Quantification of white matter fiber orientation at tumor margins with diffusion tensor invariant gradients
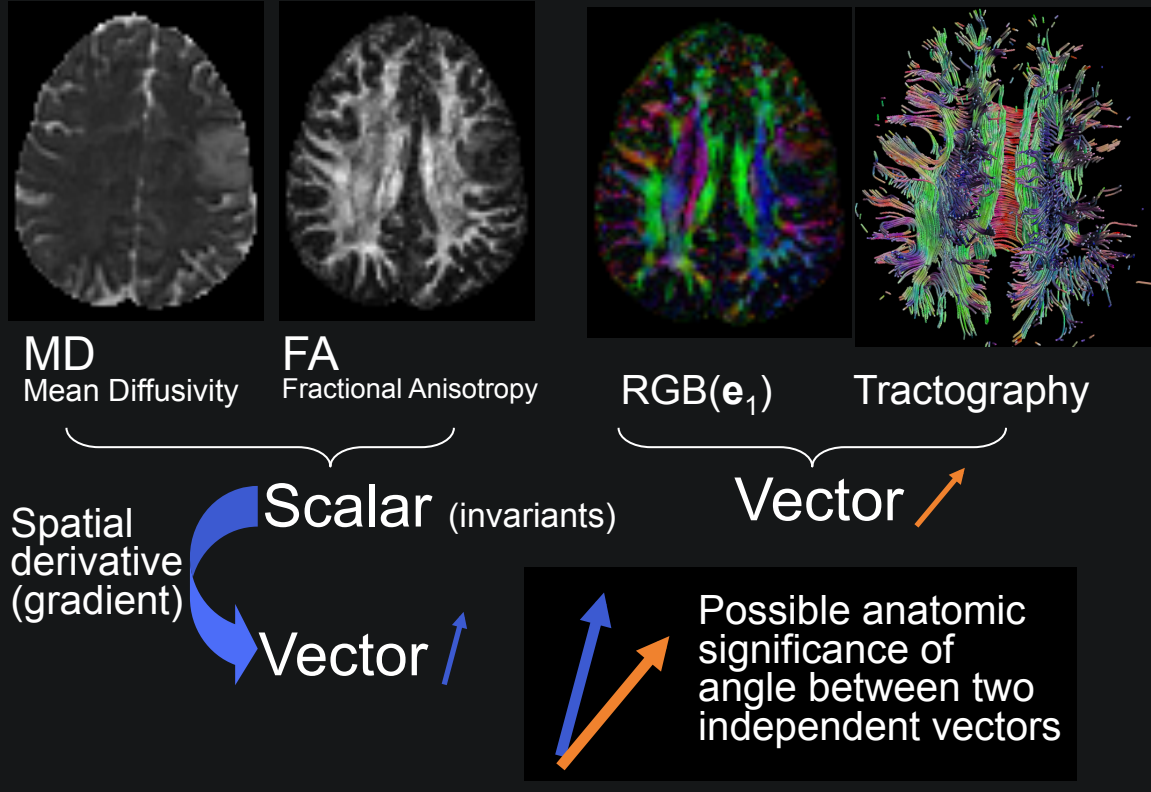
G Kindlmann[1], S Whalen[2], R O Suarez[2], A J Golby[2], C-F Westin[1]
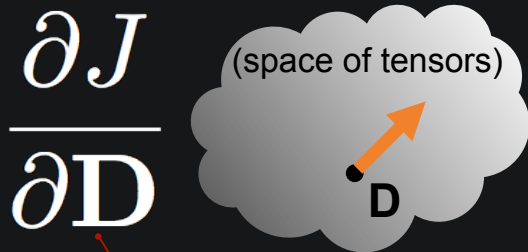
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Basic Idea

MD
Mean Diffusivity

FA
Fractional Anisotropy

RGB($\mathbf{e}_1$)

Tractography

Scalar (invariants)

Vector ↗

Spatial derivative (gradient)

Vector ↗

Possible anatomic significance of angle between two independent vectors

Technical Details: Measuring Spatial Gradients

Tensor-valued "gradients" of invariant J

$$\frac{\partial J}{\partial \mathbf{D}}$$

(space of tensors)

$\mathbf{D}$

[Ennis & Kindlmann MRM 55:136-146 (2006)]

