Real-time ultrasound elastography of the breast: state of the art

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Abstract

Purpose: To review literature date on breast free hand elastography, while presenting typical examples of breast focal lesions displaying various types of Tsukuba elasticity scores.

Background: Most of the breast cancers are more rigid than surrounding breast parenchyma. The principle of elastography relies on the relative resistance to movement of harder tissues compared to softer adjacent ones when slight pressure is applied.

Procedure details and imaging findings: Sonoelastography demonstrates the elasticity of a lesion related to the elasticity of the surrounding tissue. The final result is based on the comparison between pre- and post compression data. According to the equipment type, various colors (256 hues) or gray shades are super imposed on 2D images. Stiff areas are coded in blue or dark gray tints, while softer, elastic tissues appear in red, green or bright shades of gray. The examples presented in this paper were acquired using a Hitachi 8500 US machine. The examination protocol was in accordance with Hitachi guidelines for elastography and final assessment was based on principles of Tsukuba elasticity score.

Conclusions: Real-time breast ultrasound elastography is a fast, simple method which can improve the sensitivity and positive predictive value of conventional US when diagnosing BI-RADS 3 and 4 focal lesions. It can lead to a decreased rate of unnecessary biopsies or futile re-examinations. Elastography can provide information which is difficult or impossible to collect with conventional ultrasound alone, thus being an improved complementary method to be used along with other imaging modalities in breast diagnosis.

Key words: breast, ultrasound, elastography

Introduction

Most breast cancers are more rigid than surrounding breast parenchyma [1-3]. The core principle of elastography relies on the relative resistance to movement of harder tissues compared to softer adjacent ones when slight pressure is applied. By measuring tissular displacement induced by transducer compression it becomes possible to obtain a stiffness estimation of various structures. During this procedure maximum displacement takes place longitudinally following the perpendicular plane of the ultrasound (US) beam [1].

In the last few decades there have been several US and MRI techniques [4,5] developed in order to appreciate the mechanical answer of tissue to external stimulation [6,7]. There are three types of stimuli which can be used to induce tissue deformation: static compression, dynamic vibration and pulsed excitation (transient elastography) [6,8]. Three US based methods have been proposed for elasticity assessment: the spatial correlation method, the phase-shift tracking method, and the combined autocorrelation method (CAM) [1, 5, 9], each one with its own limits and advantages (table 1) [1].

The spatial correlation method allows the appreciation of displacement for two dimensions, longitudinal and lateral, but lengthy processing time interferes with real time evaluation. The Color Doppler based technique is fast and precise for longitudinal evaluation, but due to the aliasing artifact it can deliver erroneous values when significant displacement occurs. Also the lateral movement
compensation is reduced. The aliasing phenomenon does not appear in CAM and lateral displacement can be compensated up to 4mm [1].

Table 1. Comparative analysis of the methodologies used to assess tissue displacement [1].

<table>
<thead>
<tr>
<th>Method</th>
<th>Processing time</th>
<th>Precision</th>
<th>Displacement domain measurability</th>
<th>Slip sensitivity</th>
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<tbody>
<tr>
<td>Spatial correlation</td>
<td>Slow</td>
<td>Moderate</td>
<td>Large</td>
<td>Robust</td>
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<tr>
<td>Phase-shift tracking (Doppler color)</td>
<td>Fast</td>
<td>High</td>
<td>Narrow</td>
<td>Weak</td>
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<tr>
<td>CAM</td>
<td>Fast</td>
<td>High</td>
<td>Large</td>
<td>Robust</td>
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Modern US devices allow combined elasticity and 2D real-time assessment of tissues or lesions, using the same probe as conventional ultrasound imaging [2]. SonoeLASTography demonstrates the elasticity of a lesion related to the elasticity of the surrounding tissue [10]. The final result is based on the comparison between pre- and post compression data [2,11,12]. According to the equipment type, various colors (256 hues) or gray shades are superimposed on 2D images. Stiff areas are coded in blue or dark gray tints, while softer, elastic tissues appear in red, green or bright shades of gray [2,10,12,13].

Elastography is also applicable with 3D US, when it quantifies morphologic alterations under compression [14,15].

Multiple diagnostic criteria have been proposed for a better discrimination between benign and malignant breast tumors when using elasticity assessment, such as the visibility of a lesion on elastography, the lesion’s contours and dimension compared to conventional US, the lesion color appearance and the strain ratio. Typically, malignant tumors display larger dimensions on elastography, due to the accompanying desmoplastic reaction [10,12], whereas benign lesions appear similar or have a smaller transverse diameter than on conventional, gray scale images [11,13].

