Understanding White Matter Neuroanatomy using Diffusion Tensor Imaging

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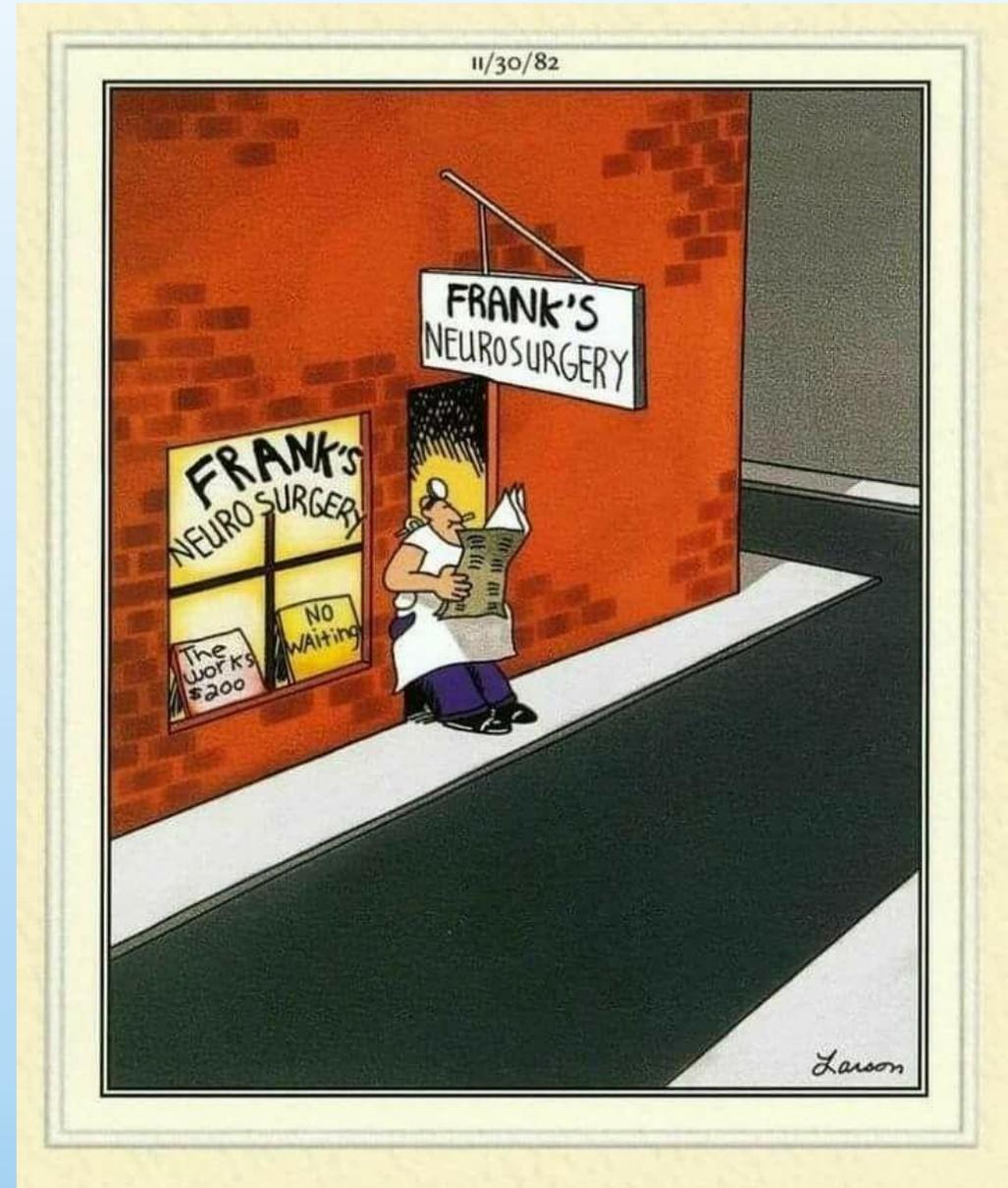THE UNIVERSITY OF KANSAS HOSPITAL

# Disclosures:

- No relevant disclosures

Objectives

- Understand the basic principles of diffusion tensor imaging.

- Understand basic white matter functional neuroanatomy.

- Understand how does a neuropsychologist makes use of white matter tractography to predict risk in neurosurgery?

- Understand the importance of collaboration and neuropsychologist integration into the neurosurgery team

Why Does Any of This Matter?
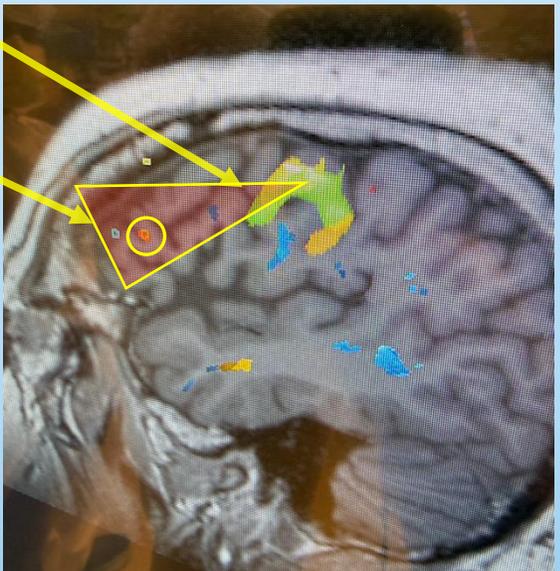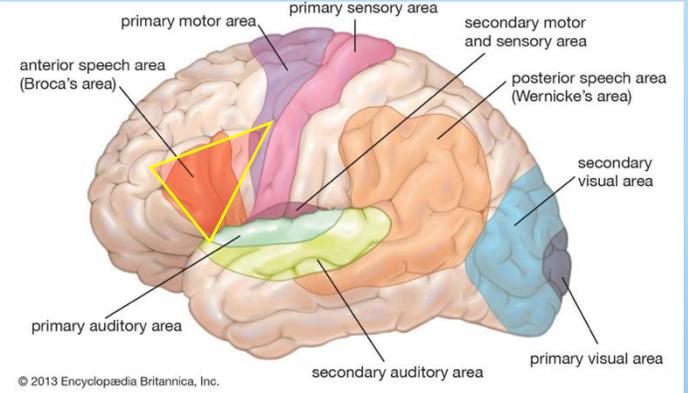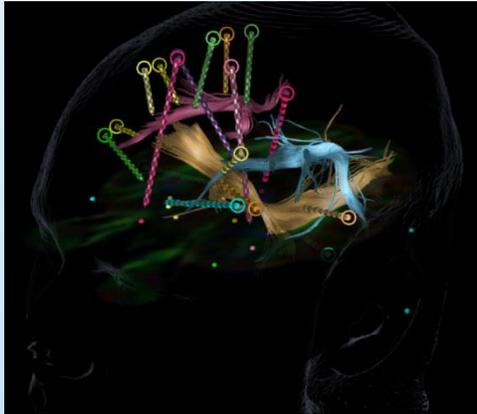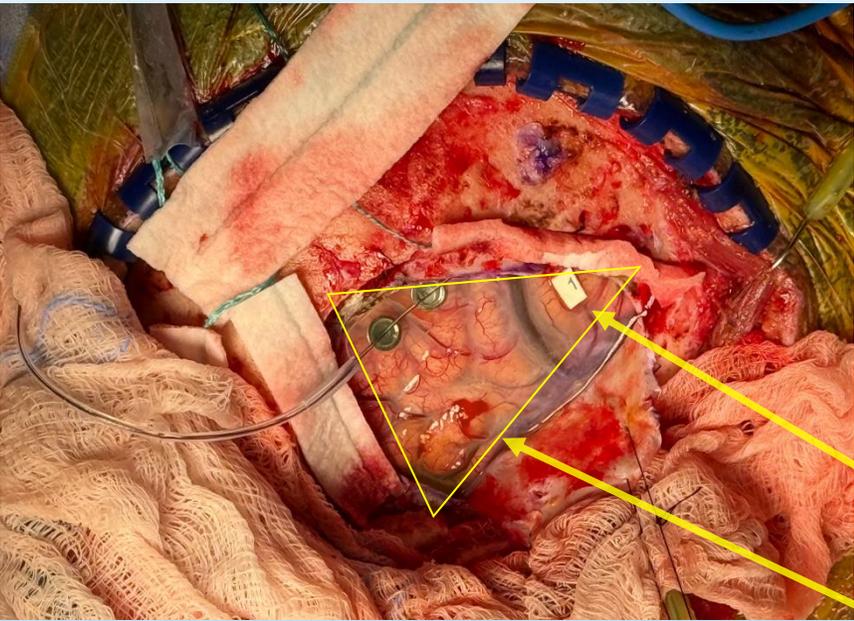
# Why Does Any of This Matter?
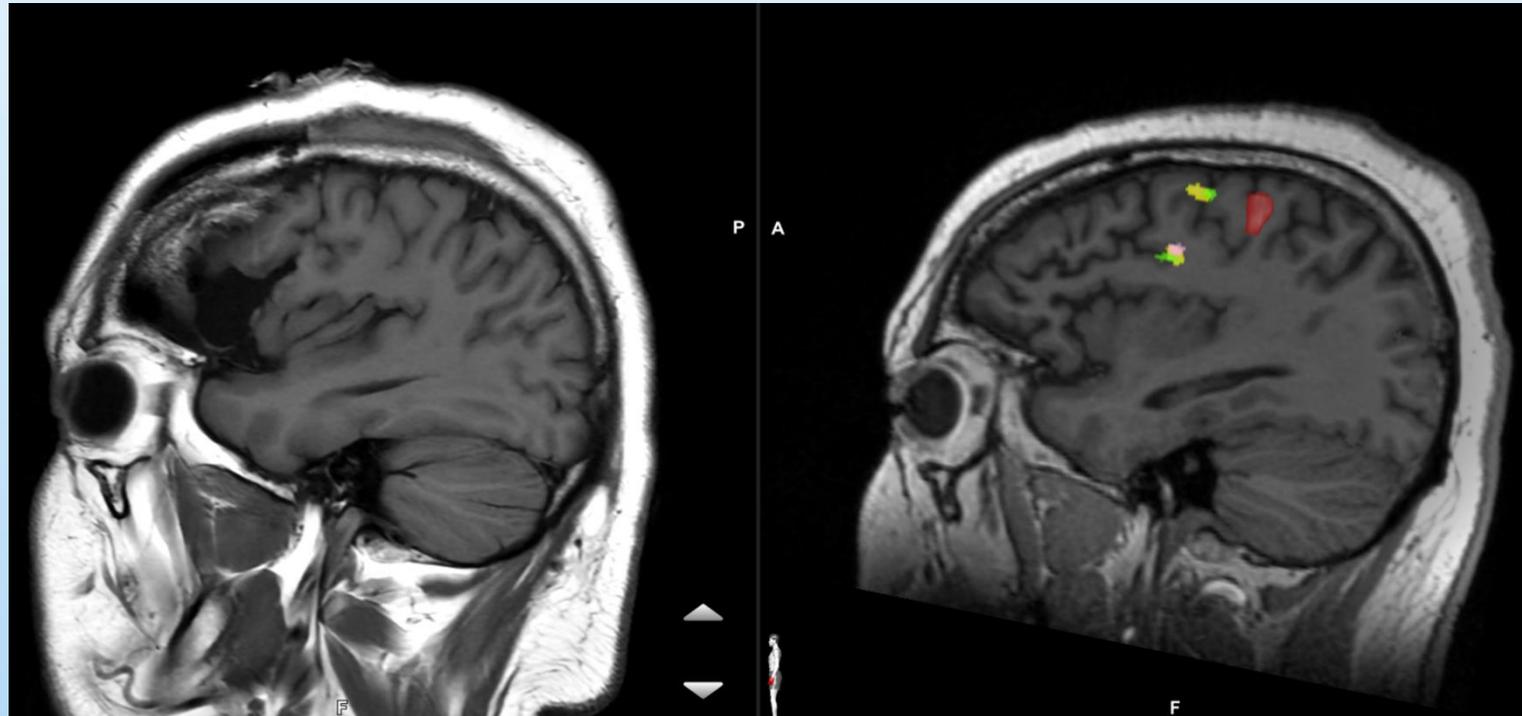
Since discharge, he has not had further seizures. He denies new language deficits or neurological changes postoperatively, except for confusion on the day of the seizures. He currently experiences intermittent head pain, which has improved and is managed with occasional acetaminophen; he has not required oxycodone recently. No ongoing symptoms related to COVID-19.
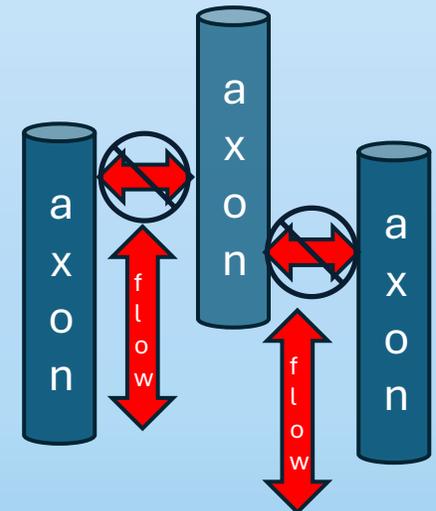
Diffusion Tensor Imaging