Smooth continuous field: **cubic spline** through discrete samples

$$\frac{\partial \mathbf{D}}{\partial \mathbf{x}}$$

(image)

$\mathbf{x}$

[Pajevic et al. JMR 154:85-100 (2002)]

$$\nabla J = \frac{\partial J}{\partial \mathbf{x}} = \frac{\partial J}{\partial \mathbf{D}} \frac{\partial \mathbf{D}}{\partial \mathbf{x}} \qquad \hat{\nabla} J = \frac{\nabla J}{|\nabla J|}$$

Definition of New Metrics

$$\mathrm{Da(FA)} \approx 0 \quad \widehat{\nabla}\mathrm{FA} \quad \widehat{\nabla}\mathrm{MD} \quad \mathrm{Da(MD)} \approx 0$$

e_1

(tumor)

Displacement:

FA lower

MD higher

Disruption/Infiltration:

$$\mathrm{Da(FA)} \approx 1 \quad \widehat{\nabla}\mathrm{FA} \quad \widehat{\nabla}\mathrm{MD} \quad \mathrm{Da(MD)} \approx 1$$

e_1

$$J = \mathrm{FA \ or \ MD}$$

Diffusion alignment: $\mathrm{Da}(J) = 1 - 2\cos^{-1}(|\mathbf{e}_1 \cdot \widehat{\nabla} J|)/\pi \in [0,1]$

Diffusion fraction: $\mathrm{Df}(J) = \widehat{\nabla} J^{\mathsf{T}} \mathbf{D} \widehat{\nabla} J / \mathrm{Tr}(\mathbf{D}) \in [0,1]$

Intuition, with Known Anatomy

$$\mathrm{Da(FA)} \approx 1$$

Gyral Ridge

$\widehat{\nabla}\mathrm{FA}$

Sulcal Bank

$$\mathrm{Da(FA)} \approx 0$$

$\widehat{\nabla}\mathrm{FA}$

e_1

Cortical Gray/White Matter

Da(FA)

1.0

0.0

Df(FA)

0.41

0.26

Clinical data: Grade II Oligodendroglioma

Da(MD)

