

# Advanced MRI in the Clinic - MR Elastography

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1

## 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

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2

## HISTORY OF MR ELASTOGRAPHY

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3

## 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

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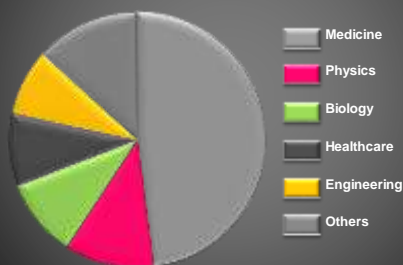
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## Development and Publications of Elastography

Total = 13,432

Year 2020= 1,669



Courtesy of Dr. Meng Yin, Mayo Clinic

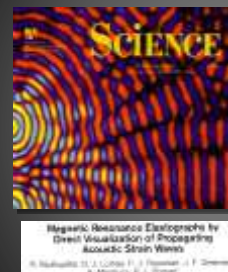
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## History of MR Elastography



1995

- 2007: Clinical use
- 2017: American Medical Association (AMA) CPT Code
- 2019: Medicare Reimbursement

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## MRE TECHNIQUE

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7

## 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*)

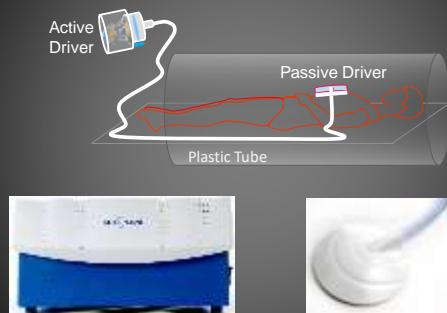
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## MR Elastography Drivers



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## Web Interface to Active Driver



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## MRE Driver Settings



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

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## Passive Driver Placement for Liver MRE



Right midclavicular  
line

Xyphoid  
process of the  
sternum

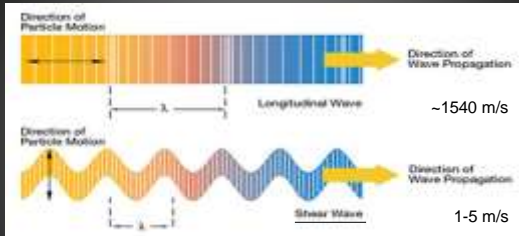
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## Shear Wave



Shear Modulus:  $G = G' + iG''$ ,  
 • **Shear Stiffness:**  $G'$   
 • **Shear Viscosity:**  $G''$   
 • **Unit:**  $\text{Pa} = \text{N m}^{-2} = \text{kg m}^{-1} \text{s}^{-2}$

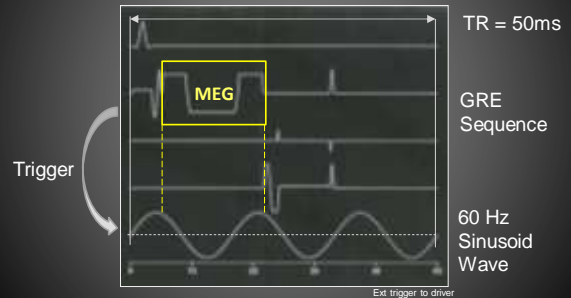
Speed:  
 $C_S = \sqrt{G/\rho}$

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## Motion Encoding Gradients (MEG) in MRE Sequence

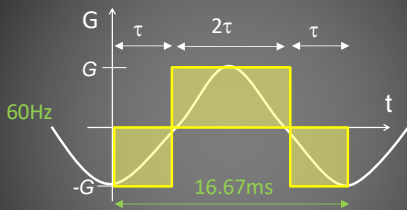


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## Encoding Sinusoidal Displacement



$$m_0(t) = (-G\tau) + G(2\tau) + (-G\tau) = 0$$

$$m_1(t) = (-G\tau^2/2) + (G(2\tau)^2/2 + G(2\tau)\tau) + (-G\tau^2/2 + (-G\tau)3\tau) = 0$$

