Applications of Ultrasound Radiation Force

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Liver Cirrhosis

- **Causes:**
  - Sustain wound healing to chronic liver injury
  - Viral; autoimmune; drug induced; cholestatic; metabolic diseases
- **Prevalence:**
  - Hundreds of millions worldwide
  - 900,000 in USA (number increasing)
- **Risk (50% 5 year mortality):**
  - Hepatic failure
  - Primary liver cancer

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Limitation of Liver Biopsy

- Pain (French survey)
- Complications
  - Hospitalization: 1~5%
  - Mortality 1/1,000~1/10,000
- Low reproducibility
  - Inter-observer variability: ~20%

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Need for Noninvasive Alternative

- Fibrosis is reversible
- Risk and cost of unnecessary biopsy
  - $2,200
  - HCV: ~25%
- New treatment development
  - Establish effectiveness
  - Optimize dosing

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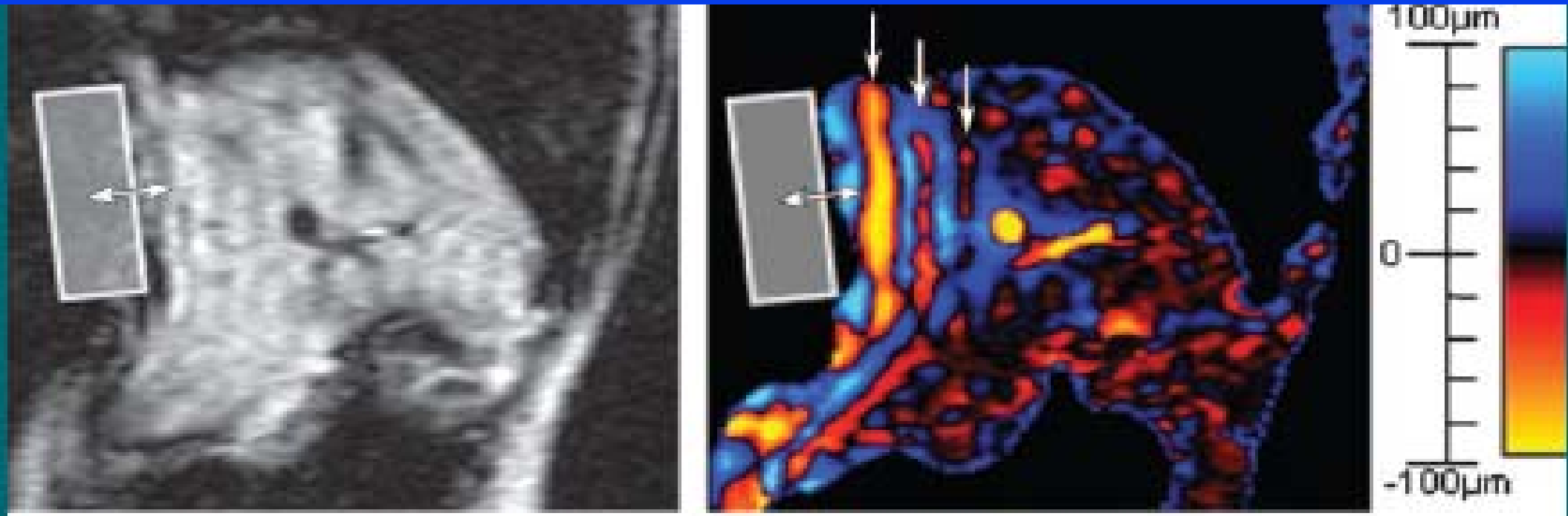
MR Elastography for Fibrosis Staging

- Slow (>20 minutes)
- Expensive
- Precise

MRE of Normal Liver

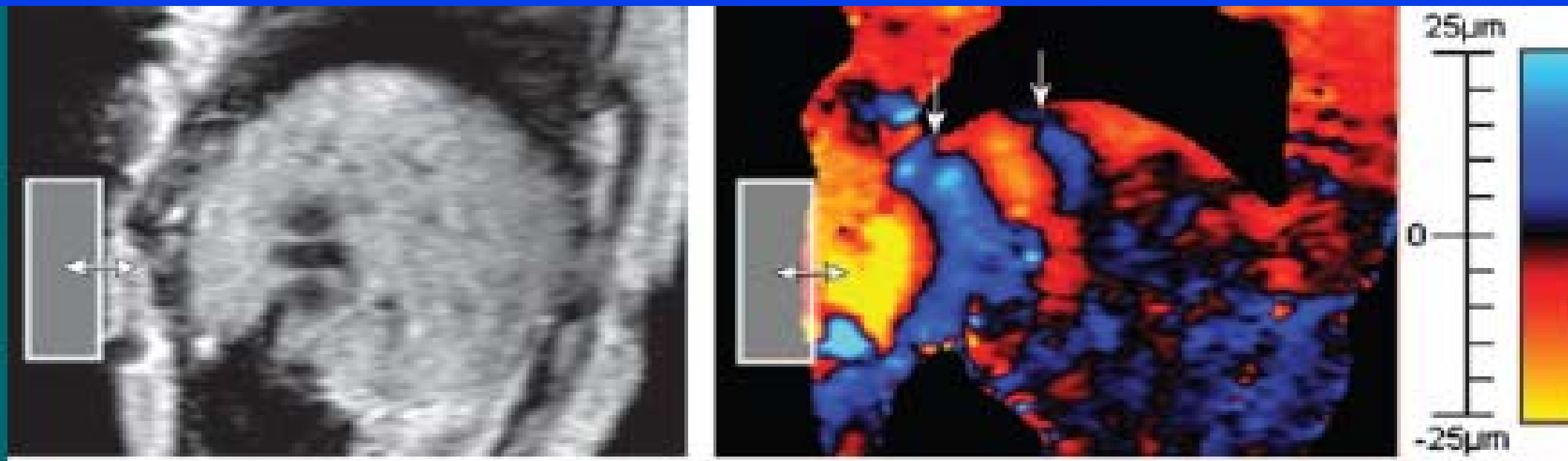


a. b.

Figure 6: MR elastographic wave images of a 21-year-old healthy volunteer (transcostal approach, 20-mm orthogonal plane). Rectangle indicates position of driver. Double-headed arrows indicate vibrational motion of driver. (a) Magnitude image. (b) Corresponding Zs phase-difference image shows shear waves (single-headed arrows) propagating in liver.

Ehman R. L. et al.

MRE of Cirrhotic Liver



a. b.

Figure 7: MR elastographic wave images of a 60-year-old patient (transcostal approach, 20° oblique plane). Rectangle indicates position of driver. Double-headed arrows indicate vibrational motion of driver. (a) Magnitude image. (b) Corresponding Zs phase-difference image shows shear waves (single-headed arrows) in liver. Wavelength is large, which indicates high liver stiffness. On the basis of wavelength measurements, mean liver stiffness was 19.2kPa Results of liver biopsy performed 4 months earlier showed cirrhosis.

