Advanced MRI in the Clinic - MR Elastography

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Outlines

• Brief History of MR Elastography (MRE)
• MRE Technique
  – Generating Mechanical Wave
  – Displacement Encoding
  – Wave Images and Stiffness Maps
  – Presentation and interpretation
• Artifacts and Pitfalls
• MRE Applications & Quality Assurance

HISTORY OF MR ELASTOGRAPHY

Tissue Stiffness and Disease

▪ Diseased tissue frequently manifests with a change in stiffness
▪ Palpation is an important part of the standard clinical exam
  ▪ Examples: Breast, Thyroid, Prostate, Liver, …
  ▪ Limitations:
    – Penetration depth
    – Accessibility of the organ
    – Skin and muscle layers

Development and Publications of Elastography

History of MR Elastography

• 2007: Clinical use
• 2017: American Medical Association (AMA) CPT Code
• 2019: Medicare Reimbursement
**Basic Principles of MRE**

1. Generate vibration or mechanical wave in the tissue/organ of interest (*Active and Passive Drivers*)
2. Image the mechanical wave with displacement encoding (*MRE Sequence*)
3. Calculate the mechanical properties such as stiffness (*Inversion Algorithm*)
4. Present the results for visualization and interpretation (*Color Maps*)

**MR Elastography Drivers**

- **Active Driver**
- **Passive Driver**
- **Plastic Tube**

Modified based on the original provided by Dr. Meng Yi, Mayo Clinic

**Web Interface to Active Driver**

**MRE Driver Settings**

- Frequency: 40 – 200 Hz
- Amplitude: 25 -75%

**Passive Driver Placement for Liver MRE**

- Xyphoid process of the sternum
- Right midclavicular line

...
Shear Wave

Speed: \( C_S = \sqrt{\frac{G}{\rho}} \)

- Shear Modulus: \( G = G' + iG'' \)
- Shear Stiffness: \( G' \)
- Shear Viscosity: \( G'' \)
- Unit: Pa = N m\(^{-2}\) = kg m\(^{-1}\) s\(^{-2}\)

\[ C_S \approx 1540 \text{ m/s} \]

1-5 m/s

Motion Encoding Gradients (MEG) in MRE Sequence

Motion Encoding Gradients (MEG)

TR = 50ms
GRE Sequence
60 Hz Sinusoid Wave

Encoding Sinusoidal Displacement

\[ m_0(t) = (-G\tau) + G(2\tau) + (-G\tau) = 0 \]
\[ m_1(t) = (-G\tau^2/2) + (G(2\tau)^2/2 + G(2\tau)\tau) + (-G\tau^2/2 + (-G\tau)3\tau) = 0 \]
\[ m_2(t) = 4G\tau^3 \]

Imaging of Mechanical Wave

Increment Trigger Delay
Cine Frame #1
Cine Frame #2
Cine Frame #3
Cine Frame #4

Inversion Algorithm

Mechanical Vibration Wave Images Stiffness Map

Review of MR Elastography (MRE)

Amplitude (um)

Modified from the original work by W. H. Lin, et al.
Failure rate = 5.8 %
Failure rate = 2.0 %

Woks in patients with R2*<400 s⁻¹ at 3T

Lung MRE with SE-EPI MRE

61, F
Normal lung
Mean: 1.2 kPa

79, M
Interstitial lung disease
Mean: 5.9 kPa

Shear Stiffness of the Lung Tissue (kPa)

Linear Regression:
GRE_TR50 = 0.99 X SE-EPI
P < 0.001

GRE MRE ≈ SE-EPI MRE

Bland-Altman
Mean difference = 0.003 (-0.08, 0.08)
Paired t-test P = 0.93 (2-sided)

Typical SE-EPI MRE Parameters
- FOV = 420 mm
- Base Resolution = 100
- Phase Resolution = 100 %
- Slice Thickness = 8.0 mm
- Slice Gap = 2.0 mm
- TR = 1200 ms
- TE = 48 ms
- Parallel Image (GRAPPA) = 2
- FS = SPAIR
- Receiver Bandwidth = 2174 Hz/Px
- 4 slices / BH (13 sec) (versus 1 slice / BH with GRE MRE)
Color Coding of Stiffness

Shear Stiffness (kPa)

- Normal: <= 2.5 kPa
- N or Inflamm: 2.5 to 2.9 kPa
- Stage 1: 2.9 to 3.5 kPa
- Stage 2: 3.5 to 4.0 kPa
- Stage 3: 4.0 to 5.0 kPa
- Stage 4: > 5.0 kPa

Courtesy of Dr. Meng Yin, Mayo Clinic

Difference in Wavelength

Normal Liver
Stage 2 Liver Fibrosis

Pitfalls in MRE Acquisition
1. Patient preparation
   - Fast 4 – 6 hrs. before MRE
2. Active driver setting
3. Passive driver placement and fixation
4. Slice positioning
   - Avoid liver dome and inferior portion
5. Breath hold
   - End of expiration to minimize variation
6. Sequence parameters

Postprandial Effect in Liver MRE
Before Meal
After Meal
Fibrosis Stage 4

Placement of ROI for Stiffness Measurement
- Sample large portion of liver
- Within area of >95% confidence
- Avoid edge of liver
- Avoid left lobe
- Avoid large blood vessel
- Avoid "Hot Spot"
- Avoid area of poor wave propagation
Liver Fibrosis

- Excessive accumulation of extracellular matrix proteins including collagen
- Occurs in most types of chronic liver diseases.
- Advanced liver fibrosis results in cirrhosis, liver failure, portal hypertension and often requires liver transplantation.
- Traditionally diagnosed with liver biopsy.

Liver MRE

Liver Fibrosis Assessment with MRE

Liver Stiffness by MRE Predicts Outcome
Nonalcoholic Steatohepatitis (NASH) with possible Cirrhosis

Portal Hemodynamics

Focal Lesion Appears as “Hot Spot”

A 63 yo Patient with Invasive Lobular Carcinoma (ILC)

Kidney MRE

Mechanical properties of the liver and spleen tissues may reflect pathophysiologic changes in both extracellular matrix and portal hemodynamics.

Normal Liver and Autoregulation
- Portal Pressure Low & Stable
- Tissue Stiffness Low & Stable

Fibrotic Liver and Impaired Autoregulation
- Portal Pressure Increased & Unstable
- Tissue Stiffness Increased & Unstable

Mechanical properties of the liver and spleen tissues may reflect pathophysiologic changes in both extracellular matrix and portal hemodynamics.

Focal lesion appears as “Hot Spot”

A 63 yo patient with invasive lobular carcinoma (ILC)

- ILC: 1.25 kPa,
- Fat = 0.51 (left) and 0.44 (right) kPa,
- Fibroglandular tissue = 0.83 (left) and 0.71 (right) kPa.

Requires motion encoding in 3 directions
- The stiffness of the normal kidneys at 60 Hz ranged from 3.5 to 5 kPa.
MRE of Meningioma

MRE Quality Assurance

Acknowedgements

THANK YOU!