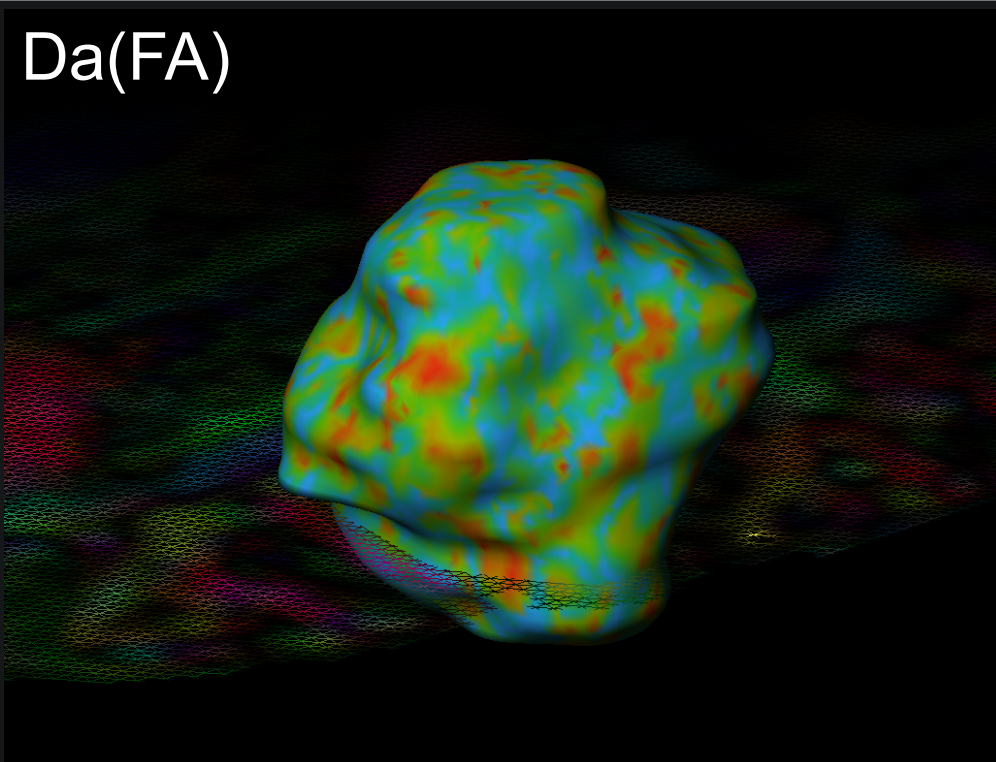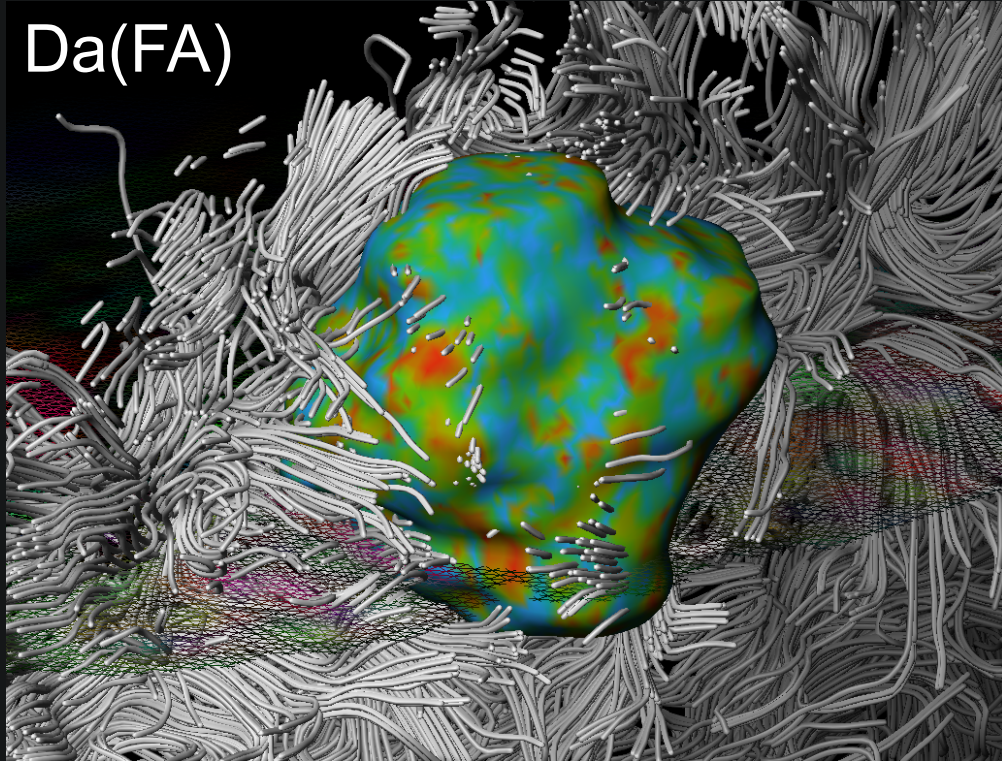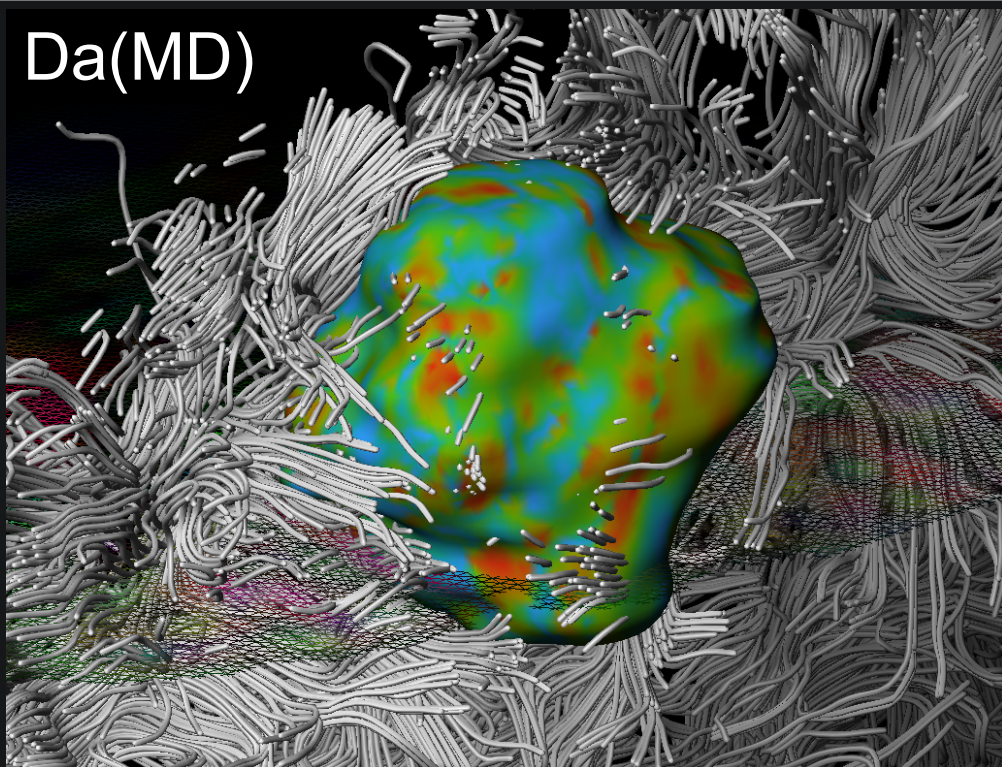