaki H et al. The difference in passive tension applied to the muscles composing the hamstrings – Comparison among muscles using ultrasound shear wave elastography. Man Ther 2016; 24: 1 – 6

[338] Du LJ, He W, Cheng LG et al. Ultrasound shear wave elastography in assessment of muscle stiffness in patients with Parkinson's disease: a primary observation. Clin Imaging 2016; 40: 1075 – 1080

[339] Eby S, Zhao H, Song P et al. Quantitative Evaluation of Passive Muscle Stiffness in Chronic Stroke. Am J Phys Med Rehabil 2016; 95: 899 – 910

[340] Lee SS, Spear S, Rymer WZ. Quantifying changes in material properties of stroke-impaired muscle. Clin Biomech (Bristol, Avon) 2015; 30: 269 – 275

[341] Lacourpaille L, Hug F, Guével A et al. Non-invasive assessment of muscle stiffness in patients with Duchenne muscular dystrophy. Muscle Nerve 2015; 51: 284 – 286

[342] Illomei G, Spinicci G, Locci E et al. Muscle elastography: a new imaging technique for multiple sclerosis spasticity measurement. Neurol Sci 2017; 38: 433 – 439

[343] Song Y, Lee S, Yoo DH et al. Strain sonoelastography of inflammatory myopathies: comparison with clinical examination, magnetic resonance imaging and pathologic findings. Br J Radiol 2016; 89: 20160283

[344] Wu CH, Chen WS, Wang TG. Elasticity of the Coracohumeral Ligament in Patients with Adhesive Capsulitis of the Shoulder. Radiology 2016; 278: 458 – 464

[345] Miyamoto H, Miura T, Morizaki Y et al. Comparative study on the stiffness of transverse carpal ligament between normal subjects and carpal tunnel syndrome patients. Hand Surg 2013; 18: 209 – 214

[346] Lee SY, Park HJ, Kwag HJ et al. Ultrasound elastography in the early diagnosis of plantar fasciitis. Clin Imaging 2014; 38: 715 – 718

[347] Ríos-Díaz J, Martínez-Payá JJ, del Baño-Aledo ME et al. Sonoelastography of Plantar Fascia: Reproducibility and Pattern Description in Healthy Subjects and Symptomatic Subjects. Ultrasound Med Biol 2015; 41: 2605 – 2613

[348] Sconfienza LM, Silvestri E, Orlandi D et al. Real-time sonoelastography of the plantar fascia: comparison between patients with plantar fasciitis and healthy control subjects. Radiology 2013; 267: 195 – 200

[349] Wu CH, Chen WS, Wang TG. Plantar fascia softening in plantar fasciitis with normal B-mode sonography. Skeletal Radiol 2015; 44: 1603 – 1607

[350] Miyamoto H, Siedentopf C, Kastlunger M et al. Intracarpal tunnel contents: evaluation of the effects of corticosteroid injection with sonoelastography. Radiology 2014; 270: 809 – 815

[351] Yoshii Y, Tung WL, Ishii T. Measurement of Median Nerve Strain and Applied Pressure for the Diagnosis of Carpal Tunnel Syndrome. Ultrasound Med Biol 2017; 43: 1205 – 1209

[352] Klauser AS, Miyamoto H, Martinoli C et al. Sonoelastographic Findings of Carpal Tunnel Injection. Ultraschall in Med 2015; 36: 618 – 622

[353] Yoshii Y, Tung WL, Ishii T. Strain and Morphological Changes of Median Nerve After Carpal Tunnel Release. J Ultrasound Med 2017; 36: 1153 – 1159

[354] Miyamoto H, Halpern EJ, Kastlunger M et al. Carpal tunnel syndrome: diagnosis by means of median nerve elasticity–improved diagnostic accuracy of US with sonoelastography. Radiology 2014; 270: 481 – 486

[355] Tatar IG, Kurt A, Yavasoglu NG et al. Carpal tunnel syndrome: elasto-sonographic strain ratio and cross-sectional area evaluation for the diagnosis and disease severity. Med Ultrason 2016; 18: 305 – 311