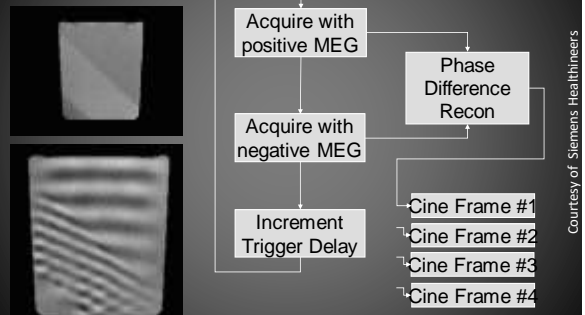
$$m_2(t) = 4G\tau^3$$

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## Imaging of Mechanical Wave



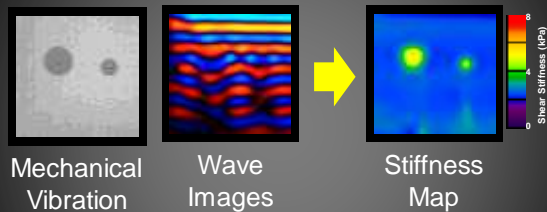
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Courtesy of Siemens Healthineers

## Inversion Algorithm

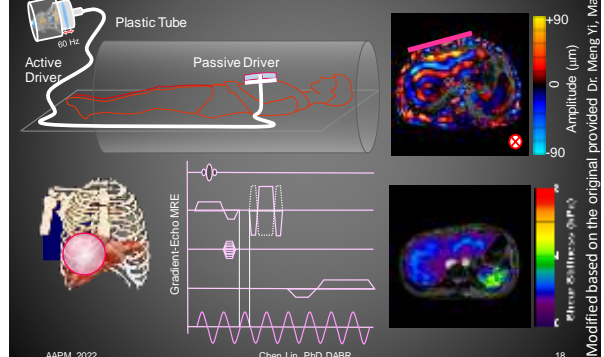


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## Review of MR Elastography (MRE)



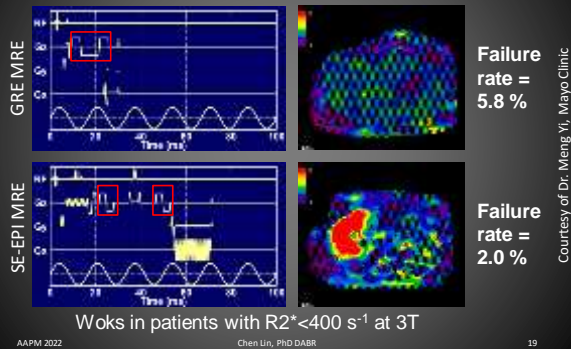
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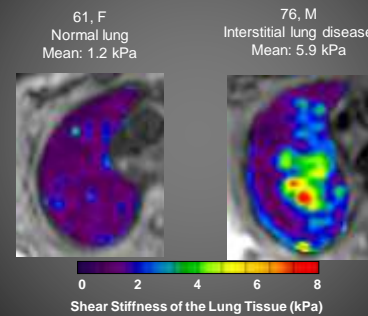
Modified based on the original provided by Dr. Meng Yi, Mayo Clinic

