Imaging of Cartilage

Diego Jaramillo, M.D., M.P.H.
Department of Radiology
Stanford Children’s Hospital
Lucas Cranach the Elder
The Fountain of Eternal Youth (1546)
Thanks to:
Ravi Reddy, PhD
Center for Magnetic Resonance and Optical Imaging
(7T Whole Body)
Bernie Dardzinski, PhD
Nancy Chauvin, MD
Victor Ho-Fung, MD
Tal Laor, MD
Osteoarthritis = cartilage loss

- Important to detect cartilage degeneration before loss of cartilage
- Decreased proteoglycan size, reduced GAG concentration, decreased collagen, increased water content
Cartilage Structure

- Mature cartilage: avascular, few cells in matrix
- Immature cartilage: well vascularized, very cellular
- Matrix:
  - Collagen: tensile strength and structure
  - Glycosaminoglycans (GAG) bind water
Cartilaginous Disturbances

- Clinical Imaging Techniques
- Immature Cartilage
  - Normal anatomy & imaging characteristics
- Articular Cartilage
• Epiphyseal separation in newborn
Clinical MRI Techniques

• Morphologic
  – PD or Intermediate (slightly higher TE)
  – T2
  – GRE
  – Gd
• IV or Intra-articular
Morphologic Evaluation of Cartilage: Relevant Questions

• Is the cartilage injured, thinned or absent?
  – SE PD or Intermediate
  – GRE

• Is the cartilage present but intrinsically abnormal?
  – SE T2
Is the cartilage injured, thinned or absent?

**SE PD or Intermediate**

- Bright cartilage
- Brighter joint fluid
- Fat suppression
- Usually 2D
- Best ligamentous depiction
• Normal Preossification
• Cartilage degeneration
  – Osteomyelelitis
  – Chronic trauma
  – Chondromalacia
T1 Gradient Recalled Echo (FLASH, VIBE, SPGR)

- Bright cartilage
- Dark joint fluid
- Poor visualization of tendons and ligaments
Intermediate and T2-weighted Gradient Recalled Echo

- High SI cartilage
- Bright fluid
- Good visualization of tendons and ligaments

Physeal Bridging
Bony Bridge Mapping
Clinical Questions

- Bony bridge
  - Location
  - Size
  - % of physis involved
  - Deformity
Growth Arrest – Bridge Mapping
T2- weighted Gradient Recalled Echo

- Smaller flip angle increases T2- weighting (darker cartilage, brighter fluid)
- Longer TE increases susceptibility (darker bones)
Gd-Enhanced T1

- Fat suppression
- 2D (SE) or 3D (GRE)
- Intermediate cartilage
- Dark fluid
- Minimal synovial enhancement
Cartilaginous Disturbances

- Clinical Imaging Techniques
- Immature Cartilage
  - Normal anatomy & imaging characteristics
- Articular Cartilage
Cartilaginous Regions (T2)

- Main Physis
- Secondary Physis
- Epiphyseal Cartilage
- Articular Cartilage

From Milgram
Normal Epiphyseal Development

- Decreased signal: weight-bearing region
  - Begins with walking
Preossification Center

- Hypertrophic changes in cartilage
- Precedes ossification
- More free water
Preossification Centers
Vascularity
Epiphyseal Vascular Canals
Epiphyseal Vascularity

VC

O

P
Global decrease in perfusion: 10-fold increase in odds of AVN
Physeal Anatomy

Physeal zone

Germinal

Proliferative

Hypertrophic

Groove of Ranvier

Epiphyseal artery

Perichondrial artery

Metaphyseal artery

Nutrient artery
Physeal – Epiphyseal Differentiation

- Physis remains hyperintense on T2
- Absence of high SI - Arrest
Columnar Architecture
Central tracts are shorter

Tibial tracts are shorter
Cartilaginous Disturbances

- Clinical Imaging Techniques
- Immature Cartilage
  - Normal anatomy & imaging characteristics
- Articular Cartilage
MR Arthrography
Cartilage Structure

- Proteoglycans immersed in collagen network
- Proteoglycans contain negatively charged glycosaminoglycans (GAG)
- GAG bind water electrically and osmotically
• Pressure drives water out of the cartilage; water returns with release (like a sponge)
T2 Mapping

- Increased T2 in areas of cartilage degeneration
- T2* mapping: faster, similar results
T2 Mapping

- Signal decay with varying TE’s
What do T2 maps reflect?