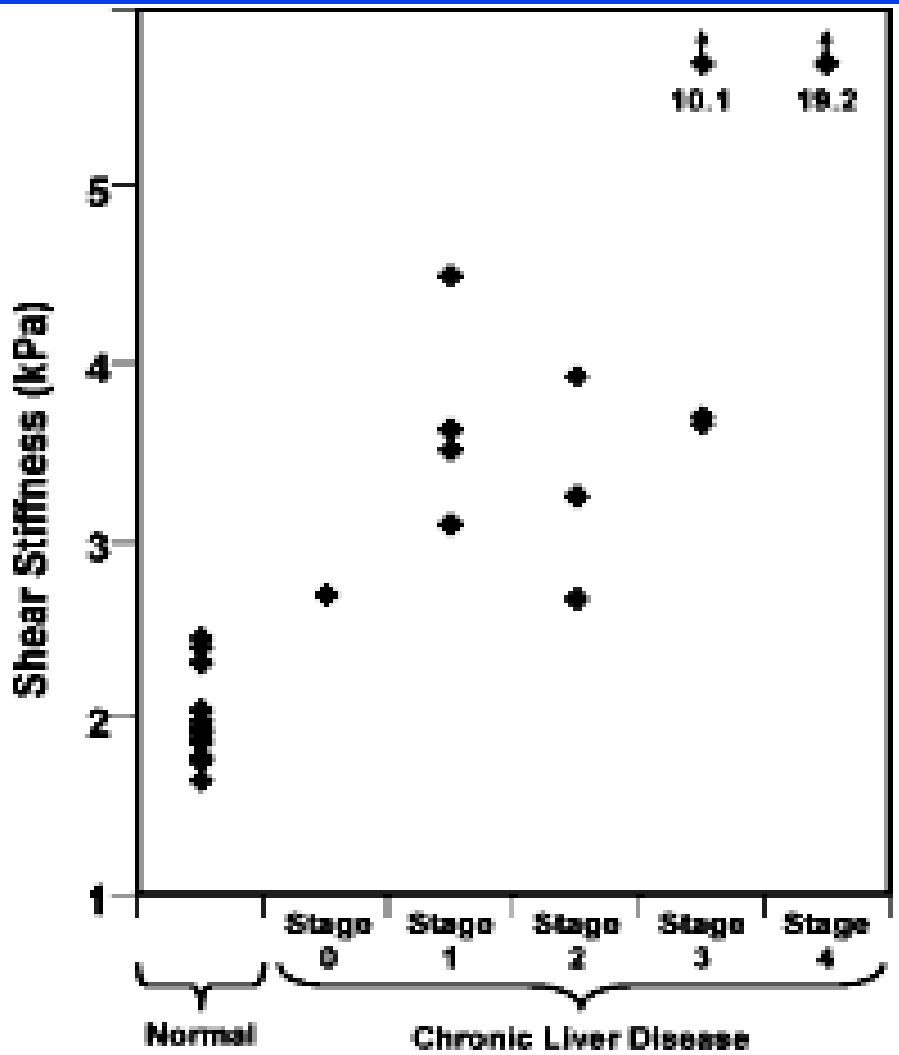


Figure 8: Graph of distribution of liver shear stiffness in 12 healthy volunteers and 12 patients with chronic liver disease and varying degrees of liver fibrosis proved with biopsy results.

Olivier Rouvière, Meng Yin, M. Alex Dresner, Phillip J. Rossman, Lawrence J. Burgart, Jeff L. Fidler, and Richard L. Ehman
MR Elastography of the Liver: Preliminary Results
Radiology 2006; 240: 440-448.

Ultrasound Elastography for Fibrosis Staging

- Fibroscan™ (Echosens, Paris)
- Sonoelasticity
- Supersonic Imagine™
- ARFI
- SDUV

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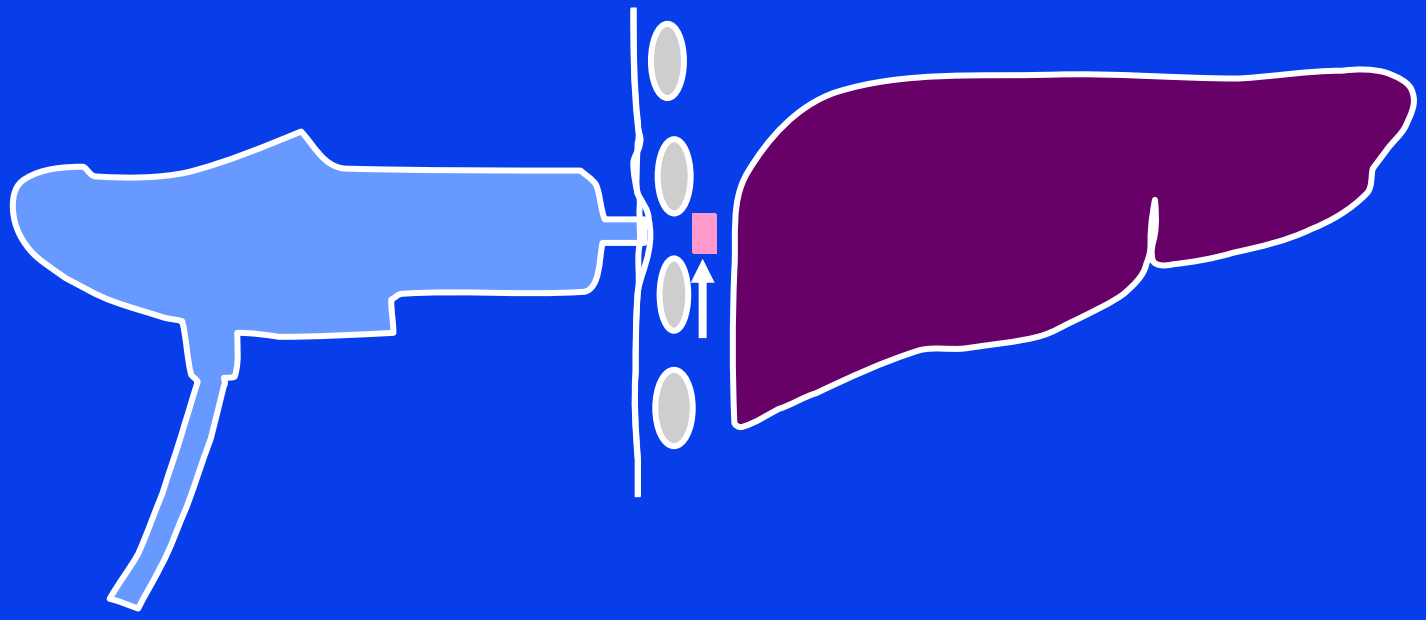
Ultrasound-based Fibroscan™



$$V = \sqrt{\mu_1 / \rho}$$

(Not 2D!)