Clinical data: Grade II Oligodendroglioma
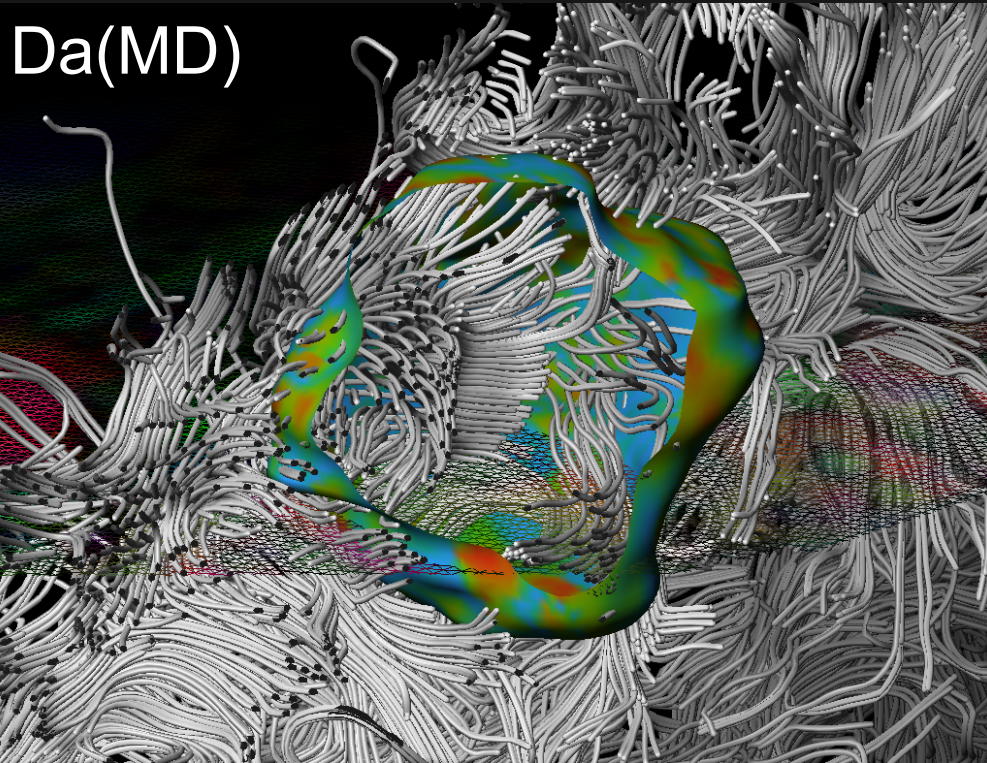
Da(FA)

