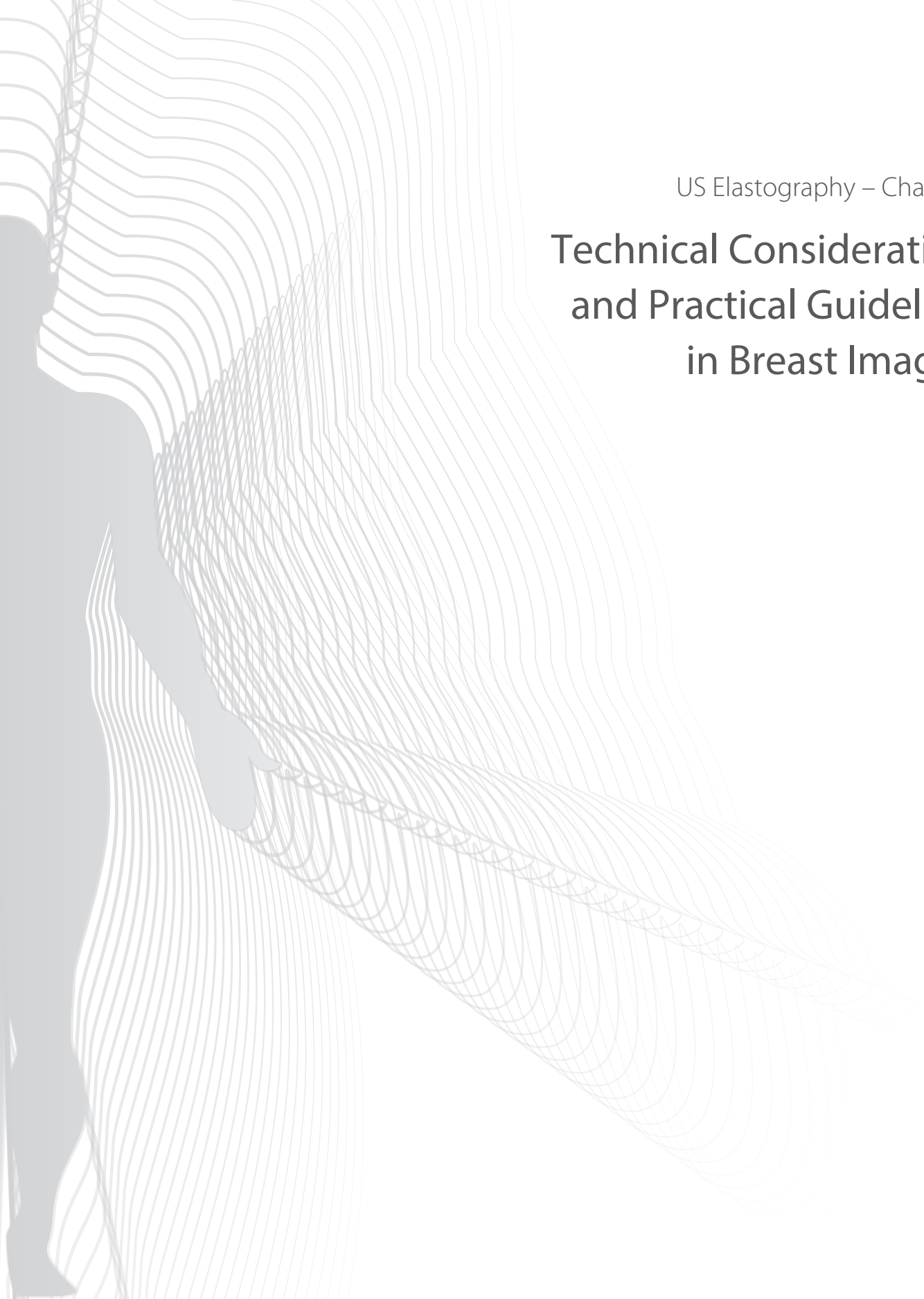
US Elastography – Chapter 2

Technical Considerations and Practical Guidelines in Breast Imaging



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Technical Considerations and Practical Guidelines in Breast Imaging

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Summary

Ultrasound elastography is one of the most recent and interesting radiological methods for non-invasive evaluation of breast masses. However, the technique is highly subjective and requires a long learning curve. Therefore, users' guidance, on the technique and its applications, is vital for high accuracy and repeatability, and in minimizing intra- and inter-operator variability. In that context, this paper complements an earlier one by the same author, the "US Elastography – Chapter 1: Principles and Applications in Breast Imaging", and specifically addresses practical issues such as technical steps and adjustments, maneuvers, technical tips and tricks on SE and SWE imaging. It aims to convey the necessary knowledge and experience about the use of US elastography specifically on a Resona 7 ultrasound system.

Introduction

The prevalence of breast masses and the poor specificity of conventional imaging methods in the differential diagnosis mandate the need for preoperative discrimination of benign and malignant pathologies with novel non-invasive, reliable and cost-effective methods. In this context, main developments in ultrasound (US) method are elasticity studies. Qualitative elasticity assessments were included in BI-RADS in 2015 as an "associated finding". However, the technique was mentioned not as an endorsement but as an acknowledgment in that classification system. This is because the technique and its results still require standardization, evidence and validation [Sigrist et al, 2017].