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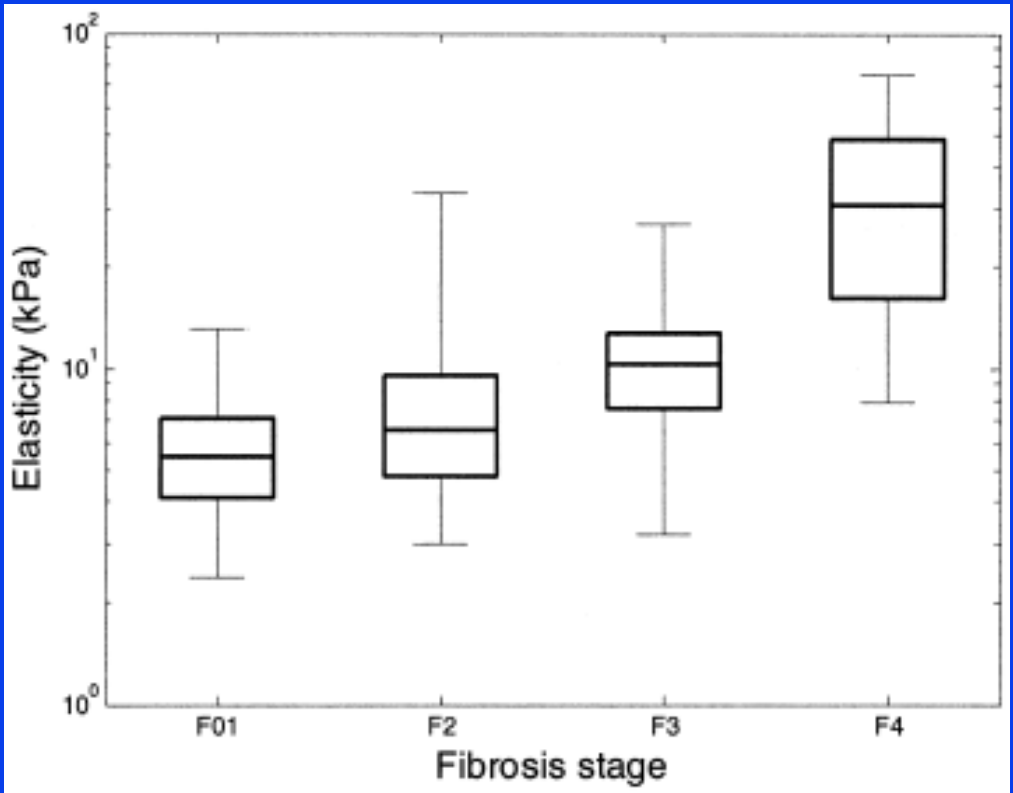
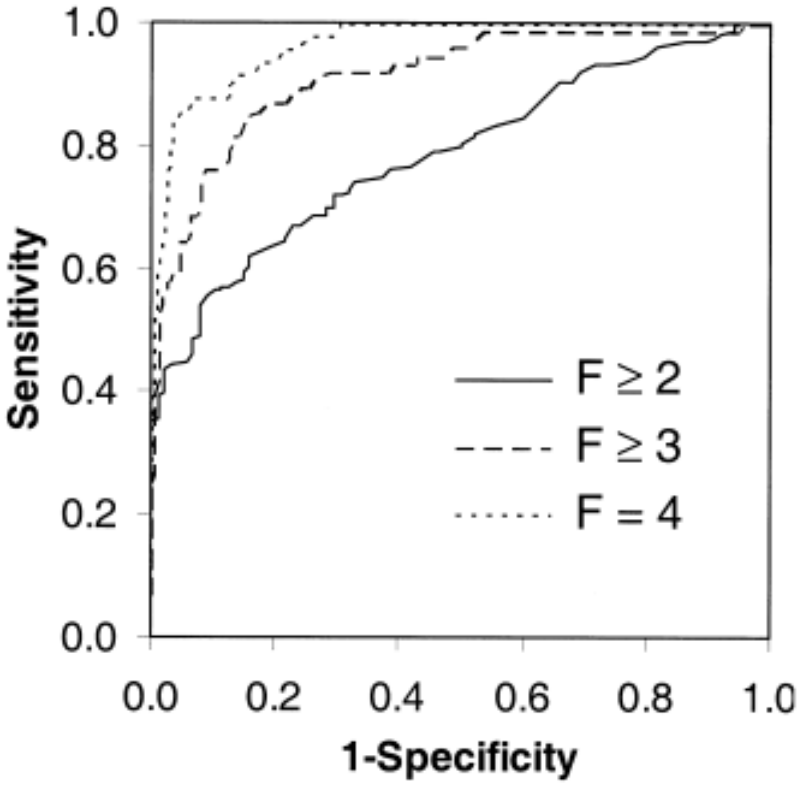
In Vivo Study by Fibroscan™





M. Ziol et al., Noninvasive assessment of liver fibrosis by measurement of stiffness in patients with chronic hepatitis C , Hepatology, 41:48-54, 2005.

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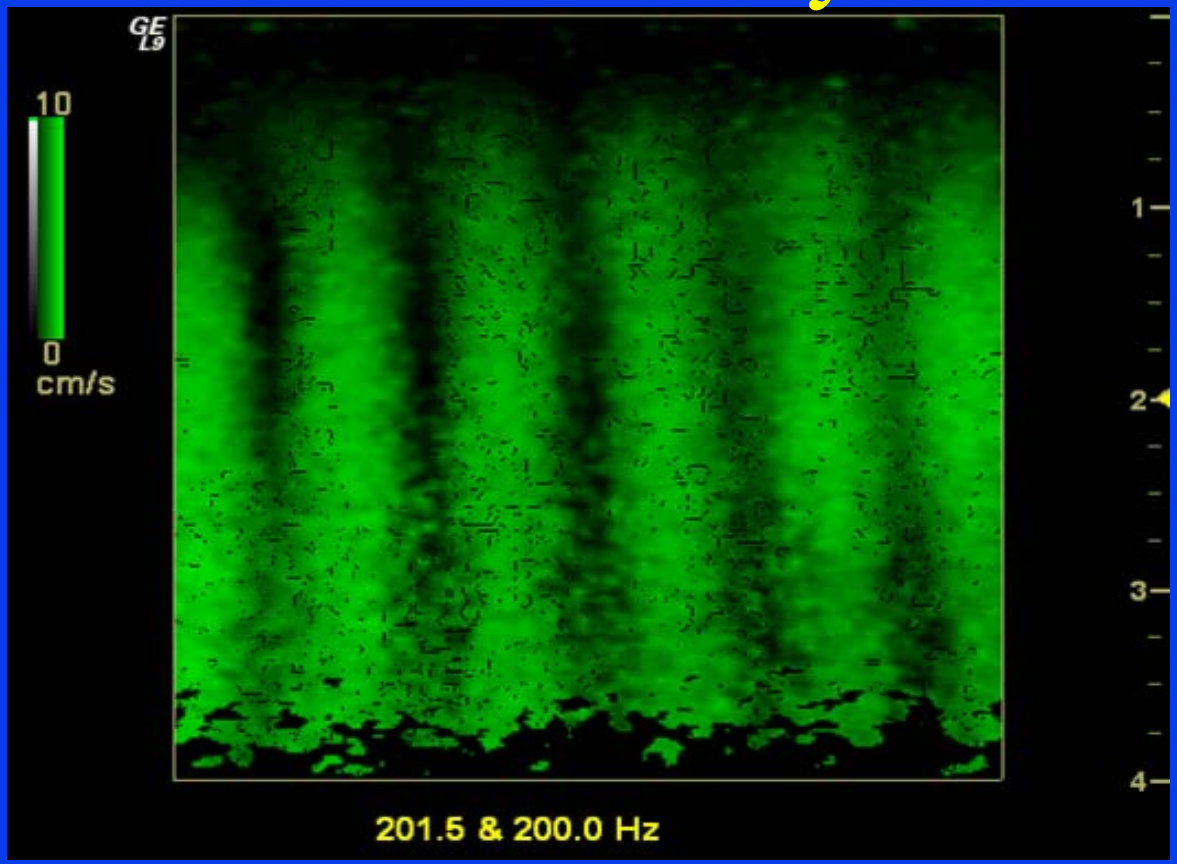
Sonoelasticity



Sonoelastographic image of shear wave interference patterns induced in a tissue-mimicking phantom using externally applied mechanical vibration.

