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
  - Presention and interpretation
- Artifacts and Pitfalls
- MRE Applications & Quality Assurance

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HISTORY OF MR ELASTOGRAPHY

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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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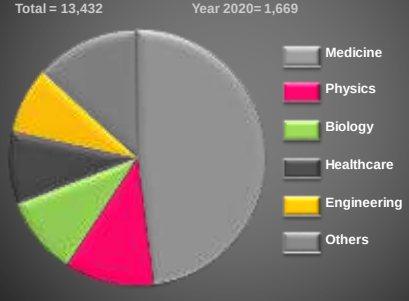
Development and Publications of Elastography



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

Courtesy of Dr. Meng Yin, Mayo Clinic

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MRE TECHNIQUE

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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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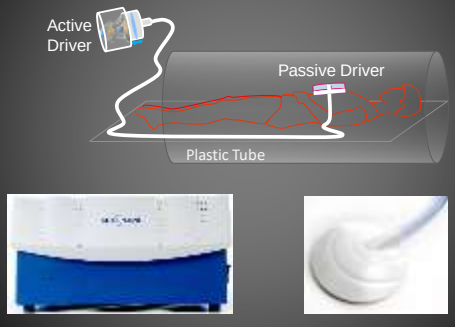
MR Elastography Drivers



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

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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

Xyphoid process of the sternum

Right midclavicular line

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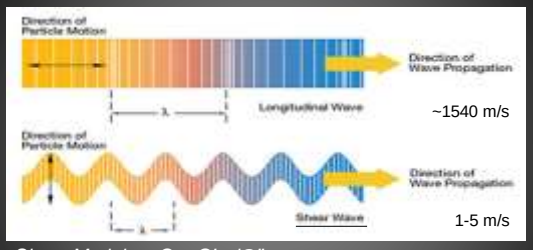
Shear Wave



Shear Modulus: G = G' + iG",

- ***Shear Stiffness**: G'*
- *Shear Viscosity: G"*
- *Unit: Pa = N m^{-2} = kg m^{-1} s^{-2}*

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

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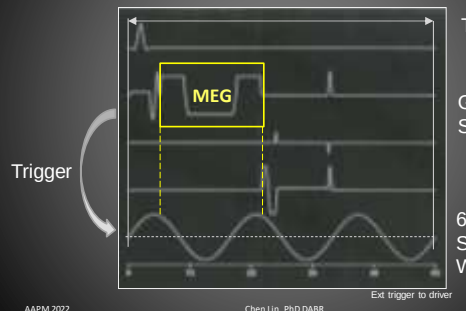
Motion Encoding Gradients (MEG) in MRE Sequence



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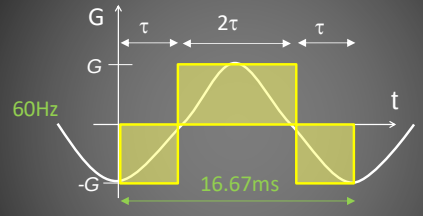
Encoding Sinusoidal Displacement



$m_0(t)$ = (-Gτ) + G(2τ) + (-Gτ) = 0

$m_1(t)$ = (-Gτ^2/2) + (G(2τ)^2/2 + G(2τ) τ) + (-Gτ^2/2 + (-Gτ)3τ) = 0

$m_2(t)$ = 4Gτ^3

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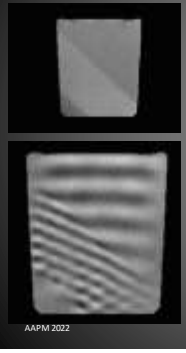
Imaging of Mechanical Wave



Acquire with positive MEG

Acquire with negative MEG

Increment Trigger Delay

Phase Difference Recon

Cine Frame #1
Cine Frame #2
Cine Frame #3
Cine Frame #4

Courtesy of Siemens Healthineers

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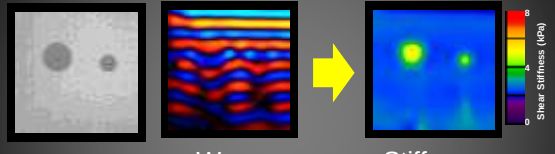
Inversion Algorithm