Strain ratio is a useful post-acquisition assessment, obtained by comparing lesion deformability with the compression response of normal neighboring tissue. There is ongoing research to establish threshold values, but generally, a ratio above 5 is considered suspicious (Fig. 1-2).

**Examination technique**

The patient is examined in the supine position [1]. The probe is placed on the area of interest so that the targeted lesion will appear in the center of the image [16]. A slight, rhythmic compression-decompression movement is applied, holding the scan plane always perpendicular on the skin surface [17], the anterior margin of the lesion and the chest wall [16].

The region of interest (ROI) must be set to include the lesion, subcutaneous layers and pectoralis muscle, without costal arches [18]. The lesion itself should not exceed 25% of the ROI’s width [19]. A minimum 5 mm thickness of normal adjacent parenchyma should be contained within the elasticity box, given the fact that lesion stiffness is assessed in relation with the average elasticity of surrounding tissue [1].

A good quality elasticity image is acquired secondary to minimal pressure which does not distort glandular tissue. If the initial compression is adequate the pectoralis muscle appears blue and the subcutaneous fatty tissue appears as a mosaic of green and red [18].

Fig. 1. Elastographic image of a malignant breast lesion. Tsukuba elasticity score 5. Strain ratio (13.87) is highly suggestive for malignancy

Fig. 2. Elastographic image of a mastopathic nodule. Tsukuba elasticity score 1. Strain ratio (1.20) is suggestive for a benign lesion
Optimal amplitude of compression-decompression movements must be kept minimal, between 0.4-0.8 mm [5] or 1-2 mm [18], according to breast volume, lesion dimension and localization. Indicated compression frequency is of 1-2/sec [18]. A scale for compression degree is usually displayed on the monitor and must be kept between levels 3 and 4. During the procedure it is mandatory to avoid lateral slipping or rotation of the US probe. A transducer stabilizer can be used in order to increase compression surface and to reduce out of plane movements [1].

A minimum two series of images must be acquired and for each lesion at least 5 seconds are necessary [16]. From the technical point of view it is recommended to avoid:

- non-perpendicular, angulated scanning of the interest area;
- lateral slipping of the transducer;
- too slow or too fast compression-decompression movements [17].

From the lesion/patient perspective it is advisable to avoid assessing:

- large lesions (over 2.5 cm in diameter);
- superficial lesions, which tend to invade breast tegument;
- very large breasts [17].

**Clinical applications**

Elastography is useful in differentiating “impure” cysts from parenchymatous nodules, for complementary evaluation of mammographically and sonographically non-specific lesions and for determining the cause of acoustic shadowing as well as for better visualization or detection of isoechoic lesions [17].

At present there are two elasticity scores proposed for characterization of focal breast lesions: Tsukuba score (Graphic scheme 1) developed by Itoh and Ueno [1] and a second one designed by the Italian Research Group (Graphic scheme 2 after Lecatelli M, Rizzotto G et al. ed.) [20].

**Tsukuba score**

Score 1 (predominantly green) is used for lesions which present similar deformability to the surrounding breast parenchyma (Fig. 3).

**Score 2 lesions** are those with an inhomogeneous deformability, the overall appearance being a mosaic pattern of green and blue (Fig. 4).

**Score 3 is attributed to lesions** with elastic (green) periphery and stiff (blue) core (Fig. 5).
Fig. 5. Real-time ultrasound elastography performed in a 33 year-old patient reveals a small hypoechoic nodule with elastic-green periphery and stiff-blue core. Tsukuba elasticity score 3. FNA (fine needle aspiration): benign cytology corresponding to a complicated cyst.

Score 4 is used for rigid (blue) nodules, not including the echoic halo (Fig. 6).

Score 5 is reserved for cases with no tissues displacement secondary to compression, within the lesion itself and also within the adjacent tissues (echoic halo included) which appear blue on the elasticity image [1] (Fig. 7).

Fig. 6. Real-time ultrasound elastography performed in a 21 year-old patient reveals a fibroadenoma-like lesion which appears to be stiffer (predominantly blue) than the neighboring tissue. Tsukuba elasticity score 4. Pathology: hyalinized fibroadenoma.

Fig. 7. Real-time ultrasound elastography performed in a 55 year-old patient reveals a small, suspicious, stiff lesion, which appears to be larger on the elastographic image, due to the accompanying desmoplastic reaction (blue halo). Pathology: ductal invasive carcinoma.