Robert M. Lerner, M.D. and Kevin J. Parker, P

Liver Elastography with Ultrasound

Real-Time Elastography for Noninvasive Assessment of Liver Fibrosis in Chronic Viral Hepatitis

Mireen Friedrich-Rust[1]
Mei-Fang Ong[1]
Eva Herrmann[1]
Volker Dries[2]
Panagiotis Samaras[1]
Stefan Zeuzem[1]
Christoph Sarrazin[1]

AJR:188, March 2007

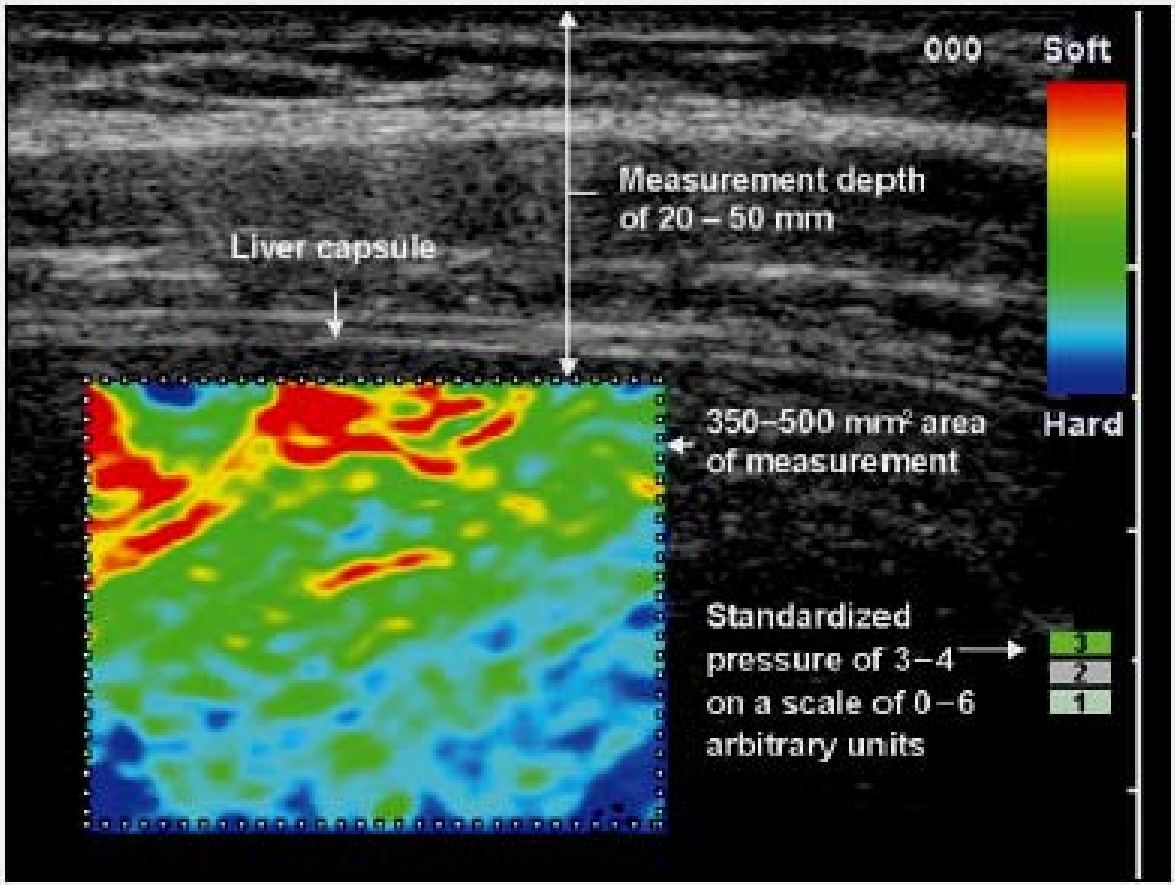


Fig. 1—Tissue elasticity distribution represented as color-coded images over conventional B-mode image. Image presents example of 34-year-old healthy female subject.