Mechanical Vibration

Wave Images

Stiffness Map

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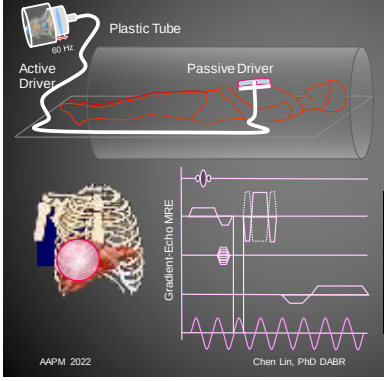
Review of MR Elastography (MRE)



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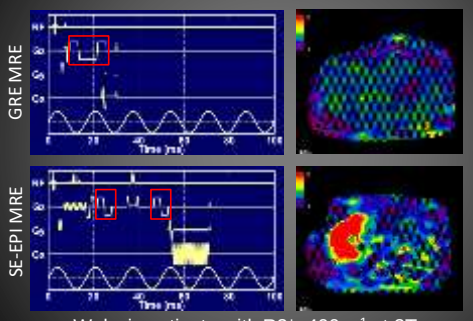
GRE MRE -> SE-EPI MRE



Courtesy of Dr. Meng Yi, Mayo Clinic

Woks in patients with R2*<400 s^{-1} at 3T

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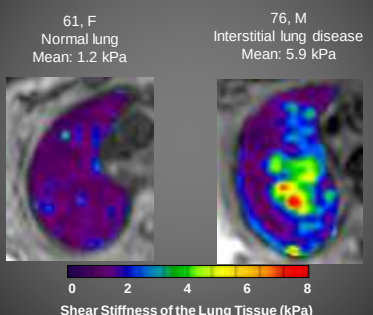
Lung MRE with SE-EPI MRE



Courtesy of Dr. Meng Yi, Mayo Clinic

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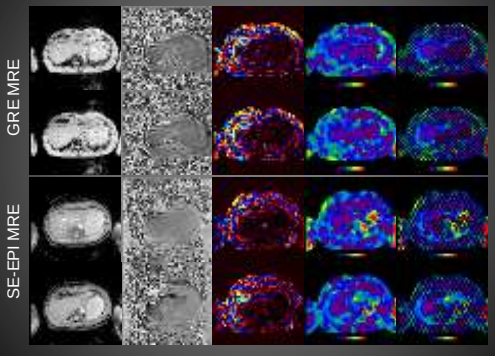
GRE MRE = SE-EPI MRE ?



Courtesy of Dr. Jun Chen, Mayo Clinic

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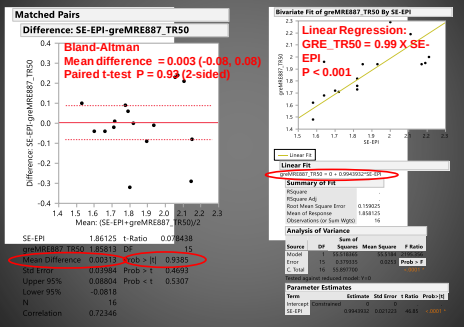
GRE MRE ≈ SE-EPI MRE



Courtesy of Dr. Jun Chen, Mayo Clinic

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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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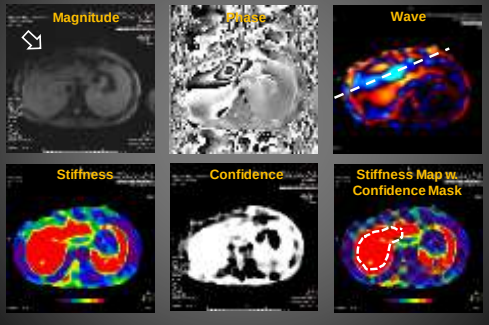
Images Produced by MRE Sequence



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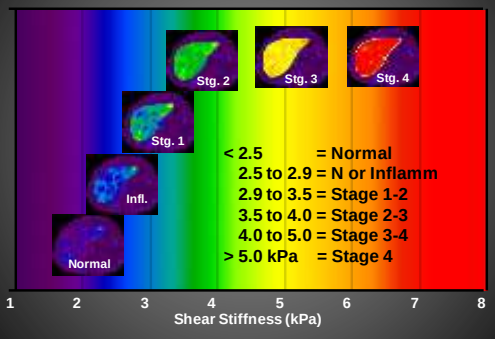
Color Coding of Stiffness