- DWI is a standard (with some modifications to make it DTI) MR study that measures the diffusivity/movement of water molecules in the brain.
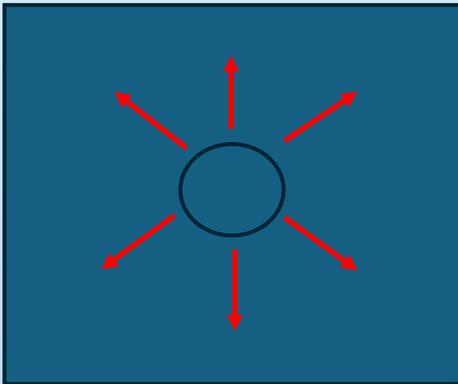
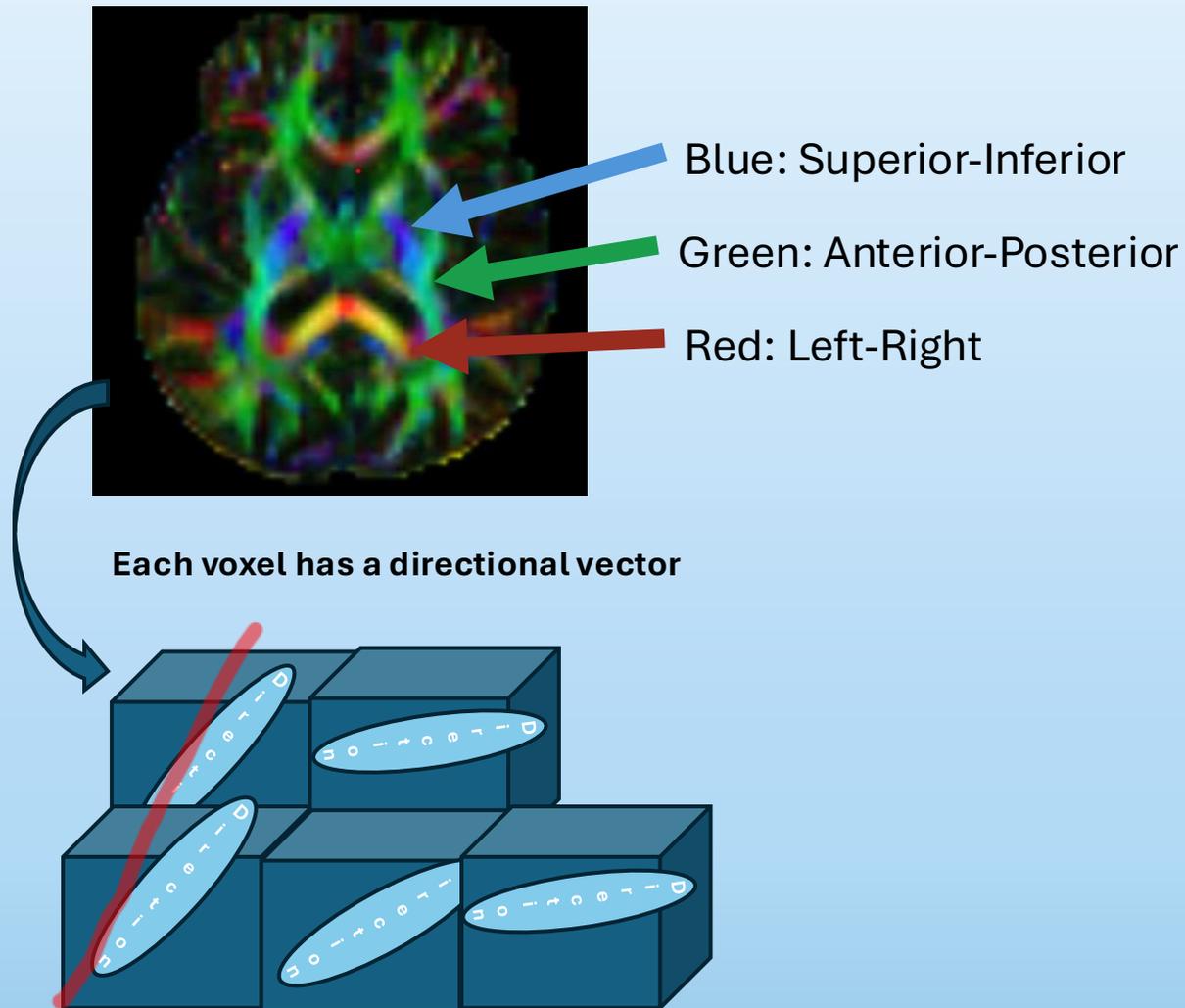Diffusion can be quantified by summing up the movement vectors in all directions. Unhindered diffusion vectors cross each other out and sum to zero (uniform or **isotropic diffusion**).

Myelin restricts the direction of water diffusion because the water can't diffuse through fat. There is restricted diffusion in a particular direction. The flow depicts directional, or **anisotropic diffusion, or fractional anisotropy**.

Processing Diffusion Images Into Tractography

Blue: Superior-Inferior

Green: Anterior-Posterior

Red: Left-Right

Each voxel has a directional vector

Programs use either **deterministic** or **probabilistic** modeling to determine which voxels most logically define a tract using some constraints such as angle or fractional anisotropy as a cutoff value.

Typically, a starting box (**region of interest** – ROI) is manually defined by the user, then the program marches through neighboring voxels until it either loses a coherent direction (e.g., too sharp of an angle) or suffers a loss of fractional anisotropy.

Completed Tractograms!
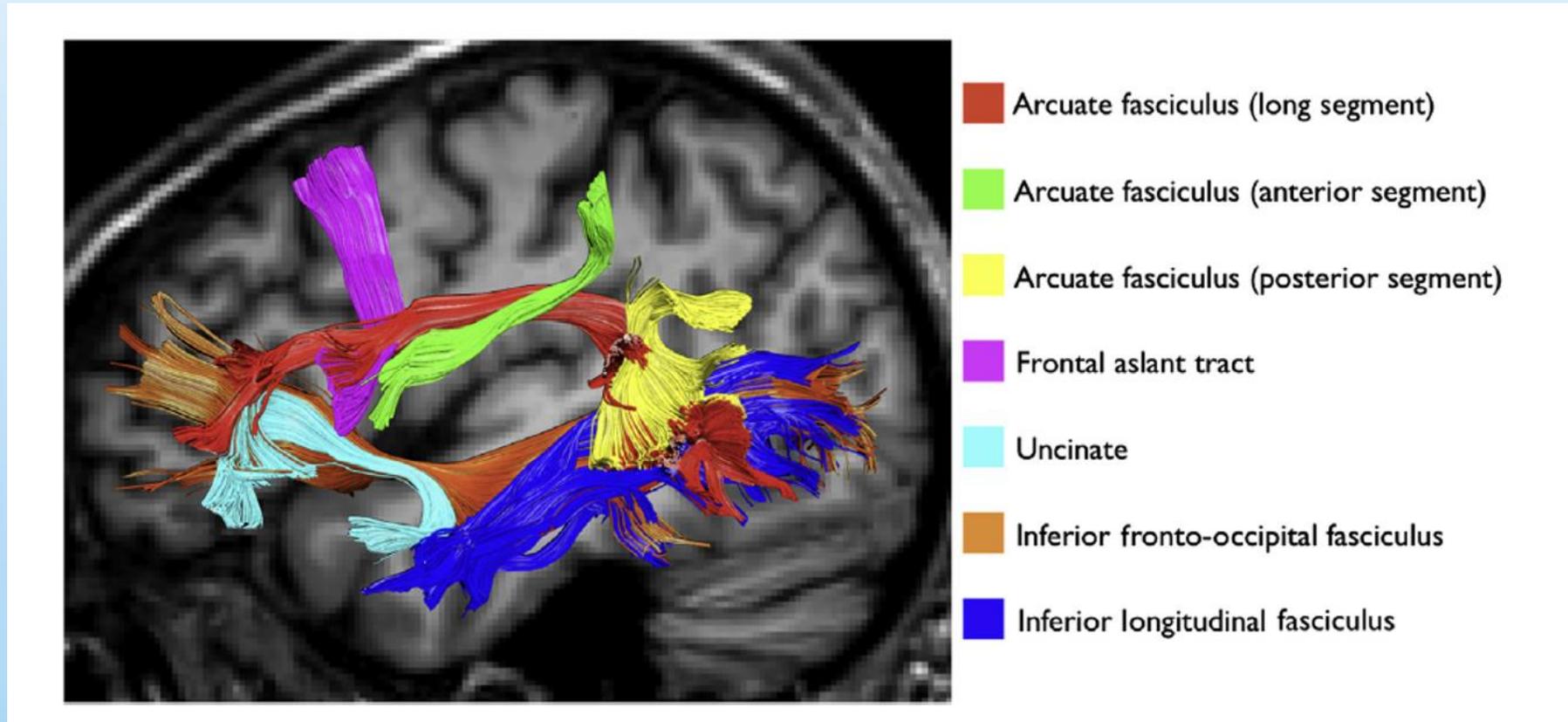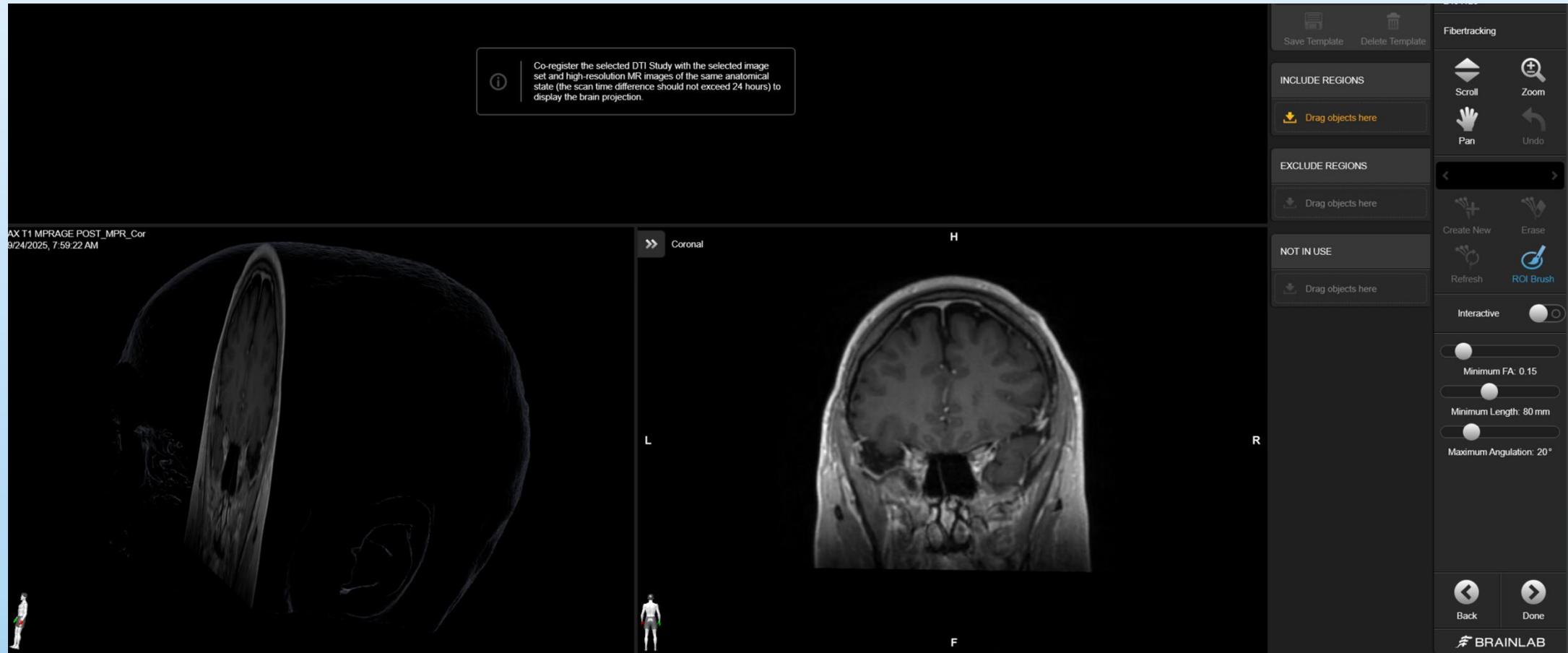
Co-Registering Tractogram

Example of ROI Analysis from Brain Lab

Example of ROI Analysis from Brain Lab

Example of ROI Analysis from Brain Lab

Example of ROI Analysis from Brain Lab

Example of ROI Analysis from Brain Lab

Pre-Programed ROI Tract vs. Hand Drawn
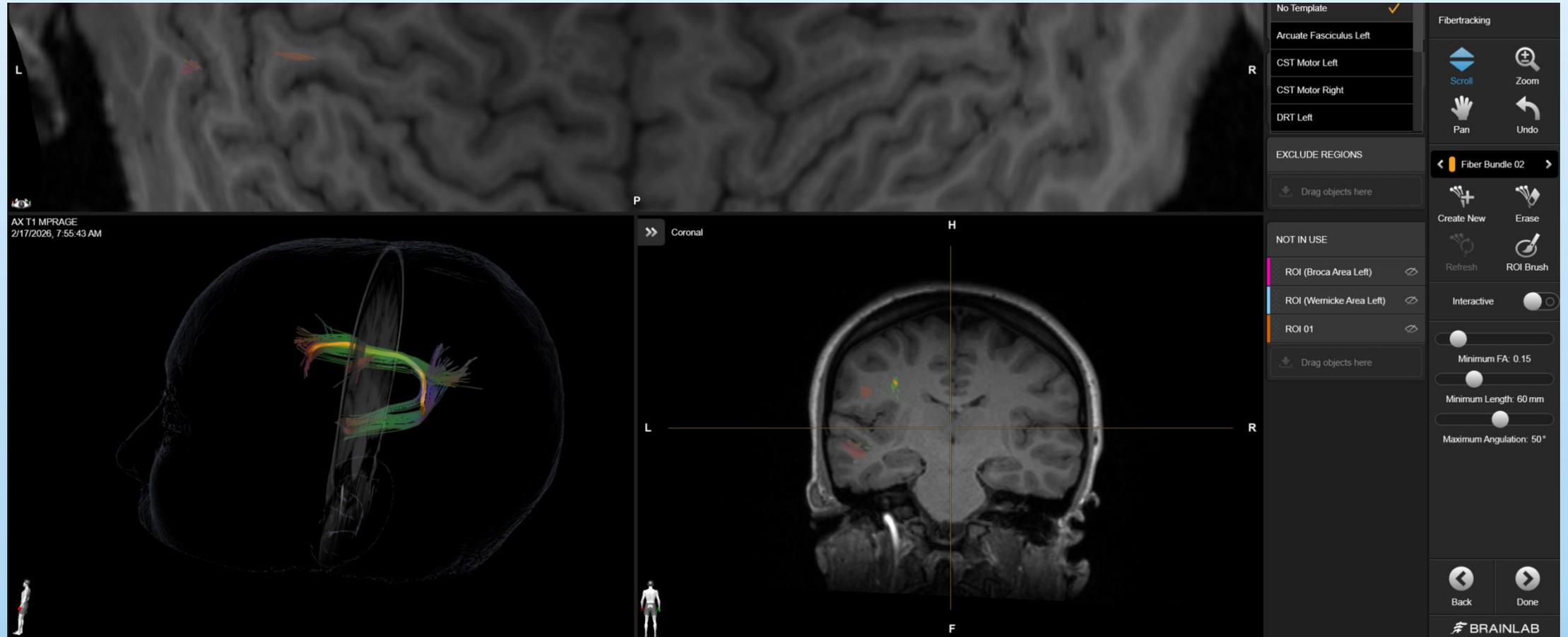
Pre-Programed ROI Tract vs. Hand Drawn
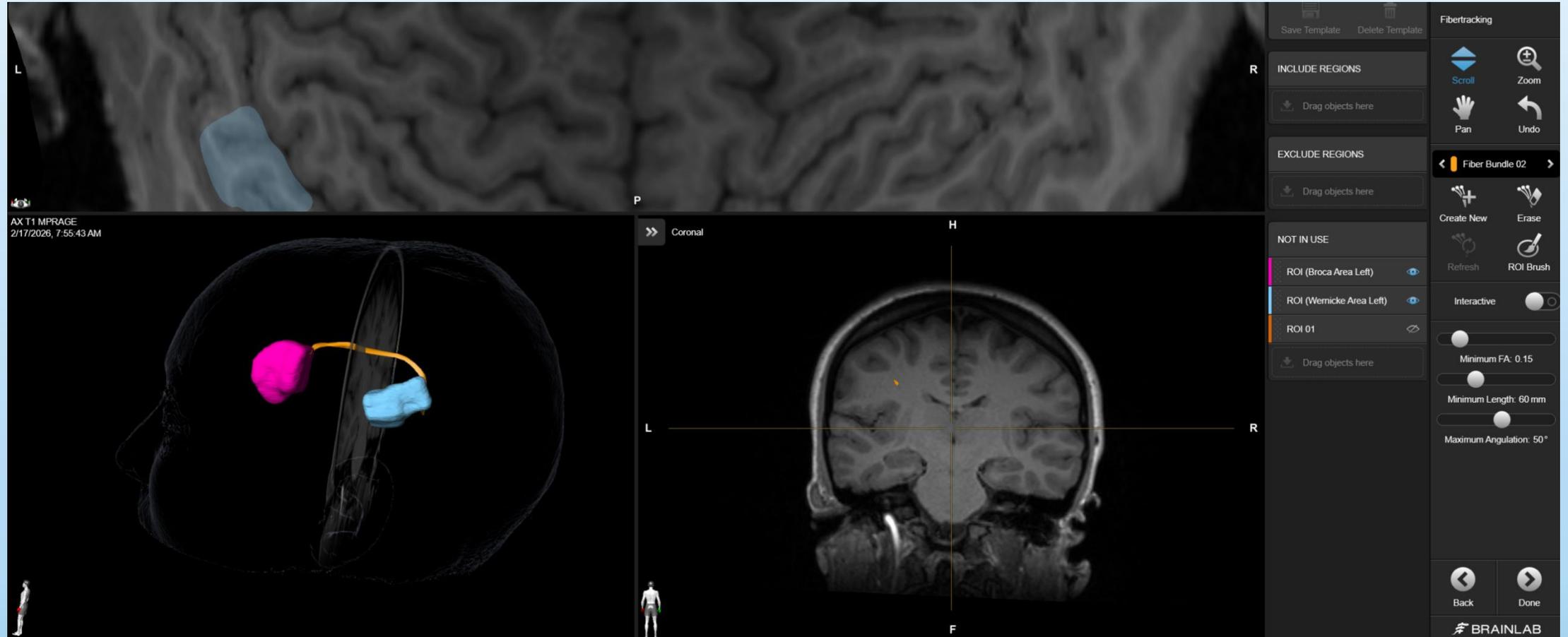
Completed Tractogram
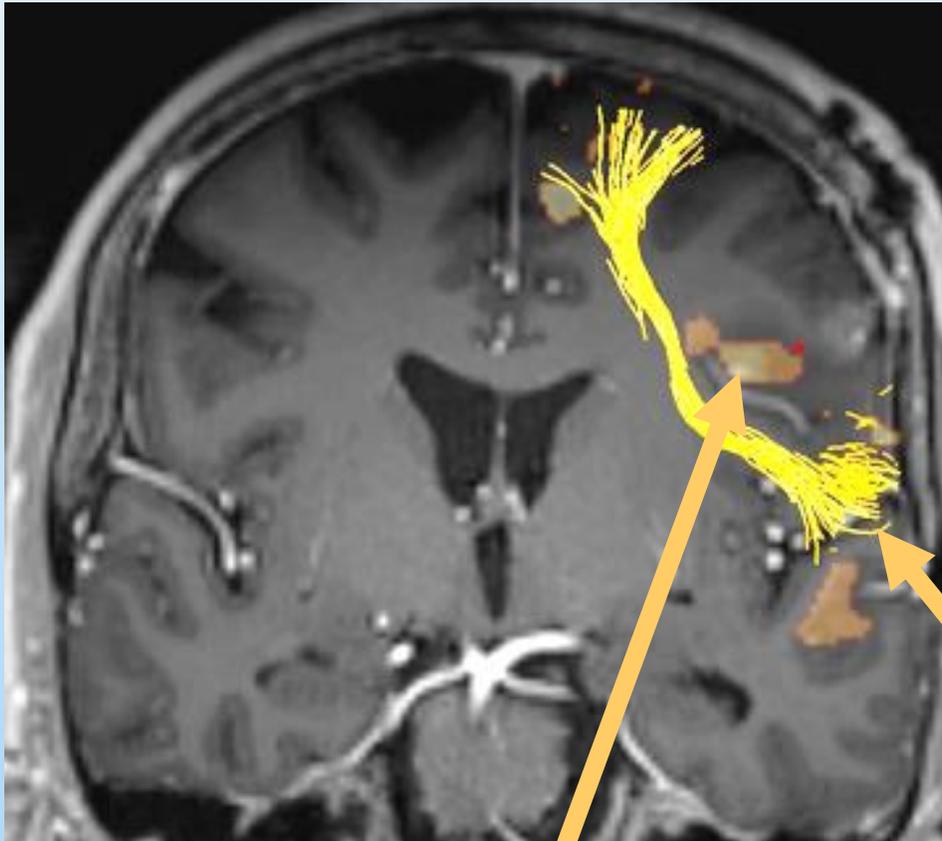
Tractograms are combined (merged) with structural and functional MR images to create a final product.