Fig. 8. Typical three layered (BGR) elastographic appearance of simple cysts

BGR represents the typical, artifactual three layered aspect (blue-green-red) encountered with cystic lesions.

Adapted graphic scheme 2 – Elasticity score proposed by the Italian research group (according to Locatelli M, Rizzato G et al) [20].
The Italian score is presented in the following graphic scheme (score 1 = BGR, score 2 = elastic, green and red mosaic lesion, score 3 = predominantly elastic, green lesion with few rigid, blue areas, score 4 = predominantly rigid lesion, score 5 = stiff, blue lesion with rigid surrounding tissue):

When assessing the elastography score it is advisable to consider horizontal color patterns rather than vertical ones which are influenced by compression [18].

Cancer probability increases along with higher scores [18]. The 1 to 3 scores are suggestive for benign lesions, while 4 or 5 elastic scores rather indicate malignant tumors [2].

Breast cysts have a characteristic three-layer aspect: blue-green-red (BGR), blue being the superficial color and red the deep one [2,17,20]. This particular stratified appearance is also encountered in complex cysts, with impure content, which are difficult to differentiate from solid nodules on conventional US [17] (Fig. 9). The BGR pattern remains the same, independent of the lesion size, thus offering the possibility of avoiding unnecessary fine needle aspiration biopsies from small, benign looking, but hypoechoic nodules on B mode US. However, deep localization or fibrotic neighboring parenchyma may determine a non-typical elastographic appearance of cystic lesions [17] corresponding to scores from 1 to 4 [11,20-22] (Fig 10).

The fibro-cystic (mastopatic) nodules often have an elasticity aspect similar to surrounding parenchyma [11] (Fig. 11).

Generally fibroadenomas appear softer or with the same elasticity as adjacent glandular tissue (87.5% have 1 or 2 elasticity scores) [23] (Fig.12). Occasionally they look more rigid, receiving 3 or 4 elasticity scores [11,23] (Fig. 13).

Fig. 9. Hypoechoic, well delimited nodule displaying a stratified appearance (BGR) on elastography. FNA: benign cytology corresponding to a complicated cyst.

Fig. 10. Atypical cyst detected in a 50 year-old patient previously diagnosed with breast fibro-cystic disease. Tsukuba elasticity score 4.

Fig. 11. Mastopatic nodule diagnosed in a 35 year-old patient. On elastography the lesion displays predominantly elastic features, similar to surrounding breast parenchyma. Tsukuba elasticity score 2. Pathology: simple adenosis.

Fig. 12. Real-time ultrasound elastography performed in a 22 year-old patient reveals a typical fibroadenoma, predominantly elastic. Tsukuba elasticity score 2.
Some breast cancers may display benign features (score 1-3) on elasticity imaging [11] such as: non-differentiated or papillary DCI, inflammatory carcinoma, hypercellular, necrotic or pseudo-cystic malignant tumors, post-biopsy hemorrhagic lesions or deep small neoplastic nodules [2,19,23]. Mucinous [2] or medullary DCI can also present as pseudo-benign tumors on sonoelastography [11]. Large cancers, over 2.5 cm in diameter, occasionally display benign elastic features (score 2) [18].

A percentage of 15.6% of focal cancers had an elastic score 3 in the Ihoh A et al. study, that is why the Japanese researchers recommend percutaneous sampling of lesions with an elastic periphery but a hard core [18] (Fig. 15).

Fig. 13. Calcified fibroadenoma diagnosed in a 38 year-old patient. The lesion appears predominantly stiff (blue) on elastography. Tsukuba elasticity score 4.

About 79% of breast carcinomas have high elasticity scores (4-5), especially if they measure less than 1.5 cm [17]. Usually, carcinomas appear larger on the elastography image as compared to the gray scale one, due to better visualization of the surrounding desmoplastic and microscopically invaded tissue [11,24] (Fig. 14). Sonoelastography is particularly useful in diagnosing atypical carcinomas such as the very small or hypoechoic ones or those associated with acoustic enhancement [17].

The average elasticity score is significantly higher for scirrhouls ductal invasive carcinoma (DCI) than for in situ carcinoma (DCIS) [1].

Fig. 14. Ductal invasive carcinoma diagnosed in a 71 year-old patient. B mode US and elastography reveal malignant features. The elastographic image of the lesion appears larger due to the surrounding desmoplastic tissue (blue halo). Tsukuba elasticity score 5.

