In vivo diffusion tensor imaging (DTI) of articular cartilage as a biomarker for osteoarthritis

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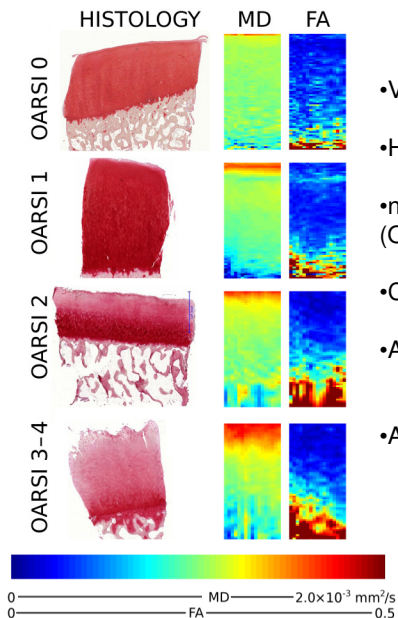
INTRODUCTION

- Diffusion of water molecules in cartilage → Cartilage integrity

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- Proteoglycan (PG) and collagen different imprint in diffusion
  1. PG → isotropic distributed → mean diffusivity (MD)
  2. Collagen architecture → fractional anisotropy (FA)

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Raya JG et al. Invest Radiol 2011;46:401–409
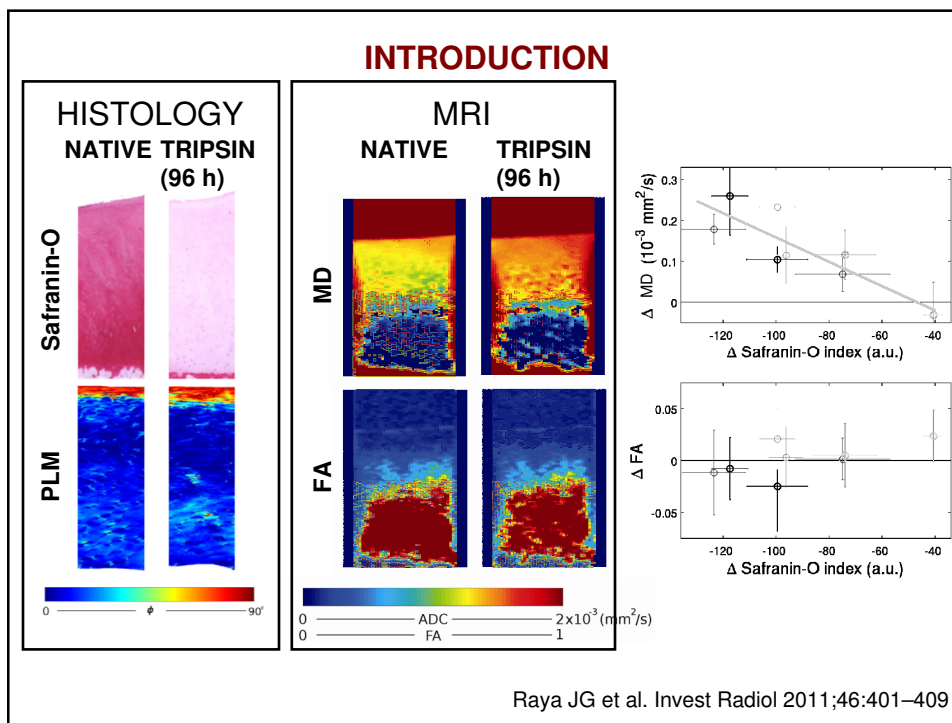
INTRODUCTION

- Validation of DTI in OA samples

- Histology reference standard (OARSI score)

- n=43 samples with early cartilage damage (OARSI 0 (14), 1 (11), 2 (12) 3-4 (6))

- Correlation DTI with OARSI score (P<0.05)

- ACCURACY = 95% to detect cartilage damage (random → accuracy=50%)

- ACCURACY = 75% to stage cartilage damage (random → accuracy=25%)