The combined use of conventional and advanced US methods, including elastography in breast can increase ultrasound study's specificity up to 99% [Bicer, 2018]. However, lower accuracy and reproducibility of elastography results still limits the use of US elastography in routine clinical practice. In that context, and as recommended by practice guidelines, proper training in performing elastography can help to achieve better accuracy and reproducibility, as well as limit intra- and inter-observer variability [Barr et al, 2015]. The length of the learning curve depends on the number of patients performed under active supervision of an experienced user of the US equipment to be used. Crucial steps and system adjustments must be shown in detail to radiologist before starting performing US elastography on actual patients. Performing an optimal study to obtain good results necessitates a structured approach and meticulous adherence to the requirements at each step and for each elastography technique, as presented below.

How to obtain a good elastogram? Basic steps

Measurements in US elastography are performed in special imaging modes that can detect tissue stiffness against the applied compression force. Several elastography techniques using different compression methods have been developed to date[1]. Although these methods share the common name (i.e., elastography), they differ significantly in terms of theory, development and accuracy. Therefore, applications and terms for the use of techniques in diagnostic evaluation are also quite different from each other. Basic procedural steps to conform highest accuracy, however, are almost similar for strain (SE) and shear-wave elastography (SWE) techniques. These steps are (1) Correct B-mode, (2) Correct position, (3) Correct region-of-interest (ROI) / field-of-view (FOV), Correct compression, and (5) Corrrect measurement (Table 1). The acquisition of optimal B-mode images has paramount importance in elastography as is also true for any US technique. This is because all of these techniques are mainly based on calculations that use raw-data from these images. These calculations cannot be performed in areas with extremely low (anechoic) B-mode signals. A proper performance during this step is the result of formal and lengthy training in radiology education. However, there are stil some tips and tricks to help novice operators, and system specific tools to optimize elastographic images. These will be explained within the text, as appropriate.

Table 1. Basic procedural steps to obtain good elastograms

Step	Goal	Objectives	
		SE	SWE
1	Correct B-mode	US elastography techniques are based on raw-data from B-mode images: Switch to elastography only after acquring optimal B-mode image.	
2	Correct position	Internal and external vibrations are meaningless if the probe moves across the target: Find a position that allows for stable vibration, compression and minimal patient motion.	Acoustic radiation force is meaningless if the probe moves across the target: Find a position that allows for stable -mild- compression and minimal patient motion.
3	Correct FOV & ROI	FOV should include various tissue types from subcutaneous fat (SCF) to pectoralis muscle, but not ribs and pleura, and full width. Lesion should account < ¼ of FOV.	FOV and ROI should include entire lesion and its periphery, if possible.
4	Correct compression & vibration	There are three main types of compression and vibration methods: It is not necessary to generate too much compression when imaging shallow lesions, but a greater one is needed for deep ones.	There will be no compression and manual vibration. Use ample of gel, and lift the probe until it gets almost loosing contact with the skin surface. E_{mean} for SCF must be measured for left and right of the image, and must be equal to each other and <15 kPA, for both.
5	Correct measurement	Ratio of lesion size in elastography to B-mode (EI/B mode ratio) should be calculated on gray scale map. Fat-to-lesion ratio (FLR) should be calculated by using SCF of the same depth as reference.	Entire lesion and its 2 mm periphery should be measured and recorded independently. Only E_{max} should be used for interpretation.

How to master a good position?

In SE, which is the most basic technique, internal or external vibration sources are used. In the external method, the user applies manual pressure on the tissue with the US probe. In the internal method, on the other hand, the US probe is kept fixed and tissue displacement is created by internal physiological movements[2]. Regardless of the technique, the vibration is meaningless if the probe moves across the target. Therefore, the user has to find a position that will allow to reach stable

vibration, compression and minimal patient motion.

In SWE, compressive waves are not created manually by the user but automatically by the US probe. Although the technique is not user dependent, large degree of variability may still occur if the probe moves across the target. Therefore, the user has to find a position that will allow to reach stable compression and minimal patient motion. The addition of a quality measure that evaluates the motion stability if it is adequate for an accurate measurement may help operator in eliminating possible false negative cases. Resona 7 system has an assistive tool (the motion stability index, M-STB) to assess such quality in 2D-SWE and pSWE (Fig. 1)[3]. This tool, along with other quality measures (IQR and median) is not only used in actual studies, but may also help novice operators to master a stable probe position during their training (Fig. 2)[4]. M-STB index is represented with five consecutive stars. Accordingly, one to three stars mean unacceptably high motion, and four to five stars mean good motion stability. For practical reasons, stars are color-coded with red and green to represent poor and good stability, respectively.

