MRI: What Can It Deliver

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What Can MRI Deliver

**Today**
- Body composition
- Proton density fat fraction (PDFF)
- Corrected T1
- “Stiffness”

**Tomorrow**
- Beyond “stiffness”

**The future**
- Pie in the sky
- Intrinsic meaning

< 30 min
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MRI-based whole body composition profiling

Advanced MR Analytics (AMRA)
Feasible and Precise

Exam 1  Exam 2  Exam 3

Exam = 5-10 minutes  Exam = 5-10 minutes  Exam = 5-10 minutes

Manual analysis = 15 hours  Manual analysis = 15 hours  Manual analysis = 15 hours

Semi-automated analysis = minutes; coefficient of variation 1.5-3.6%
Weight loss

BMI 41 kg/m²

BMI 33 kg/m²

BMI 30 kg/m²

VAT 5.7 L

VAT 4.1 L

VAT 3.1 L

SCAT 18.3 L

SCAT 12.0 L

SCAT 9.7 L

Longitudinal monitoring
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Proton Density Fat Fraction (PDFF)

\[ S(TE) = \left[ W + F \sum_{p=1}^{P} r_p e^{i2 \int_{0}^{TE} f_p(TE) \, dt} \right] e^{i2 \left( \frac{TE}{T_2^*} \right)} \]
PDFF = proportion of all MRI visible protons from fat
PDFF = proportion of all MRI visible protons from fat (triglyceride)
Proton density fat fraction

50%: ~ maximum PDFF in human liver

6.5%: hepatic steatosis
An Tang, PhD

5.5%: 95th percentile in normals
Lidia Szczepaniak, PhD

3%: metabolic syndrome
Jennifer Rehm, MD
Two Basic Approaches

Magnitude data-based MRI

Complex data-based MRI
Two Basic Approaches

Magnitude data-based MRI

Complex data-based MRI
Liver proton density fat fraction is “portable”

Geri Kang et al. JMRI 2011 Children & Adults with NAFLD
Liver proton density fat fraction can monitor change longitudinally.
Liver proton density fat fraction can be used as an endpoint in phase 2 clinical trials.
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Corrected T1

<table>
<thead>
<tr>
<th>cT1</th>
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<th>cT1</th>
<th>cT1</th>
</tr>
</thead>
<tbody>
<tr>
<td>733 ms</td>
<td>869 ms</td>
<td>906 ms</td>
<td>1055 ms</td>
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</tbody>
</table>
**Corrected T1**

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<tr>
<th>cT1</th>
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<tr>
<td>Ishak 0</td>
<td></td>
<td>Ishak 2</td>
<td></td>
<td>Ishak 3</td>
<td></td>
</tr>
</tbody>
</table>

- Body Composition
- PDFF
- cT1
- Stiffness
- Beyond Stiffness
- Future

Gradient:
- 600 ms
- ≥ 800 ms
- 1200 ms
Corrected T1

Mixed population (viral hepatitis n=31, FLD n=31, other n=17)

Detection of any disease
Cutoff cT1 $\geq 800$ ms
AUROC 0.94
sensitivity 86%
specificity 93%

T1 corrections cT1
Theory

Question:
can cT1 separate the opposing effects of free and bound water?
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“Stiffness”

Dick Ehman  Raja Muthupillai  Phil Rossman

29 September 1995
Stiffness

Ability to resist deformation from external pressure

Slide concept adapted from www.physicstutorials.org
How do you measure stiffness without palpation?

Sound (waves) travels faster through solid ground (hard) than through air (soft)
Shear Wave Propagation in Liver
MR Elastography Diagnoses Advanced Fibrosis

“Stiffness” cutoff: 3.63 kPa
Sensitivity 0.86
Specificity 0.91

AUC for diagnosis of advanced fibrosis 0.924

Loomba et al 2014
MR Elastography Not Sensitive to Early Fibrosis

Meta-Analysis

- 12 Studies
- 697 patients
Conventional MRE ("stiffness") cannot differentiate mild fibrosis from inflammation.
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Beyond Stiffness
Beyond Stiffness

Stiffness has elastic and viscous components

Elastic
- Returns to original size and shape

Viscous
- Does not return to original size and shape

Pressure released

Slide concept adapted from www.physicstutorials.org
Beyond Stiffness

Stiffness has elastic and viscous components

- Elastic: bouncy ball
- Viscous: silly putty
Beyond Stiffness

Stiffness has elastic and viscous components

Elastic

Fibrosis

Viscous

Inflammation
Beyond Stiffness

3D MR elastography analyzes wave motion in all 3 planes
Beyond Stiffness

3D MR elastography analyzes wave motion in all 3 planes.
Beyond Stiffness

3D MR elastography measures multiple tissue parameters

- Magnitude
- Stiffness = \(|G^*|\)
- Storage Mod. = \(G'\)
- Loss Mod. = \(G''\)
- Damping Rat. = \(\zeta\)
- Vol. Strain = \(\epsilon_v\)

**Fibrosis**

- 2.49 kPa
- 2.31 kPa
- 0.72 kPa
- 0.16
- 0.7%

**Inflammation?**

- 4.81 kPa
- 4.50 kPa
- 1.15 kPa
- 0.13
- 1%
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Pie in the sky

- Automation
- Blood flow
- Liver function
- Fat composition
- Glycogen content
- Fibrogenesis
- Fibrolysis

- Portal pressure
- Pancreatic beta cell function
- Metabolic pathways
- Stellate cell activation
- Mitochondrial function
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Intrinsic meaning

Chemical Shift MRI
- PDFF 25.0%
- PDFF
- Steatosis

MRE
- Shear stiffness 3.23 kPa
- Shear stiffness
- Fibrosis

Liver MultiScan
- Liver Inflammation and Fibrosis Score 2.7
- Corrected T1
- Inflammation and Fibrosis

• MRI measurements no intrinsic meaning
• Must be translated into a histology score

Current Paradigm
Intrinsic meaning

**Chemical Shift MRI**
- PDFF 25.0%
- [Triglyceride] within MRI visible protons

**MRE**
- Shear stiffness 3.23 kPa
- Elastic and viscous components of shear stiffness

**Liver MultiScan**
- Liver Inflammation and Fibrosis Score 2.7
- Corrected T1
- Water content within MRI visible protons

**Outcomes**

**Future Paradigm**
- MRI measurements acquire intrinsic meaning
- Do not have to be translated into a histology score

**Body Composition**
- PDFF
- cT1
- Stiffness
- Beyond Stiffness
- Future
Intrinsic meaning

Tetri Grid

Stiffness
Elasticity

PDFF

Future

Beyond stiffness
Intrinsic meaning

Stiffness
Elasticity

PDFF  cT1  Stiffness  Beyond Stiffness  Future

PDFF

Beyond stiffness
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