[356] Zhang C, Li M, Jiang J et al. Diagnostic Value of Virtual Touch Tissue Imaging Quantification for Evaluating Median Nerve Stiffness in Carpal Tunnel Syndrome. J Ultrasound Med 2017; 36: 1783 – 1791

[357] Kantarci F, Ustabasioglu FE, Delil S et al. Median nerve stiffness measurement by shear wave elastography: a potential sonographic method in the diagnosis of carpal tunnel syndrome. Eur Radiol 2014; 24: 434 – 440

[358] Dikici AS, Ustabasioglu FE, Delil S et al. Evaluation of the Tibial Nerve with Shear-Wave Elastography: A Potential Sonographic Method for the

450

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

Diagnosis of Diabetic Peripheral Neuropathy. Radiology 2017; 282: 494–501

[359] Ishibashi F, Taniguchi M, Kojima R et al. Elasticity of the tibial nerve assessed by sonoelastography was reduced before the development of neuropathy and further deterioration associated with the severity of neuropathy in patients with type 2 diabetes. J Diabetes Investig 2016; 7: 404–412

[360] Klauser AS, Miyamoto H, Bellmann-Weiler R et al. Sonoelastography: musculoskeletal applications. Radiology 2014; 272: 622–633

[361] Greening J, Dilley A. Posture-induced changes in peripheral nerve stiffness measured by ultrasound shear-wave elastography. Muscle Nerve 2017; 55: 213–222

[362] Klauser AS, Faschingbauer R, Jaschke WR. Is sonoelastography of value in assessing tendons? Semin Musculoskelet Radiol 2010; 14: 323–333

[363] Kot BC, Zhang ZJ, Lee AW et al. Elastic modulus of muscle and tendon with shear wave ultrasound elastography: variations with different technical settings. PLoS One 2012; 7: e44348

[364] Domenichini R, Pialat JB, Podda A et al. Ultrasound elastography in tendon pathology: state of the art. Skeletal Radiol 2017; 46: 1643–1655

[365] Drakonaki EE, Allen GM, Wilson DJ. Ultrasound elastography for musculoskeletal applications. Br J Radiol 2012; 85: 1435–1445

[366] Alfuraih AM, O'Connor P, Hensor E et al. The effect of unit, depth, and probe load on the reliability of muscle shear wave elastography: Variables affecting reliability of SWE. J Clin Ultrasound 2018; 46: 108–115

[367] Carmignani L, Gadda F, Gazzano G et al. High incidence of benign testicular neoplasms diagnosed by ultrasound. J Urol 2003; 170: 1783–1786

[368] Shah A, Lung PF, Clarke JL et al. Re: New ultrasound techniques for imaging of the indeterminate testicular lesion may avoid surgery completely. Clin Radiol 2010; 65: 496–497

[369] Sidhu PS. Multiparametric Ultrasound (MPUS) Imaging: Terminology Describing the Many Aspects of Ultrasonography. Ultraschall in Med 2015; 36: 315–317

[370] Huang DY, Sidhu PS. Focal testicular lesions: colour Doppler ultrasound, contrast-enhanced ultrasound and tissue elastography as adjuvants to the diagnosis. Br J Radiol 2012; 85 Spec No 1: S41–S53

[371] Pozza C, Gianfrilli D, Fattorini G et al. Diagnostic value of qualitative and strain ratio elastography in the differential diagnosis of non-palpable testicular lesions. Andrology 2016; 4: 1193–1203

[372] Goddi A, Sacchi A, Magistretti G et al. Real-time tissue elastography for testicular lesion assessment. Eur Radiol 2012; 22: 721–730

[373] Auer T, De Zordo T, Dejaco C et al. Value of Multiparametric US in the Assessment of Intratesticular Lesions. Radiology 2017; 285: 640–649

[374] Aigner F, De Zordo T, Pallwein-Prettner L et al. Real-time sonoelastography for the evaluation of testicular lesions. Radiology 2012; 263: 584–589

