MR Elastography: Development and Introduction into Clinical Practice

Jun Chen, PhD and Colleagues

July 12 2018
• Basics of MRE method
• Clinical Research and Applications
  • Liver
  • Renal
  • Brain
  • Breast
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  • Brain
  • Breast
Basics of MRE method

1. Vibration
2. MRE Acquisition
3. Inversion
- Basics of MRE method
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MRE in Detecting Liver Fibrosis

Diagnostic Accuracy (AUROC)

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>specificity</th>
</tr>
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<tbody>
<tr>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.10</td>
<td>0.90</td>
</tr>
<tr>
<td>0.20</td>
<td>0.80</td>
</tr>
<tr>
<td>0.30</td>
<td>0.70</td>
</tr>
<tr>
<td>0.40</td>
<td>0.60</td>
</tr>
<tr>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.60</td>
<td>0.40</td>
</tr>
<tr>
<td>0.70</td>
<td>0.30</td>
</tr>
<tr>
<td>0.80</td>
<td>0.20</td>
</tr>
<tr>
<td>0.90</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fibroscan AUROC = 0.83
MRE AUROC = 0.93

Liver stiffness measurement success rate

Success Rate
(Patients who underwent both MRE and VCTE)

MRE = 95.8% (92/96)
VCTE = 81.3% (78/96) (Criteria in Castera et al.)
VCTE = 88.5% (85/96) (Criteria in Boursier et al.)

Hepatogram

- Analyze relationships between predictor variables (imaging biomarkers) and outcome variables (histologic features)

- Damping ratio $\rightarrow$ Inflammation
- Liver stiffness $\rightarrow$ ballooning
- Fat fraction $\rightarrow$ steatosis

Yin M., Radiology 2017; Zhang X., Med Eng Phys. 2017

Courtesy Yin Meng, PhD
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Renal MR Elastography Setup

Prone position

Dual Renal MRE driver

About 4 x 5 inches
Renal MR Elastography

Anatomic MRI

Elastograms
Renal MRE:

- Evaluation of kidney function
  - Transplant kidney dysfunction
  - Fibrosis
  - ADPKD (Autosomal dominant polycystic kidney disease)
  - Lupus Nephritis
  - Hepatorenal syndrome
  - eGFS (estimated glomerular filtration rate)
  - RBF (renal blood flow)
- Evaluation of Treatment efficacy
Evaluation of TX kidney dysfunction

Example acquisitions in 42 year old male with RTX

Magnitude  Wave Image  Confidence Map

Courtesy of Paul Kennedy PhD and Dachir Taouli MD
Evaluation of TX kidney dysfunction

<table>
<thead>
<tr>
<th>Modality</th>
<th>N</th>
<th>Stable (kPa)</th>
<th>Dysfunction (kPa)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRE</td>
<td>20</td>
<td>5.22±0.83</td>
<td>7.15±2.37</td>
<td>0.038</td>
</tr>
<tr>
<td>pSWE</td>
<td>11</td>
<td>13.19±2.64</td>
<td>14.92±2.82</td>
<td>0.201</td>
</tr>
</tbody>
</table>

Courtesy of Paul Kennedy PhD and Bachir Taouli MD
Evaluation of TX kidney dysfunction

<table>
<thead>
<tr>
<th>MRE correlation with</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since Tx</td>
<td>0.464</td>
<td>0.040</td>
</tr>
<tr>
<td>GFR</td>
<td>-0.477</td>
<td>0.034</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>pSWE correlation with</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since Tx</td>
<td>0.429</td>
<td>0.289</td>
</tr>
<tr>
<td>GFR</td>
<td>0.095</td>
<td>0.823</td>
</tr>
</tbody>
</table>

Courtesy of Paul Kennedy PhD and Dachir Taouli MD

ISMRRM 2018 # 4587 MR and US elastography in renal Tx
Evaluation of TX kidney dysfunction

Medullary stiffness significantly correlated with histological degree of fibrosis
Renal blood flow and function were similarly decreased in RAS and ARAS compared to normal

Evaluation of ADPKD

Courtesy of Venkatesh Sudhakar MD
Evaluation of ADPKD

Normal: 5.1 ± 0.77 kPa

PCKD: 3.7 ± 0.5 kPa

ADPKD parenchyma is softer than normal kidney parenchyma!

P < 0.005

Courtesy of Venkatesh Sudhakar MD
Evaluation of Lupus Nephritis

ROI: entire parenchyma (green), medulla (yellow), inner cortex (blue), and outer cortex (red).