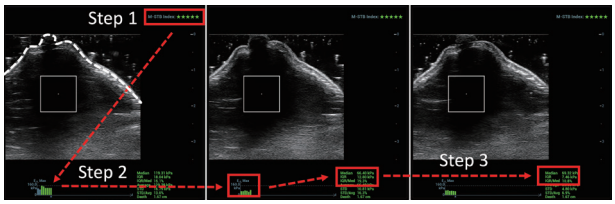

Figure 1. Mastering the probe position in pSWE. The position and stability may initially be practiced on static objects such as half-cut lemon (white dashed curve). During such practice session, operator tries to reach to best probe stability, as represented with "five green stars" on M-STB (Step 1), to remove excessive pressure on the tissue (Step 2) and finally, to reach lowest IQR/med level (Step 3).

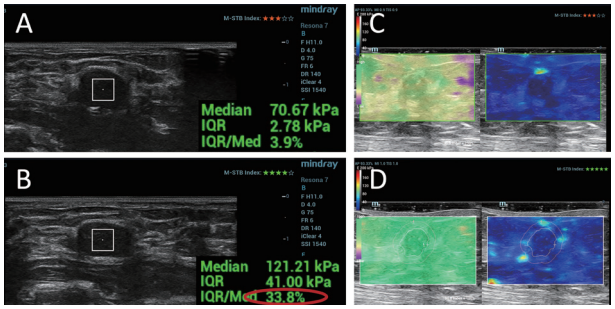

Figure 2 A-D. The use of M-STB index in pSWE (A and B) and in 2D-SWE (C and D). The index is represented with five consecutive color-coded stars. Accordingly, one to three stars mean unacceptably high motion (A and C), and four to five stars mean good motion stability (B and D). For practical reasons, stars are color-coded with red and green to represent poor and good stability, respectively. Please note that the M-STB index in Fig 2B is acceptable, however, IQR/Med is not (red ellipse), pointing to the instability of the data within the time frame.

How to select field of view

The field of view (FOV) is especially important when conducting a SE study. As discussed in previous chapter, quantitative evaluation is not possible in SE technique (Karakas, 2021). Qualitative evaluation is used instead, where two most important criteria are elastographic size and stiffness. Size refers to the largest diameter in B-mode and the elastogram. Tissues that are less compressible than surrounding tissues appear much larger in elastograms than they actually are. However, such evaluation, cannot be used in tumors that are larger than the imaging window (Fig. 3A). Other criterion, the stiffness, is assessed by comparing the tissue and its surroundings on semitransparent colored map (i.e. the elastogram). However, such evaluation necessitates the inclusion of variable tissue types within the window to compare with the lesion (Fig. 3B). In that context, FOV should include various tissue types from subcutaneous fat (SCF) to pectoralis muscle, but not ribs and pleura, and full width. The lesion should account < ¼ of such FOV.

In contrary to SE, FOV is not such a crucial factor in SWE studies. However, as such studies necessitate the measurement of the highest stiffness value of the lesion, FOV and ROI should include entire lesion and its periphery, if possible.

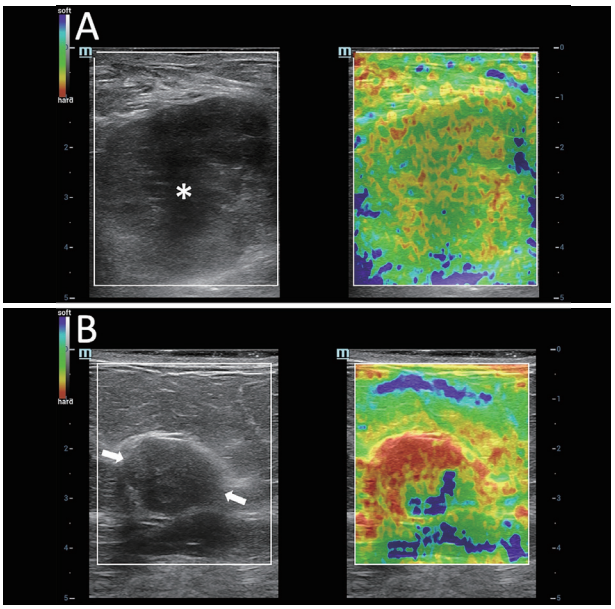

Figure 3. A and B. A very large mass (*) that overfills the field of view (A). Its largest diameter cannot be determined, making the use of EI/B mode ratio impossible. Stiffness, also, cannot reliably be assessed as the FOV does not have variable tissue types to compare with the lesion. The mass -that was actually a mucinous carcinoma- might erroneously be interpreted as benign on the basis of its color. In contrary to the lesion at Fig. 3A, a smaller lesion at Fig. 3B (arrows) accounts less than one quarter of the FOV. The FOV, itself, includes various tissue types and full width. These features assure an optimal SE assessment. However, even in under such condition, color of the target should be stable in time before making any further assumption on lesion's stiffness.

How to apply correct compression and vibration?

In order to assess the elasticity, the tissue is subjected to a compression force and the degree of distortion resulting from this force is assessed. There are several elastography techniques using different compression methods, therefore, definition and application of the compression force and the vibration in them are quite different from each other.