[375] Schröder C, Lock G, Schmidt C et al. Real-Time Elastography and Contrast-Enhanced Ultrasonography in the Evaluation of Testicular Masses: A Comparative Prospective Study. Ultrasound Med Biol 2016; 42: 1807–1815

[376] Marsaud A, Durand M, Raffaelli C et al. Elastography shows promise in testicular cancer detection. Prog Urol 2015; 25: 75–82

[377] Grasso M, Blanco S, Raber M et al. Elasto-sonography of the testis: preliminary experience. Arch Ital Urol Androl 2010; 82: 160–163

[378] Lock G, Schröder C, Schmidt C et al. Contrast-enhanced ultrasound and real-time elastography for the diagnosis of benign Leydig cell tumours of the testis – a single center report on 13 cases. Ultraschall in Med 2014; 35: 534–539

[379] Jedrzejewski G, Ben-Skowronek I, Wozniak MM et al. Testicular adrenal rest tumours in boys with congenital adrenal hyperplasia: 3D US and

elastography–do we get more information for diagnosis and monitoring? J Pediatr Urol 2013; 9: 1032–1037

[380] Bernardo S, Konstantatou E, Huang DY et al. Multiparametric sonographic imaging of a capillary hemangioma of the testis: appearances on gray-scale, color Doppler, contrast-enhanced ultrasound and strain elastography. J Ultrasound 2016; 19: 35–39

[381] Patel K, Sellars ME, Clarke JL et al. Features of testicular epidermoid cysts on contrast-enhanced sonography and real-time tissue elastography. J Ultrasound Med 2012; 31: 115–122

[382] Patel KV, Huang DY, Sidhu PS. Metachronous bilateral segmental testicular infarction: multi-parametric ultrasound imaging with grey-scale ultrasound, Doppler ultrasound, contrast-enhanced ultrasound (CEUS) and real-time tissue elastography (RTE). J Ultrasound 2014; 17: 233–238

[383] Yusuf G, Konstantatou E, Sellars ME et al. Multiparametric Sonography of Testicular Hematomas: Features on Grayscale, Color Doppler, and Contrast-Enhanced Sonography and Strain Elastography. J Ultrasound Med 2015; 34: 1319–1328

[384] Fang C, Konstantatou E, Romanos O et al. Reproducibility of 2-Dimensional Shear Wave Elastography Assessment of the Liver: A Direct Comparison With Point Shear Wave Elastography in Healthy Volunteers. J Ultrasound Med 2017; 36: 1563–1569

[385] Rafailidis V, Robbie H, Konstantatou E et al. Sonographic imaging of extra-testicular focal lesions: comparison of grey-scale, colour Doppler and contrast-enhanced ultrasound. Ultrasound 2016; 24: 23–33

[386] Pedersen MR, Møller H, Osther PJS et al. Comparison of Tissue Stiffness Using Shear Wave Elastography in Men with Normal Testicular Tissue, Testicular Microlithiasis and Testicular Cancer. Ultrasound Int Open 2017; 3: E150–E155

[387] Rocher L, Criton A, Gennisson JL et al. Testicular Shear Wave Elastography in Normal and Infertile Men: A Prospective Study on 601 Patients. Ultrasound Med Biol 2017; 43: 782–789

[388] Ucar AK, Alis D, Samanci C et al. A preliminary study of shear wave elastography for the evaluation of unilateral palpable undescended testes. Eur J Radiol 2017; 86: 248–251

[389] Dikici AS, Er ME, Alis D et al. Is There Any Difference Between Seminomas and Nonseminomatous Germ Cell Tumours on Shear Wave Elastography? A Preliminary Study. J Ultrasound Med 2016; 35: 2575–2580

[390] Rocher L, Glas L, Bellin MF et al. Burned-Out Testis Tumours in Asymptomatic Infertile Men: Multiparametric Sonography and MRI Findings. J Ultrasound Med 2017; 36: 821–831

[391] Trottmann M, Rübenthaler J, Marcon J et al. Differences of standard values of Supersonic shear imaging and ARFI technique – in vivo study of testicular tissue. Clin Hemorheol Microcirc 2016; 64: 729–733

