What is Elastography?

- Elastography is a non-invasive form of tissue characterization with the goal of analyzing tissue stiffness.
- Analyzing tissue stiffness gives additional diagnostic criteria that current ultrasound imaging does not provide.
  - Malignancies are often stiffer than benign lesions.
  - Fibrotic tissue is stiffer than normal tissue.

- Elastography is non-invasive, no radiation, easy to learn, and relatively low cost.

- Elastography alone will not give the diagnosis; it should be used in conjunction with all ultrasound information to increase the sensitivity and specificity of the diagnosis.
- B-mode imaging and patient history remain a critical part of the exam.
- Echo texture, borders, shadowing, and other characteristics are all important diagnostic criteria for the correct interpretation of the disease state of the patient.

- All current Elastography techniques have advantages and disadvantages. There is no single method that offers a total clinical solution.
- There are still diagnostic issues with some lesions that do not behave as expected, i.e., soft appearing metastases & hard appearing hemangiomas.
Types of Elastography

Two types of Imaging Elastography

- Strain Imaging (Relative)
  - External manual compression
  - Internal compression (breathing/pulsation)

- Shear wave (Quantitative)
  - Point Quantification
  - 2D Imaging

Strain Elastography

- Real-time technique
- Displays the relative of tissues in the FOV, Therefore a given tissue may have a different color in each elastogram
- Linear and curve transducers
- Clinical applications
  - Breast
  - Thyroid
  - Prostate

Strain Elastography

- An ultrasound technology that analyses the property of elasticity or strain to evaluate tissue stiffness
- It produces a color coded (or black and white map) superimposed on the 2D grayscale image
- Qualitative: Best used when comparing a lesion with surrounding tissue
Strain Elastography

- Strain Elastography is considered a compression technique.
- Comparison of different regions of strain.
  - Clearly delineates stiff lesions.
  - Requires “reference” region.
- For breast tissue strain ratio works well and has correlated to *BIRADS classification of lesion.
- For breast lesions an E/B ratio greater than 1 is positive.
- Qualitative measure of stiffness.

Strain: E/B Ratio

- Routine measurement used in Strain Elastography.
- Details:
  - Measure the width of a lesion on the elastogram.
  - Measure the width of the lesion on the B-mode image.
  - Calculate the ratio.
  - Greater than or equal to 1 indicates stronger likelihood of malignancy.
  - Below 1 indicates stronger likelihood of a benign lesion.

Shear wave Elastography (SWE)

- A technology that quantifies tissue stiffness by analyzing generated shear waves in a sampled area
- Measures tissue stiffness as an absolute value
- No need for reference tissue
- Can be used for diffuse disease

Elastography Measures Stiffness

- Doesn’t measure fibrosis only!
- Measures stiffness that is influenced by
  - Fibrosis
  - Increased Hepatic Pressure
  - Portal Hypertension
  - Hepatic Congestion
  - Increased Blood flow from food digestion
  - Inflammation

Shear wave Elastography (SWE)

- Shear waves cause motion perpendicular to the direction of propagation
- Speed 1 - 10 m/s
- Shear Wave can be quantified
  - Directly in m/s
  - Indirectly for elasticity in kPa (multiple assumptions in the equation)

Shear waves travel much slower than longitudinal waves

Shear wave Elastography (SWE)

- Shear waves are generated perpendicular to the ultrasound pulse (stronger pulse used for shear wave elastography)
- Velocity of shear waves indicates stiffness
- Quantitative measure of stiffness

“External” Shear wave Generation

- Mechanical vibrator:
  - Used in MR-Elastography, Transient Elastography
  - Able to induce significant displacement (which results in big shear wave)

“Push Pulse” Shear wave Generation

- Acoustic radiation force, (ARFI), generated by a “push pulse”
- No need for additional equipment.
- Applicable even when there is ascites.
Shear wave Calculation

Shear velocity is calculated from the arrival times at each point. Elasticity is calculated by the speed of the shear wave.

Shear wave Propagation

- A stiff lesion – the shear waves speed up as they pass through the lesion (slower if soft tissue)
- Mapped with choice of maps:
  - Color map
  - Propagation map - pictorial depiction of the shear waves as they pass through tissue

Propagation map

- Propagation map Advantages:
  - Assess quality of shear waves
  - Guide measurement placement
- The ‘rainbow’:
  - Arrival time – time taken to travel across the Region of Interest (ROI)
  - Direction of travel – blue is closest to the push pulse

Propagation map display

- Factors affecting shear waves:
  - Shear waves do not propagate through fluids (e.g., blood vessels, cysts)
  - “…strength of the push, variations in attenuation, absorption and reflection of the pushing beam, ultrasound scatter density, tissue continuity, very high or very low shear wave speed, and shear wave scattering, reflection or refraction.”