Vibrometry Measurements of Liver Stiffness in Humans

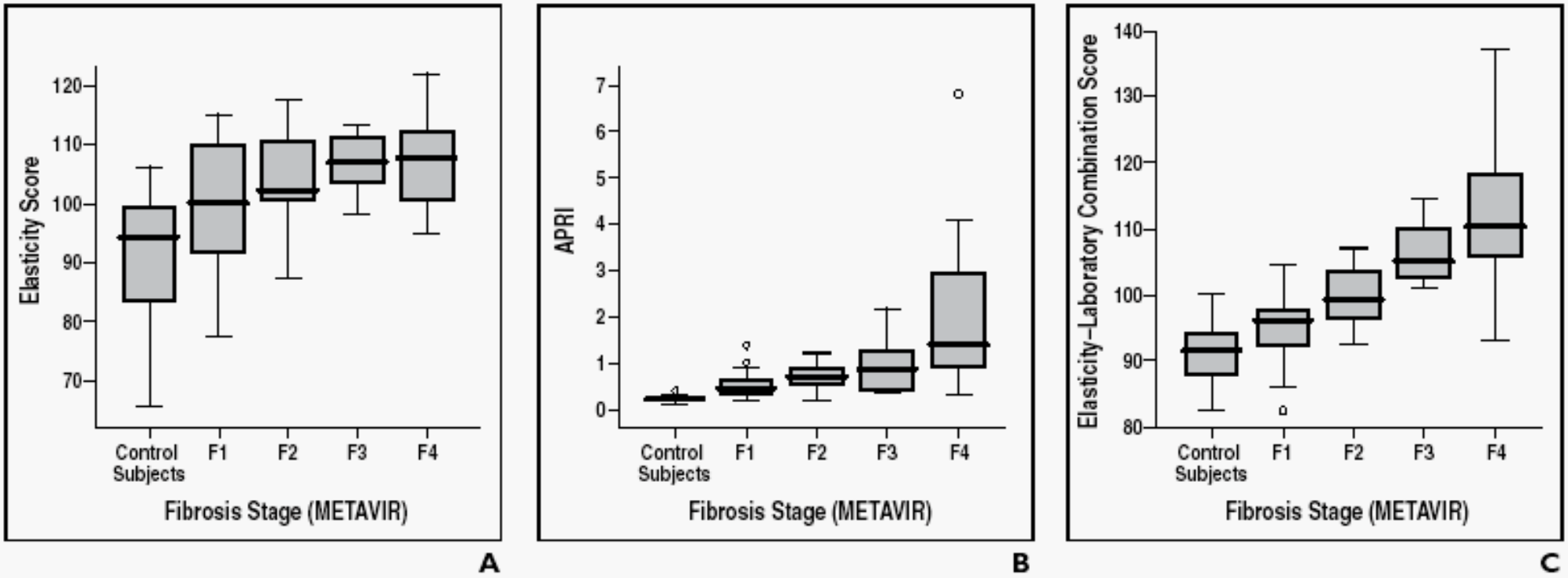


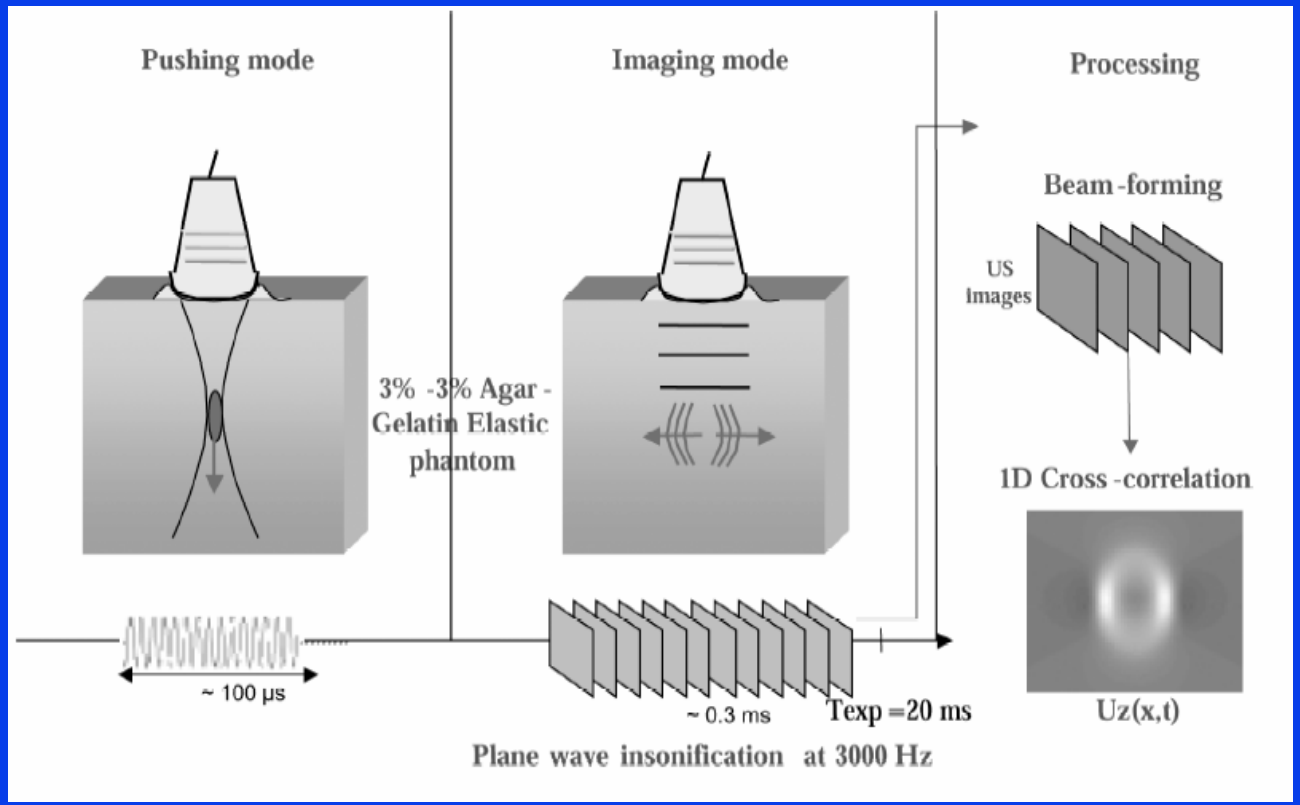
Fig. 2—Box plots show correlation between noninvasive tests and histologic results from liver biopsy. Top and bottom of boxes represent first and third quartiles, respectively. Length of box represents interquartile range within which 50% of values are located. Thick line through each box represents median. Error bars mark minimum and maximum values (range). Small circles represent outliers.

A, Real-time elastography. Skewed data for control subjects might be explained by inhomogeneous group of patients, whereas skewed data for fibrosis stage F2 can be explained by small number of patients in this group.

B, Aspartate transaminase–to–platelet ratio index (APRI). Skewed data are equalized when using log scale for APRI score.

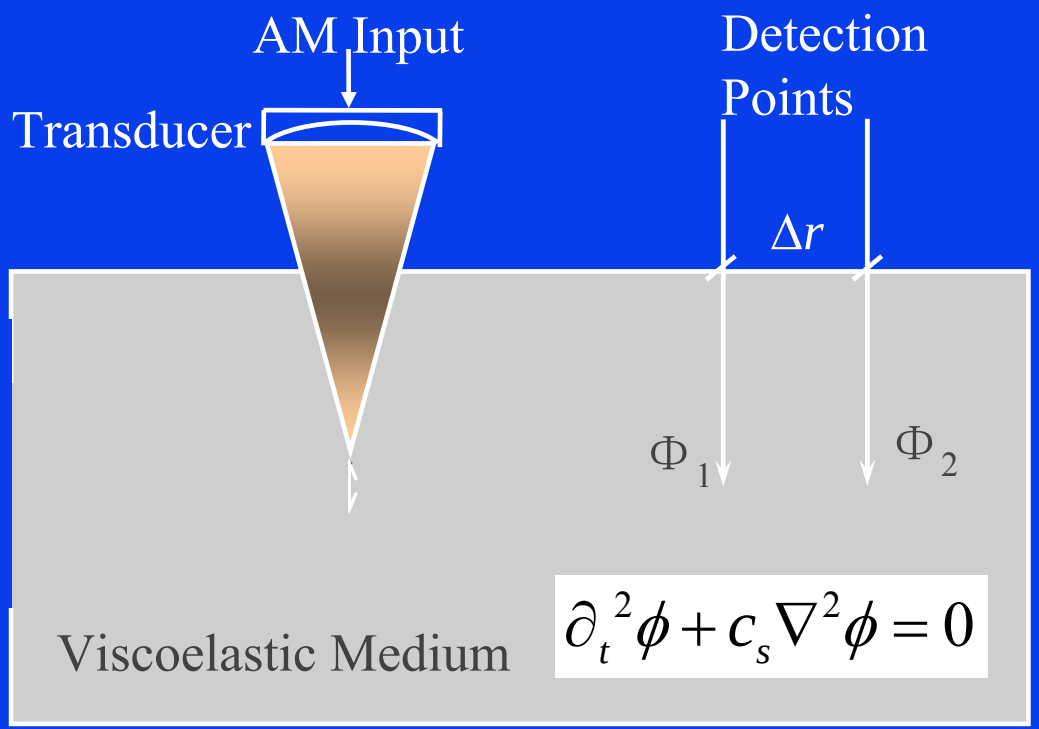
C, Elasticity–laboratory combination values for each fibrosis stage.

Supersonic Shear Imaging



Mathias Fink, University Paris VII, France

Proposed Method (SDUV)



$$c_s = \sqrt{\frac{2\left(\mu_1^2 + \omega^2\mu_2^2\right)}{\rho\left(\mu_1 + \sqrt{\mu_1^2 + \omega^2\mu_2^2}\right)}}$$

$$c_s(\omega) = \frac{\omega \cdot \Delta r}{\phi_2 - \phi_1}$$

- Depends only on local μ_1 and μ_2 (Voigt model)

Device independent (beam shape, Tx)

Independent of ultrasound intensity

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Advantages of SDUV

- Shearwave Dispersion Ultrasound Vibrometry

  SDUV
- Truly quantitative
- Elasticity & viscosity
- Does not require direct inversion
- Applicable to ascites patients
- “Virtual biopsy” guided by 2D B-scan