In SE, which is the most basic technique, internal or external vibration sources are used, as discussed previously. In the extrernal method, which is the most suitable for breast imaging- operator applies manual pressure on the tissue with the US probe. The tissue displacement that develops in parallel with the applied stress is calculated to estimate tissue deformation. Since the magnitude of the applied stress can be very difficult to control due to the variability inherent in manual compression, results are completely operator dependent. In order to minimize inter and intraoperator variability, external compression and vibration should be conducted in a very standartized way. Accordingly, there are three main types of compression/vibration methods in breast SE imaging: No compression, minimal compression and significant compression (Fig. 4). It is not necessary to generate too much compression and vibration (in terms of preloading and amplitude) when imaging shallow lesions, but a greater one is needed for deep ones. The frequency of the vibration, on the other hand, is same for all depths, and equals to two per second.

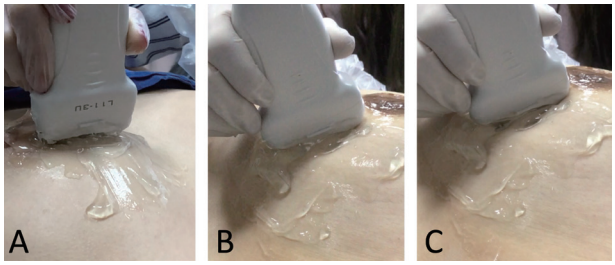

Figure 4 A-C. The amplitude of compression during breast SE. The probe is almost lifted off the skin in Fig. 4A, and such a mild level is most suitable for SWE procedure. The compression level in Fig. 4B is moderate. Such level is preferred in many patients, and in all superficial lesions. The compression level in Fig. 4 C is high. Such level should only be applied for deeply-seated lesions. Higher compresions are unnecessary and should be avoided.

The addition of a quality measure that demonstrates the adequacy of the amplitude and the frequency of the compression and vibration for an accurate measurement may help operator in eliminating possible false positive cases. Resona 7 system has an assistive tool (real-time strain E curve) to assess such quality in SE (Fig. 5). This tool, is not only used in actual studies to avoid excessive pressure, but may also help novice operators to master to apply adequate level of compression and vibration during their training (Fig. 6).

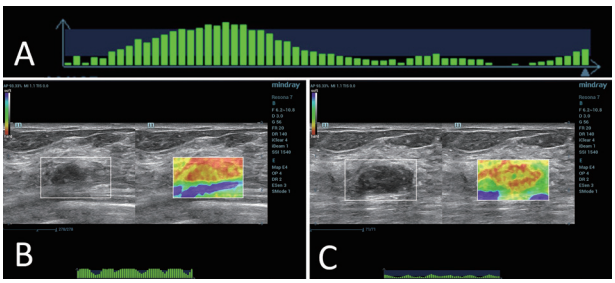

Figure 5 A-C. Real time strain E curve in SE (A). The X-axis represents time and Y-axis represents pressure. The curve at Fig. 5B reveals an excessive pressure and unsteady vibration frequency. Optimization of the pressure and the frequency result in a better colored-map (C).

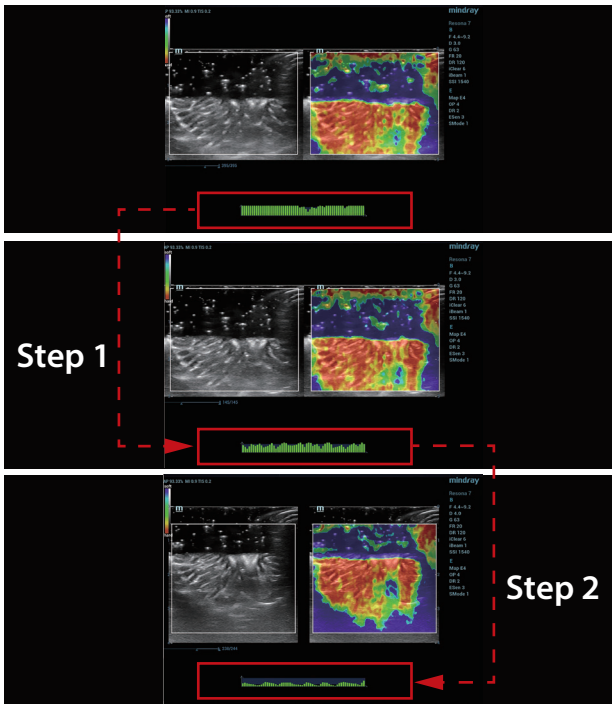

Figure 6. Mastering the probe pressure and vibration in SE. The pressure at the initial compression and during vibration may initially be practiced on static objects such as half-cut lemon. During such practice session, operator tries to remove excessive pressure as represented with saturated bars at the real-time strain E curve (Step 1), and finally, to reach sinusioidal pattern (Step 2).

In SWE, which is a more advanced technique, tissues are exposed to dynamic stress through the use of an external vibration source. The vibration source in clinical applications is the US probe. In SWE, the technique is not user dependent, unlike the SE detailed in the previous section, since the compressive waves are not created manually by the user but automatically by the US probe. However, some degree of variability may occur if too much pressure is applied on the probe causing an artificial increase in measured values[3]. In order to minimize inter and intraoperator variability, the initial compression should be applied in a very standartized way. Ideally, no compression should be applied to the skin. Moreover, the probe should be elevated until merely loosing contact with the skin (Fig 7).