## GRE MRE -> SE-EPI MRE



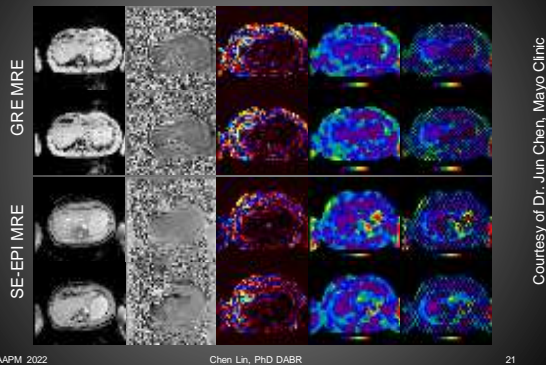
19

## Lung MRE with SE-EPI MRE



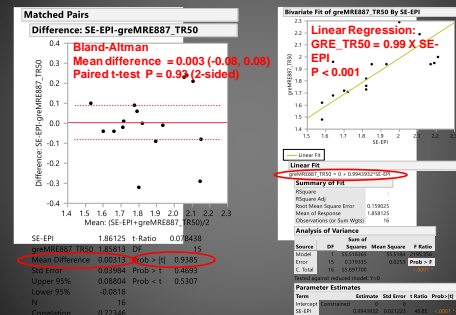
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## GRE MRE = SE-EPI MRE ?



21

## GRE MRE $\approx$ SE-EPI MRE



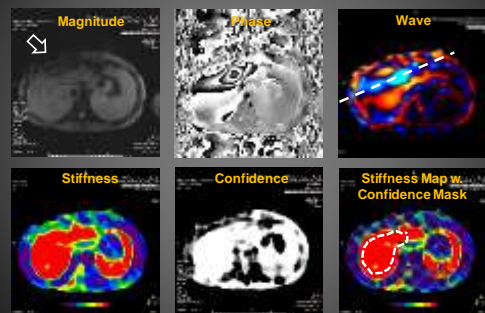
22

## 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)
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23

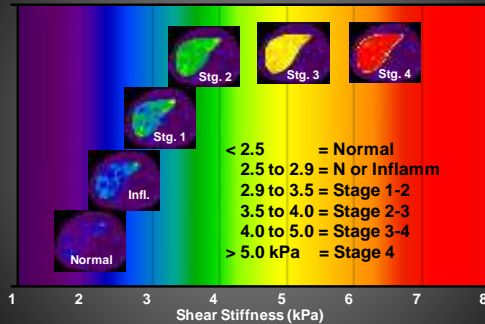
## Images Produced by MRE Sequence



24



## Color Coding of Stiffness



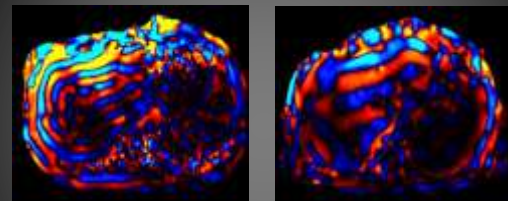
Courtesy of Dr. Meng Yin, Mayo Clinic

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## Difference in Wavelength



Courtesy of Melissa Bridges M.D., Mayo Clinic

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## Pitfalls in MRE Acquisition

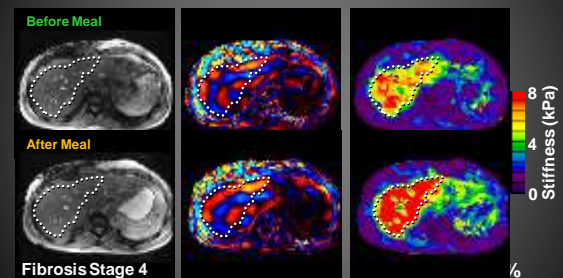
1. Patient preparation
  - Fast 4 – 6 hrs. before MRE
2. Active driver setting
3. Passive driver placement and fixation
4. Slice positioning
  - Avoid liver dome and inferior portion
5. Breath hold
  - End of expiration to minimize variation
6. Sequence parameters

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## Postprandial Effect in Liver MRE



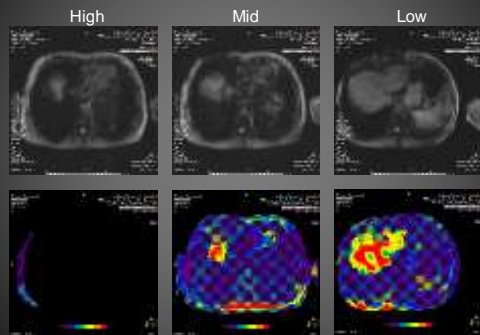
Yin M, et al. Am J Roentgenology 2011

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## MRE Slices too high



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## Placement of ROI for Stiffness Measurement

