Elastography: from concept to clinical applications

Introduction

Elastography is a non-invasive technique in which stiffness or strain images are used to help detect or classify anatomical areas with different elasticity patterns. Elastography has been shown to be useful in differentiating healthy tissue from tissue that is undergoing change such as a tumor.

According to findings in recent literature,[1,2,3,4,5] when mechanical compression or vibration is applied, a tumor may deform less than the surrounding tissue (i.e. the strain in a tumor will be less than the surrounding tissue). Elastograms, or images of tissue strain, have been shown to be affected by the degree to which a tumor adheres to its surroundings, indicating a potential for tumor mobility characterization to enhance diagnostic confidence and treatment management.

Elastography is not a new concept. Estimation of tissue hardness is a very ancient diagnostic tool. Palpation was practiced by Egyptian physicians as early as 2600 BC.

> *"It is the business of the physician to know, in the first place, things similar and dissimilar; ...which are to be perceived in the sight, and the touch..." -Hippocrates.*

To this day, the relationship of tissue elasticity and hardness to palpability follows the basic principle that to be palpable, the object must be harder than the tissue surrounding it. The fingers displace tissue downward, and pressure receptors on the fingers sense the local stress values.

The stress is higher on fingers overlying a superficial "hard" lesion and lower overlying "softer" surrounding tissues.

Ultrasound Elastography

Strain Imaging elastography is a frequently adopted technique in clinical practice, using conventional signals (either radiofrequency or quadrature echo data) from clinical systems acquired before and after a tissue deformation is applied. Source of deformation can be either external (e.g. manual compression) or internal due to physiological movements (cardiovascular pulsation or patient breathing). Autocorrelation methods are used to compute the relative hardness information (local strains).

Elastography general steps include:

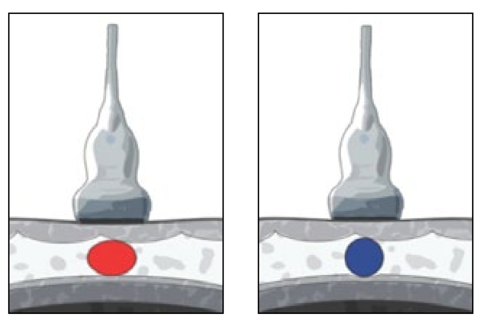
1. Deforming the imaged tissue using an external or internal stimulus.
2. Measuring tissue response under deformation.
3. Comparing pre-compression waveform to a similar segment in the post-compression waveform using autocorrelation method to estimate strain from relative tissue motion.

Softer tissues compress like a sponge, with the tissue closest displacing much more than tissues further away resulting in a larger change in the rate of displacement versus depth, resulting in large strain values.

Qualitative elastography in clinical practice

Elastography can help clinicians detect abnormal tissues by assessing their stiffness in relationship to surrounding tissue. Ultrasound elastography is a non-invasive, diagnostic technique performed in correlation with conventional B-Mode ultrasound.

The LOGIQ* consoles use a quasi-static strain imaging software (Figure 1) that estimates the strain in the region of interest after a manual compression (or any other source of mechanical deformation).



The soft lesion deforms under pressure.

This hard lesion does not deform under pressure.

$$\text{Elasticity} = \frac{\text{Stress}}{\text{Strain}}$$

Stress: *axial force applied to lesion*

Strain: *tissue deformation due to applied stress*

Figure 1. **The LOGIQ elastogram is achieved by positioning the ROI box around the region of interest and then applying slight compressions at the skin surface with the transducer. Stiffer tissue distorts less than softer tissue and variations can be shown on an elastogram.**

The calculation creates an elastogram represented as a color overlay on top of the B-Mode image representing tissue elasticity (Figure 2). The strain distributions, displayed by using a chromatic scale usually assigned from Red (Elastic/Soft) to Blue (Stiff/Hard), are superimposed to the B-Mode in a user selected ROI. This color-scale bar can be inverted or changed based on user preference while always keeping H (Hard) at the bottom of the scale.