Raya JG et al. Radiology (accepted)

INTRODUCTION

- Diffusion of water molecules in cartilage → Cartilage integrity

- Proteoglycan (PG) and collagen different influence in diffusion
  1. PG → isotropic distributed → mean diffusivity (MD)
  2. Collagen → anisotropic → fractional anisotropy (FA)

- But in vivo DTI of the articular technically challenging
  1. Short T2 ≈ 30 ms
  2. High resolution ≤ 0.6 mm
  3. Complex knee anatomy → B_0 B_1^+ Inhomogeneity

- Failure of standard diffusion sequences → New sequences

INTRODUCTION: Line Scan Diffusion Imaging sequence
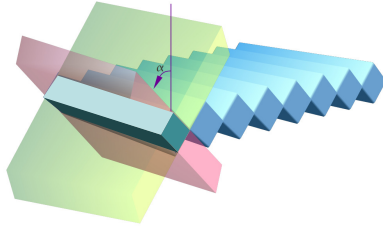
Advantages of the LSDI:
1. SE-based $\rightarrow$ insensitive to B_0 and B_1^+ inhomogeneity
2. No phase encoding $\rightarrow$ insensitive to motion artifacts
3. Short TR $\rightarrow$ much faster than SE

Disadvantages of the LSDI:
1. Low SNR $\rightarrow$ Use of 7 T + 28 Ch receive coil

OBJECTIVE

To assess the value of in vivo DTI of
articular cartilage for the
early diagnosis of OA
as compared with the T2 relaxation time.

Raya JG et al. Radiology 2012;262:550-559

METHODS: Experimental design

SUBJECTS

1. **16 asymptomatic volunteers** (age 30.7±2.3 y) **10 scanned twice**
   exclusion: knee pain, surgery or trauma

2. **10 OA subjects** (mean age 61.2±8.3 y) from NYU-HJD OA knee cohort
   inclusion: intact cartilage surface + signal alteration in T2w TSE fs

7 T (Siemens) and 1 Ch transmit, 28 Ch receive knee coil (QED)

IMAGE PROTOCOL

1. High-resolution T2*-weighted fat-saturated GRE
   (TE/TR=9.2/40 ms, Matrix=256×256×192, isotropic voxel size=0.5 mm^2, flip angle = 15°, fat-saturation, acquisition time=10 min)

2. LSDI sequence
   (TE/TR/TReff=46/180/2890 ms, Matrix=256×128, in-plane=0.6×0.6 mm^2, *b*-values=5, 450 s/mm^2, 6 directions, fat-saturation, acquisition time=14 min)

3. Multislice Multiecho spin-echo sequence
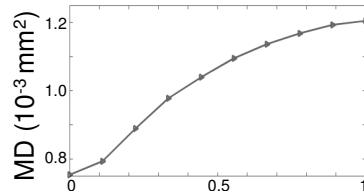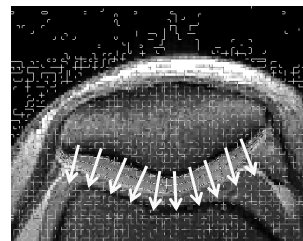   (TE/TR=16/3500 ms, Matrix=256×128, ETL=6, fat-saturation, acquisition time=10 min)