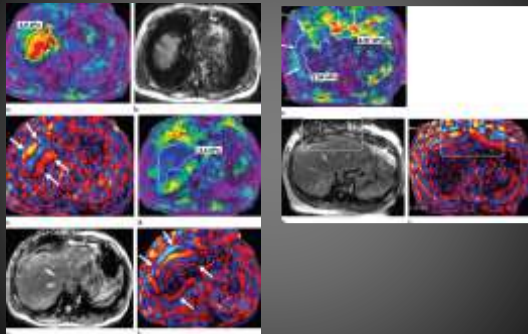
- Sample large portion of liver
- Within area of >95% confidence
- Avoid edge of liver
- Avoid left lobe
- Avoid large blood vessel
- Avoid "Hot Spot"
- Avoid area of poor wave propagation

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## "Hot Spot"



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Guglielmo et al RadioGraphics 2019

## MRE APPLICATIONS & QUALITY CONTROL

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## 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.

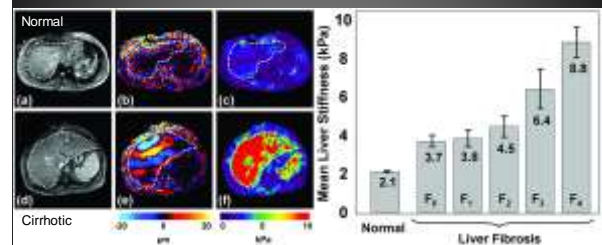
"NIH Manuscript and Lancel 2008

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## Liver Fibrosis Assessment with MRE



Mariappan et al Clin Anat. Jul 2010; 23(5): 497-511

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## Liver MRE



American College of Radiology Appropriateness Criteria for Chronic Liver Disease

*MRE provides the best evidence for diagnosing liver fibrosis, ahead of ultrasound-based elastography*

J Am Coll Radiol 2017;14:S103-17



American Gastroenterological Association Guideline: Elastography in Evaluation of Liver Fibrosis

*"In adults with NAFLD... MRE is superior, rather than VCTE, for detection of cirrhosis"*

Gastroenterology 2017;152:1536-43.



Evaluation of hepatic fibrosis: A Review from the Society of Abdominal Radiology Disease Focus Panel

*"MR elastography is the most accurate noninvasive method of diagnosing liver fibrosis"*.

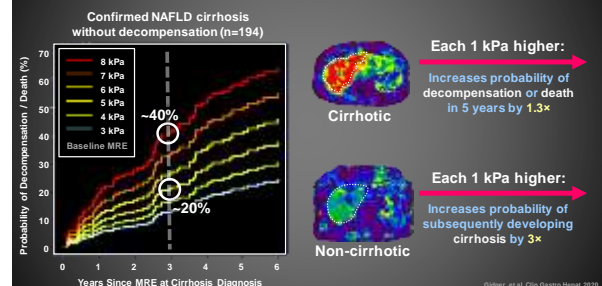
Abdom Radiol (NY). 2017 Aug;42(8):2037-53.

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## Liver Stiffness by MRE Predicts Outcome



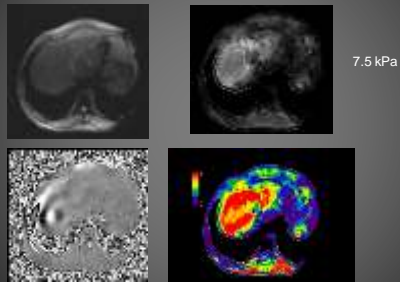
Gohar, et al. Clin Gastro Hepatol 2020

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## Nonalcoholic Steatohepatitis (NASH) with possible Cirrhosis