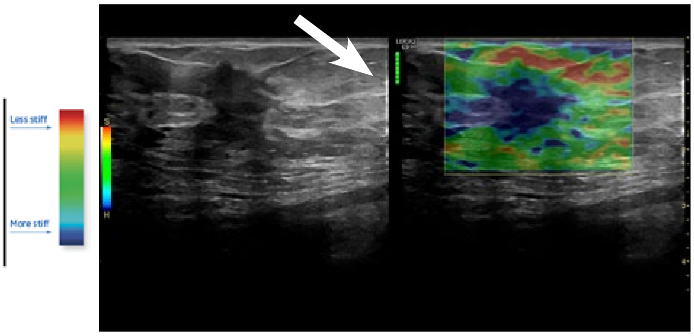


Figure 2. **Dual mode imaging can display the acoustic properties in a standard B-mode image and the elastic properties of the lesion simultaneously.**

A quality indicator in the form of a bar or a graph provides visual feedback to monitor the compression technique and helps make elastography reproducible and easy to learn. A green bar for consecutive frames, or a consistent graph in a high level shape means that the deformation is correct and the processed signal is relevant to the exam (Figure 2, white arrow).

Measurements can be made to further help the utility of this technique. The Dual Trace tool gives the operator the ability to trace the contour of the lesion in B-Mode. The system automatically shows the same trace line on the elastography image showing the difference between the lesion size depicted in the two modes. (Figure 3A). The ability to measure independently the size of the lesion both in the ROI elastogram (A) and in B-Mode (B) and calculate the A/B Ratio of the two measurements (Figure 3B) can help the study of the suspicious area. Referring to literature,[2] it seems that the interaction between a lesion and surrounding tissues could lead to either a wider or smaller color depiction in the elastogram than in B-Mode, due to changes in anatomy elasticity.

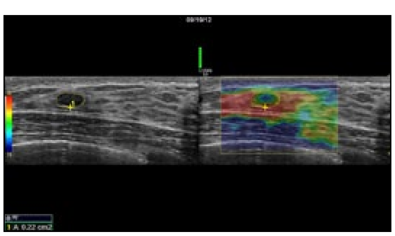


Figure 3A.
Dual Trace of a lesion size.

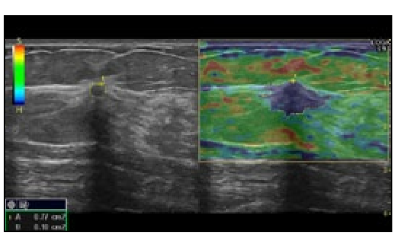


Figure 3B.
A/B Ratio tool: different sizes of the same lesion in Elastogram and B-Mode.

Figure 3.

While a qualitative color-coded elastogram provides tissue characterization information that is complementary to B-Mode data, a comprehensive clinical assessment can benefit from additional tools, such as targeting stiff tissue in a prostate gland for biopsy (Figure 4).

In addition to elastography, several LOGIQ systems offer advanced tools such as Query/Retrieve Multi-modality Imaging capabilities (e.g. Live Ultrasound and MRI – Figure 5) enabling comprehensive patient management. With the leadership series of LOGIQ products, the Volume Navigation Imaging option can be added to provide detailed visualization of the morphologic tissue features.

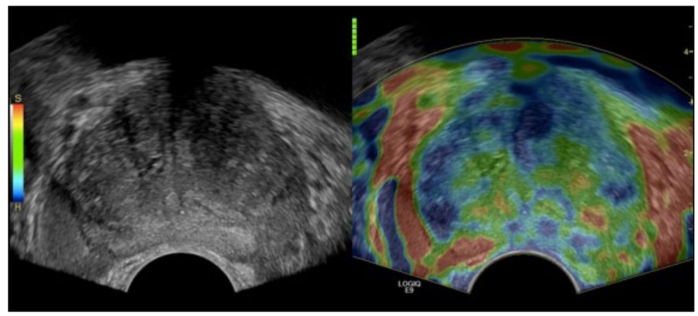


Figure 4. **LOGIQ advanced tools combined with elastography can help study suspicious lesions with confidence.**

