Dr Ehman

Dr An

Dr Amadio

Dr Spelsberg (retired)

Dr Hawse

Elastography development for muscle → thigh

Role of TIEG1 in tendon

Development mechanical test

Set up of elastography platform

Muscle and liver applications

New role of TIEG1 in muscle
Elastography development for muscle → thigh

Set up of elastography platform
Muscle and liver applications
Richard L. Ehman, MD
Mayo Clinic Center for Advanced Imaging Research
ehman.richard@mayo.edu
Magnetic Resonance Imaging (MRI)

Liver Stiffness:
6.5 kPa
(~3 x normal)
Relevance of Tissue Mechanical Properties

Musculoskeletal Physiology

Biomechanics Of Injury

Prosthetics

Safety Devices

Surgical Simulation
Using shear waves to assess the stiffness of materials
Magnetic Resonance Elastography

Magnetic Resonance Elastography by Direct Visualization of Propagating Acoustic Strain Waves

R. Muthupillai, D. J. Lomas, P. J. Rossman, J. F. Greenleaf, A. Manduca, R. L. Ehman

Richard Ehman
Magnetic Resonance Elastography

- Main current application: Assessing liver fibrosis
- Acquisition time: ~1 minute
- FDA-cleared since 2009
- Installed clinical base ~1300 clinical systems
• A leading cause of death world-wide
• Increasing prevalence of conditions that cause hepatic fibrosis
  • Hepatitis C - 170 M people globally
  • Hepatitis B
  • Obesity / Fatty liver disease
• Fibrosis can be reversed, if diagnosed early and treated
Liver Biopsy

- Invasive
  - Pain
  - Complications
- Expensive
- Poor repeatability
  - Sampling error

Progression of Liver Disease

Normal

Fibrosis

Reversible
Silent

Cirrhosis

Irreversible
High mortality
MR Elastography

**Acoustic waves at 60Hz**

**Imaging time: 15 sec**

**Displacement (mm)**

**Shear Stiffness (kPa)**

MRE Abdominal Driver

MRE Vibration Source
Two Patients with Chronic Liver Disease: Is Hepatic Fibrosis Present?

[Diagram showing shear stiffness in kPa for two patients with chronic liver disease, with one patient having a shear stiffness of 2.2 kPa and the other having 5.9 kPa.]
76 yo Patient - Alcohol

Abstinent 9 months later
Liver Magnetic Resonance Elastography (MRE)

Cutoff Values for Alcoholic Liver Fibrosis Using Magnetic Resonance Elastography Technique

Sabine F. Bensamoun, Gwladys E. Leclerc, Laëtitia Debernard, Xiaobin Cheng, Ludovic Robert, Fabrice Charleux, Colette Rhein, Jean-Paul Lattrive

First published: 06 December 2012 | https://doi.org/10.1111/acerv.12025 | Cited by: 16

Measurement of liver stiffness with two imaging techniques: Magnetic resonance elastography and ultrasound elastometry

Sabine F. Bensamoun PhD, Lu Wang MS, Ludovic Robert Mr, Fabrice Charleux MD, Jean-Paul Lattrive MD, Marie-Christine Ho Ba Tho PhD

Diagnostic Performance: MRE vs Fibroscan

Hsu, Clin Gastro Hepatol. 2018
Pooled Analysis, n=230

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<td>0.9</td>
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<td>0.9</td>
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Richard Ehman
Advanced Multiparametric 3D MRE

| $|G^*|$ | $G'$ | $G''$ | $\zeta = \frac{G''}{2G'}$ | $m$ | $\Delta V$ | $OSS$ |
|---|---|---|---|---|---|---|
| 2.49 kPa | 2.31 kPa | 0.72 kPa | 0.16 | 22.5 m$^{-1}$ | 0.7% | 0.02% |
| “Stiffness” | Storage Modulus | Loss Modulus | Damping Ratio | Attenuation | Volumetric Strain | Shear Strain |
Hepatic MRE in Mouse Models of Fatty Liver Disease

Electromechanical Driver
Silver Needle

Birdcage Coil

Wave-X
Wave-Y
Wave-Z
Elastogram

- Wave-X: 80 Hz, 140 Hz, 200 Hz
- Wave-Y
- Wave-Z
- Elastogram

Stiffness (kPa)

Richard Ehman
Value of Damping Ratio as Biomarker

Fat Food Diet & Fructose Water (FFD)
- Stiffness (kPa)
- Damping Ratio
- Fat Fraction (%)

FFD
- Stiffness (kPa)
- Damping Ratio

Standard Diet
- Damping Ratio

Fat Fraction (%)

Time (weeks)
MR Elastography

- Brain
- Liver
- Kidney
- Prostate
- Muscle
- Bone
- Breast
- Cord
- Lung
- Heart
- Disc
- Pancreas
- Artery
- Cartilage
Assessing the Biomechanical Properties of the Brain

“Pillow Driver”
Meningioma
Two Patients with Meningiomas

Pt. A

Pt. B

Wave Images

Elastograms

Stiffness (kPa)
Characterizing Neurodegenerative Disease?