- Collagen content
- Collagen degradation: increased $T2$
- Collagen alignment
- Water content
- Small effect of Proteoglycans
Average T2 Profile in ROI

$T_2$ decreases from superficial tangential to deep zones
T2 Cartilage Mapping

Gray-scale map converted to the color-coded map with colors corresponding to a range of T2 relaxation times

Higher water content (cartilage degeneration)
14 year-old normal weight boy  14 year-old obese boy

*Higher T2 relaxation times (red) within the articular cartilage due to increased water content & break-down of proteoglycans*

Chauvin N et al, SPR 2015
Obese children demonstrated higher T2 relaxation times (mean: 50 msec) within the deep cartilage of the medial femoral condyle compared to normal weight subjects (mean: 48 msec) (p<0.01)
Color-Coded T2* Map
Clinical Uses

• T2 mapping sequence to a routine knee protocol (3 T): improved sensitivity for cartilage lesions from 74.6% to 88.9%, small reduction in specificity.
• In children, increased T2 related to JIA progression
UTE T2*

- T2* in deep layers of the cartilage
- Less affected by calcium content.
Ultrashort TE

- Detects signal with short T2, T2*
- High SI
  - deepest layer of uncalcified cartilage
  - adjacent calcified cartilage

Radiology 2010; 254: 837-845
Fixed Charge Density

- Electrical charge = GAG concentration
- Directly: Na 23 imaging
- Indirectly: dGEMRIC
Sodium Imaging

• Advantages:
  – Accurate quantitation of Proteoglycans
  – Short (25 min.) volume acquisition

• Disadvantages:
  – Low SNR
  – Requires ≥ 3T (ideally 7T)
  – Resolution inferior to that of proton MRI
Sodium MR of human cartilage degeneration

- A. Healthy subject
- B. Symptomatic osteoarthritic subject
Glycosaminoglycan (GAG) Imaging [dGEMRIC]

- Electrical charge = GAG concentration
- GAG repels Gd(DTPA)$^{-2}$
- Gd(DTPA)$^{-2}$ concentration inversely related to GAG content
dGEMRIC - Technique

• IV injection of double dose of Gd(DTPA)-2
• 30-60 minutes and exercise
• T1 map options:
  – SE with varying TR
  – IR with varying TI
  – GRE with varying flip angles
dGEMRIC – GAG specific

Normal

Abnormal
dGEMRIC

- T1 mapping
- Field dependent
  - Better at 1.5T
- Time dependent
- Provides indirect MR arthrographic images
T1rho (Spin Lock) MR Imaging

- Detects regions of decreased PG concentration; collagen dependence
- Combined with either 2D FSE or 3D gradient echo to image cartilage volume rapidly
- Major drawback: lack of availability
Arthroscopy and $T_{1\rho}$

Excellent correlation between arthroscopy and $T_{1\rho}$ MRI!

Chem. Exchange Saturation Transfer (CEST) Imaging

- Saturation specific to –OH protons on GAG (gag-CEST)
- Saturation transfer with adjacent bulk water leading to decreased water magnetization
gag-CEST

- Magnetization Transfer Contrast-based technique
- Specific to GAG
- Better at 7T
- Recent studies show gag-CEST at 3T comparable to d-GEMRIC
DTI in Articular Cartilage

- Maps reflect the alignment of collagenous fibers in cartilage
- Diffusivity decreases from the surface to the tide mark
- Increased ADC and decreased FA in subjects with OA
  Radiology. 2012 Feb;262(2):550-9
Increased Diffusion in Girl with Hip Pain

- Increased ADC and decreased FA in subjects with OA

Epiphyseal DWI
Take Home Points

• Immature cartilage is cellular and vascular (not amenable to techniques that look at cartilage matrix)

• Physeal Abnormalities
  – Ischemia, direct injury or repeated trauma
  – Physeal imaging for early growth disturbance
  – Bony bridge mapping with MIP from 3D- GRE
Take Home Points

- **PD**: evaluation of immature cartilage integrity
- **T2**: intra-epiphyseal pathology
- **Gd**: cartilaginous ischemia, revascularization
- “Biochemical Evaluation”
  - T2, T2*: easy, collagen and water dependent
  - dGEMRIC: GAG specific, needs Gd, indirect arthrography
  - T1 rho, GAG-CEST: relatively GAG specific