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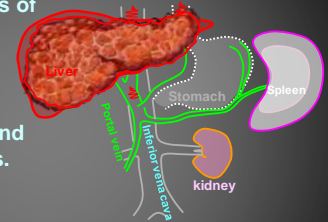
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37

37

## Portal Hemodynamics

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**

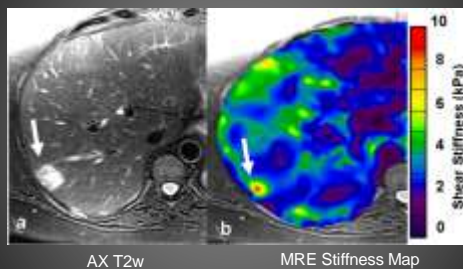
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## Focal Lesion Appears as "Hot Spot"



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39

## Breast Coil and MRE Driver

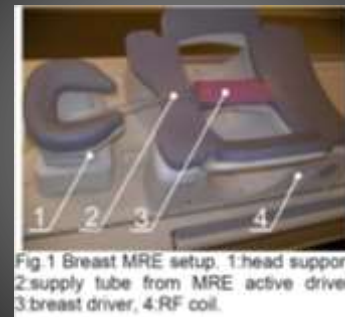


Fig.1 Breast MRE setup. 1:head support, 2:supply tube from MRE active driver, 3:breast driver, 4:RF coil.

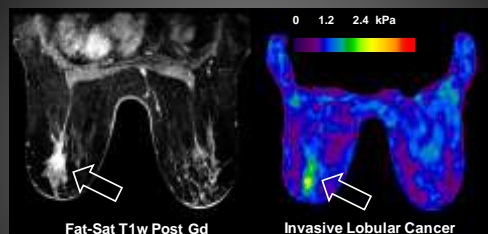
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## A 63 yo Patient with Invasive lobular Carcinoma (ILC)



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

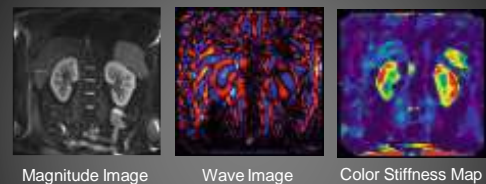
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41

## Kidney MRE



Magnitude Image Wave Image Color Stiffness Map

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

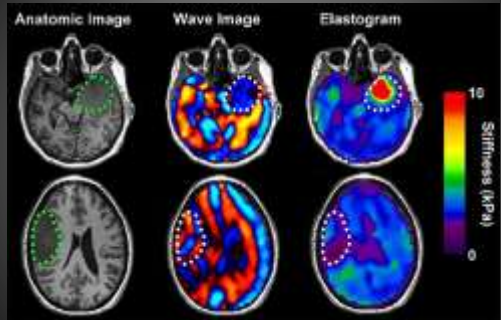
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42

## MRE of Meningioma



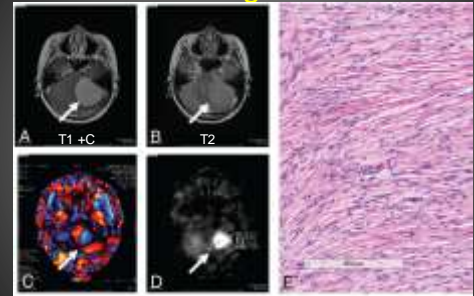
Murphy M.C. et. al., Neuroimage 187 (2019)

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## Cerebellopontine Angle Meningioma



MeanSS = 4.4 kPa; maxSS = 7.2 kPa

Fibrous meningioma

N. Sakai et al. AJNR 2016

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## MRE Quality Assurance



- 1) Draw circular ROI ( ~80 cm<sup>2</sup> ) on Stiffness Map.
- 2) Record Mean and Std. dev. (The nominal stiffness of Resonant MRE phantom is 3 kPa.)

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## Acknowledgements



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# THANK YOU !

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