METHODS: Image processing

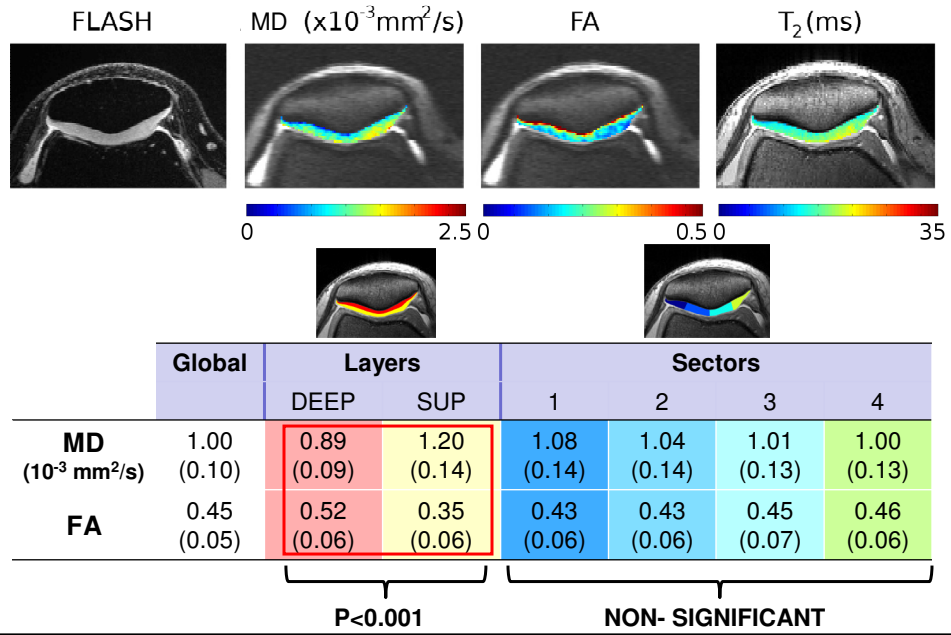1. Cartilage segmentation (MSME) and parameter calculation (MD, FA,T2)

2. MRI parameter profiles
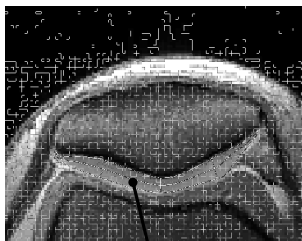
Mean, STD
Test-retest reproducibility
‖
Root mean square of the Coefficient of variation

MD (10^{-3} mm^2)
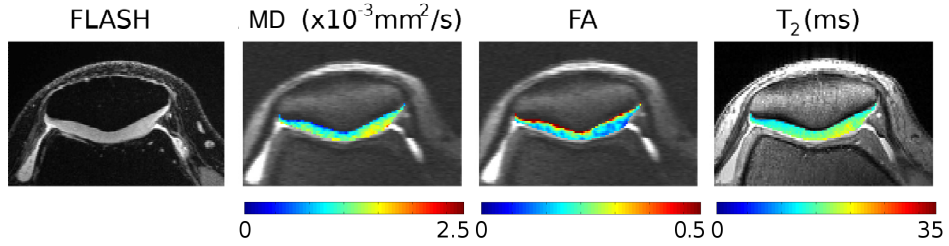
Bone-cartilage interface (0) → articular surface (1)
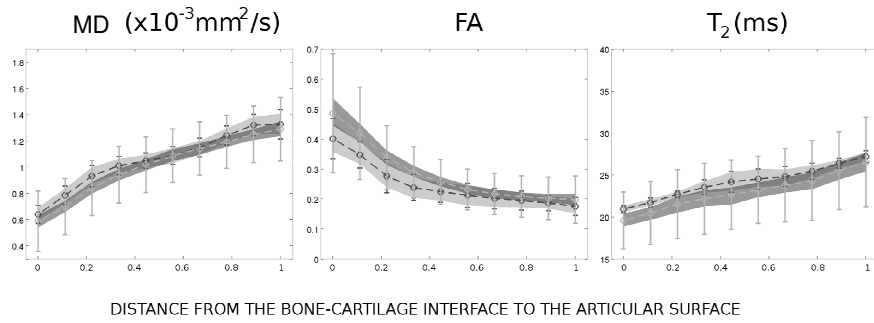
RESULTS: Asymptomatic volunteer

FLASH   MD (x10⁻³mm²/s)   FA T_2(ms)

	Global	Layers		Sectors			
		DEEP	SUP	1	2	3	4
MD (10^{-3} mm²/s)	1.00 (0.10)	0.89 (0.09)	1.20 (0.14)	1.08 (0.14)	1.04 (0.14)	1.01 (0.13)	1.00 (0.13)
FA	0.45 (0.05)	0.52 (0.06)	0.35 (0.06)	0.43 (0.06)	0.43 (0.06)	0.45 (0.07)	0.46 (0.06)