Clinical data: Grade II Oligodendroglioma

Da(FA)

Clinical data: Grade II Oligodendroglioma

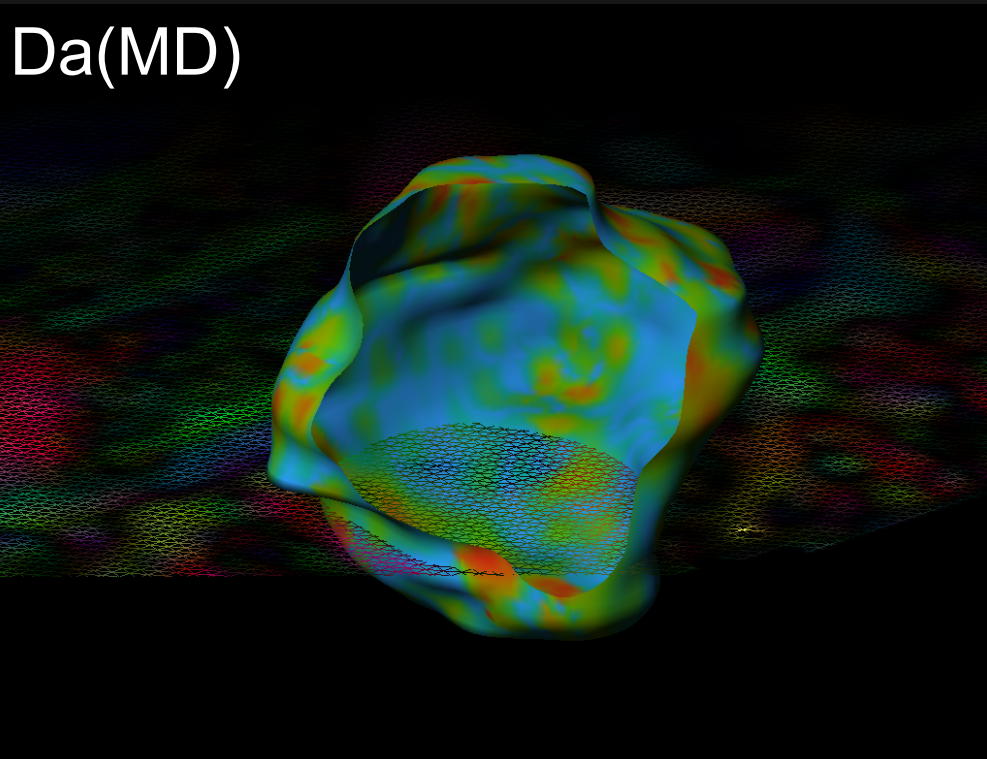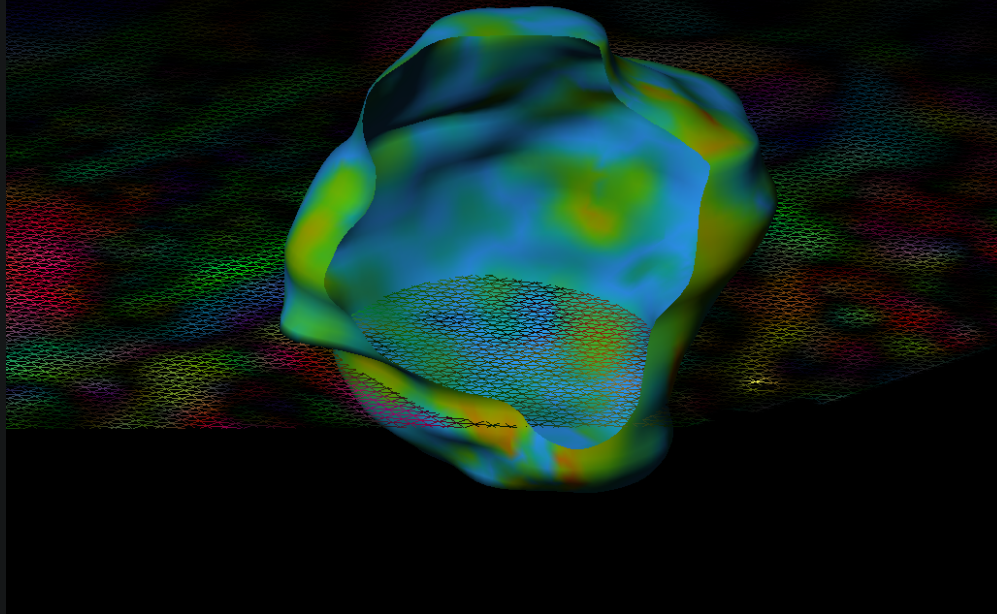Da(MD)

Clinical data: Grade II Oligodendroglioma

Da(MD)