Fig. 15. Real-time ultrasound elastography performed in a 36 year-old patient reveals a non-specific, hypoechoic lesion with an elastic periphery and a stiff core. Tsukuba elasticity score 3. Pathology: ductal invasive carcinoma.

Suspicious or indeterminate, mammographically detected microcalcification foci, that are larger than 10 mm, have different mean elasticity scores related to their etiology: fibro-cyst changes are associated with an average score of 1.3 ± 0.5, whereas the malignant ones are associated with an average score of 3.0 ± 1.1 [25]. According to Choi, elastography has the potential of improving conventional US accuracy in detecting and differentiating lesions associated with suspicious, mammographically detected microcalcifications [25] (Fig. 16 A and B).

False positive results may be determined by hyalinized or calcified fibroadenomas, cystoatetonecrosis (CSN), papillomas (Fig. 17), complicated cysts, sclerosing adenosis or fibro-cystic displasia (Fig. 18) [2,19]. CSN associated with fibrosis is stiffer and sometimes larger on the elastographic images as compared to the gray-scale counterpart (Fig. 19) [11].
Fig. 16A. Mammographically detected, suspicious microcalcifications in a 54 year-old patient. Pathology: intraductal carcinoma with microinvasive foci.

Fig. 16B. Real-time ultrasound elastography reveals a stiff glandular area, otherwise non-detectable on the conventional, gray-scale image.

Fig. 17. Intracystic papilloma diagnosed in a 41 year-old patient. Real-time ultrasound elastography reveals a three layered lesion containing a stiff (blue) polypoid proliferation.

Fig. 18. Real-time ultrasound elastography in a 41 year-old patient reveals a small, isoechoic, indeterminate nodule which appears stiffer than neighboring glandular tissue. Tsukuba elasticity score 4. Pathology: atypical ductal hyperplasia.

Fig. 19. CSN (cyto-steato-necrosis) diagnosed in a 58 year-old patient. Real-time ultrasound elastography reveals a stiff area. Tsukuba elasticity score 5.
Sonoelastography is useful in elucidating acoustic attenuations: an elasticity score of 2 or 3 corresponds to benign microcalcifications, fibrotic or cicatrical lesions, whereas an elasticity score of 4-5 is found in neoplasia (Fig. 20), sclerosing adenosis or radial scars [11,17] (Fig. 21).

Fig. 20. B mode ultrasound performed in a 52 year-old patient reveals a glandular area with posterior shadowing. Note the obvious stiffer correspondent on the elasticity image. Tsukuba score 5. Pathology: lobular invasive carcinoma with atypical lobular hyperplasia.

Elastography is not indicated for the evaluation of postoperative changes, diffuse lesions or large ones, which exceed the probe length or its field of view (FOV) [16].

Sonoelastography is less sensitive than standard US when dealing with non-focal anomalies [18].

Some studies demonstrate the value of elastography in benign-malignant differentiation of lymph nodes [26] (Fig. 22-23).

Fig. 22. Benign axillary lymph node. Normal elastographic appearance.

Fig. 23. Metastatic axillary lymph node detected in a patient diagnosed with ductal invasive carcinoma. The elastographic image reveals a large, significantly rigid lymph node.

Elastography is also influenced by the breast type, a higher sensitivity being observed for adipose breasts [8].

Elastography has a limited application in very dense, fibrous parenchyma, in case of hematomas or breast implants [17].

When considering benign lesions with elasticity scores 1-3 and malignant lesions with elasticity scores 4-5, the reported sensitivity and specificity of sonoelastography ranged between 77.9-96%, respectively 87-91.5% [1,2,8,11,23,27-31]. The higher values were obtained with the assessment of smaller lesions, under 2 cm in diameter [23]. Elastography proved to be superior (92% specificity) to conventional US (82% specificity) when evaluating BI-RADS 3 lesions [8].

Fig. 21. Radial scar diagnosed in a 37 year-old patient. Tsukuba elasticity score 5.
Conclusions

Real-time breast ultrasound elastography is a fast, simple method which can improve the sensitivity [10,16,32] and positive predictive value (VPP) of conventional US when diagnosing BI-RADS 3 and 4 focal lesions. It can lead to a decreased rate of unnecessary biopsies or futile re-examinations [2,29].

Focal, mass-like lesions with elastic score 1 are highly suggestive for benign tumors [18]. Elastography can provide information which is difficult or impossible to collect with conventional ultrasound alone. It is therefore an improved complementary method which can be used along with other imaging modalities in breast diagnosis [11].

References

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