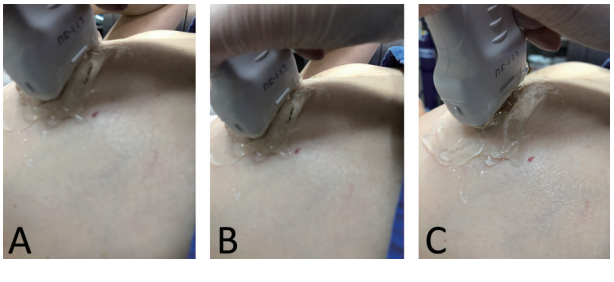

Figure 7 A-C. The amplitude of compression during breast SWE. Operator lifts the probe until almost loosing the contact with the skin (C). This is called «glueing». The correct compression is reached somewhere between Fig. 7B and 7C. Higher compression (A) is unnecessary and should be avoided.

In SWE, and unlike SE, there is no automated quality measure that demonstrates the adequacy of the compression for an accurate measurement. However, the operator may measure the median elastometric value (E_{median}, kPa) of subcutaneous fat (SCF) over the lesion to assess the adequacy and the distribution of the compression (Fig. 8 and 9).

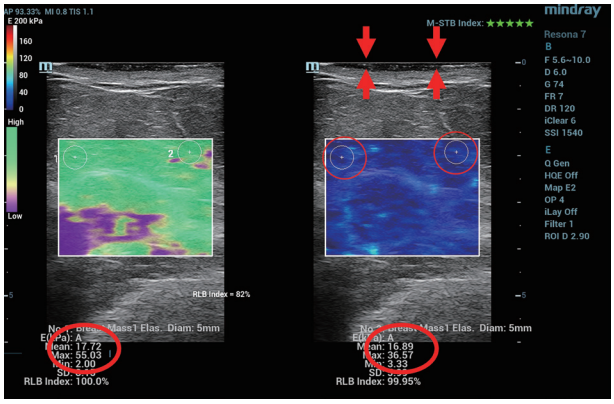

Figure 8. Assesment of preloading. E_{mean} of SCF is measured at the right and the left of the image (red circles). These values should rougly be equal to each other, and around 15 kPa, for both (red ellipses). The transonic gel should be equally spread under the probe and ample to assure glueing (red arrows).

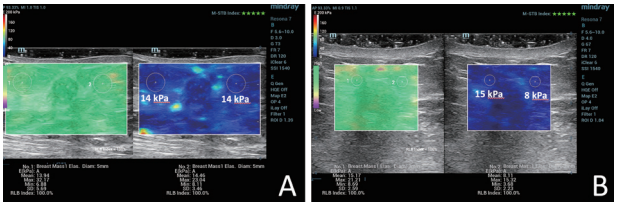

Figure 9. Assesment of preloading. The image at left (A) is an example to perfect preloading. E_{mean} of SCF at the right and the left of the image are equal to each other, and around 15 kPa. The image at the left (B) is an example to substandard technique. Probe pressure is sufficient but unequal (15 kPa vs 8 kPa). Transonic gel at the top is evenly spread but excessive, indicating overelevation of the probe.

How to perform necessary measurements?

In SE, calculations give a qualitative estimate of Young's coefficient (E) and thus tissue elasticity. In qualitative evaluation, the two most important criteria are size and stiffness. Size refers to largest diameter in B-mode and the elastogram. Tissues that are less compressible than surrounding tissues appear much larger in elastograms than they actually are. This situation leads to a mismatch in terms of tumor's size between B-mode and elastogram images. This discordance can be expressed as the ratio of lesion size in elastography to B-mode (EI / B-mode ratio) (Figure 10 A). This ratio -along with stiffness, is a principal part of the well-known Tsukaba scoring system [Itoh et al, 2006]. However, this system has some limitations that are attempted to be eliminated by semi-quantitative evaluations[6]. Strain ratio (fat to lesion ratio / FLR) is used for this purpose (Figure 10 B). FLR is the ratio of strain in subcutaneous fat to strain in the mass [Ueno et al, 2007]. The elastic coefficient of adipose tissue is constant at different compression degrees. Thus, the FLR provides a semi-quantitative measure showing the relative stiffness of the lesion [Ricci et al, 2014]. However, operator must consider several technical issues to use strain of SCF for correct referencing: (1) ROI for SCF must contain only fatty tissue, (2) Measurements should be taken at the same depth in the image, as the degree of compression varies with depth, and (3) ROI for both tissue (SCF and the lesion) should include ample volume to represent the tissue elasticity correctly (Fig. 11).