Courtesy of Jing Guo PhD
Evaluation of Lupus Nephritis

To detect LN-nRF

AUROC:
MRE  = 0.81
DWI  = 0.63
BOLD = 0.76

Healthy controls (CTR); Patients with lupus nephritis of normal renal function (CKD = 1) and impaired renal function (CKD = 2/3/4), ***p < 0.001, **p < 0.01, *p < 0.05.

Courtesy of Jing Guo PhD

Evaluation of hepatorenal syndrome

MRE to detect HRS

AUROC:
90Hz  = 0.94
60Hz  = 0.89

Perfusion Effect: Renal Arterial Stenosis

Lizette W et al. Investigative Radiology 2011;46(8);509-514
Perfusion Effect: Renal Arterial Stenosis

Control (D: a–c), chronic RAS (D: d–f) animals
*P < 0.05 versus control kidney, †P < 0.05 versus contralateral kidney.

Lizette W et al. Investigative Radiology 2011;46(8);509-514
Medullar stiffness increased due to ARAS and decreased in response to the shockwave treatment of ARAS, which was significantly correlated to the change of medullar fibrosis.

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Brain MRE setup

T1w  Wave X  Y  Z  Elastogram

Displacement (μm)

Shear Stiffness (kPa)
Meningioma


• Physical consistency has important implications for operative procedures
Alzheimer’s Disease

- Significantly reduced brain tissue stiffness in Alzheimer’s Disease (AD)

Murphy et al. (2011) JMRI 34: 494-498.
Slip Interface Imaging (SII)

Octahedral Shear Strain (OSS) ➞ Surgical Findings

Slip Interface ➞ No adhesion
No slip Interface ➞ Adhesion

No adhesion
Adhesion

Yin Z. et al., ISMRM 2016, 4175
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<tr>
<th>Likelihood of malignancy</th>
<th>Category 0:</th>
<th>Mammography: Incomplete – Need Additional Imaging Evaluation and/or Prior Mammograms for Comparison</th>
<th>Ultrasound &amp; MRI: Incomplete – Need Additional Imaging Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category 1:</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Category 2:</td>
<td>Benign</td>
<td></td>
</tr>
<tr>
<td>0% - 2%</td>
<td>Category 3:</td>
<td>Probably Benign</td>
<td></td>
</tr>
<tr>
<td>2% - 95%</td>
<td>Category 4:</td>
<td>Suspicious</td>
<td>Mammography &amp; Ultrasound:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Category 4A: Low suspicion for malignancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Category 4B: Moderate suspicion for malignancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Category 4C: High suspicion for malignancy</td>
</tr>
<tr>
<td>95%-100%</td>
<td>Category 5:</td>
<td>Highly Suggestive of Malignancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Category 6:</td>
<td>Known Biopsy-Proven Malignancy</td>
<td></td>
</tr>
</tbody>
</table>

- Category 4 has a large range of likelihood of malignancy, from 2% to 95%, which prompt many patients with only benign lesions being biopsied.
- While a high sensitivity can be achieved by breast MRI, high specificity or low false positive rate is desired to avoid biopsies on benign lesions to reduce medical cost, medical complications and patient anxieties.
Breast Self-exams: Palpation

- Normal breast tissue feels soft
- Breast lump can feel very stiff

[Image of a woman's breast being examined]

[Images of soft and stiff objects]

A 41-year-old female patient with invasive ductal carcinoma

- **MRI BI-RADS:**
  - 6 Known biopsy proven malignancy.

- **MRE**
  - Adipose tissue = 0.41 ± 0.10 kPa,
  - glandular tissue = 0.90 ± 0.18 kPa
  - IDC = 1.42 ± 0.17 kPa.
A 21 yo female volunteer without known breast disease

MRE:

- Fat stiffness = 0.30 - 0.59 kPa
- Fibroglanular stiffness = 0.57 - 1.0 kPa
On-going studies at Mayo:

- MRE to reduce false positive ratio in BIRADS 4 and 5 (less biopsies in benign lesions).
- MRE to characterize/predict breast cancer in patients with dense breast tissue.
Magnetic Resonance Elastography

- Provides an array of new quantitative imaging biomarkers
- Basic technology platform now widely deployed worldwide
- Established as a reliable, more comfortable, and less costly alternative to liver biopsy for assessing hepatic fibrosis
- Many other promising applications (including kidney) are being explored

Thank you!