Visualization and quantification of collagen fibers in a partially torn ligament using magic angle imaging

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Declaration of Financial Interests or Relationships

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I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.
Cruciate ligament preserving implants MUST have “healthy ligaments”

- Total knee replacement with cruciate ligaments retained
- Partial or unicompartmental knee replacement with cruciate ligaments retained
Healthy Ligament?

- Hook test
- Invasive
- Subjective
How can we measure ligament health with little or no MR signal?

Conventional MRI

Magic Angle MRI

Healthy ligament

Magic Angle MRI

? Damaged ligament

dipolar anisotropy
magic angle effect

Chang et al. 2014
Post mortem tendon

0.2mL injected collagenase

Molecular structure disrupted

Loss of magic angle effect

Parallel to $B_0$ Magic Angle

Tendon

Fullerton & Rahal 2007
Post mortem tendon
Laser induced lesion
Thermal damage
Unravelling collagen fibers
Loss of magic angle effect
Spontaneous injury model

Taylor-Brown et al. 2015
Method

- 3T Siemens Verio
- 12 Channel head coil
- 3D T1 FLASH volume in 9 orientations to $B_0$

- 10 dog knees
- Vet assessed disease
- Post processing pipeline:

Registration & Alignment
- 9 volumes are matched to the initial position

Magic Angle Contrast
- Standard deviation across 9 volumes

Segmentation & Voxel orientations
- Identifies voxels with a magic angle effect by thresholding
- Computes the net voxel orientation map

Collagen fiber visualization
- ParaView - 3D visualization of fiber tracts

Alignment Index
- A ratio of the fraction of orientations within a 20° cone centred at the selected direction.
  - 0 = isotropic collagen
  - 1 = anisotropic collagen
  - AI changes visualized on a hemisphere
Results

Healthy Knee

Medial Femoral condyle

Damaged Knee

Medial Femoral condyle

Anteromedial band partial rupture

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Results – Collagen fibers

Healthy Canine CCL

Damaged Canine CCL

Anteromedial band partial rupture

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Results – Alignment Index

Healthy Knee

Posterolateral fiber bundle

Aligned fibers in the healthy anteromedial fiber bundle

Damaged Knee

Disorganised fibers in the torn anteromedial fiber bundle

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ECM degenerates causing ligament rupture

Partial rupture clearly visible with magic angle imaging

AI visualizes and quantifies changes in collagen fiber alignment within the same ligament

Healthy collagen = >0.18

Unhealthy collagen = 0.06

dipolar anisotropy

magic angle effect
Magic Angle reduced?

Ligament Origin

Greatest magic angle effect

Greatest magic angle in ligament

Cartilage

Reduced magic angle in lesion

OCD lesion

4mm

5mm

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1st visualization of a CCL partial tear with magic angle imaging

Potential to become a non-invasive alternative to arthroscopy

Could assess and monitor ligament damage and repair
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Rotatable Main Field MRI Scanner for Angle Sensitive Imaging