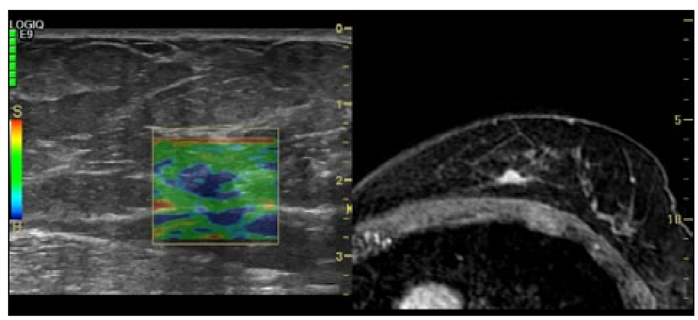


Figure 5. **Volume Navigation Fusion[1] imaging fuses previously acquired PET, MR, CT, or Ultrasound volume dataset with real-time ultrasound scanning to help correlate and evaluate complementary information from different image modalities.**

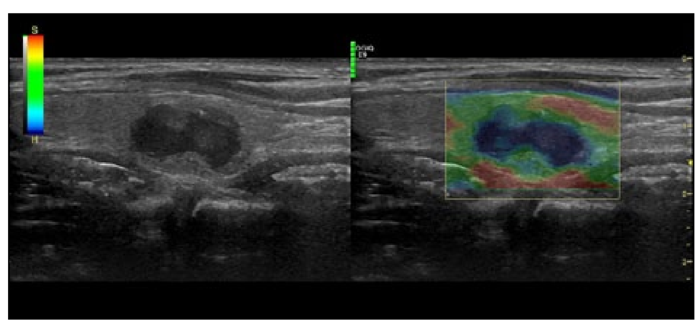


Figure 6. **Side-by-side of a thyroid lesion with heterogeneous B-Mode and a mixed pattern in the elastogram.**

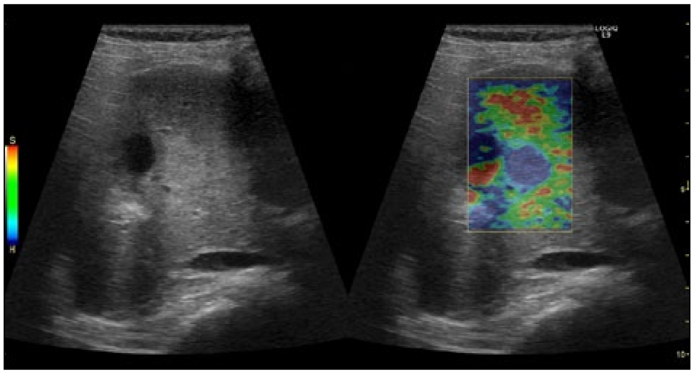


Figure 7. **Side-by-side ultrasound display of multiple liver lesions with varied stiffness.**

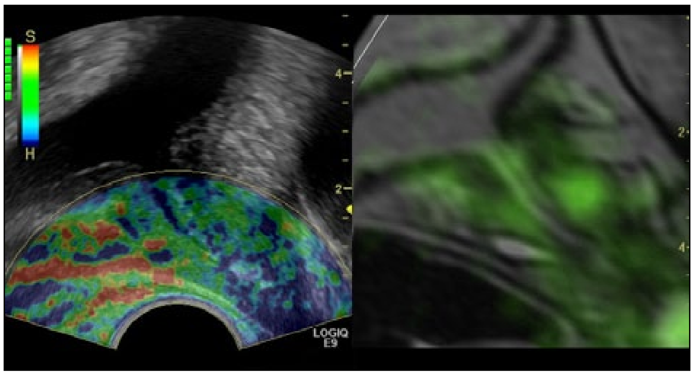


Figure 8. **Fusion of ultrasound elastography with weighted MRI using Volume Navigation helping with correlation of this suspicious lesion.**

Elastography is featured on a range of GE transducers, including high and low frequency linear transducers (for breast, small parts, and musculoskeletal applications – Figure 6), low frequency linear transducers, convex transducers (for abdominal applications – Figure 7), and endocavitary transducers (for prostate and gynecological studies – Figure 8) expanding the use of elastography to a variety of clinical applications.