[392] De Zordo T, Stronegger D, Pallwein-Prettner L et al. Multiparametric ultrasonography of the testicles. Nat Rev Urol 2013; 10: 135–148

[393] D'Anastasi M, Schneevoigt BS, Trottmann M et al. Acoustic radiation force impulse imaging of the testes: a preliminary experience. Clin Hemorheol Microcirc 2011; 49: 105–114

[394] Trottmann M, Marcon J, D'Anastasi M et al. Shear-wave elastography of the testis in the healthy man – determination of standard values. Clin Hemorheol Microcirc 2016; 62: 273–281

[395] Zieman SJ, Melenovsky V, Kass DA. Mechanisms, pathophysiology, and therapy of arterial stiffness. Arteriosclerosis, thrombosis, and vascular biology 2005; 25: 932–943

[396] Mahmood B, Ewertsen C, Carlsen J et al. Ultrasound Vascular Elastography as a Tool for Assessing Atherosclerotic Plaques – A Systematic Literature Review. Ultrasound international open 2016; 2: E106–E112

[397] de Korte CL, Pasterkamp G, van der Steen AF et al. Characterization of plaque components with intravascular ultrasound elastography in human femoral and coronary arteries in vitro. Circulation 2000; 102: 617–623

[398] de Korte CL, van der Steen AF. Intravascular ultrasound elastography: an overview. Ultrasonics 2002; 40: 859–865

[399] Majdouline Y, Ohayon J, Keshavarz-Motamed Z et al. Endovascular shear strain elastography for the detection and characterization of the severity of atherosclerotic plaques: in vitro validation and in vivo evaluation. Ultrasound in medicine & biology 2014; 40: 890–903

[400] Schaar JA, De Korte CL, Mastik F et al. Characterizing vulnerable plaque features with intravascular elastography. Circulation 2003; 108: 2636–2641

[401] Dahl JJ, Dumont DM, Allen JD et al. Acoustic radiation force impulse imaging for noninvasive characterization of carotid artery atherosclerotic plaques: a feasibility study. Ultrasound in medicine & biology 2009; 35: 707–716

[402] Czernuszewicz TJ, Homeister JW, Caughey MC et al. Non-invasive in vivo characterization of human carotid plaques with acoustic radiation force impulse ultrasound: comparison with histology after endarterectomy. Ultrasound in medicine & biology 2015; 41: 685–697

[403] Meshram NH, Varghese T, Mitchell CC et al. Quantification of carotid artery plaque stability with multiple region of interest based ultrasound strain indices and relationship with cognition. Physics in medicine and biology 2017; 62: 6341–6360

[404] Emelianov SY, Chen X, O'Donnell M et al. Triplex ultrasound: elasticity imaging to age deep venous thrombosis. Ultrasound in medicine & biology 2002; 28: 757–767

[405] Xie H, Kim K, Aglyamov SR et al. Staging deep venous thrombosis using ultrasound elasticity imaging: animal model. Ultrasound in medicine & biology 2004; 30: 1385–1396

[406] Rubin JM, Xie H, Kim K et al. Sonographic elasticity imaging of acute and chronic deep venous thrombosis in humans. Journal of ultrasound in medicine: official journal of the American Institute of Ultrasound in Medicine 2006; 25: 1179–1186

[407] Takimura H, Hirano K, Muramatsu T et al. Vascular elastography: a novel method to characterize occluded lower limb arteries prior to endovascular therapy. Journal of endovascular therapy: an official journal of the International Society of Endovascular Specialists 2014; 21: 654–661

[408] Yi X, Wei X, Wang Y et al. Role of real-time elastography in assessing the stage of thrombus. International angiology: a journal of the International Union of Angiology 2017; 36: 59–63

[409] Dharmarajah B, Sounderajah V, Rowland SP et al. Aging techniques for deep vein thrombosis: a systematic review. Phlebology 2015; 30: 77–84