Images can be viewed on either a neuronavigation program such as Brain Lab or Stealth or can be imported into PACS.

Frontal Aslant Tract (FAT)

Expressive language fMRI activity

Completed Tractogram Continued
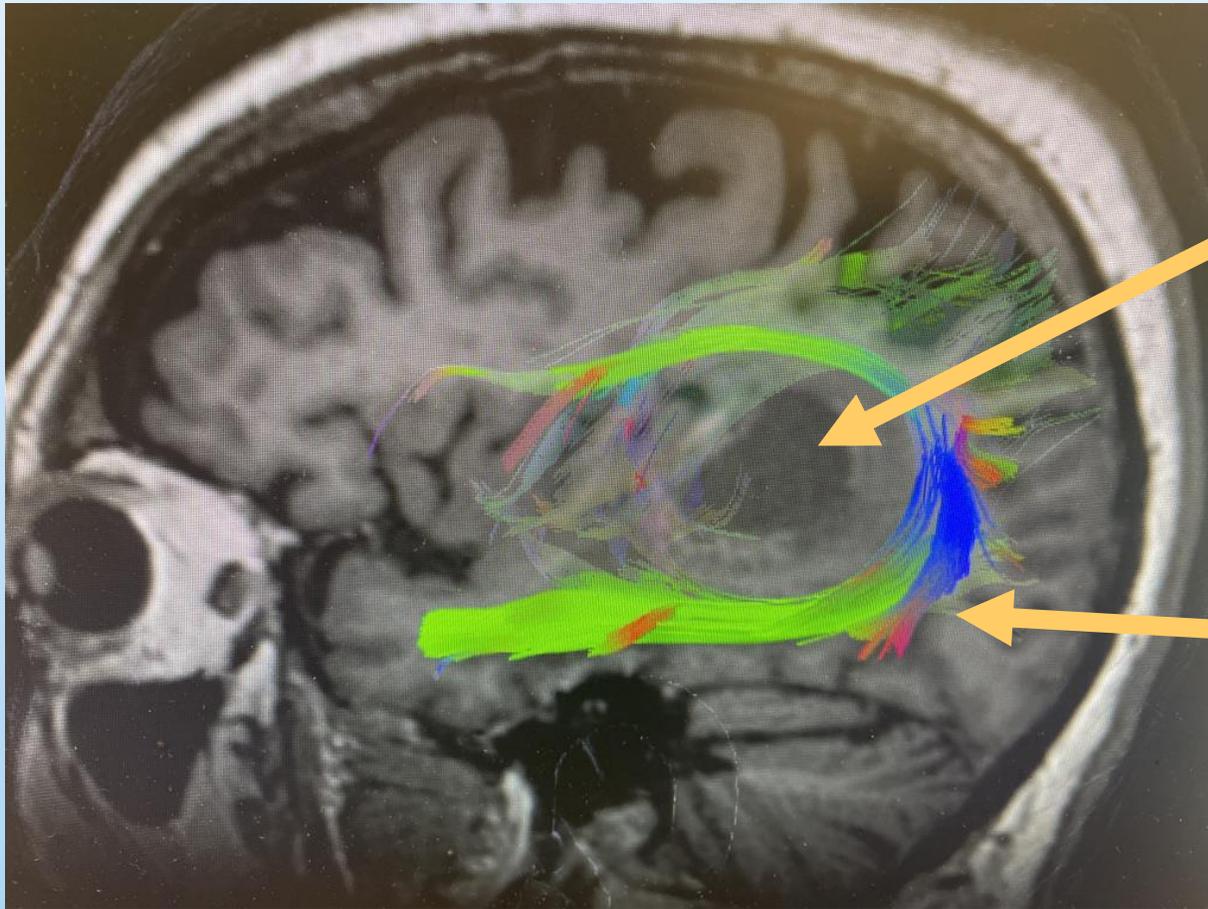
Large cystic mass underlying the supramarginal gyrus and temporal lobe.

Tractogram showing portions of the Arcuate Fasciculus and Inferior Longitudinal Fasciculus.

What If There Is No Underlying DTI Data?
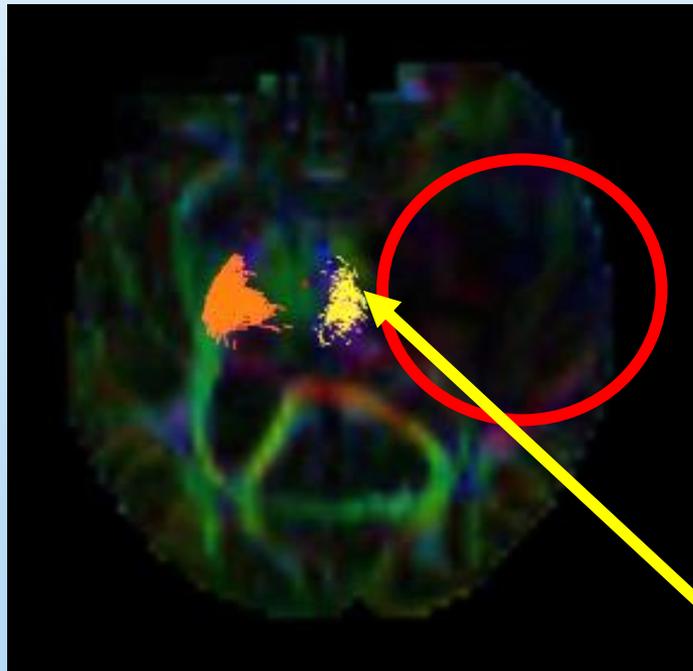
Tumor edema causes loss of diffusion signal (restricted diffusion)
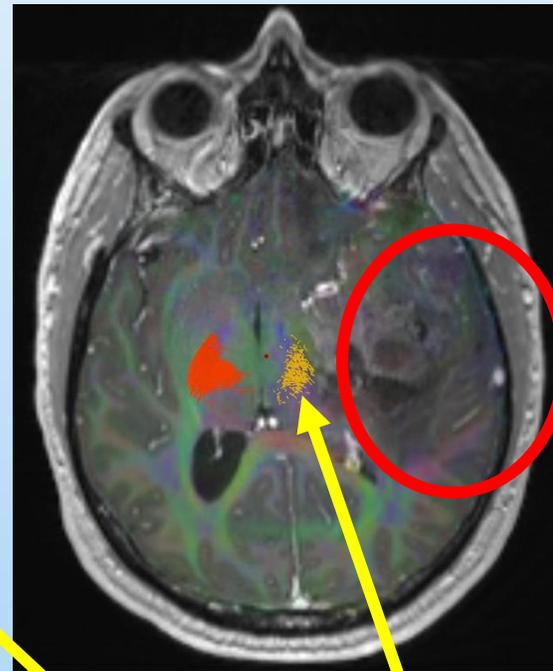
The posterior limb of the internal capsule (the corticospinal tract) is deflected to the left due to mass effect
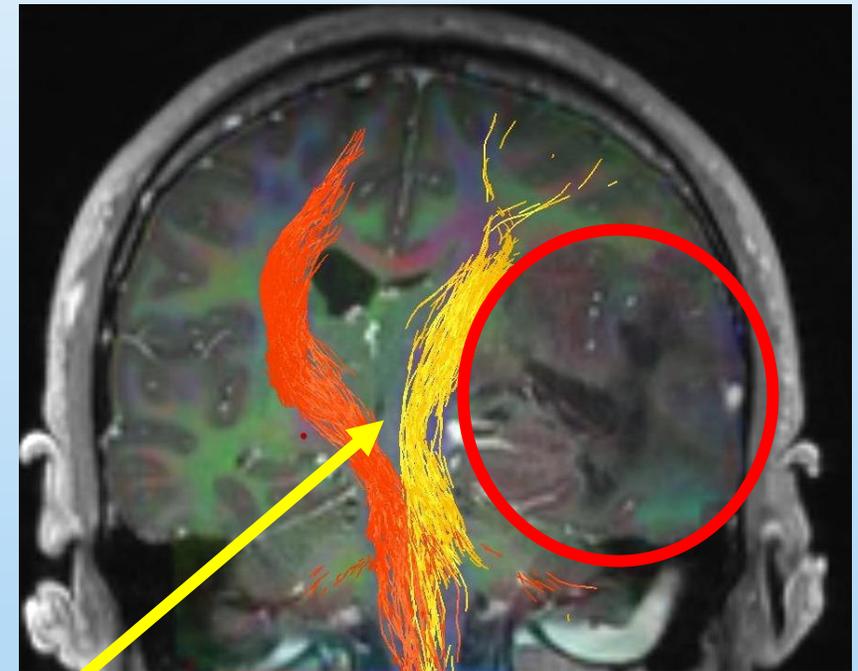
What If There Is No Underlying DTI Data Continued

The right CST is smaller compared to the left. Is this anatomical (compacted by mass effect) or is there missing data?

While the neurosurgeon will see that this corticospinal tract on the right is anterior to the lesion, it is possible that part of the CST overlaps with the AVM. This needs to be communicated directly with the surgeon (possible false negative error!).
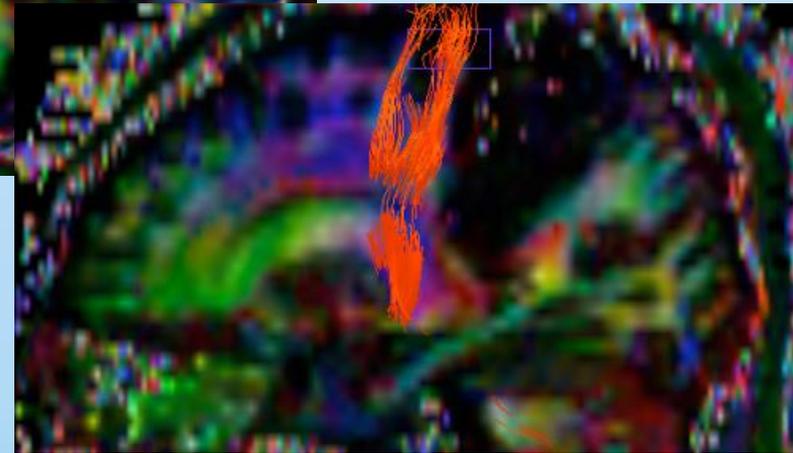
Functional Neuroanatomy of White Matter

- Tracts to be most familiar with:

  - Language Tracts

  - Cortical Spinal Tract

  - Optic Radiations

  - Other Tracts

Dominant Arcuate Fasciculus
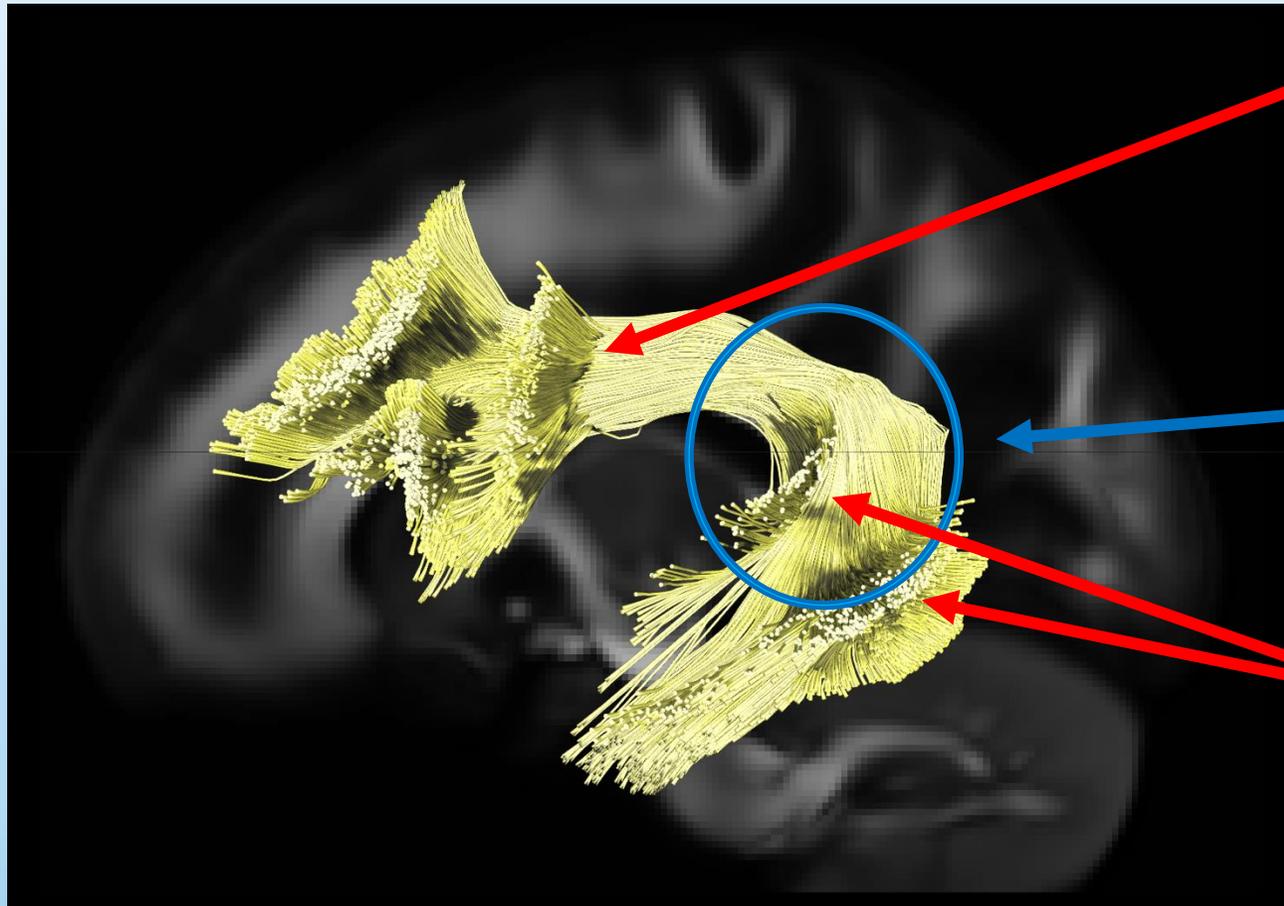
Direct connections to Ventral Premotor Language Area (area 55b).

- Non-fluent Speech

Area particularly sensitive to cortical stimulation mapping:

- Phonemic Language
- Repetition

Direct connections to Wernicke's distributed network.

- Phonemic Aphasia
- Conduction Aphasia

Dominant Inferior Frontal Occipital Fasciculus
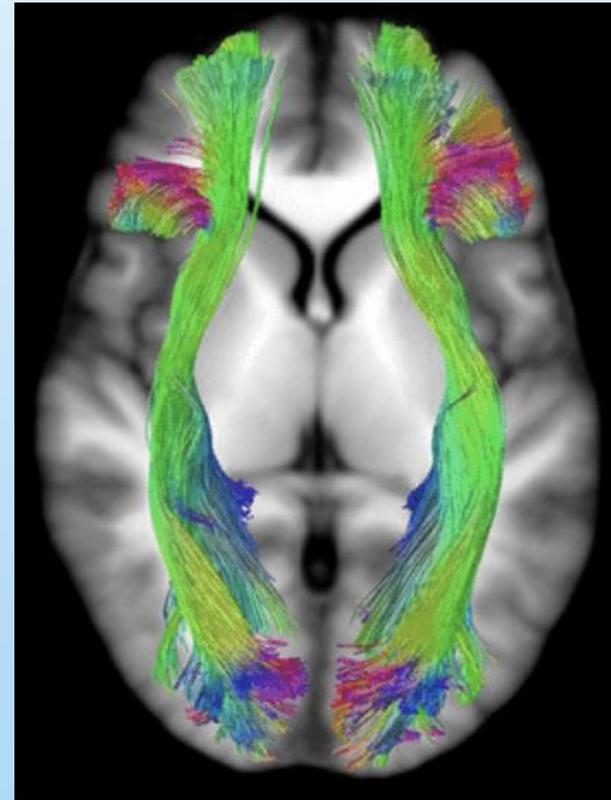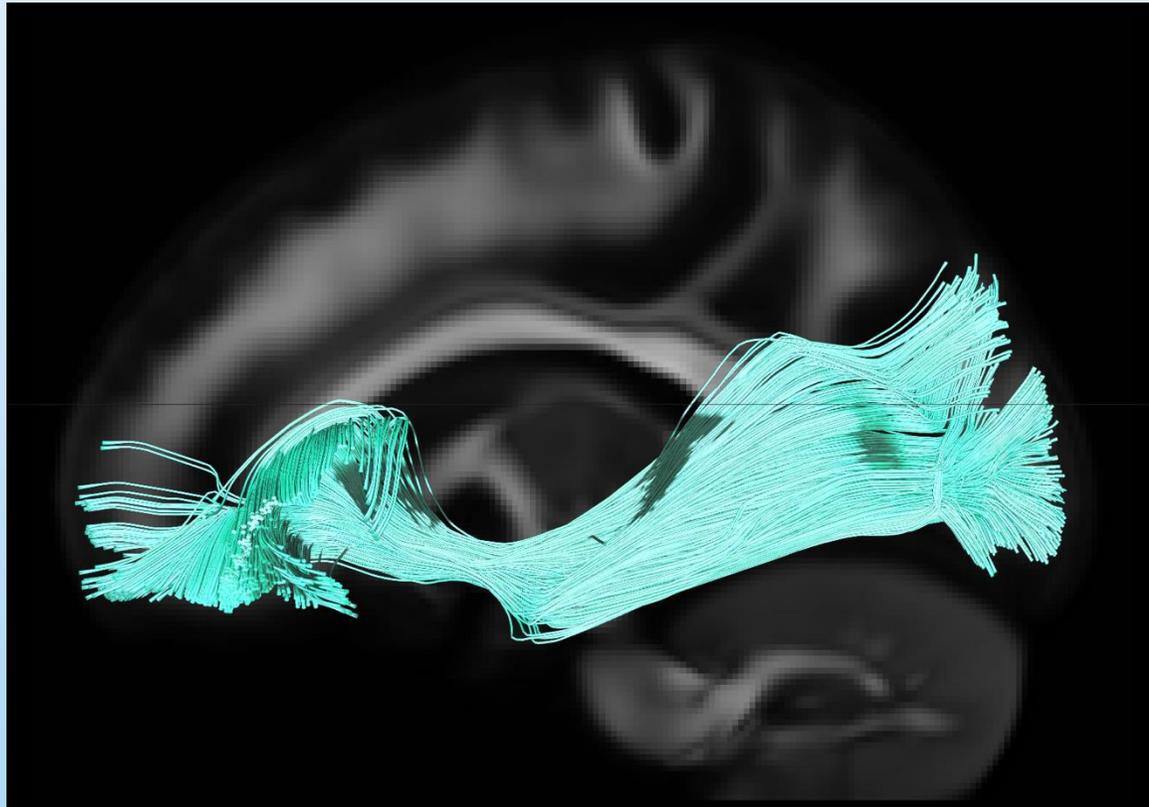
Inferior Frontal Occipital Fasciculus Continued
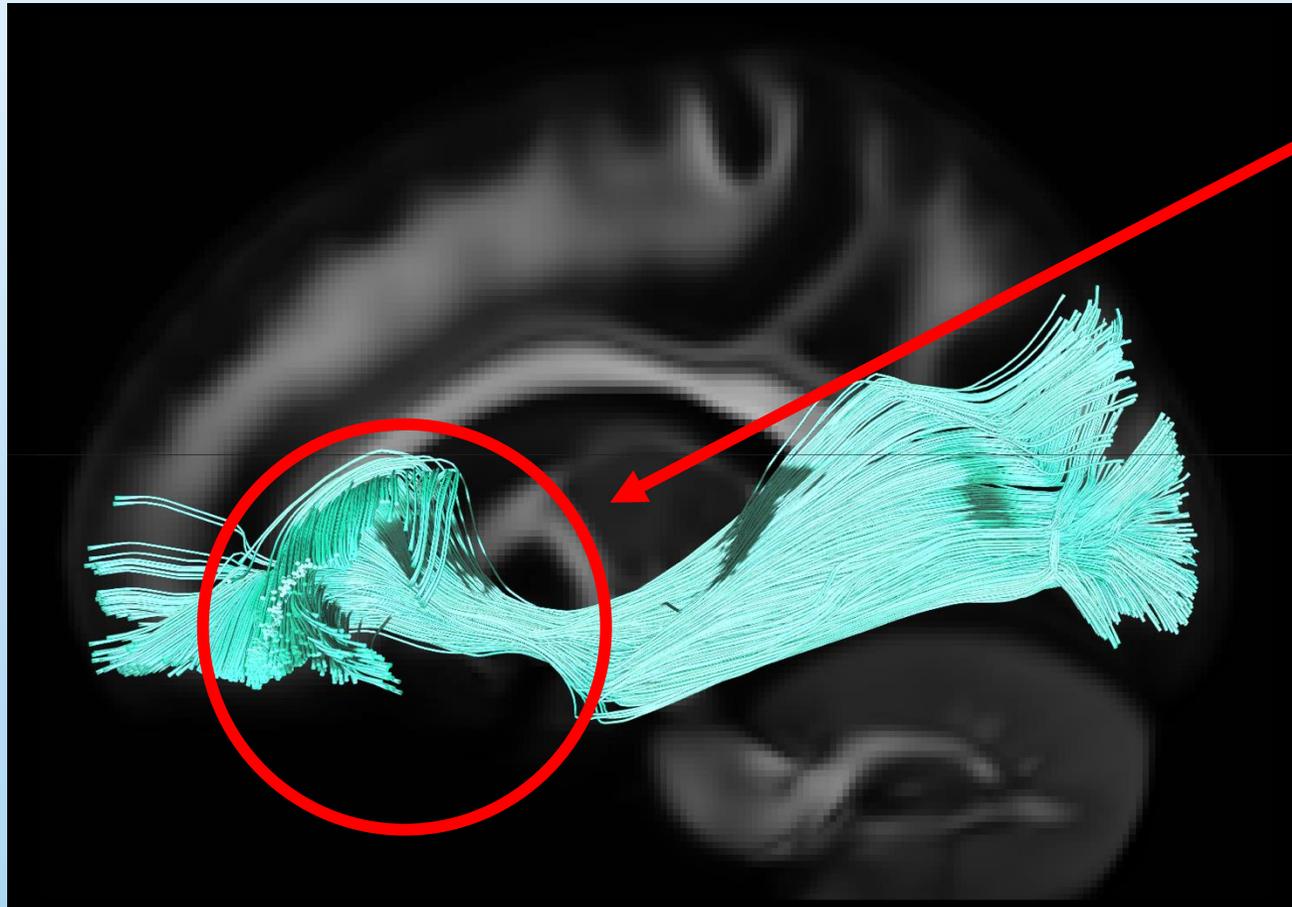
IFOF is considered a major semantic language structure. Damage to this (particularly anteriorly) can lead to semantic paraphasic errors.

This is a...
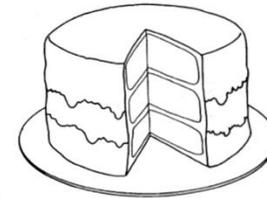
This is a...

Voxel-Based Lesion-Symptom Analysis of IFOF

CrossMark

ORIGINAL ARTICLE

The left inferior fronto-occipital fasciculus subserves language semantics: a multilevel lesion study

Fabien Almairac · Guillaume Herbet · Sylvie Moritz-Gasser ·
Nicolas Menjot de Champfleur · Hugues Duffau

Dominant Inferior Longitudinal Fasciculus
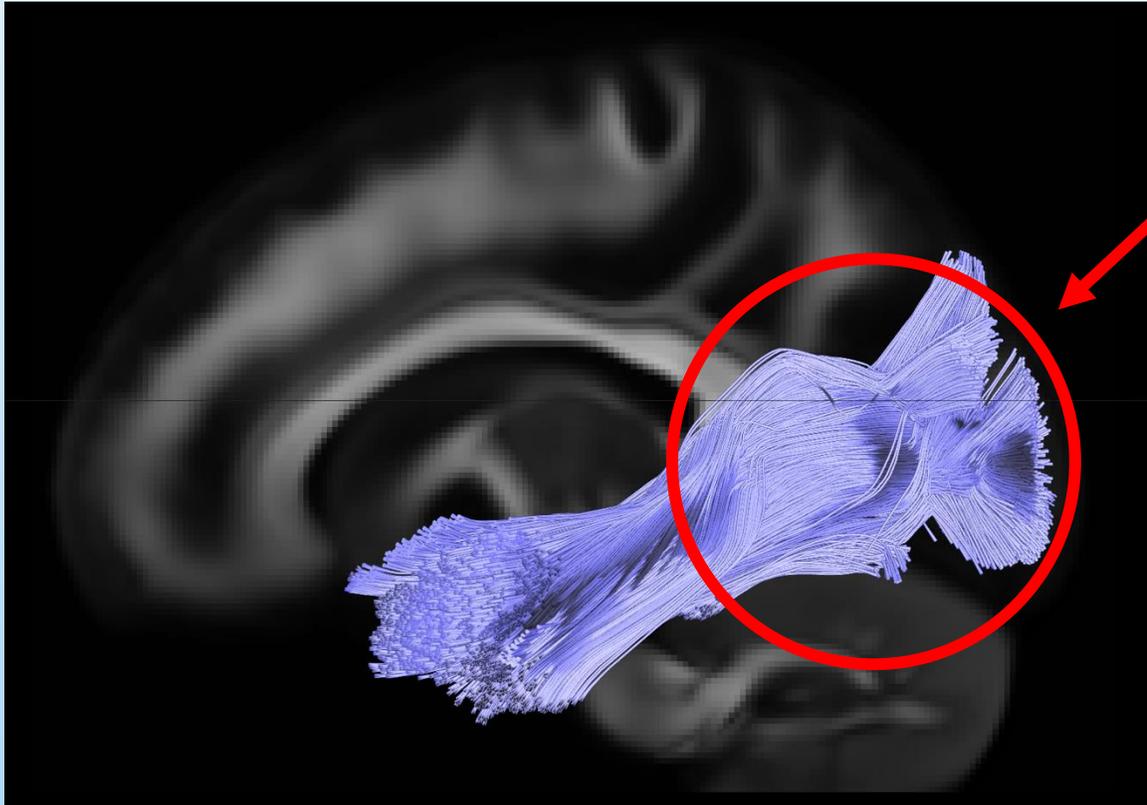
The ILF (along with the IFOF and UF) is associated with semantic language and is often associated with naming deficits on cortical stimulation mapping.

Thought to be a part of the dorsal stream and therefore subserve object recognition.