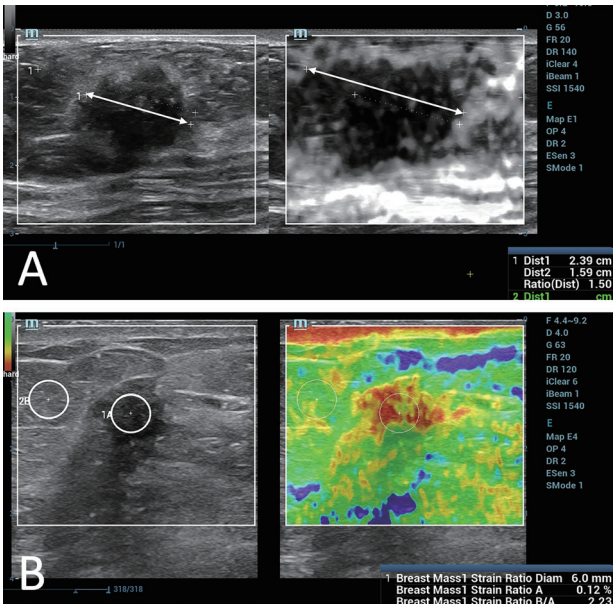

Figure 10 A and B. Fundamental measurements in SE are EI/B mode ratio (A) and FLR (B). Ratio of lesion size in elastography to B-mode should be calculated on gray-scale maps using the longest diameter of the leson (white lines). Fat-to-lesion ratio (FLR) should be calculated by using SCF of the same depth (or closest depth, if not possible) as reference (small white circle). ROIs should be large enough to represent the tissue elasticity with confidence.

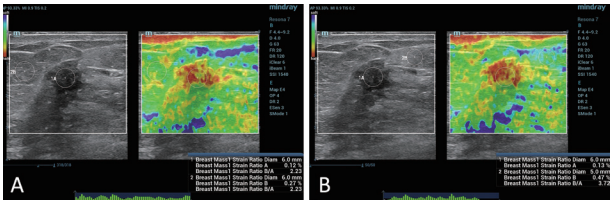

Figure 11 A and B. Differences in FLR values with varying depth. Although the elastic coefficient of adipose tissue is relatively constant at different compression degrees, it still varies with position. Reference SCF should be at the same depth with the lesion to represent the neighbouring tissue elasticity with confidence.

In SWE, calculations give a quantitative estimate tissue elasticity (stiffness). In that context, there are three different quantitative measurements that are linked and derived from each other[7]. Of them, Young's modulus E (kPa) is the most frequently used one. In routine SWE applications, elasticity measurements can be made from a certain area (ROI) of the mass entering the field of view (FOV); from the entire mass (A), around mass' periphery (shell); or from the entire mass including a certain thickness around it (A') (Fig 12). Although all three values (A, shell, A') are

usually given in the radiological report, the measurement that is essential for diagnosis is generally the one obtained for A' (Fig. 13). Usually, the highest stiffness (E_{max}) within the lesion and its surroundings is taken into consideration.

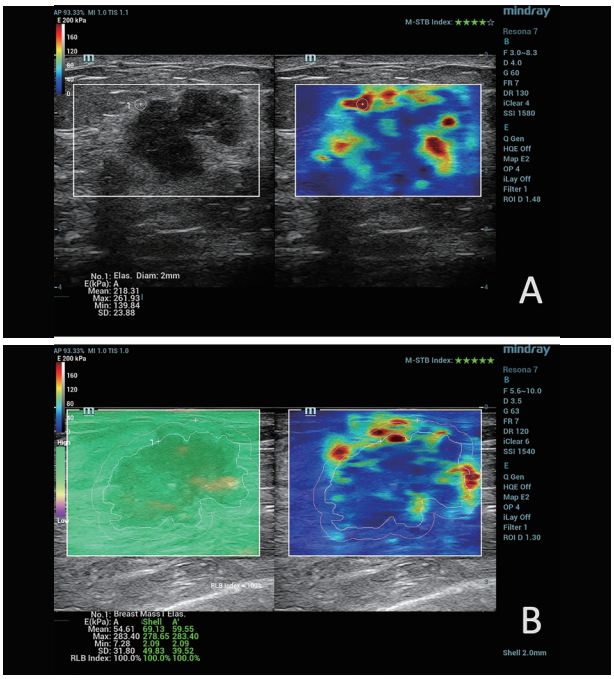

Figure 12 A and B. Fundamental measurement in SWE is the highest stifness (E_{max}, kPa). This value may be obtained using an ROI placed on the most stiff area within the lesion and its surroundings shown on color elastograms (A) or, alternatively, from the entire mass including a certain thickness around it (B). For the latter approach, distinguishing the mass lesion from surrounding tissues in elastograms presents difficulties in most cases. For this reason, the above-mentioned measurements are performed on the simultaneous B-mode images shown side by side with the elastogram.