[410] Aslan A, Barutca H, Ayaz E et al. Is real-time elastography helpful to differentiate acute from subacute deep venous thrombosis? A preliminary study. Journal of clinical ultrasound: JCU 2018; 46: 116–121

[411] Su Y, Liu W, Wang D et al. Evaluation of abdominal aortic elasticity by strain rate imaging in patients with type 2 diabetes mellitus. Journal of clinical ultrasound: JCU 2014; 42: 475–480

[412] Zheng XZ, Yang B, Wu J. A comparison of the approaches to assess the abdominal aortic stiffness using M-mode ultrasonography, tissue tracking and strain rate imaging. JNMA: journal of the Nepal Medical Association 2013; 52: 500–504

[413] Korshunov VA, Wang H, Ahmed R et al. Model-based vascular elastography improves the detection of flow-induced carotid artery remodeling in mice. Scientific reports 2017; 7: 12081

[414] Ribbers H, Lopata RG, Holewijn S et al. Noninvasive two-dimensional strain imaging of arteries: validation in phantoms and preliminary experience in carotid arteries in vivo. Ultrasound in medicine & biology 2007; 33: 530–540

[415] Couade M, Pernot M, Prada C et al. Quantitative assessment of arterial wall biomechanical properties using shear wave imaging. Ultrasound in medicine & biology 2010; 36: 1662–1676

[416] Widman E, Maksuti E, Amador C et al. Shear Wave Elastography Quantifies Stiffness in Ex Vivo Porcine Artery with Stiffened Arterial Region. Ultrasound in medicine & biology 2016; 42: 2423–2435

[417] Guo Y, Wang Y, Chang EJ et al. Multidirectional Estimation of Arterial Stiffness Using Vascular Guided Wave Imaging with Geometry Correction. Ultrasound Med Biol 2018; 44: 884–896

[418] Maksuti E, Bini F, Fiorentini S et al. Influence of wall thickness and diameter on arterial shear wave elastography: a phantom and finite element study. Physics in medicine and biology 2017; 62: 2694–2718

[419] Maksuti E, Widman E, Larsson D et al. Arterial Stiffness Estimation by Shear Wave Elastography: Validation in Phantoms with Mechanical Testing. Ultrasound in medicine & biology 2016; 42: 308–321

[420] Widman E, Maksuti E, Larsson D et al. Shear wave elastography plaque characterization with mechanical testing validation: a phantom study. Physics in medicine and biology 2015; 60: 3151–3174

[421] Ramnarine KV, Garrard JW, Dexter K et al. Shear wave elastography assessment of carotid plaque stiffness: in vitro reproducibility study. Ultrasound in medicine & biology 2014; 40: 200–209

[422] Ramnarine KV, Garrard JW, Kanber B et al. Shear wave elastography imaging of carotid plaques: feasible, reproducible and of clinical potential. Cardiovascular ultrasound 2014; 12: 49

[423] Garrard JW, Ramnarine K. Shear-wave elastography in carotid plaques: comparison with grayscale median and histological assessment in an interesting case. Ultraschall in der Medizin 2014; 35: 1–3

[424] Lei Z, Qiang Y, Tianning P et al. Quantitative assessment of carotid atherosclerotic plaque: Initial clinical results using ShearWave™ Elastography. Int J Clin Exp Med 2016; 9: 9347–9355

[425] Lou Z, Yang J, Tang L et al. Shear Wave Elastography Imaging for the Features of Symptomatic Carotid Plaques: A Feasibility Study. Journal of ultrasound in medicine: official journal of the American Institute of Ultrasound in Medicine 2017; 36: 1213–1223

[426] Garrard JW, Ummur P, Nduwayo S et al. Shear Wave Elastography May Be Superior to Greyscale Median for the Identification of Carotid Plaque Vulnerability: A Comparison with Histology. Ultraschall in der Medizin 2015; 36: 386–390

[427] Couade M, Pernot M, Messas E et al. In vivo quantitative mapping of myocardial stiffening and transmural anisotropy during the cardiac cycle. IEEE transactions on medical imaging 2011; 30: 295–305