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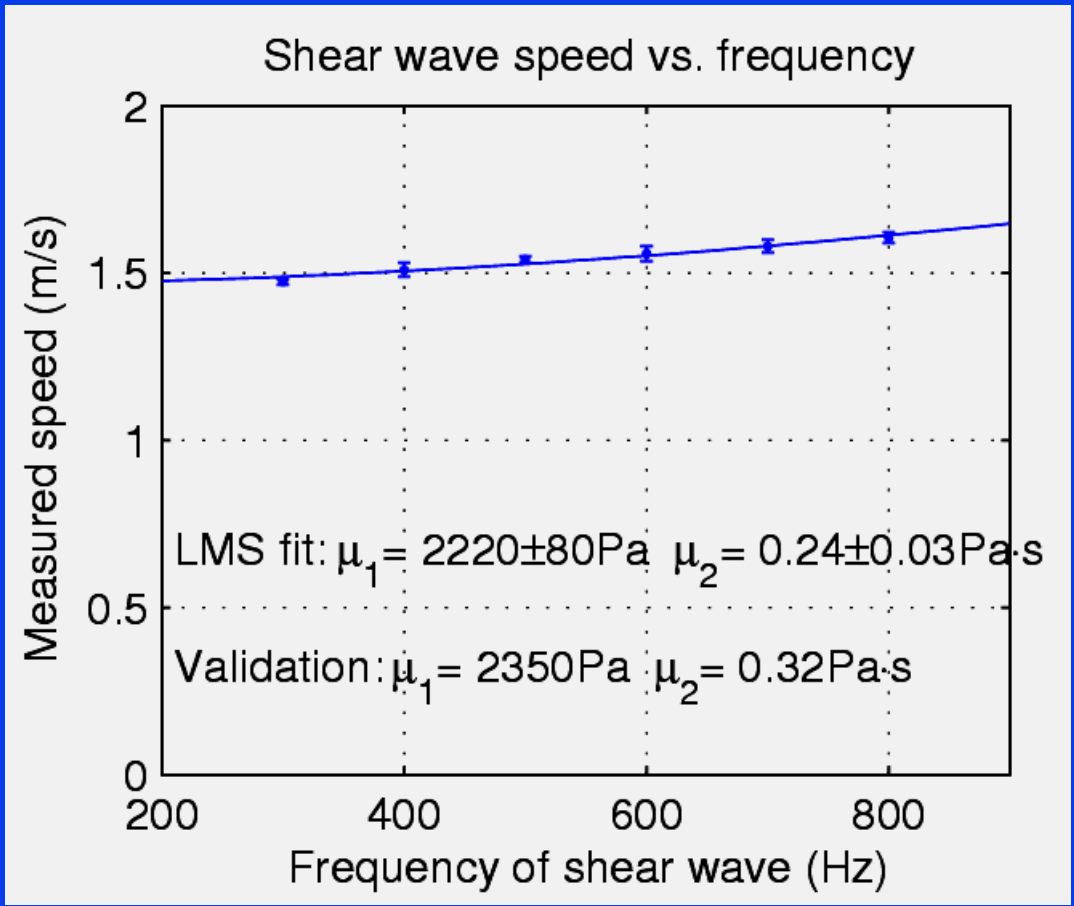
Test of Accuracy



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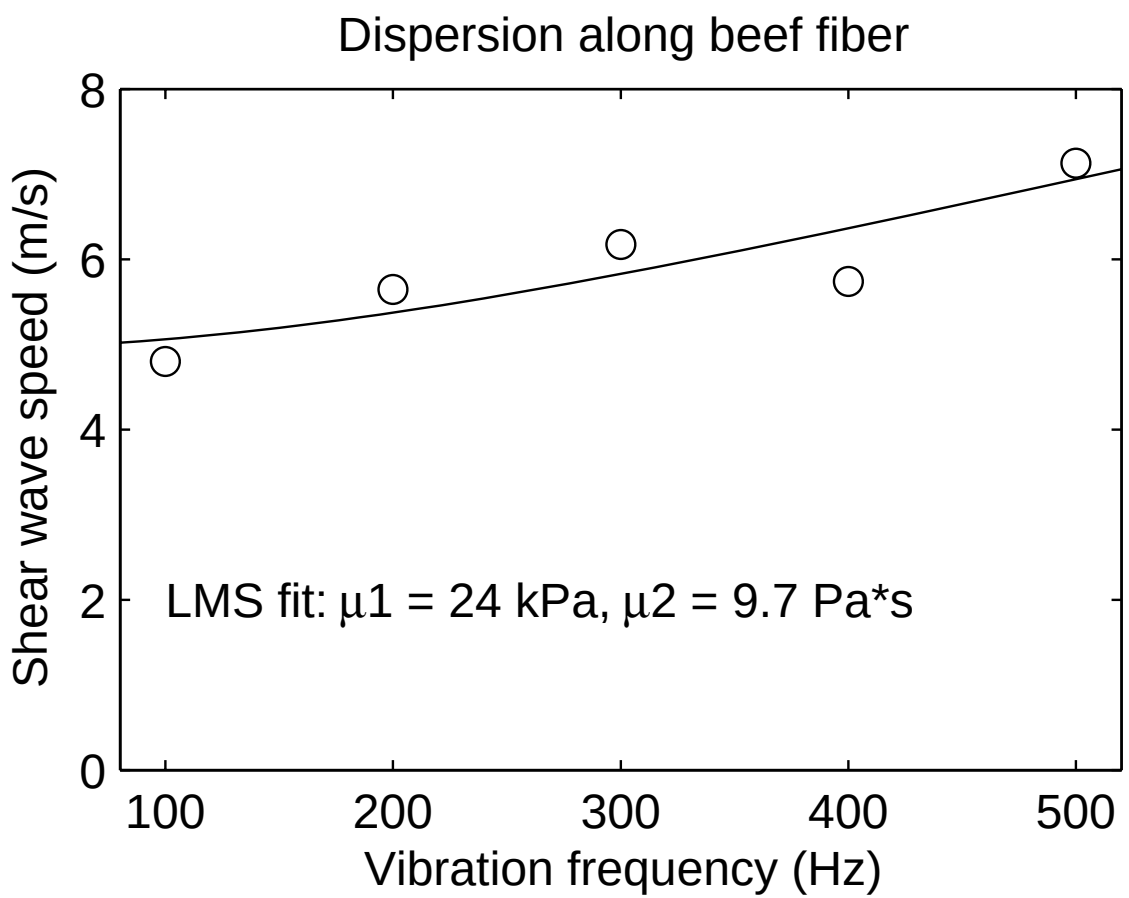
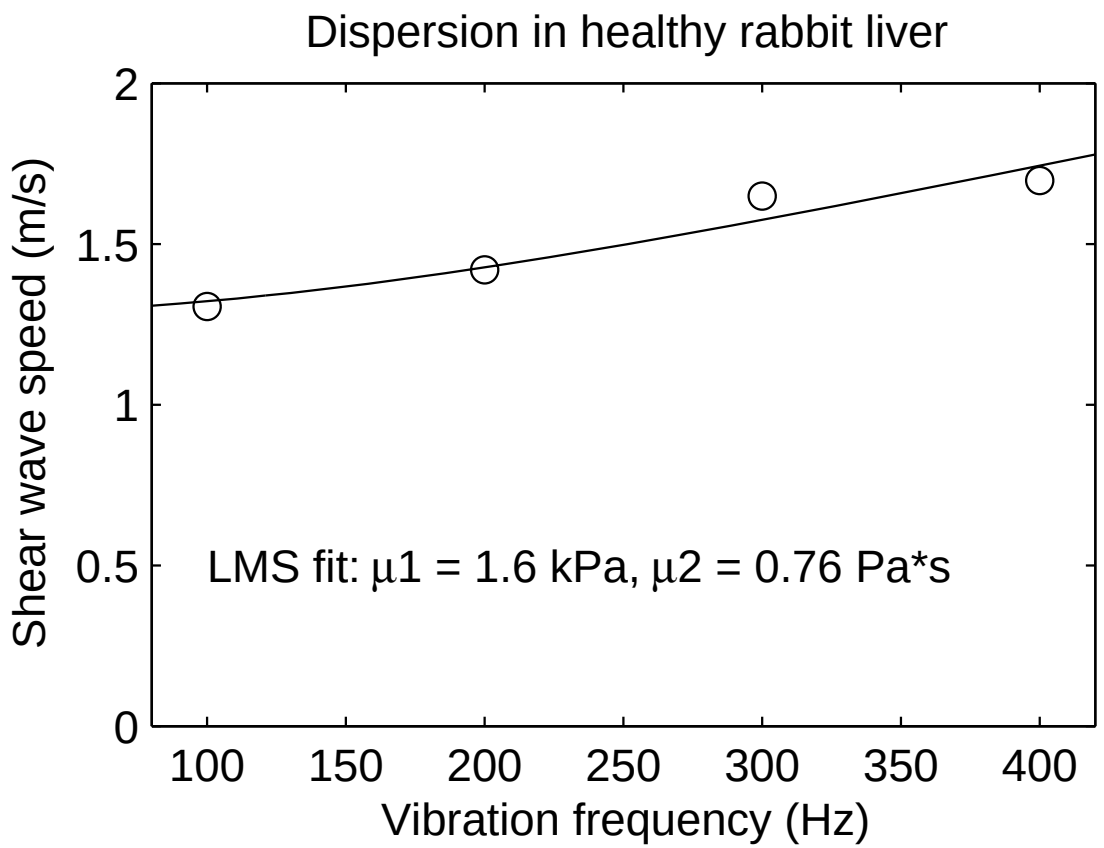
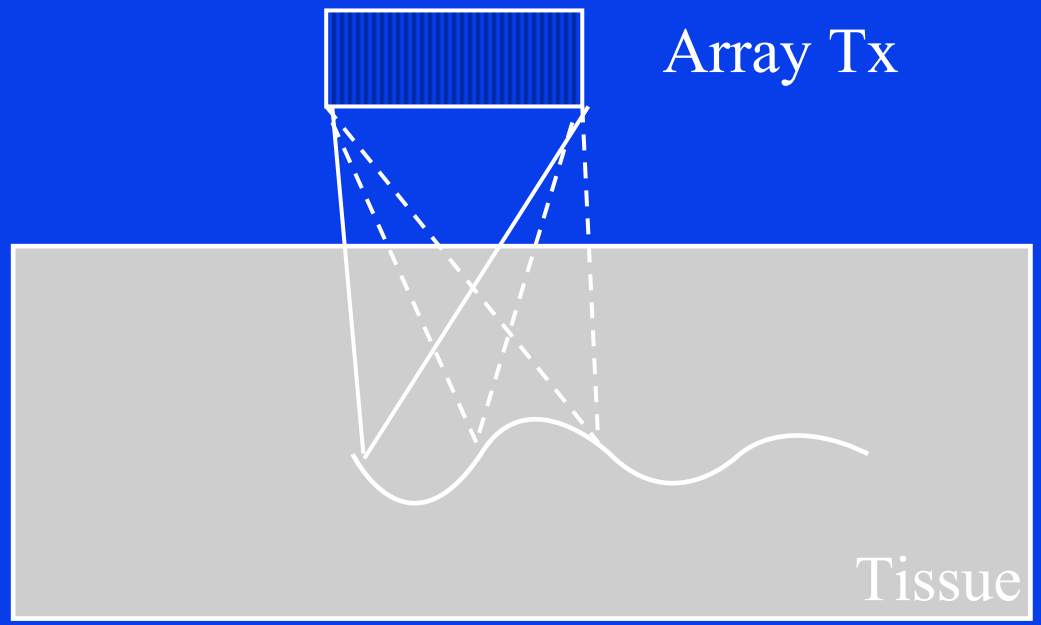
Beef Muscle Results