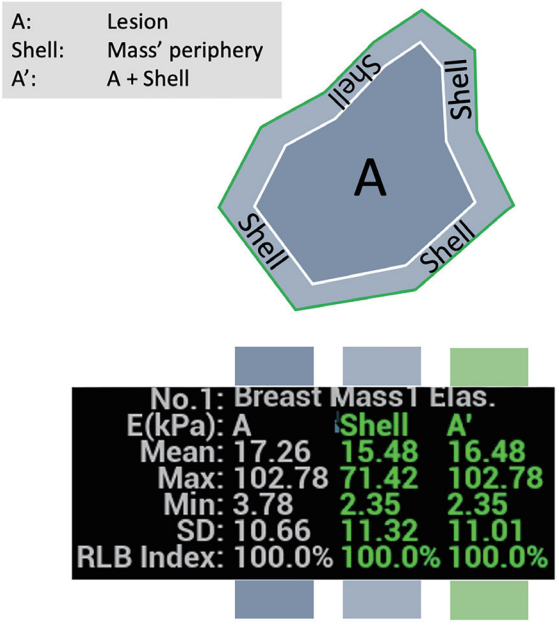

Figure 13. Marked areas and summary measures for the mass on SWE images

Limitations of SWE and image optimization

As stated before, shear waves are detected using echos. Therefore, they cannot be detected in areas with extremely low (anechoic) B-mode signals. On elastograms, these regions appear signal void and are not color-coded. Examples are very stiff lesions such as invasive cancers with significant shadowing (Fig. 14 A). However, the desmoplastic reaction will be stiff and appear as a "red halo" surrounding the lesion (Fig. 14 B). In such cases, the use of low frequency (<9 MHz) transducers may help operator, as these have better penetration than commonly used 11 to 14 MHz transducers for breast ultrasonography.

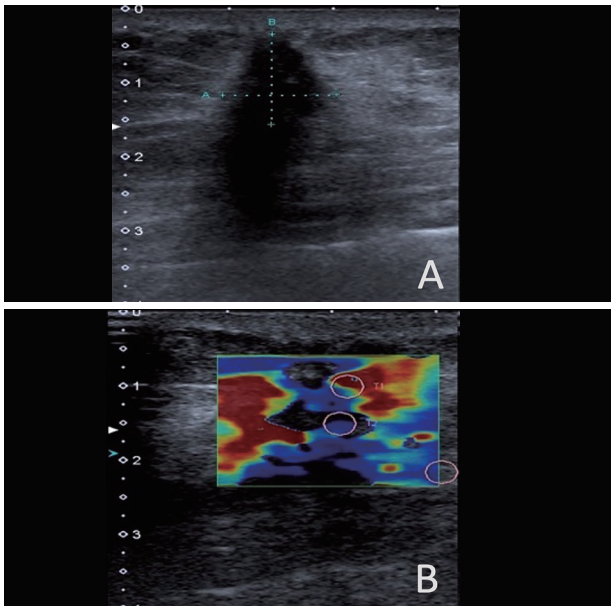

Figure 14 A and B. A very stiff invasive cancer with significant posterior shadowing (A). The waveform from the lesion itself is not interpretable whereas the waveform in the adjacent peritumoral tissue is still interpretable. In such cases, a "red halo" that surrounds the lesion points to peritumoral desmoplasia.

The absence of shadowing on B-mode images and signal-void in SWE does not always guarantee the adequacy of signals for an accurate elastographic measuerement (Fig. 15 A). The addition of a quality measure that evaluates the shear waves generated and determines if they are adequate for an accurate measurement will help in eliminating possible false negative cases [Barr, 2014]. Resona 7 system has two related assistive tools (RLB index and quality map) to assess such quality in 2D-SWE (Fig. 15). Of them, the RLB index helps the operator to judge the effectiveness of the elastographic measurement. The index is represented in percentage. The higher the RLB Index, the more reliable the signal. For practical reasons, the index is also color-coded with red, yellow and white to represent low, medium and high reliability, respectively. Quality map on same images further helps to judge the region suitable for elasto measurement. The map is color-coded with purple, yellow and green to show areas of low, medium and high reliability within the FOV, respectively. Accordingly, purple areas are not suitable for elastometric measurements (15 A-C, Fig 16).

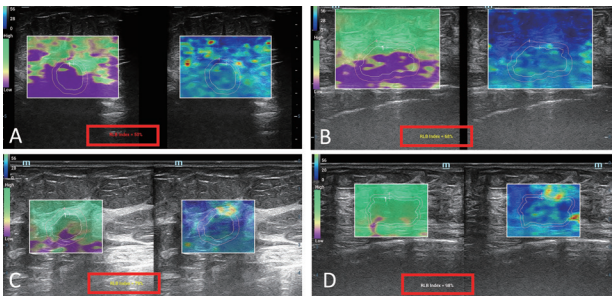

Figure 15 A-D. The use of RLB index and the quality map on two different patients. The initial frame of the first patient (A and C) had initially low reliability (RLB index: 50%, color-coded with red). This frame should not be used for measurement. Subsequent frame had medium reliability (RLB index: 79%, color-coded with yellow). This frame may be used for measurement, however posterior part of the lesion should be avoided as it had low-quality data (color-coded with purple). In another patient (B and D), the inital frame (B) had medium reliability. However, the majority of the lesion had low-quality data (RLB index : 68%, color-coded with yellow), hence was unsuitable for elastographic measurement. The subsequent frame (D) had high reliability (RLB index : 98%, color-coded with white) and high-quality data within the lesion (color-coded with green).