[428] Pernot M, Couade M, Mateo P et al. Real-time assessment of myocardial contractility using shear wave imaging. Journal of the American College of Cardiology 2011; 58: 65–72

[429] Strachinaru M, Bosch JG, van Dalen BM et al. Cardiac Shear Wave Elastography Using a Clinical Ultrasound System. Ultrasound in medicine & biology 2017; 43: 1596–1606

[430] Bernal M, Gennisson JL, Flaud P et al. Shear wave elastography quantification of blood elasticity during clotting. Ultrasound in medicine & biology 2012; 38: 2218–2228

[431] Mfoumou E, Tripette J, Blostein M et al. Time-dependent hardening of blood clots quantitatively measured in vivo with shear-wave ultrasound imaging in a rabbit model of venous thrombosis. Thrombosis research 2014; 133: 265–271

[432] Kobayashi Y, Omichi K, Kawaguchi Y et al. Intraoperative real-time tissue elastography during laparoscopic hepatectomy. HPB (Oxford) 2018; 20: 93–99

[433] Platz Batista da Silva N, Schauer M, Hornung M et al. Intrasurgical dignity assessment of hepatic tumours using semi-quantitative strain elastography and contrast-enhanced ultrasound for optimisation of liver tumour surgery. Clin Hemorheol Microcirc 2016; 64: 735–745

[434] Jung EM, Platz Batista da Silva N, Jung W et al. Is Strain Elastography (IO-SE) Sufficient for Characterization of Liver Lesions before Surgical Resection–Or Is Contrast Enhanced Ultrasound (CEUS) Necessary? PLoS One 2015; 10: e0123737

[435] Kawaguchi Y, Tanaka N, Nagai M et al. Usefulness of Intraoperative Real-Time Tissue Elastography During Laparoscopic Hepatectomy. J Am Coll Surg 2015; 221: e103–e111

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[436] Sastry R, Bi WL, Pieper S et al. Applications of Ultrasound in the Resection of Brain Tumours. J Neuroimaging 2017; 27: 5 – 15

[437] Chauvet D, Imbault M, Capelle L et al. In Vivo Measurement of Brain Tumour Elasticity Using Intraoperative Shear Wave Elastography. Ultraschall in Med 2016; 37: 584 – 590

[438] Chan HW, Pressler R, Uff C et al. A novel technique of detecting MRI-negative lesion in focal symptomatic epilepsy: intraoperative Shear-Wave elastography. Epilepsia 2014; 55: e30 – e33

[439] Selbekk T, Brekken R, Indergaard M et al. Comparison of contrast in brightness mode and strain ultrasonography of glial brain tumours. BMC Med Imaging 2012; 12: 11

[440] Ji S, Hartov A, Roberts D et al. Data assimilation using a gradient descent method for estimation of intraoperative brain deformation. Med Image Anal 2009; 13: 744 – 756

[441] Joldes GR, Wittek A, Couton M et al. Real-time prediction of brain shift using nonlinear finite element algorithms. Med Image Comput Comput Assist Interv 2009; 12: 300 – 307

[442] Carter TJ, Sermesant M, Cash DM et al. Application of soft tissue modelling to image-guided surgery. Med Eng Phys 2005; 27: 893 – 909

[443] Scholz M, Noack V, Pechlivanis I et al. Vibrography during tumour neurosurgery. J Ultrasound Med 2005; 24: 985 – 992

[444] Fleming IN, Kut C, Macura KJ et al. Ultrasound elastography as a tool for imaging guidance during prostatectomy: initial experience. Med Sci Monit 2012; 18: CR635 – CR642

[445] Uramoto H, Nakajima Y, Ohtaki K et al. Intraoperative ultrasound elastography has little diagnostic benefit for deeper tumours of the lung. Eur J Cardiothorac Surg 2016; 49: 1538 – 1539

[446] Parekattil S, Yeung LL, Su LM. Intraoperative tissue characterization and imaging. Urol Clin North Am 2009; 36: 213 – 221, ix

Săftoiu A et al. The EFSUMB Guidelines… Ultraschall in Med 2019; 40: 425–453

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