Semi-Quantitative Elastography† in clinical practice

In addition to breast imaging, where elastography is used to help lesion classification and surgical planning, other growing applications include small parts (e.g. thyroid, testicles), musculoskeletal, EUS (pancreas, lymph nodes, and GI tract), prostate and liver evaluations (focal liver lesions classification, treatment monitoring, diffuse liver disease staging and monitoring).

To provide semi-quantitative measurements aiming to enhance the user confidence, some LOGIQ platforms offer an elastography semi-quantitative package including:

- E-Index (Elasticity Index)
- E-Ratio (providing the Elasticity Ratio between two regions of interest)
- Q-Analysis (providing semi-quantitative analysis for the tissue elasticity over a selected range of frames inside a cine loop)

Semi-Quantitative Elastography measurements

The LOGIQ Elasticity Index (**E-Index**) is defined as a value between 0.0 and 6.0, and it is measured within a drawn Region of Interest (ROI) selected by the user. The ROI can be manually or automatically traced as a circle or free hand shape, with size and position modifiable by the operator. The higher the E-Index value, the stiffer the tissue.

When the user draws a region of interest (ROI), the system calculates the average E-value inside the ROI (Figure 9).

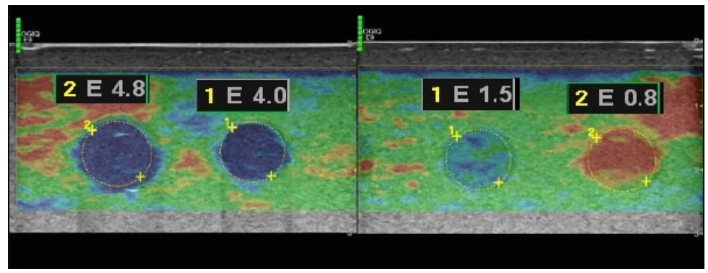


Figure 9.

E-Ratio measures the E-Index Ratio between two E-Indexes calculated in two selected ROIs. For example, the first ROI can be drawn on a normal tissue and the 2nd ROI on a suspicious area. The user provides two ROIs, and the system calculates and displays the E-Ratio between the ROIs.

The LOGIQ system elastography semi-quantification is performed on **Raw Dataset**, available with GE's advanced Raw Data processing capabilities. This enables the user to get semi-quantitative measurements independent from the user color elastogram settings with high data consistency.

The **Q-Analysis** feature displays the Elasticity values (E-Index and E-Ratio) over a multiple frame acquisition. Once a cine loop is acquired, the user can access the Q-Analysis Package (Figure 10).

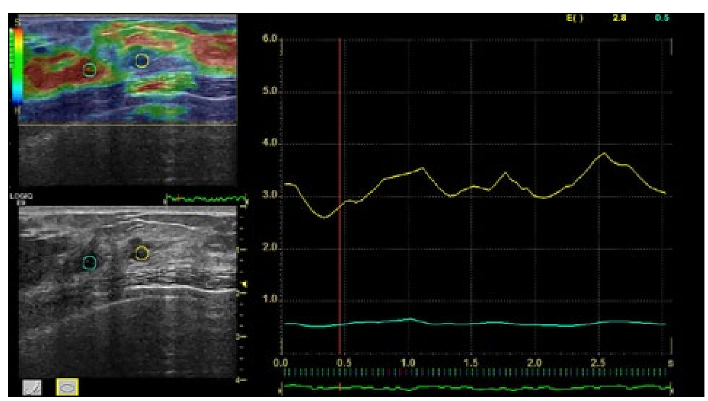
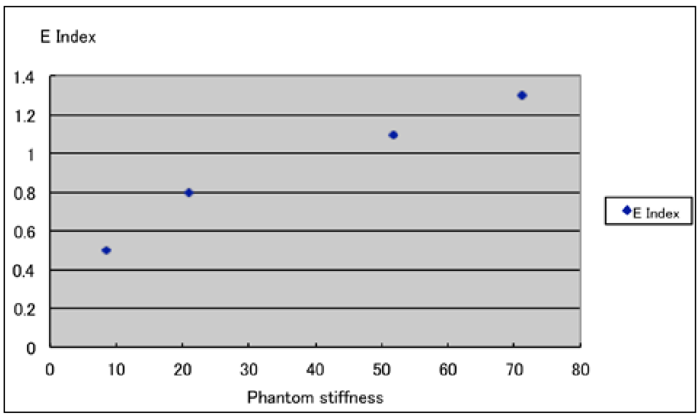