P<0.001   NON- SIGNIFICANT

RESULTS: Test-retest reproducibility
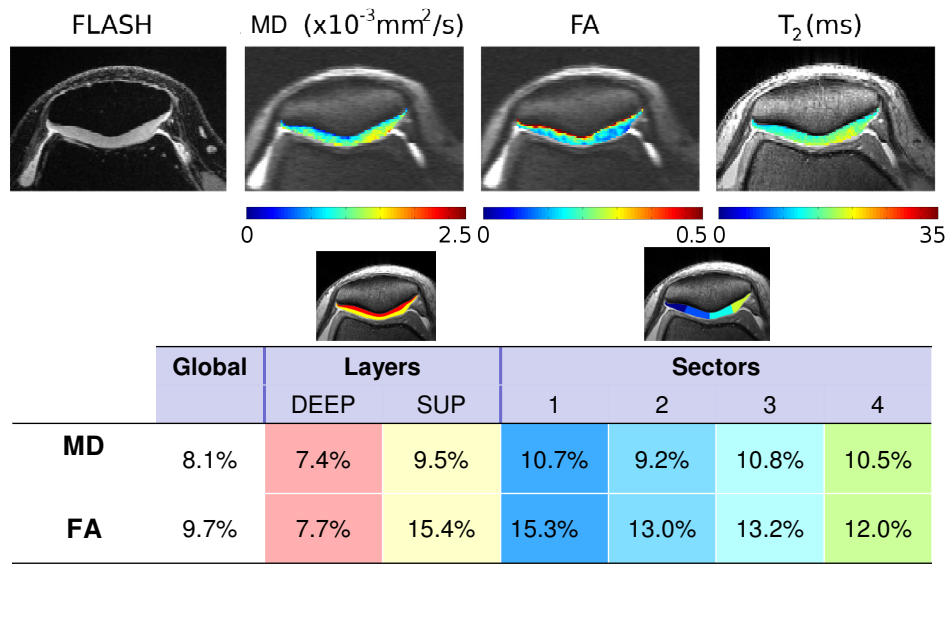
FLASH   MD (x10⁻³mm²/s)   FA T_2(ms)

	Global	Layers		Sectors			
		DEEP	SUP	1	2	3	4
MD	8.1%	7.4%	9.5%	10.7%	9.2%	10.8%	10.5%
FA	9.7%	7.7%	15.4%	15.3%	13.0%	13.2%	12.0%

RESULTS: Asymptomatic volunteer

FLASH   MD (x10⁻³mm²/s)   FA   T₂(ms)

PROFILES

MD (x10⁻³mm²/s)   FA   T₂(ms)

DISTANCE FROM THE BONE-CARTILAGE INTERFACE TO THE ARTICULAR SURFACE

RESULTS: OA subject 1

FLASH   MD (x10⁻³mm²/s)   FA   T₂(ms)

PROFILES

MD (x10⁻³mm²/s)   FA   T₂(ms)

DISTANCE FROM THE BONE-CARTILAGE INTERFACE TO THE ARTICULAR SURFACE

RESULTS: Asymptomatic vs. OA

MD $(\times 10^{-3} mm^2/s)$ FA T_2 (ms)