Types of Shear wave Technology

- Transient Elastography (1D-SWE)
- Acoustic Radiation Force (push-pulse)
  - Point based (P-SWE)
  - 2D Imaging (2D-SWE)
- Magnetic resonance elastography (MRE)
1D-SWE: Transient Elastography

- Echosens: Fibroscan
- One dimensional (line)
- No ultrasound image stand alone system
- External Vibration to create shear waves
- Quantitative

Advantages:
- Ease of use
- Large number of studies and meta-analyses
- CPT Code available

Disadvantages:
- Can not be used if ascites is present
- Can not determine where measurement is taken
- Need for recalibration of the probe every 6-12 months

P-SWE (Point Shear wave Elastography)

- ARFI (Acoustic Radiation Force Imaging) pulse used to generate shear wave in a small (1cc) ROI
- Real-time imaging so masses and large vessels can be identified and avoided
- Can systematically select different parts of the liver to sample

Advantages:
- Highly reproducible
- Bota et al, in a meta analysis found that P-SWE shows a higher rate of reliable measurements and a similar predictive value to 1D-SWE for significant fibrosis and cirrhosis

Disadvantages:
- Fewer studies than 1D-SWE
- No CPT Code

2D-SWE (2D Shear wave Elastography)

- Multiple measurements using a push-pulse over a large FOV
- Can be done as a single image or real-time
- Real-time image so vessels and masses can be avoided
- Color coding aids in assessment
- Allows for averaging over a larger area

Advantages:
- Highly reproducible
- Color coding aids in assessment
- Bavu et al, higher accuracy than 1D-SWE in assessing mild and intermediate stages of fibrosis
- Ferraioli et al, 2D-SWE was more accurate than 1D-SWE in assessing significant fibrosis

Disadvantages:
- Fewer studies than 1D-SWE
- No CPT Code
Shear wave Elastography

- 2D-SWE
  - Customized ROI
  - Measurement is averaged from the sample box
  - Color coded Elastogram
  - Can utilize quality assurance of the sample

- P-SWE
  - Fixed ROI
  - Measurement is averaged from the sample box
  - No color coded Elastogram
  - No method of sample quality assurance

MRE

- Device is placed on patient to generate shear waves in the liver, special MRI sequence to image the mechanical waves and processing software to produce color-scaled tissue stiffness images
- Entire liver is evaluated
- Color codes the tissue stiffness and is quantifiable – Results displayed as shear modulus (3X Young’s Modulus)

Liver Disease

- According to the Centers for Disease Control and Prevention (CDC), an estimated three-and-a-half million people in the United States have a chronic hepatitis C infection. Most people infected with the hepatitis C virus (HCV) don’t even know they have it.
- Over the course of years, HCV infection can cause major damage to the liver. For every 100 people with chronic HCV infection, between five and 20 people will go on to develop cirrhosis, according to the CDC. In fact, HCV infection is the leading cause of cirrhosis and liver cancer.

- Chronic liver disease is a substantial world-wide problem
- Its Major consequence is increasing deposition of fibrous tissue within the liver leading to the development of cirrhosis with its consequences - portal hypertension, hepatic insufficiency and HCC
- The stage of liver fibrosis is important to determine prognosis, surveillance, prioritize for treatment and potential for reversibility
Cirrhosis is considered the end stage of chronic liver disease of ANY etiology and results from progressive fibrogenesis.

- Hepatitis C
- Hepatitis B
- Alcohol
- NASH
- Cholestatic
- Autoimmune
- The process of fibrosis is dynamic and regression of fibrosis is possible with treatment of the underlying conditions.

Liver Disease: Clinical Interest

- Varied causes:
  - Hepatitis (B and C), 540 million people worldwide affected
  - Chronic alcohol abuse
  - Non-alcoholic fatty liver disease (obesity, diabetes, elevated triglycerides)
  - Drug induced liver injury

- Serial evaluation of these patients must be simple, cost effective and easily reproducible.

- Ultrasound Elastography is non-invasive, no radiation, relatively inexpensive and easy to learn.