Courtesy of Dr. Meng Yin, Mayo Clinic

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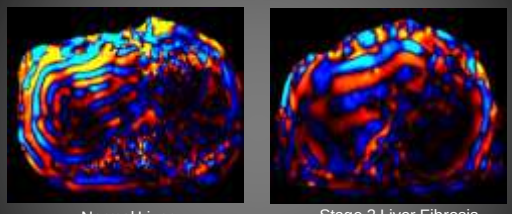
Difference in Wavelength



Normal Liver

Stage 2 Liver Fibrosis

Courtesy of Mellena 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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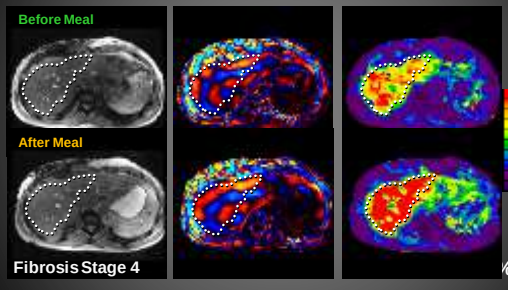
Postprandial Effect in Liver MRE



Yin M, et al. Am J Roentgenology 2011

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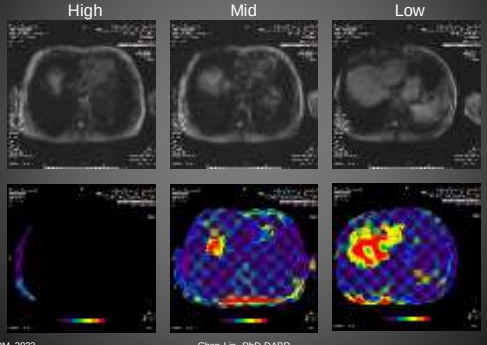
MRE Slices too high



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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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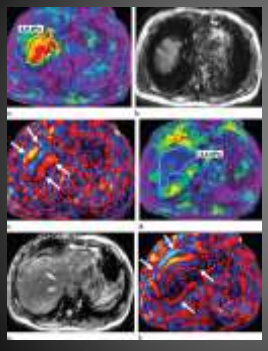
"Hot Spot"



Guglielmo et al RadioGraphics 2019

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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 Lancet 2008

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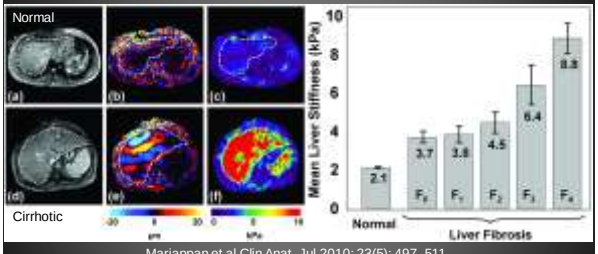
Liver Fibrosis Assessment with MRE



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 gives the highest rating 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 suggested, 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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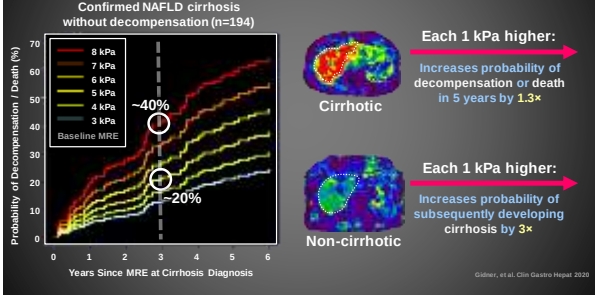
Liver Stiffness by MRE Predicts Outcome



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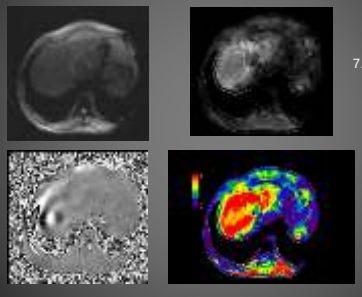
Nonalcoholic Steatohepatitis (NASH) with possible Cirrhosis



Northwestern University Feinberg School of Medicine, Chigaco, IL, U.S.