Elastogram

Shear Stiffness (kPa)
Patients with Alzheimer’s disease have significantly decreased brain stiffness, compared with age-matched, cognitively-normal subjects.

MRE in Neurodegenerative Disease

Normal Control
87 y female

AD Patient
87 y female

Normal Control
65 y male

FTD Patient
65 yr male
Magnetic Resonance Elastography

• Provides an array of new quantitative imaging biomarkers
• Basic technology platform now widely deployed worldwide
• Established as a reliable, comfortable, and less costly alternative to liver biopsy for assessing hepatic fibrosis
• Brain imaging is likely to be the next well-established clinical application of MRE
• Unique tool for studying musculoskeletal biomechanics...
Thigh muscle Magnetic Resonance Elastography (MRE)

Technical Note | Free Access |

Determination of thigh muscle stiffness using magnetic resonance elastography

Sabine F. Bensamoun PhD, Stacie I. Ringleb PhD, Laurel Littrell MD, Qingshan Chen PhD, Michael Brennan MD, Richard L. Ehman MD, Kai-Nan An PhD

First published: 22 December 2005 | https://doi.org/10.1002/jmri.20487 | Cited by: 95

Original article

Identification and Quantification of Myofascial Taut Bands With Magnetic Resonance Elastography

Qingshan Chen MS a, Sabine Bensamoun PhD a, Jeffrey R. Basford MD, PhD b, Jeffrey M. Thompson MD b, Kai-Nan An PhD b
Characterize the mechanical properties of soft tissue (muscle and liver) to provide quantitative measurements to the clinician

- Assess the degree of disease severity
- Follow treatment effects
- Improve knowledge of the behavior, the mechanism of the tissue: personalized treatments
2002: The first MRE muscle study → Calf muscle

“To investigate whether a new tissue-imaging technique, magnetic resonance elastography (MRE), offers a viable, noninvasive way to study healthy and diseased muscle”

Context

Basford et al., 2002
How to induce the waves inside the muscle?

Mechanical driver (low frequency: 120Hz)

Alternating current

Driver

Pressure

speaker

Silicone tube

Pneumatique driver

Pressure

Waves are propagated with and without Subcutaneous tissues

6 months after

Difficult to see the waves II subcutaneous adipose tissue

Vastus medialis

Sartorius
How to induce the waves inside the muscle?

2004 – 2006 Mayo Clinic

Pressure
speaker
Silicone tube

Pressure

2007

RESOUNDANT

2013

Sabine Bensamoun
Experimental Set-up to analyze the muscle in passive and active condition

Muscle is characterized: passive (relaxed) and active (contracted) conditions
MR Elastography Platforms

2007: First platform

Institut Faire Faces (IFF)

2013: Second platform

Centre d’Imagerie Medicale Avancée de Compiègne (CIMA)

2018: Third platform

Polyclinique St Côme

2021: Forth platform

Institut Faire Faces (IFF)
Thigh muscle MRE tests

1.5T MRI machine (GE), Gradient echo sequence, field of view: 24 cm, 256x64 acquisition matrix

The total scan time was about 38 s

Development of MRE protocols to visualize the displacement of the waves in all the thigh muscles

Quantify the viscoelastic properties of all the thigh muscles
Protocols for the different acquisitions of the phase images

Axial anatomical image

Coronal anatomical image

Phase image superimposed on the anatomical image

Sabine Bensamoun
Valorizations

23 Articles

Sabine Bensamoun
Dystrophy Muscular Duchenne (DMD)

- Measurement of the mechanical properties
- Development of the MRE protocols

Development of a non invasive tool to follow the treatment

Lack of muscle  
Sr: non affected  
Target injection

To evaluate the functional properties of individual muscle before and after treatment

Sabine Bensamoun
• The present protocol is capable to measure the elastic properties ($\mu$) for DMD

• Adipous tissue $\mu$ DMD > $\mu$ Sain: new observation, must be confirm with more patients

• Relax Muscle $\mu$ DMD > $\mu$ Sain: fatty infiltration

• Contracted Muscle $\mu$ DMD < $\mu$ Sain: decrease of contractibility
Technical note

Elastic properties of skeletal muscle and subcutaneous tissues in Duchenne muscular dystrophy by magnetic resonance elastography (MRE): A feasibility study

S.F. Bensamoun a,*,1, F. Charleux b,2, L. Debernard a,1, C. Themar-Noel c,2, T. Voit c,d,2
Despite the difference in appearance between humans and animals they have a very similar genetic → **99% between Mice and Men**