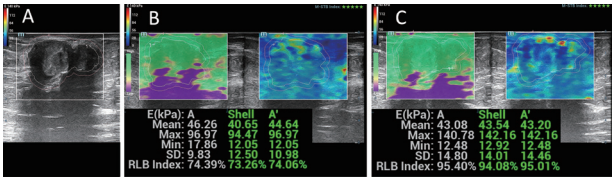

Figure 16 A-C. The use of the quality map in the evaluation of a malignant lesion. Boundary markings for the mass and its its periphery at B-mode image (A). In the image B, the mass is half purple, indicating that the shear waves are not adequate for interpretation, especially at the posterior parts of the lesion. In the image C, the mass is all green, indicating that the shear waves are adequate for interpretation. Without the quality map, the lesion could have erroneously been classified as negative[8].

There are several maneuvers and adjustments to increase the reliability of elastograms for adequate measurements. The use of low frequency transducers to increase ultrasonic penetration and to move the ROI box closer to the source are some of basic options (Fig 17). However, operator may still not able to produce a ROI that is sutiable to measure. Such conditions necessitate the use of image optimization tools of Resona 7 (Fig. 17 and 18). Of them,"E Quality" is used to select different THI frequency values (i.e. penetration preferred, general mode, or resolution preferred). "HQElasto" mode, on the other hand, turns-on the high-quality scanning mode to optimize penetration. In such setting, the system turns into single-frame scanning mode.

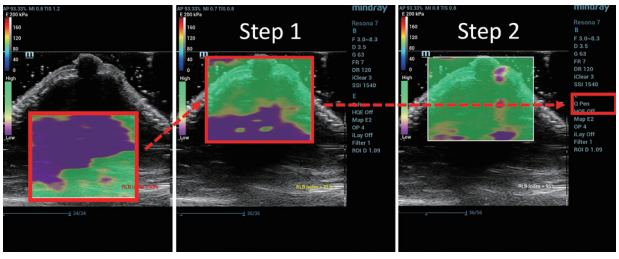

Figure 17. Basic optimization steps at SWE to increase penetration. During the procedure, operator minimizes the distance between the lesion and the probe by approching the former from different angles, by moving the ROI closer to the source (Step 1) and by selecting penetration mode of "E Quality" function (Step 2).

Figure 18. Image optimization options at the elasto panel of Resona 7 (red frames). The penetration, hence the reliability can be increased by switching E Quality to "Pen" and by activating "HQElasto" mode.

Conclusion

US elastography is a very powerful method to evaluate the nature breast masses. However, there are several techniques and procedures exclusive to the method.

Operators should be thoroughly familiar with them and apply technical steps, adjustments, and maneuvers, as appropriate. No measurement and interpretation should be attempted before producing an optimal elastogram (Fig 19).

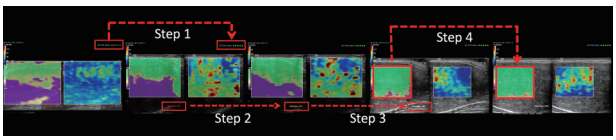

Figure 19. Necessary steps in obtaining optimal image. The initial scan had poor motion stability and masurement reliability. After correct position (Step 1) very good motion stability was reached. Measurement reliability, however, was still poor than moderate (Step 2) . After several attempts (Step 3) good motion stability and image reliability were reached. The final scan had very good motion stability, measurement reliability and penetration map for a confident measurement (Step 4). Before all these optimization steps E_{max} was measured as 72 kPa, whereas it was actually 130 kPa.

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[1]. For a through discussion on this subject, please refer to Karakas HM. ENG-Principles and Applications in Breast Imaging White Paper-210285X10P-20210419. 2021 Shenzen Mindray Bio-Medical Electronics Co.,Ltd

[2]. External compression is the preferred method in breast imaging.

[3]. In Resona 7, 2D-SWE is called STE (sound touch elastography) and pSWE is called STQ（sound touch quantification).

[4]. The median is the value separating the higher half from the lower half of pSWE data points. For the data set it may be thought of as the middle value. The interquartile range (IQR), also called the midspread or middle 50%, is a measure of statistical dispersion, being equal to the difference between upper and lower quartiles IQR/Med is generally used as an indicator of data quality and allows operator to assess the stability of the data. On the context of pSWE, values equal or less than 15% are preferred.

[5]. This is known as “preloading"

[6]. For a through discussion on this subject, please refer to Karakas HM. ENG-Principles and Applications in Breast Imaging White Paper-210285X10p-20210419.2021 Shenzen Mindray Bio-Medical Electronics Co., Ltd

[7]. These are shear wave velocity Cs (m/sec), shear modulus G (kPa) and Young's modulus E (kPa).

[8]. For the interpretation of E (kpa) measurements, please refer to Karakas HM. ENG-Principles and Applications in Breast Imaging White Paper-210285X10P-20210419. 2021 Shenzen Mindray Bio-Medical Electronics Co.,Ltd

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