	Sensitivity	Specificity	Threshold
MD	90%	81%	1.20×10^{-3} mm^2/s
FA	80%	88%	0.25
T2	60%	68%	29 ms
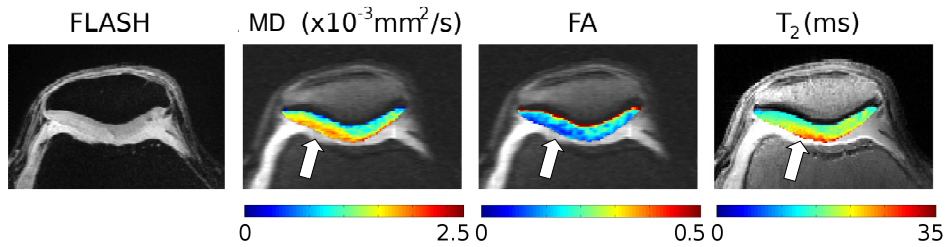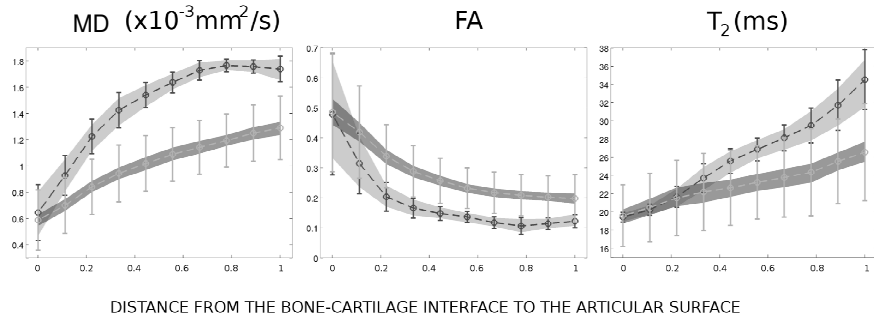
Healthy   OA   Healthy   OA   Healthy   OA
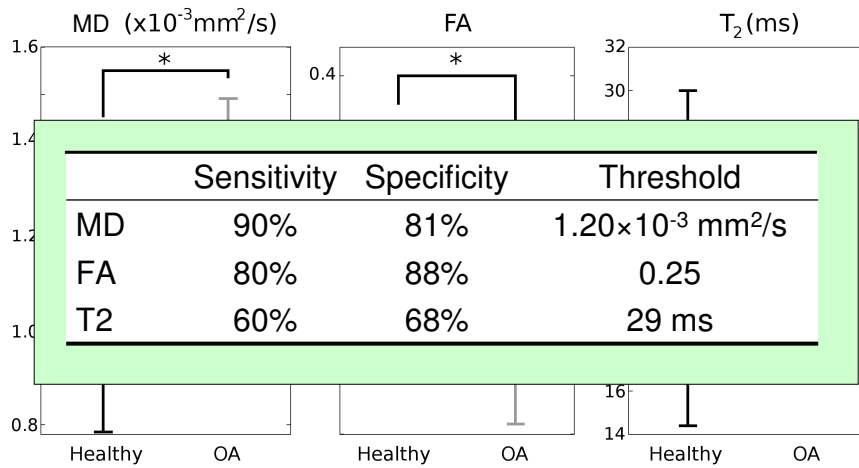
* P <0.01 (Wilcoxon test)

+ Outlier

LIMITATIONS

- Small number of patients, patient selection criteria

- Only 5 slices were acquired (SAR)

- Difference in age between asymptomatic and OA

- Test-retest reproducibility only in asymptomatic subjects

DISCUSSION AND CONCLUSION

- In vivo DTI of the articular cartilage is feasible

- Comparison between asymptomatic and OA subjects
    1. MD was significantly increased in OA (P<0.01)
    2. FA was significantly decreased in OA (P<0.01)
    3. T2 showed NO difference between asymptomatic and OA
        - Reduced dynamic of T2 at 7T
        - DTI is sensitive to earlier degeneration

- Diagnostic value of MRI parameters
    1. MD and FA has specificity and sensitivity 80–90%
    2. T2 had lower specificity and sensitivity 60–68%
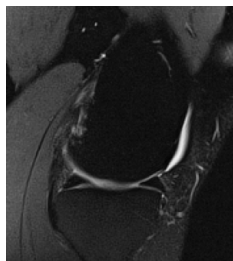
OUTLOOK: DTI OF ALL KNEE COMPARTMENTS

MD (10^{-3}mm^2/s) FA

ASYMPTOMATIC

OA (KL II)

