SNR IMPACTS THE ACCURACY AND PRECISION OF KNEE ARTICULAR CARTILAGE T2 RELAXATION TIME MEASUREMENTS

B.J. Dardzinski¹, E. Schneider²

¹Merck Sharp & Dohme Corp., West Point, PA USA
²Imaging Institute, Cleveland Clinic, Cleveland, OH USA and SciTrials LLC, Rocky River, OH

The authors have no conflicts with the work reported in this study.

MRI Assessments of Cartilage

- **Morphological MRI**
  - Insensitive to early stage cartilage lesions
  - Outerbridge I – softening / swelling
  - Unexposed (no risk) and Incidence (at risk, no symptoms or ROA) have equal incidence of early defects (WORMS <5)

- **T2**
  - collagen integrity, [GAG], orientation dependent

- **T1 (dGEMRIC)**
  - [GAG] charge-based, orientation independent

- **T1rho**
  - collagen integrity, [GAG], orientation dependent (less than T2)
T2 Assessments

- Are not absolute
- Values are:
  - Spatially dependent
    - Knee positioning (magic angle)
    - Cartilage plate
    - Cartilage zone
  - MR System Dependent
    - Magnetic Field Strength
    - Refocusing flip angle
    - Acquisition sequence
    - Analysis method
    - Image noise, particularly last echo

Introduction

- OAI opted for 3T
  - Increased SNR allowed higher spatial resolution
- In 2003:
  - Not many 3T MR systems
  - Only one knee coil (USAI)
  - However other options in development
  - Pilot study to evaluate impact two different knee coils
    - Similar transmit design (similar excitation / refocusing pulses)
    - Different detection design (different SNR)
Structure of Articular Cartilage

- Proteoglycans
- Type II Collagen Matrix
- Fiber reinforced composite matrix

Effect of Collagen Orientation on MR Signal Intensity

Images courtesy of Doug Goodwin, MD
Dartmouth Medical School
SNR 1.5T vs. 3T

$$SNR = \frac{S}{\sigma_n}$$

<table>
<thead>
<tr>
<th>ROI</th>
<th>SNR (BW = 125)</th>
<th>SNR (BW = 250)</th>
<th>Ratio</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>53</td>
<td>109</td>
<td>2.1</td>
<td>61</td>
</tr>
<tr>
<td>Cartilage</td>
<td>22</td>
<td>46</td>
<td>2.1</td>
<td>29</td>
</tr>
<tr>
<td>Fat</td>
<td>74</td>
<td>132</td>
<td>1.8</td>
<td>84</td>
</tr>
<tr>
<td>Muscle</td>
<td>26</td>
<td>42</td>
<td>1.6</td>
<td>31</td>
</tr>
</tbody>
</table>

T2 Map Comparison
1.5 vs. 3 Tesla
**T2 Comparison**

<table>
<thead>
<tr>
<th>ROI</th>
<th>1.5T</th>
<th>3T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone</td>
<td>123 ± 5</td>
<td>122 ± 7</td>
</tr>
<tr>
<td>Cartilage</td>
<td>50 ± 6</td>
<td>43 ± 5</td>
</tr>
<tr>
<td>Muscle</td>
<td>39 ± 4</td>
<td>38 ± 6</td>
</tr>
<tr>
<td>Fat</td>
<td>123 ± 9</td>
<td>128 ± 8</td>
</tr>
</tbody>
</table>

**Objective**

- Determine the accuracy and precision of cartilage T2 measurements using two different RF Coils
  - Similar transmit (quadrature)
  - Dissimilar receive (quadrature vs 8 channel phased array)
QTR vs. QT8PAR

<table>
<thead>
<tr>
<th>Inner height</th>
<th>180 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner width</td>
<td>190 mm</td>
</tr>
<tr>
<td>Inner Circumference</td>
<td>580 mm</td>
</tr>
<tr>
<td>Equivalent diameter</td>
<td>184 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Min inner height</th>
<th>130 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min inner width</td>
<td>140 mm</td>
</tr>
<tr>
<td>Inner Circumference</td>
<td>420 mm</td>
</tr>
<tr>
<td>Equivalent diameter</td>
<td>134 mm</td>
</tr>
<tr>
<td>Thigh/Calf inner height</td>
<td>180 mm</td>
</tr>
<tr>
<td>Thigh/Calf inner width</td>
<td>185 mm</td>
</tr>
</tbody>
</table>