What consumers are hearing

1 in 30 Baby Boomers has Hep C, and most don’t even know it.
**Why is Staging Important in Management**

- Prognosis
  - Assessment of urgency for Rx.
- Surveillance in chronic patients (e.g., HCC, varices)
- Baseline for monitoring Rx efficiency
- Tailoring a treatment algorithm (e.g., prolonged Rx duration in HCV cirrhosis)
- Drug reimbursement

**Elastography: Clinical Interest**

- Liver biopsy remains the gold standard
- Ultrasound (2D/Doppler) findings can be correlated with cirrhosis
- Shear wave elastography is becoming recognized as an efficient way to evaluate liver fibrosis and early cirrhosis
Elastography: Clinical Interest

- New treatments for Hepatitis C include (Sovaldi or Harvoni) effective but expensive. A 12 week course bears a $95,000 price tag.
- Medications for Hepatitis C treatment cost Medicare $4.5 billion last year.
- Some insurers have required patients to be F3 or F4 to qualify for treatment.

Shear wave Imaging Protocol

Protocol and Guidelines Development

- EFSUMB: European Federation of Societies for Ultrasound in Medicine and Biology
  - Elastography Guidelines in 2013
- WFUMB: World Federation of Ultrasound in Medicine and Biology
  - Elastography Guidelines in March 2015
- SRU: Society for Radiologists in Ultrasound June 2015
- QIBA: Quantitative Imaging Biomarkers Alliance

Example Protocol: Liver

- Fasting
  - Recommendation: avoid eating 4-8 hours, avoid alcohol 12 hours
- Supine position, right arm elevated above the head for optimal intercostal access (left lateral decubitus position ok)
- Optimize the B-mode image — “best acoustical window”
- Measurements should be taken during breath hold in a neutral breathing position (not inspiration or expiration)
- Avoid the first cm from the liver capsule
**Example Protocol: Liver**

- Avoid large vessels and bile ducts
- Transducer should be perpendicular to liver capsule
- Record median value from multiple measurements
  - Recommendation: 10 measurements
- Apply minimum transducer pressure
- Limited depth sensitivity
  - around 6 cm

**Transducer Positioning**

- Maintain perpendicular transducer angle in elevation

**Transducer Positioning**

- Maintain perpendicular transducer angle to the liver capsule
- Intercostal approach—“best acoustic window”
- Perpendicular to the transducer surface with capsule oriented parallel to the transducer face
  - Upper right lobe (segments V/VIII)
  - Avoid large vessels and bile ducts and cysts
  - Light transducer pressure

**Acquisition & Measurement Example**

- Repeat until 10 measurements are obtained
  - Maintain the same position/acoustic window for all 10 measurements

**Display Maps**

**Display Maps**
Propagation Mode Examples

Soft Inclusion
- Speed [m/s]
- Elasticity [kPa]
- Propagation [Vessel Related Contours]

Hard Inclusion

SWE Examples

Propagation Mode Examples

- Guides reliable placement of measurement ROI

Good Quality - SWE

Example Of Good Quality Shear Wave

Poor Quality - SWE

Example Of Poor Quality Shear Wave

Fibrotic Liver - SWE

Fibrotic Liver
Common Artifacts

- Shear waves do not propagate thru fluids (i.e. blood vessels, cysts)
- Reverberation
- Breathing Motion

Fluid Artifacts

Reverb or Pressure Artifacts

Motion Artifacts

- Vertical color changes
Staging

- Comparative Scoring Matrix - Fibrosis

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Fibrosis</td>
<td>No Tissue</td>
</tr>
<tr>
<td>1</td>
<td>Early Fibrosis</td>
<td>Resonant probe, increased stiffness</td>
</tr>
<tr>
<td>2</td>
<td>Moderate Fibrosis</td>
<td>Fibrotic bands, increased stiffness</td>
</tr>
<tr>
<td>3</td>
<td>Severe Fibrosis</td>
<td>Fibrotic bands, increased stiffness</td>
</tr>
<tr>
<td>4</td>
<td>Cirrhosis</td>
<td>Fibrotic bands, increased stiffness</td>
</tr>
</tbody>
</table>

Summary

Strain
- Measures Tissue Deformation
  - Mechanical Compression
  - Respiration/Cardiac Motion
- Qualitative
  - Results show as color coded comparing one area to another i.e. the lesion shown stiffer than the surrounding tissue

Shear Wave
- Measures Velocity or Elasticity of shear wave
  - Mechanical Vibration
  - Push pulse
- Quantitative
  - Units m/s or kPa

Conclusion

- Detection of significant fibrosis and cirrhosis is important for diagnosing, determination of treatment, prognosis and follow-up of chronic liver disease
- Literature supports the non-invasive use of various Elastography techniques to assess liver stiffness
- To obtain accurate liver stiffness measurements adherence to a strict protocol is required
- Both patient factors and imaging factors effect results