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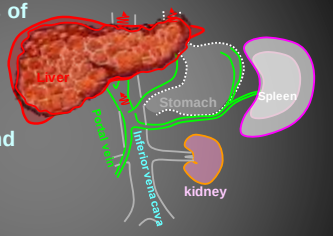
Portal Hemodynamics

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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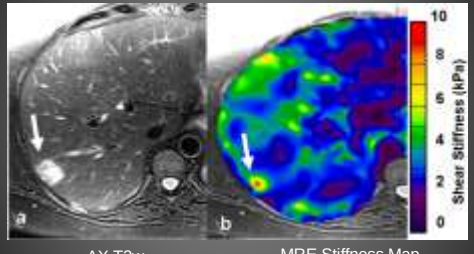
Focal Lesion Appears as "Hot Spot"



AX T2w MRE Stiffness Map

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Breast Coil and MRE Driver

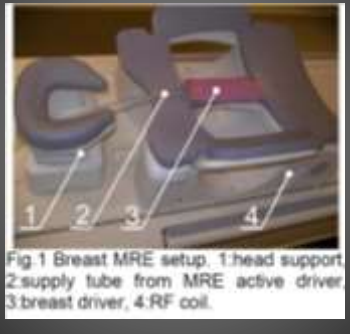

Fig.1 Breast MRE setup. 1:head support, 2:supply tube from MRE active driver, 3:breast driver, 4:RF coil.

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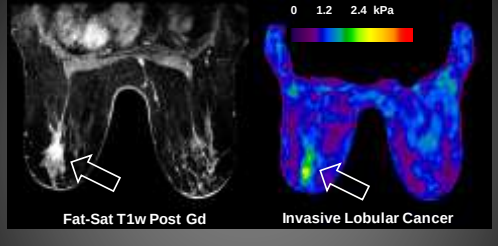
A 63 yo Patient with Invasive lobular Carcinoma (ILC)



- 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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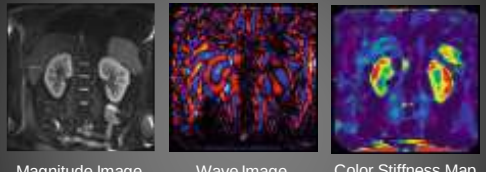
Kidney MRE



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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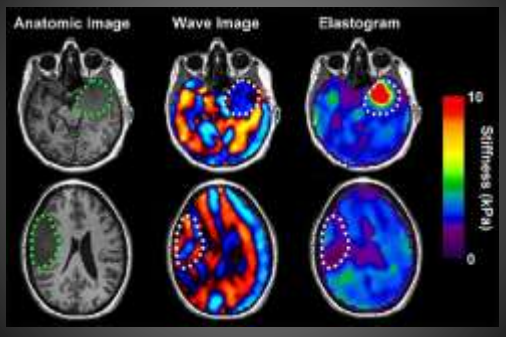
MRE of Meningioma



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

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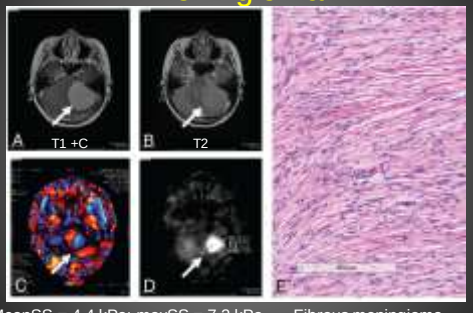
Cerebellopontine Angle Meningioma



MeanSS = 4.4 kPa; maxSS = 7.2 kPa Fibrous meningioma

N. Sakai et al, AJNR 2016

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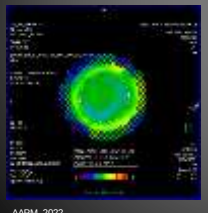
MRE Quality Assurance



1) Draw circular ROI (~80 cm^2) on Stiffness Map.
2) Record Mean and Std. dev. (The nominal stiffness of Resoundant MRE phantom is 3 kPa.)

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Acknowledgements

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Mayo Clinic

Dr. Jun Chen
Mayo Clinic

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THANK YOU !

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