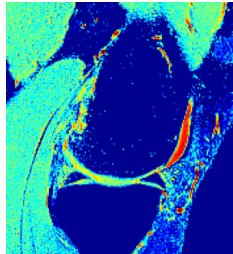0 —— ADC —— 2.5x10^3 (mm^2/s)

0 —— FA —— 0.5
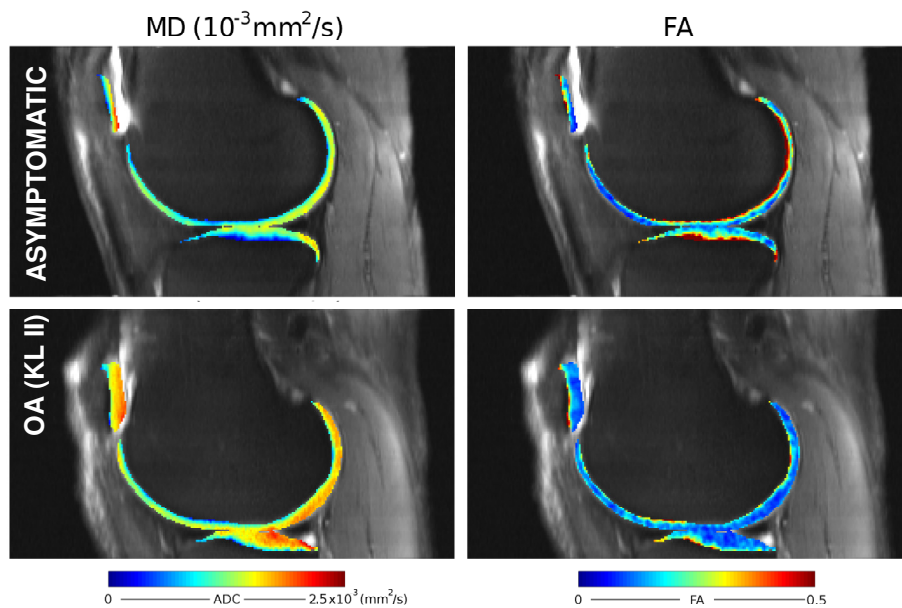
OUTLOOK: DTI OF CARTILAGE REPAIR
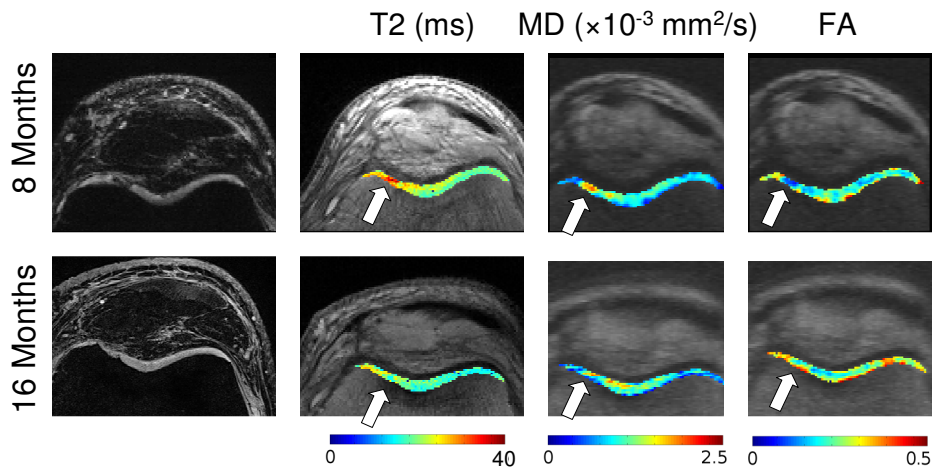
OUTLOOK: DTI AT 3T

Radial spin echo diffusion (RAISED) sequence
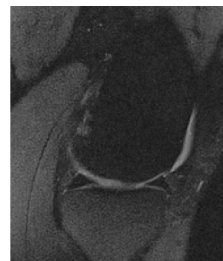(Resolution=0.6×0.6×3 mm^3, acquisition time 17:30 min, b=0, 400 s/mm^2)