Inferior Longitudinal Fasciculus Continued

Check for updates
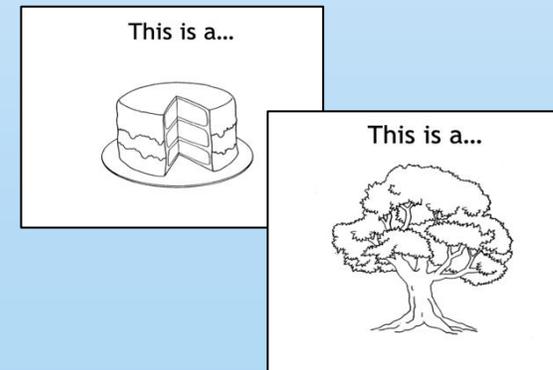
Functional Anatomy of the Inferior Longitudinal Fasciculus: From Historical Reports to Current Hypotheses

Guillaume Herbet[1,2,3]*, Ilyess Zemmoura[4,5] and Hugues Duffau[1,2,3]

[1] Department of Neurosurgery, Gui de Chauliac Hospital, Montpellier University Medical Center, Montpellier, France,
[2] INSERM-1051, Team 4, Saint-Eloi Hospital, Institute for Neurosciences of Montpellier, Montpellier, France, [3] University of Montpellier, Montpellier, France, [4] Department of Neurosurgery, Tours University Medical Center, Tours, France, [5] UMR 1253, iBrain, INSERM, University of Tours, Tours, France

Inferior longitudinal Fasciculus Continued

RESEARCH ARTICLE

WILEY

Deficits in naming pictures of objects are associated with glioma infiltration of the inferior longitudinal fasciculus: A study with diffusion MRI tractography, volumetric MRI, and neuropsychology

Costanza Papagno[1,2] | Riccardo Pascuzzo[3] | Camilla Ferrante[4] | Alessandra Casarotti[5] | Marco Riva[5,6] | Luigi Antelmi[3] | Antonio Gennari[3] | Giulia Mattavelli[7,8] | Alberto Bizzi[3]

TABLE 7 Model 2 results showing the association of ILF damage with each neuropsychological test before surgery, adjusted for the other tests.

Neuropsychological test	Coefficient estimate (SE)	Adjusted odds ratio (95% CI)	z-score	p-value
Object naming	0.316 (0.146)	1.372 (1.098–1.928)	2.166	.0303*
Phonemic fluency	0.001 (0.040)	1.001 (0.925–1.086)	0.027	.9787
Semantic fluency	−0.070 (0.048)	0.932 (0.841–1.021)	−1.465	.1429
TMT	−0.007 (0.010)	0.993 (0.972–1.013)	−0.703	.4822
Model intercept	−10.022 (6.201)	4×10^{-5} (3×10^{-11}–0.404)	−1.616	.1061

Note: Significant values are indicated with an asterisk in the last column. This model (Model 2) is globally significant ($p = .0348$) as estimated by a likelihood ratio test for comparing this model against the model without regressors. Confidence intervals (CI) are computed through profile-likelihood method.
Abbreviations: ILF, Inferior Longitudinal Fascicle; TMT, Trail Making Test; SE, Standard Error.
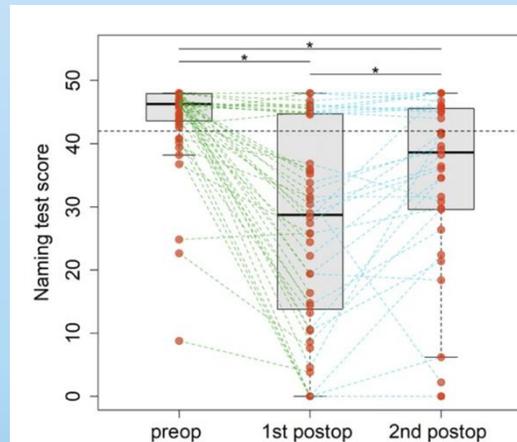

FIGURE 4 Longitudinal comparison of naming test performance among pre- and two postoperative evaluations.

TABLE 8 Model 3 results showing the association between naming test scores and percentage of postoperative lesions in each fascicle, adjusted for the other fascicles.

Fascicle	Beta coefficient (standard error)	p-value
ILF	−56.78 (20.34)	.0082*
IFOF	−13.72 (14.80)	.3598
UF	6.88 (11.00)	.5355
AF	−33.01 (26.88)	.2272
Model intercept	41.12 (7.71)	<.0001*

Note: Coefficients and p-values were estimated through a robust linear regression model (Model 3) that included the postoperative naming test performance as dependent variable, and the percentage of postoperative lesions in each fascicle as regressor. Overall, the model was significant (robust Wald Test, $p < .0001$). Significant regressors are indicated with an asterisk in the last column.
Abbreviations: AF, Arcuate Fasciculus; IFOF, Inferior Fronto-Occipital Fasciculus; ILF, Inferior Longitudinal Fasciculus; UF, Uncinate Fasciculus.

Reading Deficits Associated with ILF Damage

White Matter Microstructure Integrity in Relation to Reading Proficiency

C. Nikki Arrington[a],[1], Paulina A. Kulesz[a], Jenifer Juranek[b], Paul T. Cirino[a], and Jack M. Fletcher[a]

[a]Texas Institute for Measurement, Evaluation and Statistics (TIMES), and Department of Psychology, University of Houston, 4849 Calhoun Rd., Houston, TX 77204, USA

[b]Department of Pediatrics, Division of Developmental Pediatrics, The University of Texas Medical School at Houston, 6655 Travis St. Suite 1000, Houston, TX, 77030, USA

Abstract

Components of reading proficiency such as accuracy, fluency, and comprehension require the successful coordination of numerous, yet distinct, cortical regions. Underlying white matter tracts allow for communication among these regions. This study utilized unique residualized tract – based spatial statistics methodology to identify the relations of white matter microstructure integrity to three components of reading proficiency in 49 school - aged children with typically developing phonological decoding skills and 27 readers with poor decoders. Results indicated that measures of white matter integrity were differentially associated with components of reading proficiency. In both typical and poor decoders, reading comprehension correlated with measures of integrity of the right uncinate fasciculus; reading comprehension was also related to the left inferior longitudinal fasciculus in poor decoders. Also in poor decoders, word reading fluency was related to the right uncinate and left inferior fronto - occipital fasciculi. Word reading was unrelated to white matter integrity in either group. These findings expand our knowledge of the association between white matter integrity and different elements of reading proficiency.

The left inferior longitudinal fasciculus supports orthographic processing: Evidence from a lesion-behavior mapping analysis

Ke Wang[a],[1], Xiaonan Li[a],[b],[1], Ruiwang Huang[c], Junhua Ding[d], Luping Song[e],[*], Zaizhu Han[a],[*]

[a] State Key Laboratory of Cognitive Neuroscience and Learning & IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing 100875, China
[b] CAS Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Beijing 100101, China
[c] School of Psychology, South China Normal University, Guangzhou 510631, China
[d] Department of Neurosurgery, Baylor College of Medicine, Houston 77030, USA
[e] Shenzhen University General Hospital, Department of Rehabilitation Medicine, Shenzhen 518055, China

ABSTRACT

Orthographic processing is a critical stage in visual word recognition. However, the white-matter pathways that support this processing are unclear, as prior findings might have been confounded by impure behavioral measures, potential structural reorganization of the brain, and limited sample sizes. To address this issue, we investigated the correlations between the integrity of 20 major tracts in the whole brain and the pure orthographic index across 67 patients with short-term brain damage. The integrity of the tracts was measured by the lesion volume percentage and the mean fractional anisotropy value. The orthographic index was calculated as the residual of the orthographic tasks after regressing out corresponding nonorthographic tasks and the orthographic factor from the principal component analysis (PCA) on the basis of four orthographic tasks. We found significant correlations associated with the left inferior longitudinal fasciculus (ILF), even after controlling for the influence of potential confounding variables. These observations strengthen evidence for the vital role of the left ILF in orthographic processing.

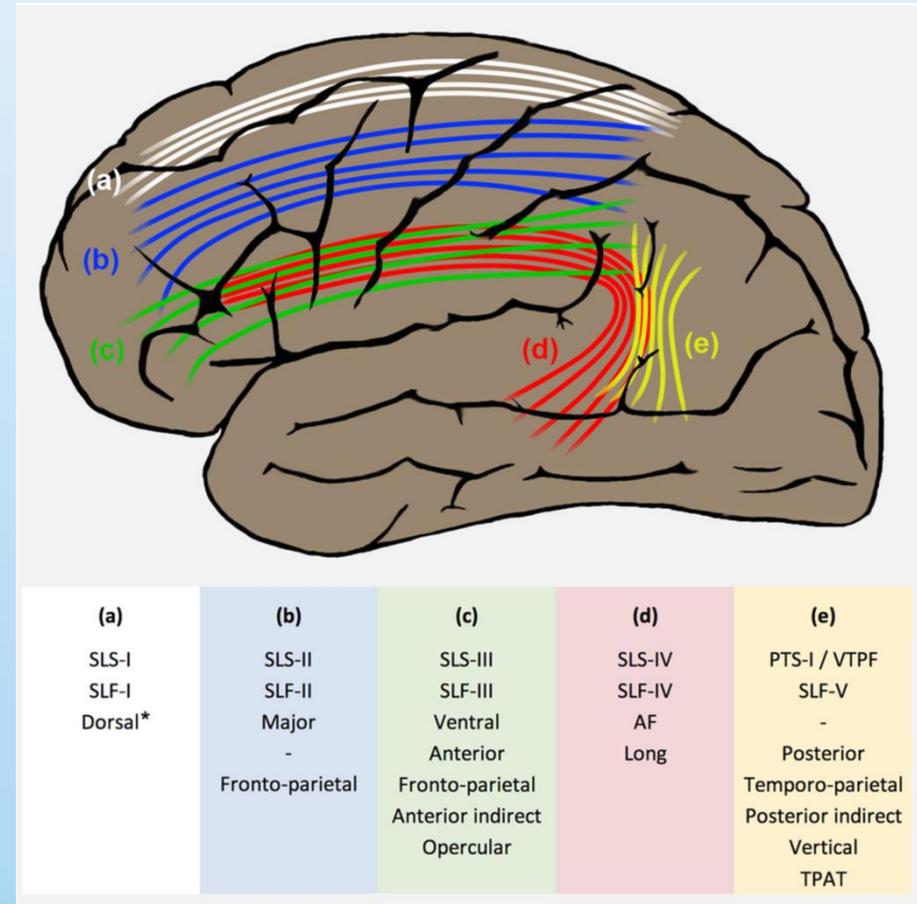# Dominant Superior Longitudinal Fasciculus
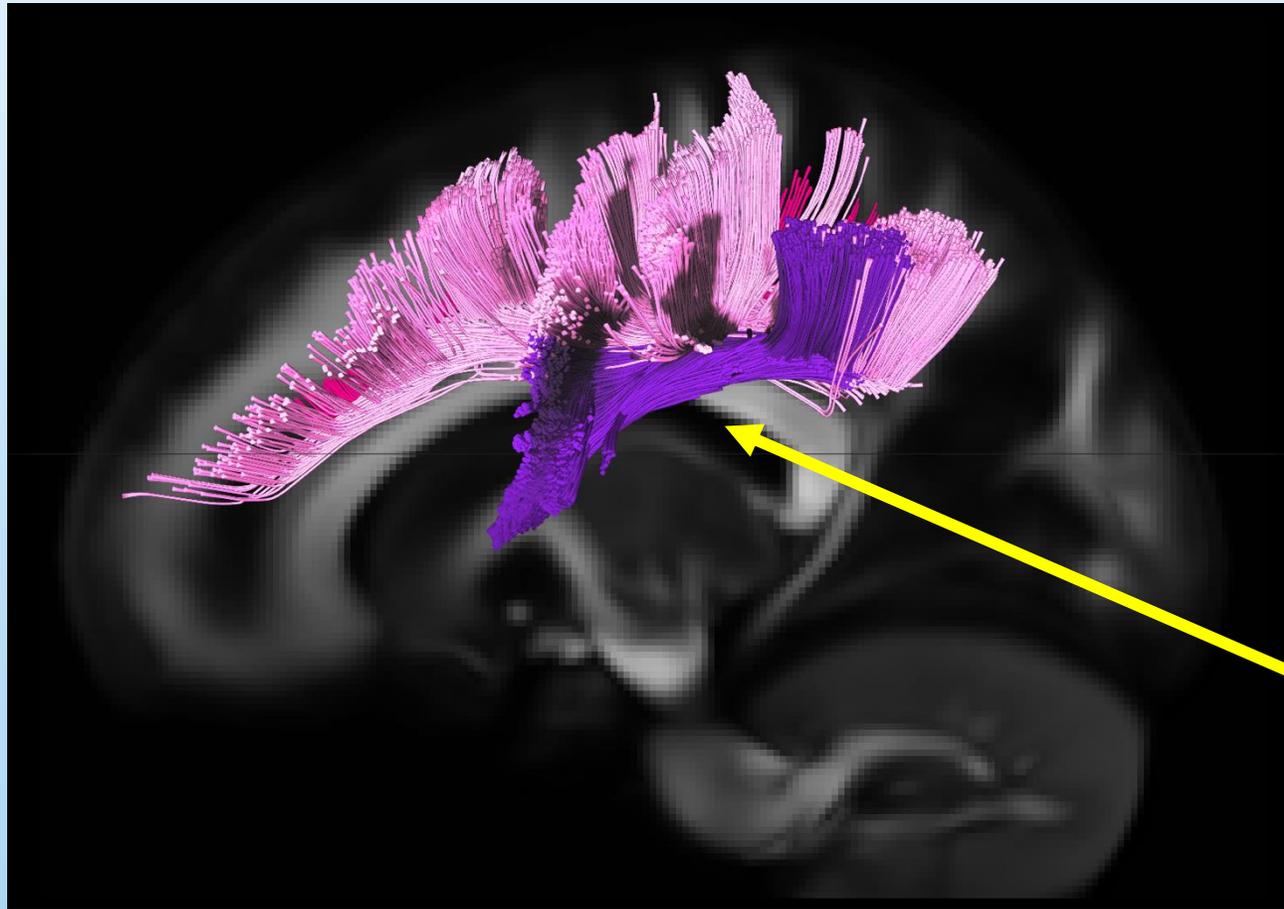
Thought to be related to syntactic processing and motor planning during speech.