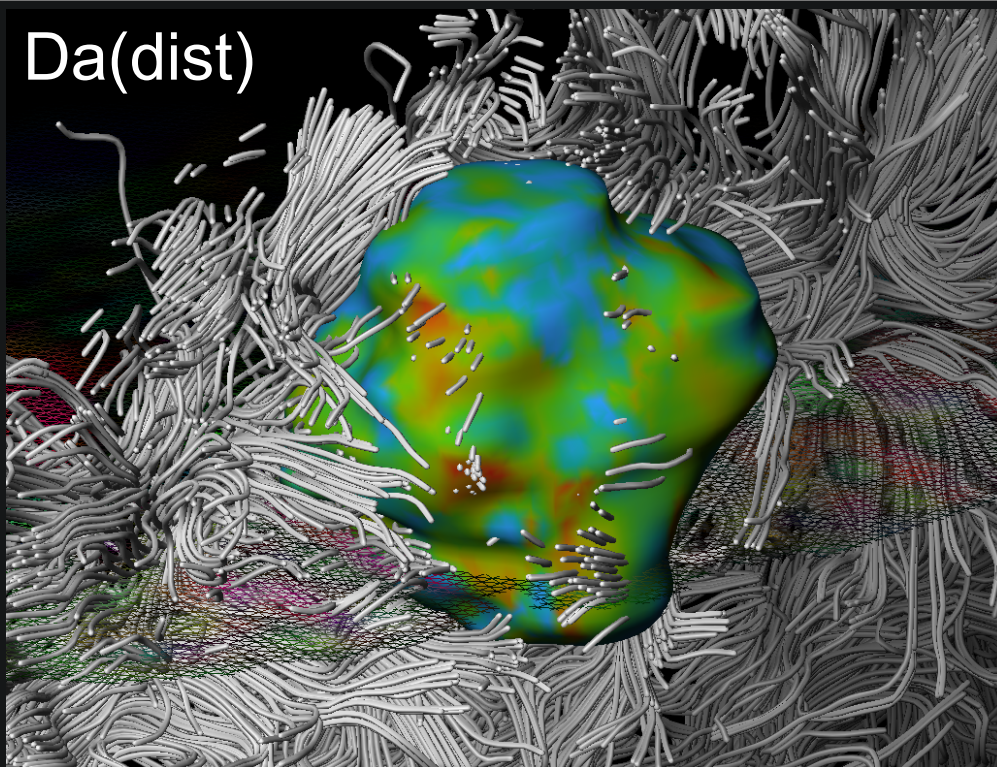

Clinical data: Grade II Oligodendroglioma

Da(MD)

Clinical data: Grade II Oligodendroglioma

Da(dist) (distance map of tumor segmentation)
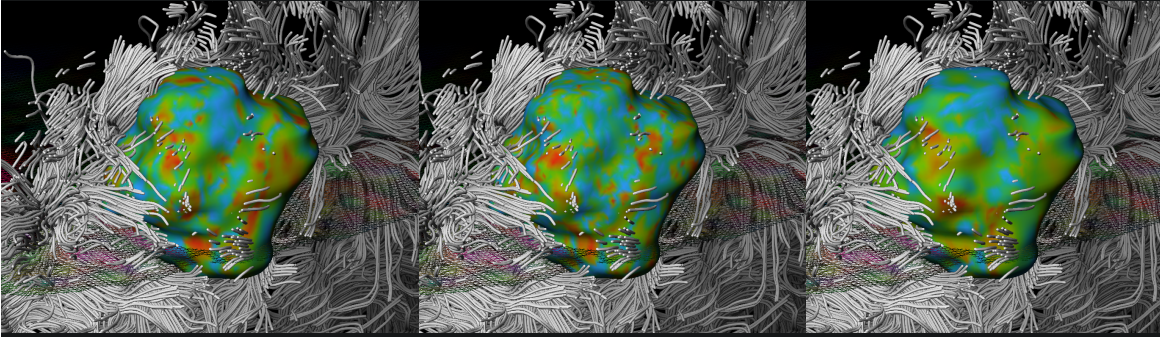

Clinical data: Grade II Oligodendroglioma

Da(dist)

Clinical data: Grade II Oligodendroglioma

Da(MD)   Da(FA)   Da(dist)

- Visualization of new metrics influenced by segmentation, though metrics don't depend on it

- Investigating integrals of metrics over whole tracts for tract classification (deflected vs displaced)

Conclusions

- New Metrics:
    - Diffusion Angle (Da) & Diffusion fraction (Df)
    - Quantify fibers relative to affected regions

- More evaluation required

- Different strategy: one vs. two model properties

- Thank you.

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