Methods

**Coil A**
- Patient X
- 10 min
- Patient X

**Coil B**
- Patient X
- 10 min
- Patient X

10 subjects (3 men) 52.2 yrs, 28.2 BMI
12 knees (6 progression, 6 incident)
10 femoro-tibial joints were eligible
ROIs for SNR Calculation

SNR @ 10 msec Echo Time
Tibial Cartilage

- SI = 256
  \( \sigma_{\text{noise}} = 18.9 \)
  SNR = 13.5
- SI = 39.5
  \( \sigma_{\text{noise}} = 1.88 \)
  SNR = 21
SNR @ 70 msec echo time

Tibial Marrow

<table>
<thead>
<tr>
<th>Region-of-Interest</th>
<th>Mean ± SD</th>
<th>RMS CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>5.0% ± 3.5%</td>
<td>5.3%</td>
</tr>
<tr>
<td>Lateral</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

* = P < 0.001

SNR @ 70 msec echo time

Tibial Cartilage

<table>
<thead>
<tr>
<th>Region-of-Interest</th>
<th>Mean ± SD</th>
<th>RMS CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial</td>
<td>8.1% ± 7.7%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Lateral</td>
<td>3.4%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>

* = P < 0.001
Central Zone

Superficial Zone

* = P < 0.001

* = P < 0.01
Some Caveats on T2

T2 Example - Infrapatellar Fat Pad

94.7 ± 6.5 msec
Tibial Cartilage

[Graph showing number of voxels vs. error (msec) with different curves for QTR 6pt, QTR 7pt, QTR 8PAR 6pt, QTR 8PAR 7pt, and QTR 8PAR 8pt.]

Correlation Map

QT8PAR 6pt Fit

[Graph showing T2 data with a fit line and error map.]
Findings

- SNR higher in QT8PAR
- Global T2 longer with QT8PAR
  - cMF (45.9ms/50.7ms)
  - MT (41.6ms/48.2ms)
  - muscle (37.9ms/40.7ms)
- T2 precision better with QT8PAR
  - cLF, cMF, and infrapatellar fat
Findings

• Due to anatomy, T2 values differ spatially
  – cLF has the longest value (52ms)
  – LT has the shortest (40.6ms)
• SNR can vary spatially depending upon coil
• With higher SNR, significantly longer T2 values
  – Deep cartilage T2 values were most affected
• T2 changes with SNR can be larger than the impact of changing magnetic field strength

What does this mean for analyzing the OAI data?

• Same USAI QTR coils
  – Used from 2004 – early 2012
• Failing quality assurance
  – No replacements have been available for past 2yrs
  – Replaced with InVivo QT8PAR
    • Spring 2012
T2 Summary

- Monitors rotational freedom of water motion
- Sensitive to both collagen integrity, [GAG] in cartilage
  - hydration
- Orientation dependent
- Equipment, acquisition and analysis dependent
  - Analysis precision – varies with plate and zone
    - (0.5-2% RMS CV%)
  - Measurement precision – varies with plate and zone
    - (3.3-10.9% RMS CV%)
  - Include quality control ROIs
  - Accommodate for noise in analysis

T2 values are higher in disease, possibly sensitive to early OA

- Reversible (exercise)
- Small changes, 1-3ms
- Higher T2 in
  - Knee Pain
  - Cartilage or meniscal defects
  - Weaker quadriceps muscles
  - Increases with age, but no diff in rate of change with early OA
T2 in Clinical Research

- Pair the acquisition and analysis
  - Ensure accuracy and sensitivity to change with phantoms
- Perform within subject comparisons for longitudinal change
- Use an intrinsic reference tissue (if possible)
  - Cartilage in a different compartment
  - No gold standard
- Tailor the acquisition to the clinical question
  - Cartilage repair vs. OA vs. deep cartilage change due to trauma
- Difficult to perform meta-analyses

Acknowledgments

- The OAI and this pilot study are conducted and supported by NIAMS in collaboration with the OAI Investigators and Consultants
- The research reported in this abstract was supported in part by contracts N01-AR-2-2261, N01-AR-2-2262 and N01-AR-2-2258
- We are grateful to the Ohio State University and Memorial Hospital of Rhode Island OAI study teams for recruitment of the study subjects and acquisition of the MR exams