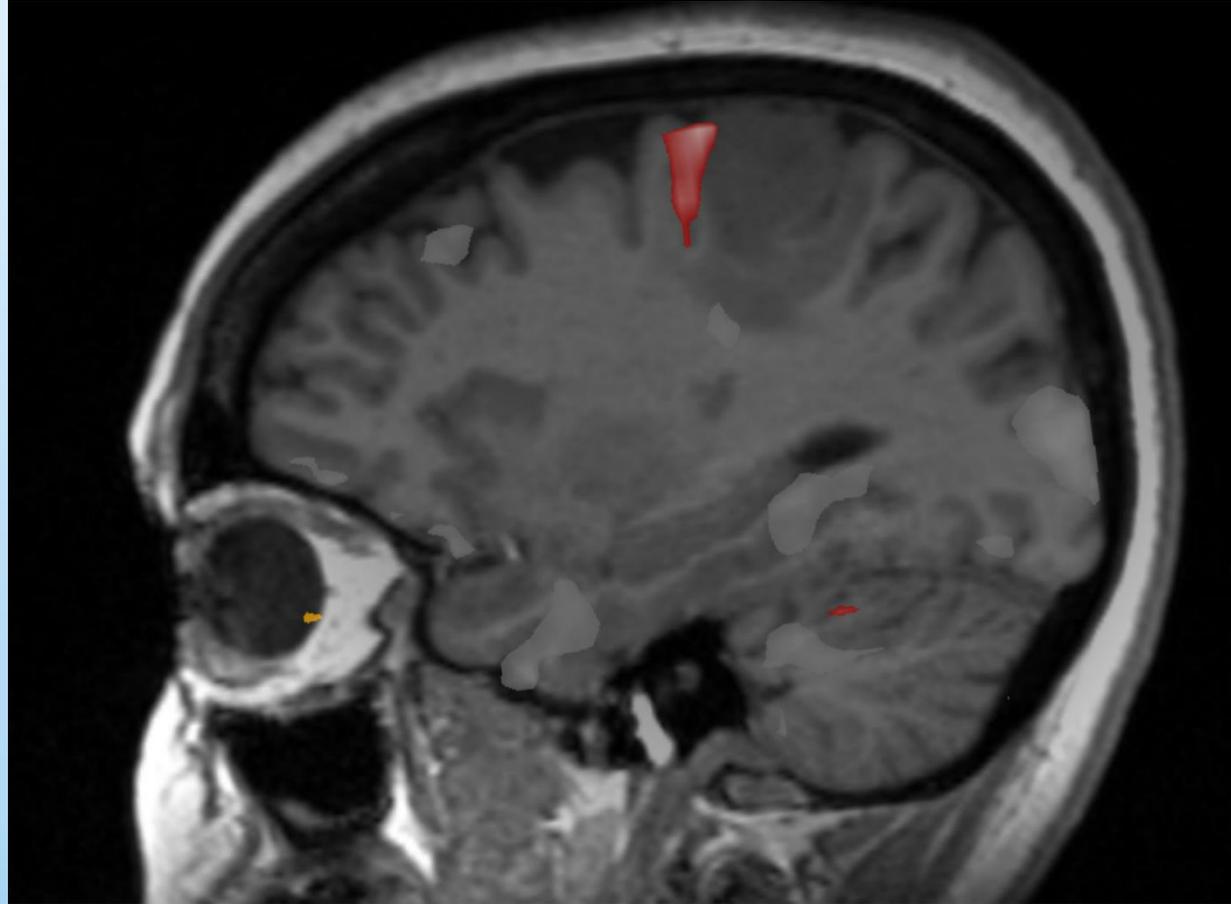SLF-3 in particular is likely part of the language system.

Superior Longitudinal Fasciculus Nomenclature

For our purposes, the Superior Longitudinal Fasciculus involves SLF-1, SLF-2, & SLF-3.

SLF-4 and SLF-5 are (for our purposes) the Arcuate Fasciculus.

(a)	(b)	(c)	(d)	(e)
SLS-I	SLS-II	SLS-III	SLS-IV	PTS-I / VTPF
SLF-I	SLF-II	SLF-III	SLF-IV	SLF-V
Dorsal*	Major	Ventral	AF	-
	-	Anterior	Long	Posterior
	Fronto-parietal	Fronto-parietal		Temporo-parietal
		Anterior indirect		Posterior indirect
		Opercular		Vertical
				TPAT

Oliveira, João & Raquelo-Menegassio, Antônio & Maldonado, Igor. (2021). What's your name again? A review of the superior longitudinal and arcuate fasciculus evolving nomenclature. Clinical Anatomy. 34. 10.1002/ca.23764.

Example of Dominant SLF III & Language

Example of SLF III & Language Continued
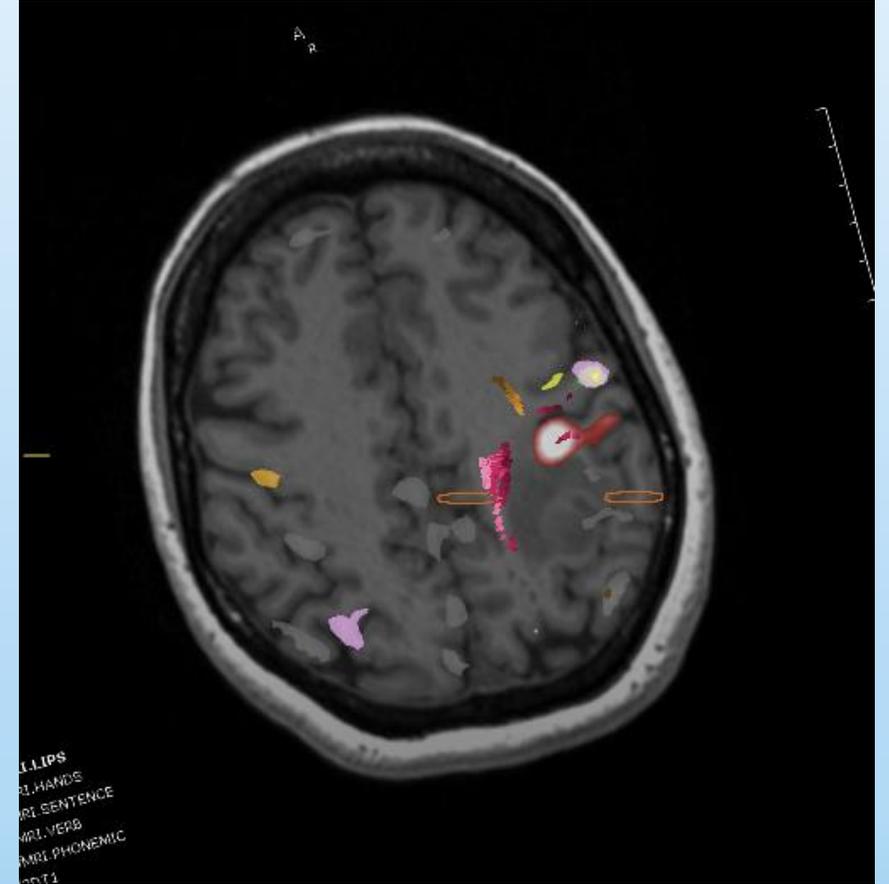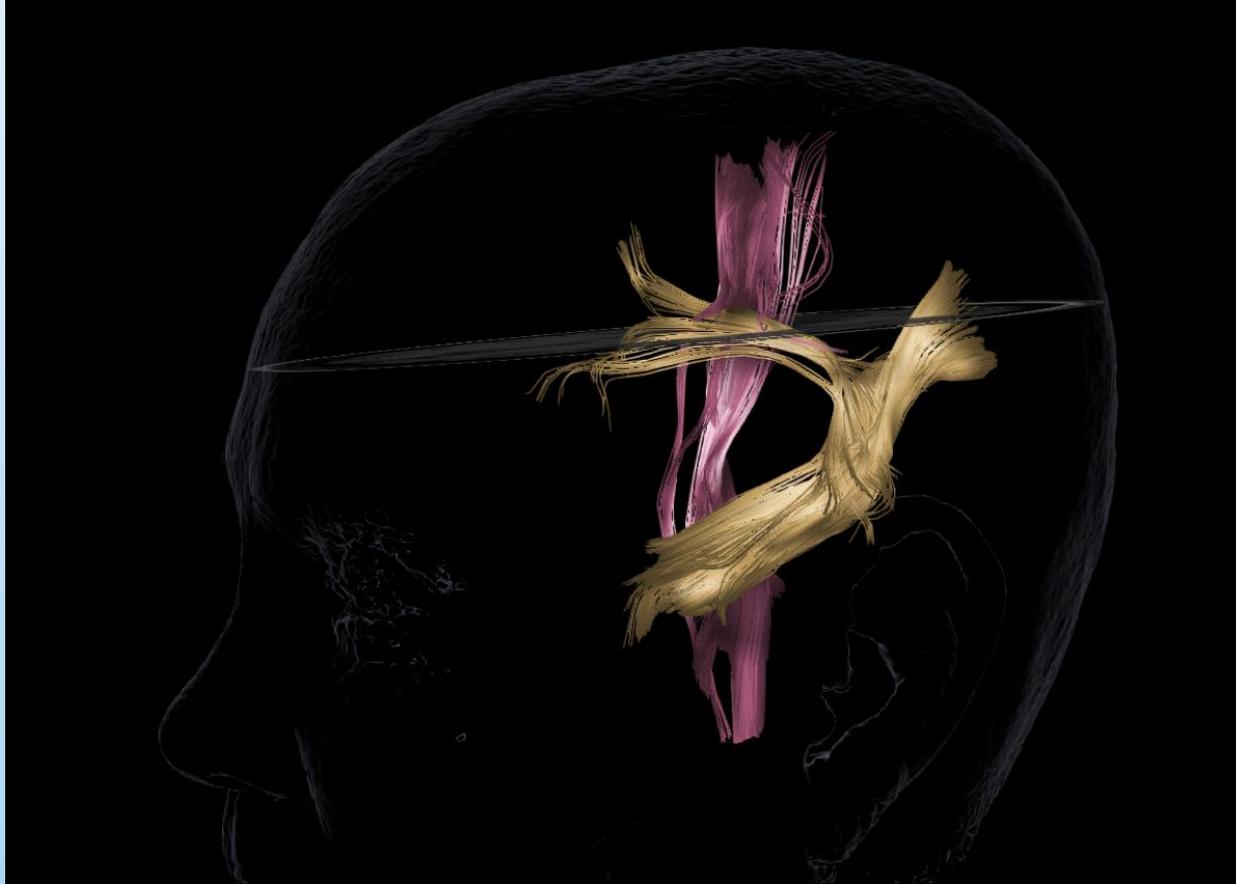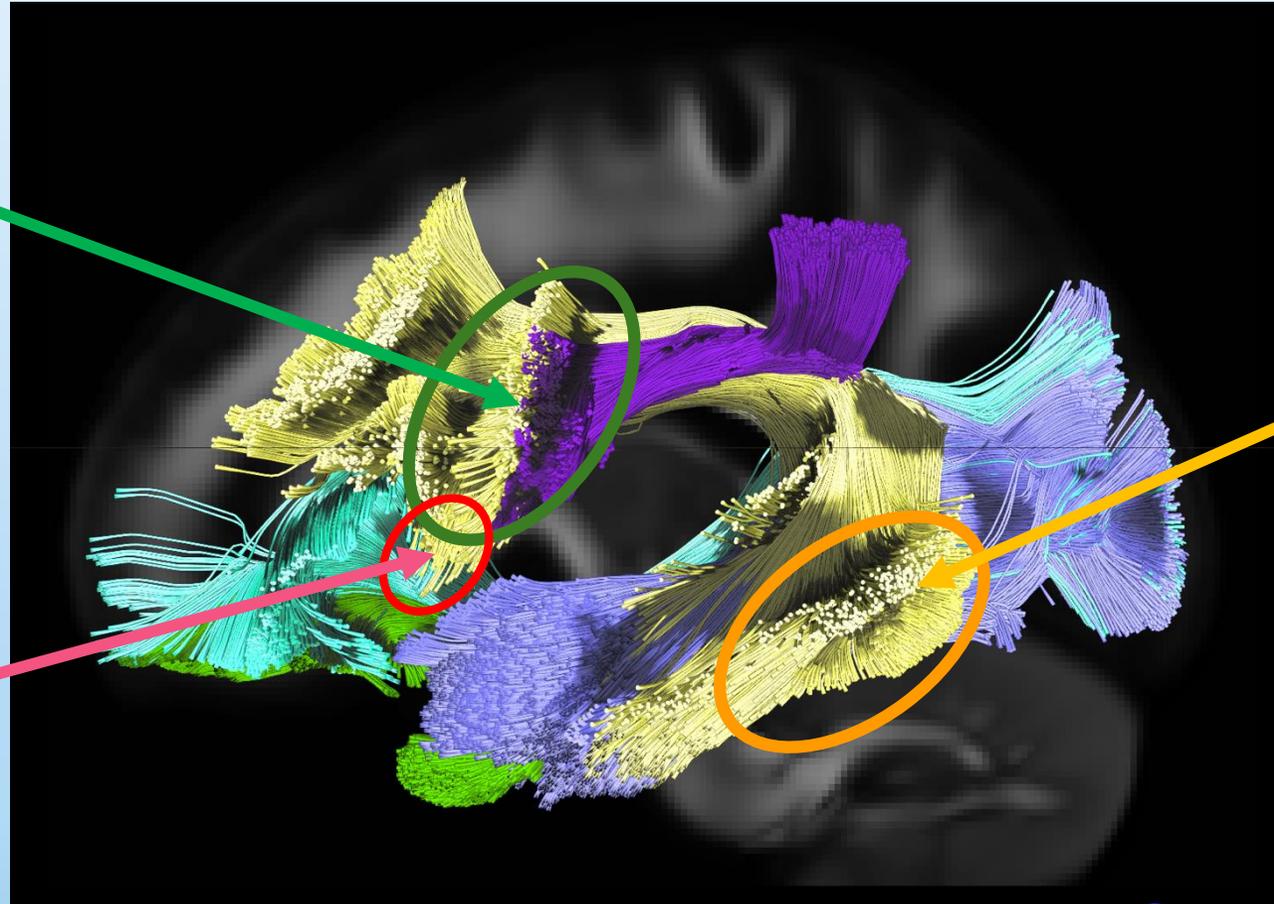
Example of SLF III & Language Continued
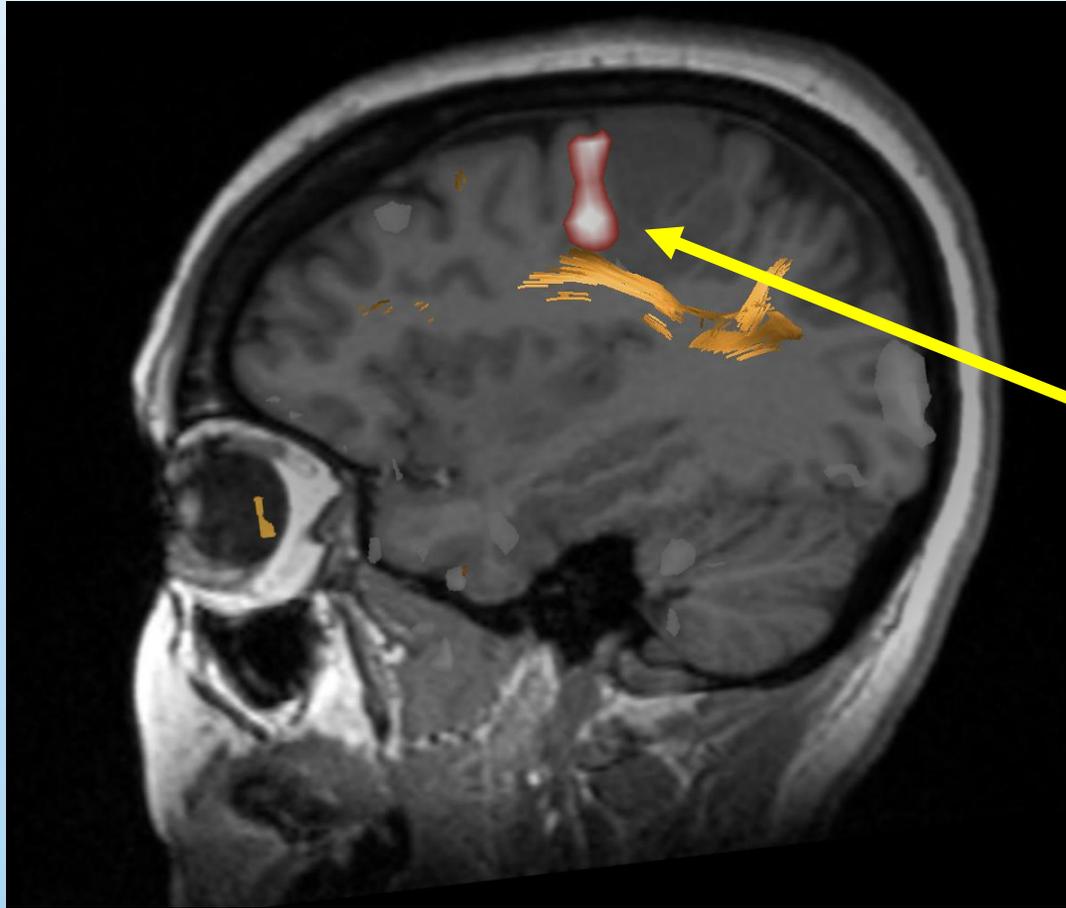
Cortical stimulation at the base of the mass during resection revealed speech arrest.
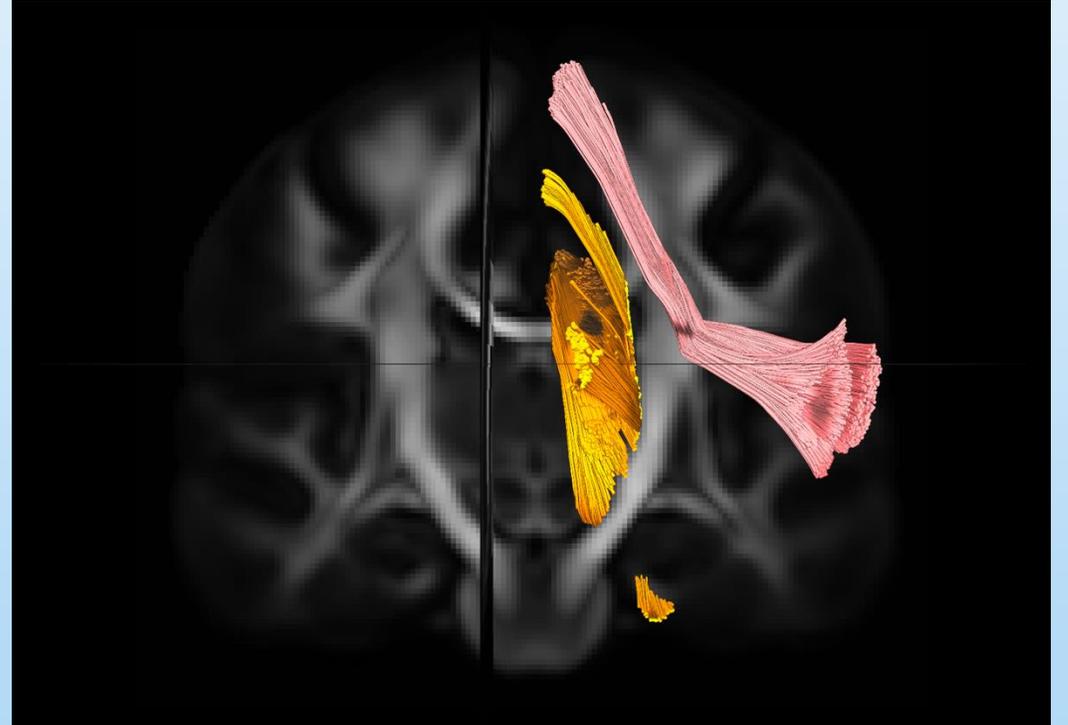
Language System Of The Brain

