QUANTITATIVE MRI

Sharmila Majumdar, PhD
Musculoskeletal Quantitative Imaging Research Group
Dept. of Radiology and Biomedical Imaging
University of California, San Francisco
**Early Stage: Cartilage**
Biochemical Changes

- Loss of proteoglycan
- Disorganization of collagen structure

**Late Stage: Morphological Changes**

**OSTEOARTHRITIS**

Normal

![Cartilage Image](image1)

Osteoarthritis

![Diagram of osteoarthritis](image2)

**$T_1^\rho, T_2$**

![MRI images](image3)
PRECISION IMAGING & OSTEOARTHRITIS

Later Stage:

Radiological Diagnosis

Cartilage Morphology

Bone Shape

Muscle Composition & Size

Early Stage: Cartilage

Cartilage and Meniscus Biochemistry

Meniscus

PET-MR: +Bone remodeling
COLLAGEN CONTENT & ORIENTATION

- Superficial Zone
- Transition Zone
- Radial Zone

Tidemark
Calcified cartilage
Subchondral bone plate
Vascular plexus

Under Load

Zheng and Xia Lab, Osteoarthritis and Cartilage, 2009

Alkahadled And Xia Lab, JMRI, 2005

Zheng and Xia Lab, Osteoarthritis and Cartilage, 2009
$T_1^\rho$ - PROTEOGLYCAN

3 month old  
9 month old

Center for Magnetic Resonance and Optical Imaging, UPENN, NCRR (Courtesy Ravi Reddy)
ACL INJURY AS A MODEL FOR OSTEOARTHRITIS

Osteoarthritis (OA): degenerative cartilage disease

- Affecting 32.6% of those 65+ in USA
- Other joint tissues are also implicated in OA

1 Center for Disease Control (CDC): http://www.cdc.gov/arthritis/basics/osteoarthritis.htm

ACL Injury is associated with OA
- Young and active population
- Despite surgical reconstruction
- Abnormal joint biomechanics
- Unclear connection between injury and cartilage degeneration

Meniscus – Plays a major role in whole joint function

http://orthoinfo.aaos.org/figures
https://usatthebiglead.files.wordpress.com/
http://faculty.washington.edu
Changes in Compartments and Layers of Cartilage Reflect Degeneration

2-YEAR FOLLOW UP

* p < 0.05 compared to controls

Su et al, Osteoarthritis Cartilage 2013

NIH K25-AR053633, R01-046905
✓ $T_{1p}$ and $T_2$ predict cartilage loss over 2 yrs

55 subjects with no or mild OA Follow-up over 2 years
2 groups with and without progression

In 120 subjects with and without knee OA, the study found that **T₁ρ** and **T₂** reflect cartilage degeneration in different compartments and layers. The table below summarizes the Pearson’s r (P value) for self-report symptoms, pain, ADL physical function:

<table>
<thead>
<tr>
<th></th>
<th>Self-report Symptoms</th>
<th>Self-report Pain</th>
<th>Self-report ADL</th>
<th>Physical Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Femoral Superficial</strong></td>
<td>0.29 (0.014)</td>
<td>0.29 (0.001)</td>
<td>0.25 (0.006)</td>
<td>0.23 (0.039)</td>
</tr>
<tr>
<td><strong>T₁ρ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tibial Deep</strong></td>
<td>0.25 (0.007)</td>
<td>0.25 (0.007)</td>
<td>0.25 (0.007)</td>
<td><strong>ns</strong></td>
</tr>
<tr>
<td><strong>T₁ρ</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
✓ Going Beyond Averaging Compartments and Layers Reflecting Local Degeneration

$T_{1\rho}$ & $T_2$ (Increased in ACL Injury at baseline)

* $T_2$ showed similar trends to $T_{1\rho}$.
Going Beyond Averaging Compartments and Layers Reflects Local and Higher Correlations with Symptoms/Pain

$T_{1p}$ – Biochemical degeneration is higher in osteoarthritic cartilage.

Greater the degeneration -- **Higher** the pain and symptoms.

Difference between OA and non OA.
Chronic knee pain was defined as patient timepoints which reported knee pain, aching, or stiffness over half of the days of the month for more than six months of the past 12 months.
Better feature extraction to combine with other biomarkers
Bone shape shows ethnic differences, and related to OA

| Test Set ROC (Sensitivity/Specificity/AUC) (Mean ± CI95) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Patella          | Tibia           | Femur           | PTF             |
| All              | 65.5 ± 0.381    | 52.5 ± 0.369    | 56.6 ± 0.368    | 57.3 ± 0.367    |
| Biomarkers       | 63.9 ± 0.255    | 71.8 ± 0.235    | 76.2 ± 0.207    | 75.2 ± 0.207    |
| Fusion           | 70.3 ± 0.251    | 66.4 ± 0.250    | 72.5 ± 0.223    | 73.0 ± 0.233    |

- The activations are quite varied across each bone
- Pointing to a multifactorial combination of biomarkers behind chronic knee pain
- Differs in different individuals

An example in a DMOAD trial $T_1\rho$ and $T_2$ Mapping with Corresponding Volumetric and Thickness Measurements.
Issues with $T_2$ and $T_{1\rho}$ Mapping and Solutions

- Lack of standardized data acquisition and processing
- Needs documentation of inter-vendor variations
- Needs standardized and automated processing
- Needs fast imaging

QIBA MSK Committee: 70+ members (30+ active members) from 40+ academic institutes and industrial partners

QIBA Profile: MR-based cartilage compositional biomarkers ($T_{1\rho}$, $T_2$) for risk prediction, early diagnosis and monitoring of treatment of degenerative joint disease
✓ Multi-vendor Multi-site $T_{1\rho}$ and $T_2$ Imaging

- Implemented MAPSS $T_{1\rho}$ and $T_2$ imaging on major MR platforms
- Harmonized protocols and central processing: inter-vendor inter-site variations ~10%\(^1\)
- Further mitigate variations and develop fast imaging
- Develop a MSK phantom with NIST with reference $T_1$, $T_2$, $T_{1\rho}$ values

\(^1\)Kim et al Osteoarthritis Cartilage 2020

Sponsored by Arthritis Foundation and NIH/NIAMS R01AR077452
Thank You

OREF/Goldberg Arthritis Research Award

Arthritis Foundation

AOSSM