Figure 10. **Here the user can place up to eight ROIs on the Elastogram image (or relative B-Mode image) and the system automatically displays the graph of the E-index values along the acquired frames. As depicted in this figure, similar hypoechoic areas in B-Mode can show very different E-Index values related to a different stiffness.**

The system automatically skips the non-consistent frames, including those between each compression and decompression, from the acquired clip. It will also allow the user to manually disable or enable frames as needed. The user can "anchor" the ROI to the target while moving along multiple frames to compensate for breathing or compression differences. The pertinent E-values will update as intended coincident with target position.

The numeric values can be exported in ASCII format through the "Export Traces" function and be further reprocessed by the user offline.

The LOGIQ semi-Quantification tool provides relative measurement, so these values themselves are not providing a value in kPa. However, it has been observed that E-Index and E-Ratio may correlate with kPa as demonstrated from measurements on dedicated Elastography Phantom (Figure 11).



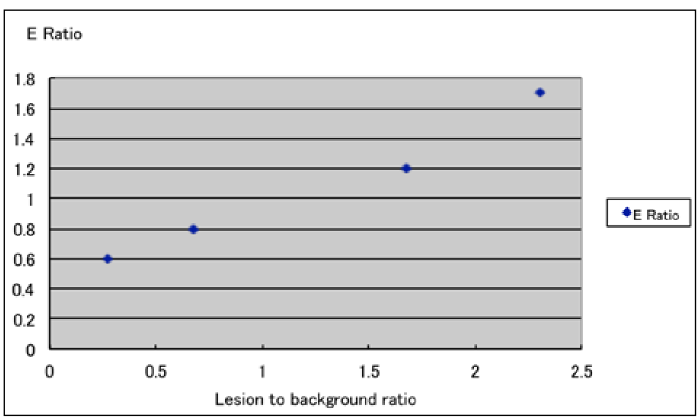


Figure 11. **E-index and E-Ratio results obtained while scanning on a an elasticity QA phantom (CIRS-Model 049).**

Semi-Quantitative Elastography and Raw Data Processing

Both quantitative strain data and strain ratio values are part of the **Raw Data storage** in cine memory. When replaying or scrolling through an elastography cine loop, additional manipulations such as changing measurement ROI position, adding measurements, adding ROIs, or re-calculating ratios can be done immediately after the exam is completed or any time later on a recalled loop.

GE's Raw Data processing gives the user the opportunity to re-work previously acquired elastography cine loops and perform the semi-quantification at a later stage once the patient has gone or even after days or weeks.

With GE Raw Data imaging, the E-values (E-Index and E-Ratio) do not depend on the elastography color appearance set up by the user, but are part of the Raw Data information stored. Even with any changes the user applies to the elasto color map (i.e. changing the soft/hard compression, gain, etc….), these E-values will not change.

Conclusions

The uses of elastography in Ultrasound have been growing over the past 10 years since its initial use with breast lesion assessment and has recently spread into several other clinical applications. Today, elastography is still regarded as a fundamental adjunct diagnostic tool for ultrasound imaging. Several elastography techniques are currently being investigated to find the most reliable and consistent solution with lower user dependency and higher reproducibility in different clinical applications. Quantitative technique and semi-Quantitative packages have been recently added to provide the user with objective data and measurements to help in interpretation and comparison of data. Elastography could be beneficial to patient care and management, but any new clinical technique requires a long learning process to understand the pathophysiology behind it, the response of anatomies in normal and pathological conditions, the relation with standard ultrasound patterns and the clinical needs. To support this learning process and help the user have a better understanding of the elastography physical basis and clinical applications, the European Federation for Ultrasound Societies in Medicine and Biology (EFSUMB) is currently preparing "EFSUMB Recommendations and Guidelines on the Clinical Use of Elastography." Reference this publication upon its availability.

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† Semi-Quantitative Elastography described in this material has not been cleared by the U.S. FDA and is not available for promotion or sale in the United States.

DOC1010543