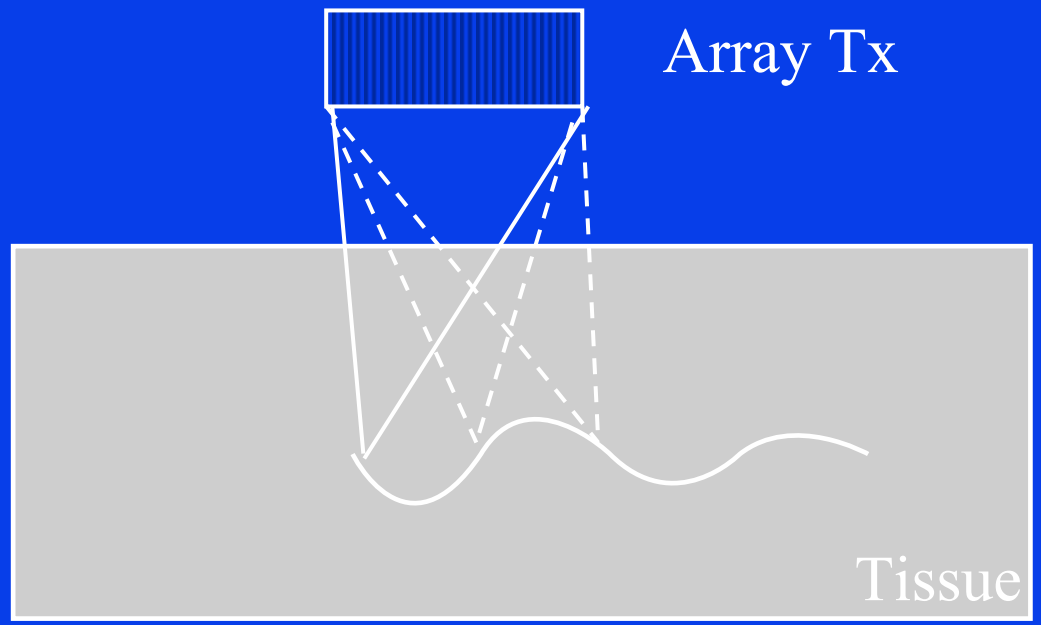
Rabbit Liver Results



SDUV with a Single Array Tx



SDUV with a Single Array Tx



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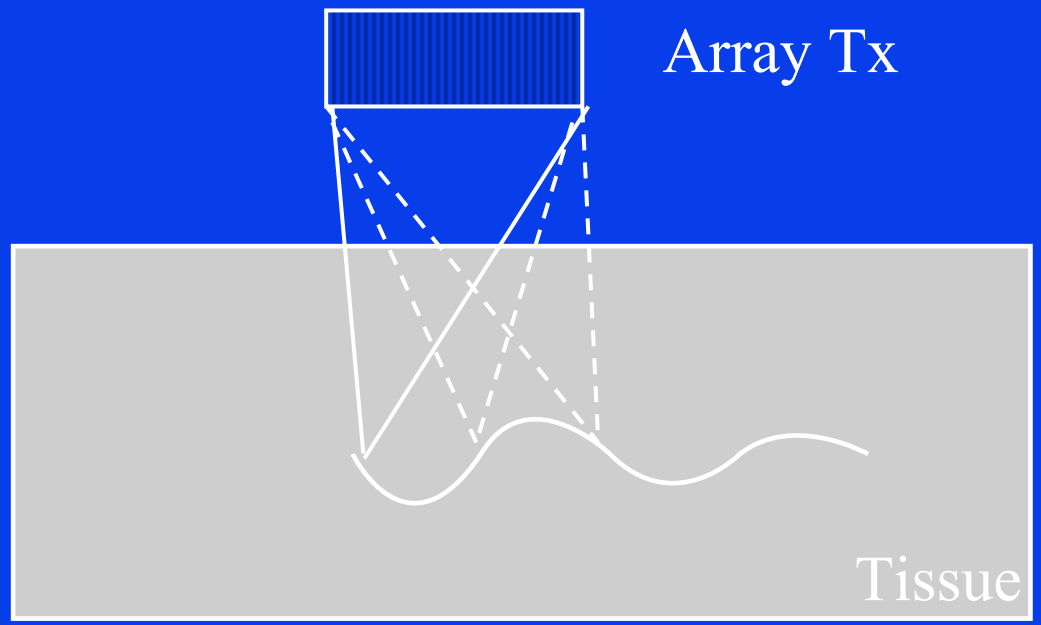
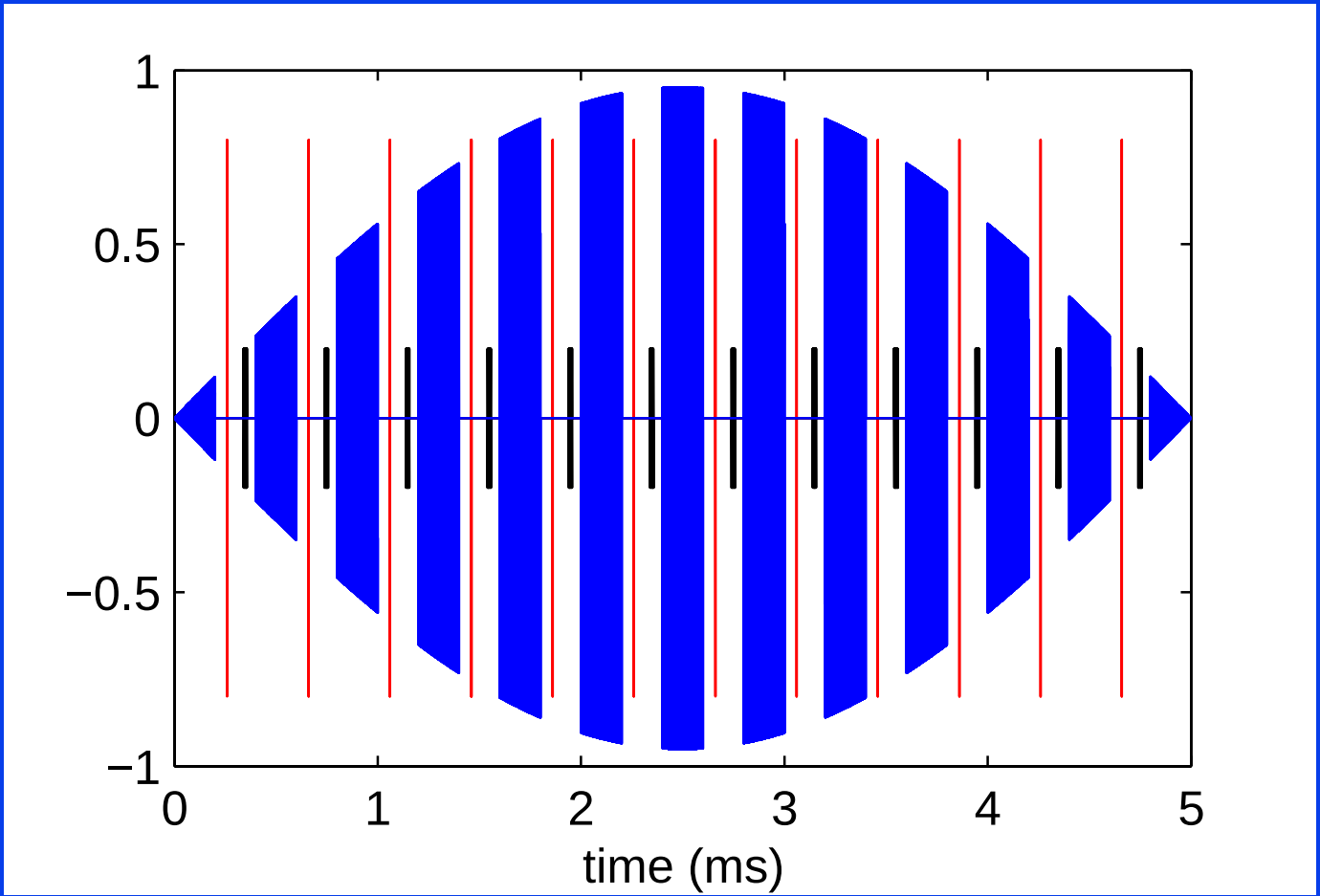
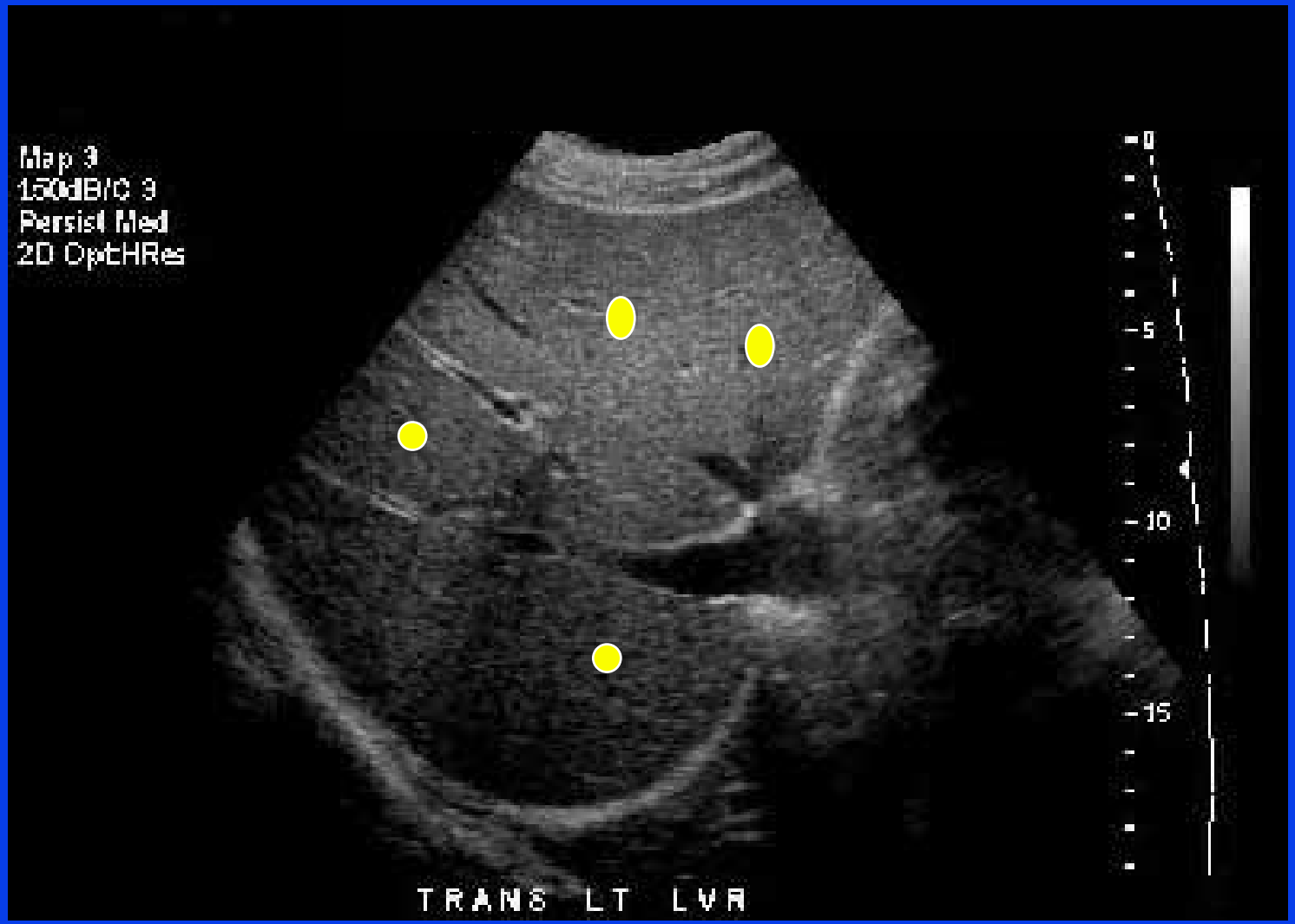


Intermittent Vibration and Detection



SDUV Vibrometry “Biopsy” of Liver



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SDUV Summary

- SDUV is not dependent on instrument characteristics.
- SDUV is fast.
- SDUV can be done with software alterations of modern ultrasound scanners.
- SDUV measures both elasticity and viscosity.

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Mayo Ultrasound Laboratory 2/07

Thank You