Ventral Premotor Language Area (Area 55b)

Traditional Wernicke's Area

Traditional Broca's Area

Frontal Aslant Tract

Frontal Aslant Tract

CASE REPORT - BRAIN TUMORS

Check for updates

Two cases of SMA syndrome after neurosurgical injury to the frontal aslant tract

Kevin Agyemang[1,2] · Anna Rose[1] · Mustafa El Sheikh[1] · Mutiu Asha[1,2] · Emanuela Molinari[1,2] · Natasha E. Fullerton[1,2] · David Brennan[1] · Athanasios Grivas[1,2]

Abstract
Supplementary motor area (SMA) syndrome is characterised by transient disturbance in volitional movement and speech production which classically occurs after injury to the medial premotor area. We present two cases of SMA syndrome following isolated surgical injury to the frontal aslant tract (FAT) with the SMA intact. The first case occurred after resection of a left frontal operculum tumour. The second case occurred after a transcortical approach to a ventricular neurocytoma. The clinical picture and fMRI activation patterns during recovery were typical for SMA syndrome and support the theory that the FAT is a critical bundle in the SMA complex function.

Bilateral white matter structure that connects the supplemental motor area to the frontal operculum. In the dominant hemisphere this connection is between SMA and Broca's area.
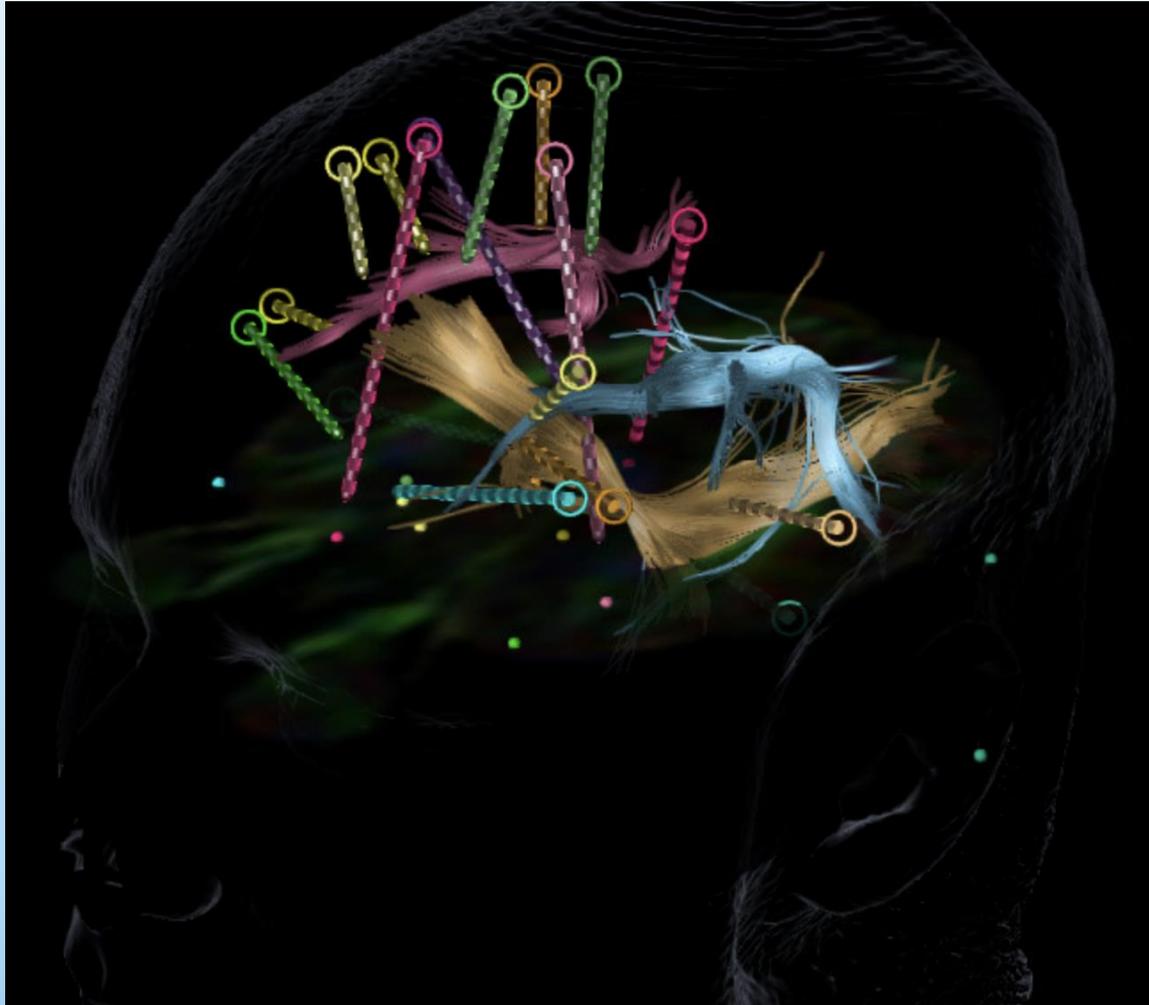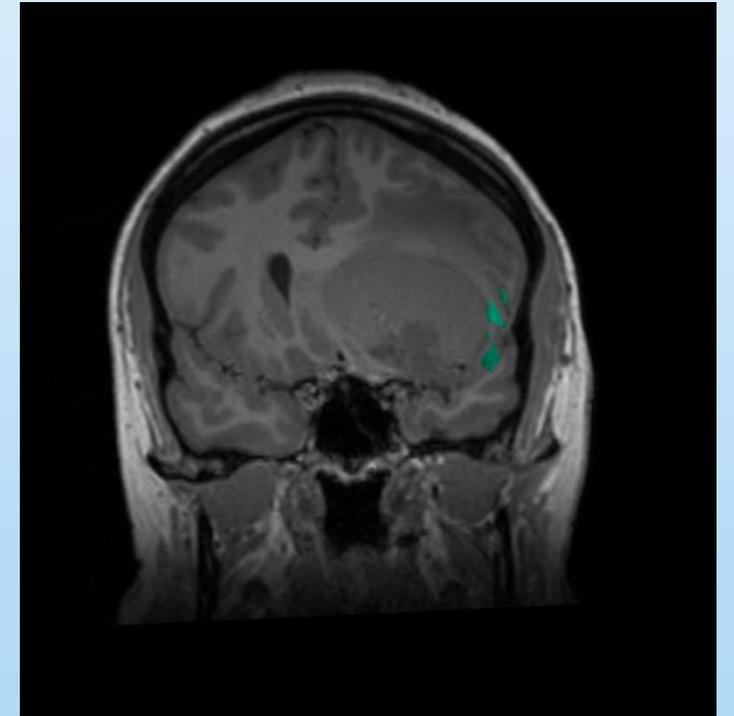
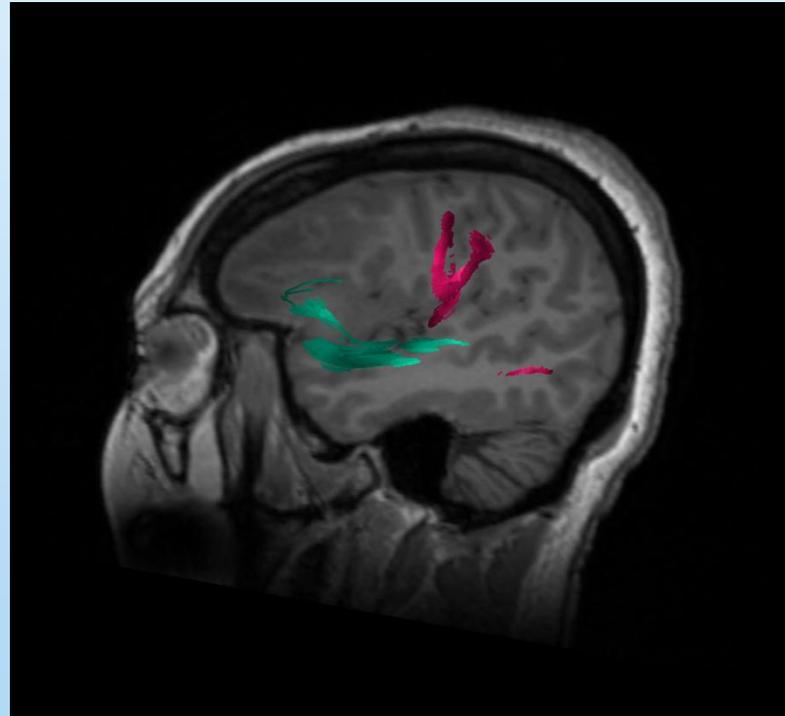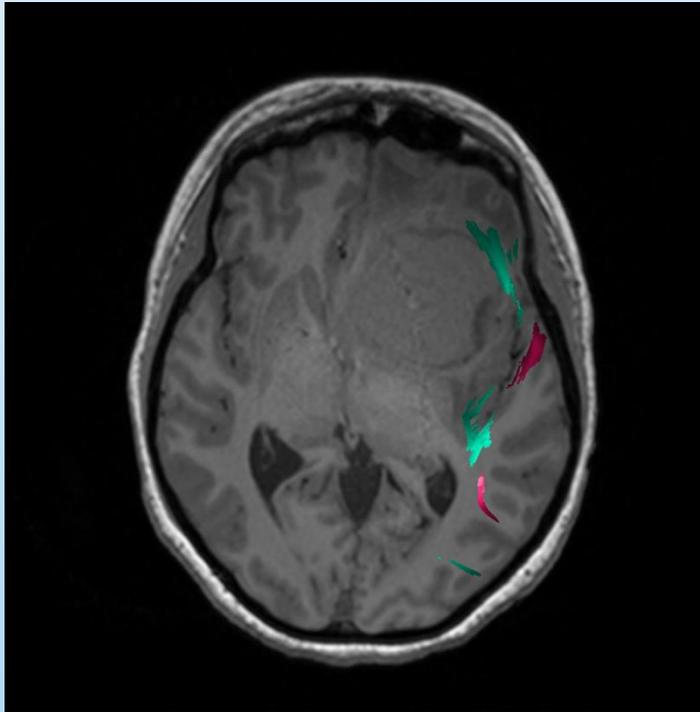# Optic Radiations
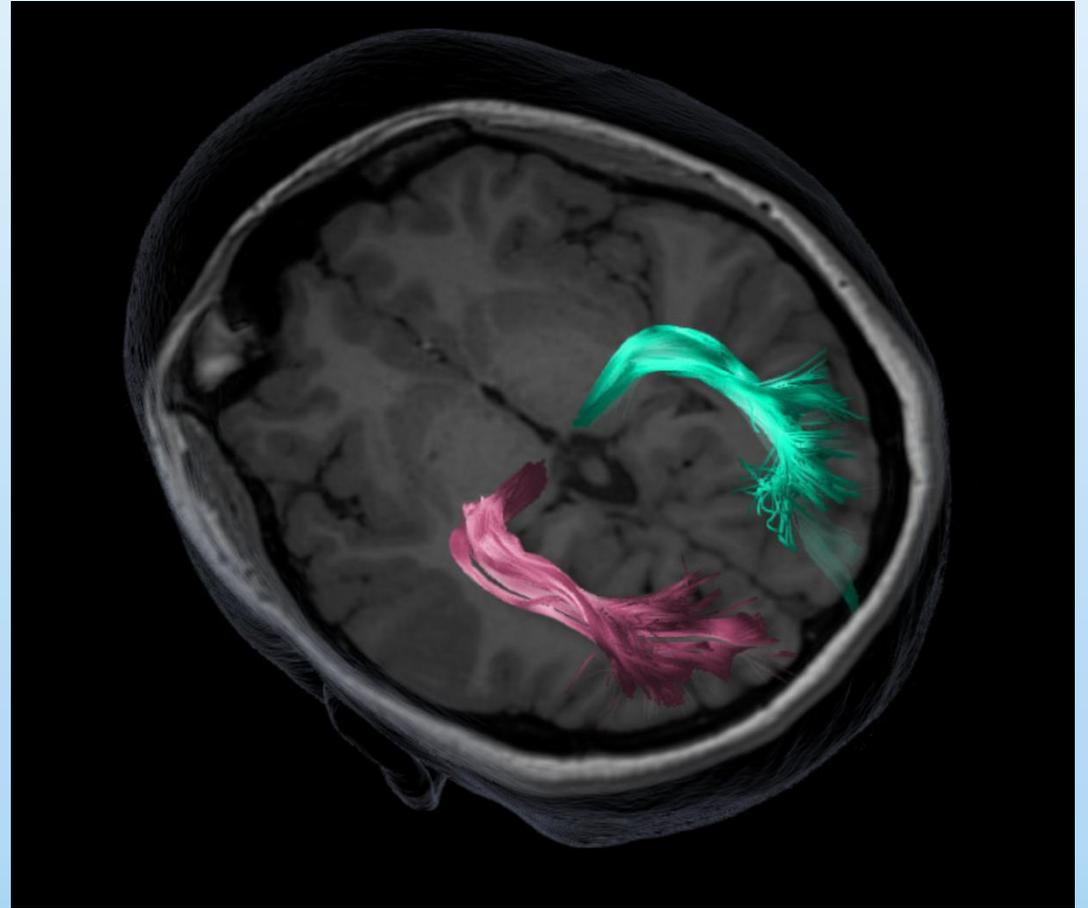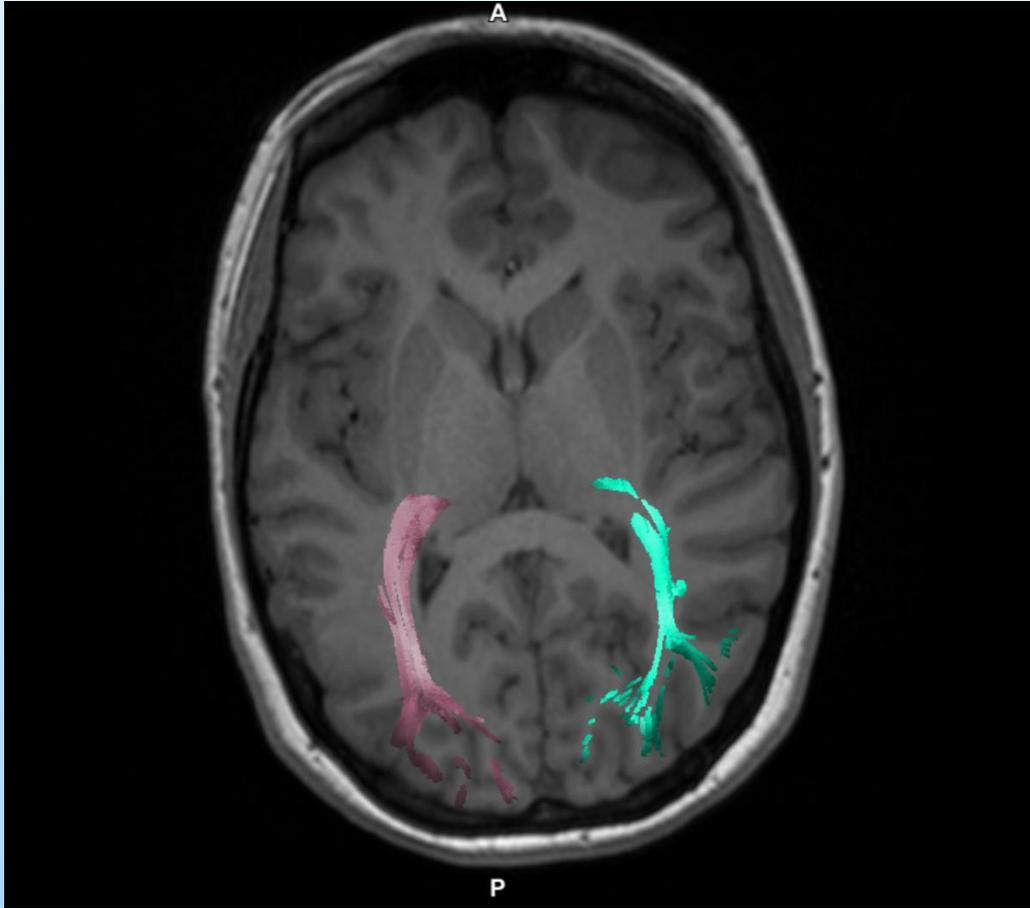
Corticospinal Tract
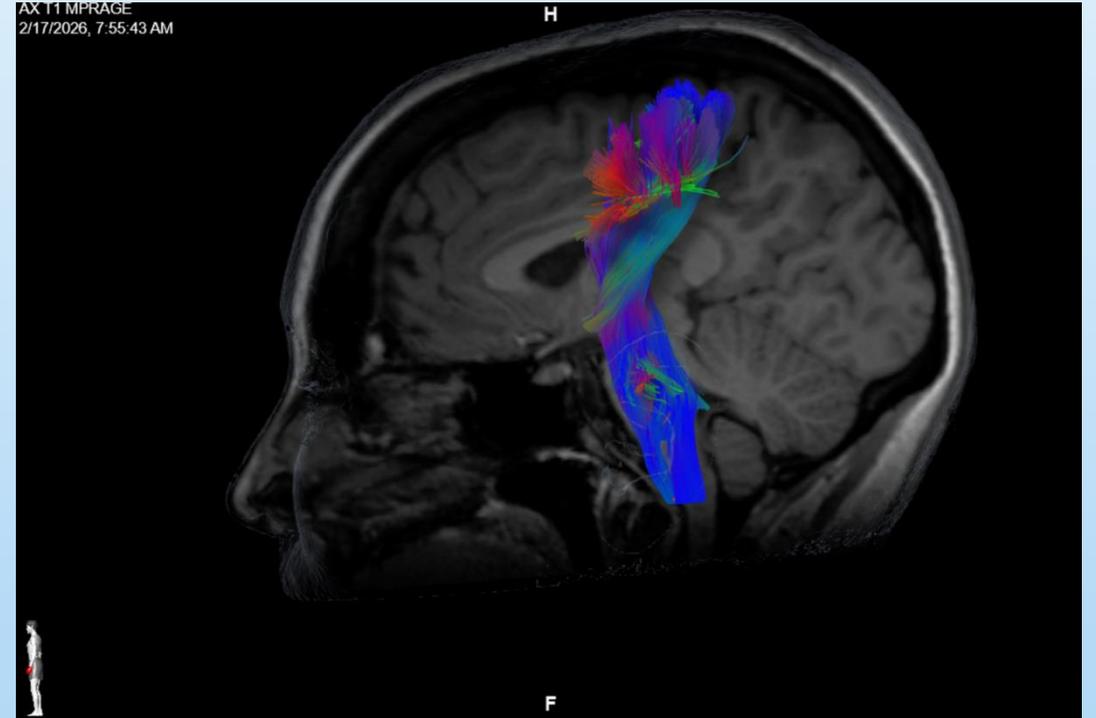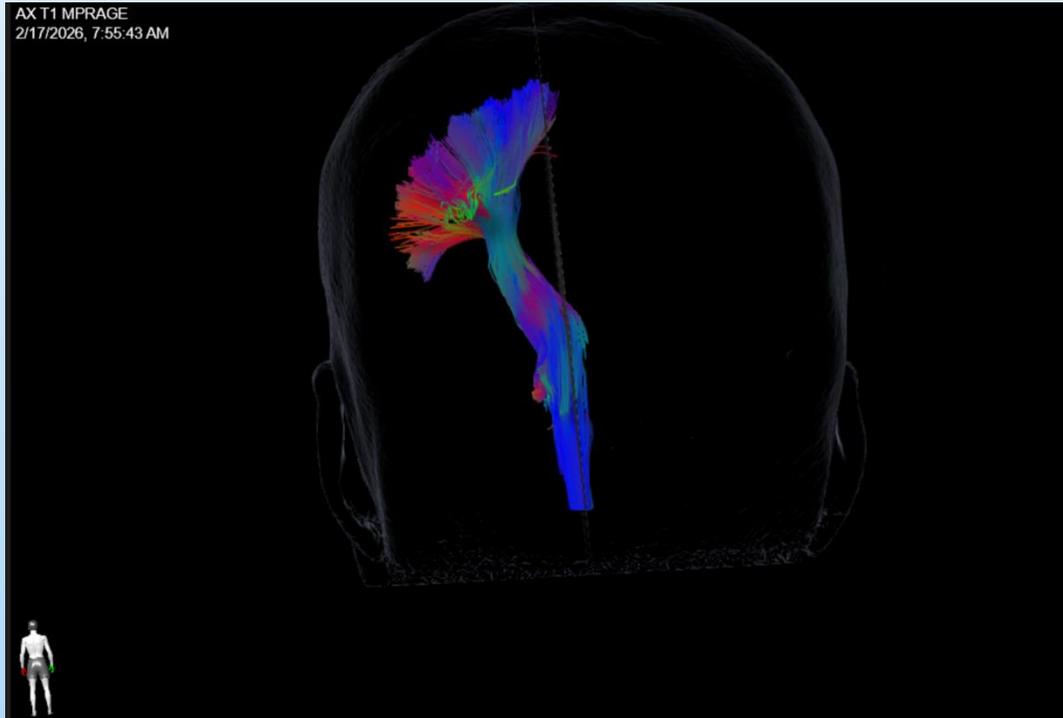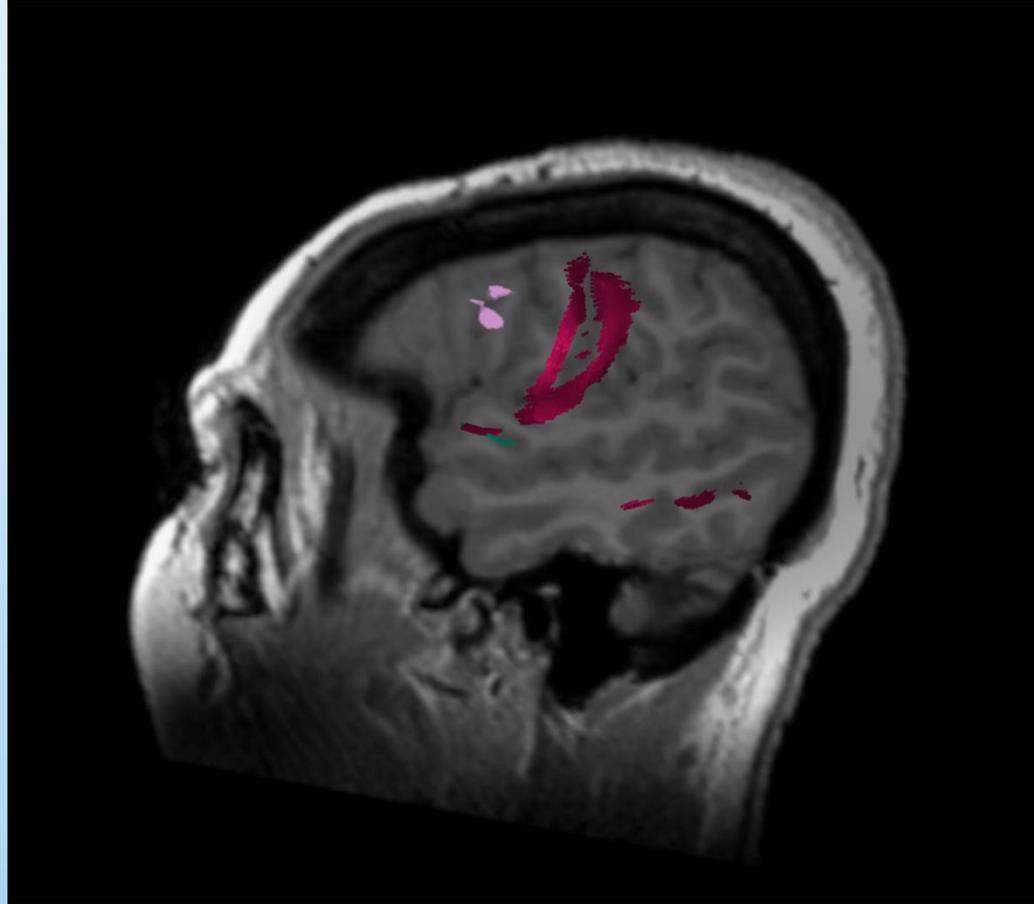
Examples of Various Uses For Tractography

Using tractograms to predict mapping outcomes in Phase II epilepsy studies with sEEG bedside mapping.

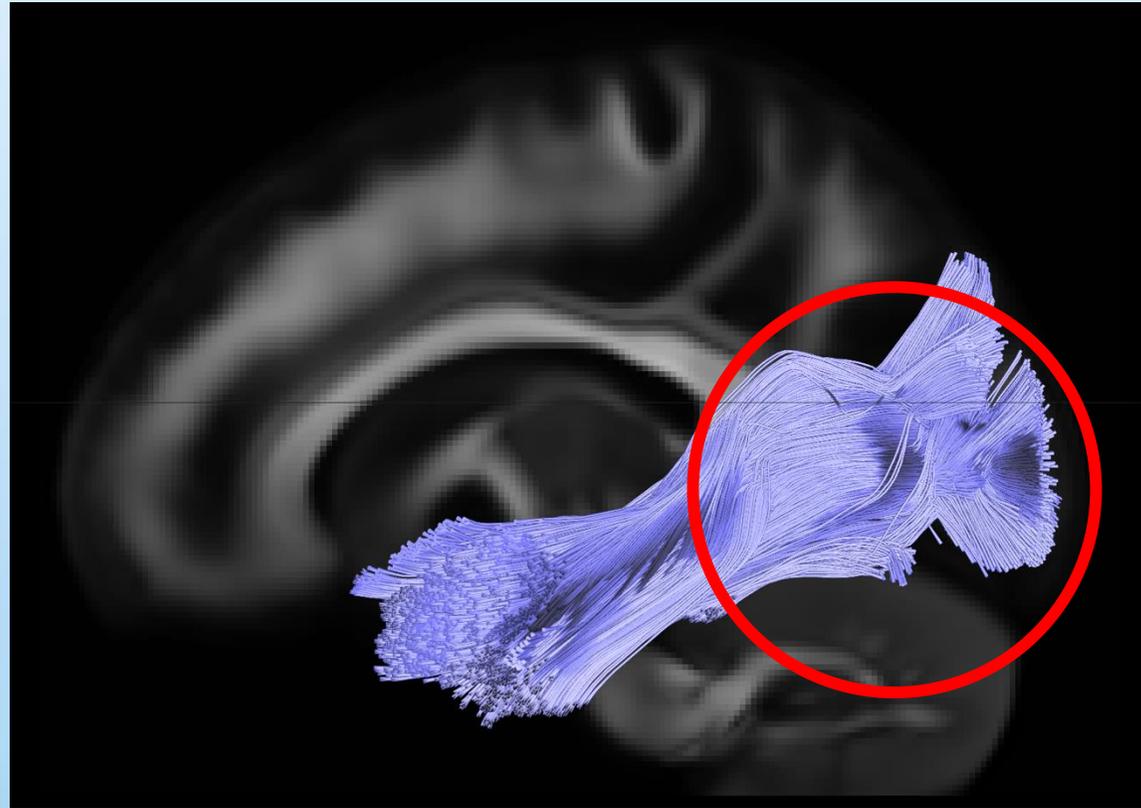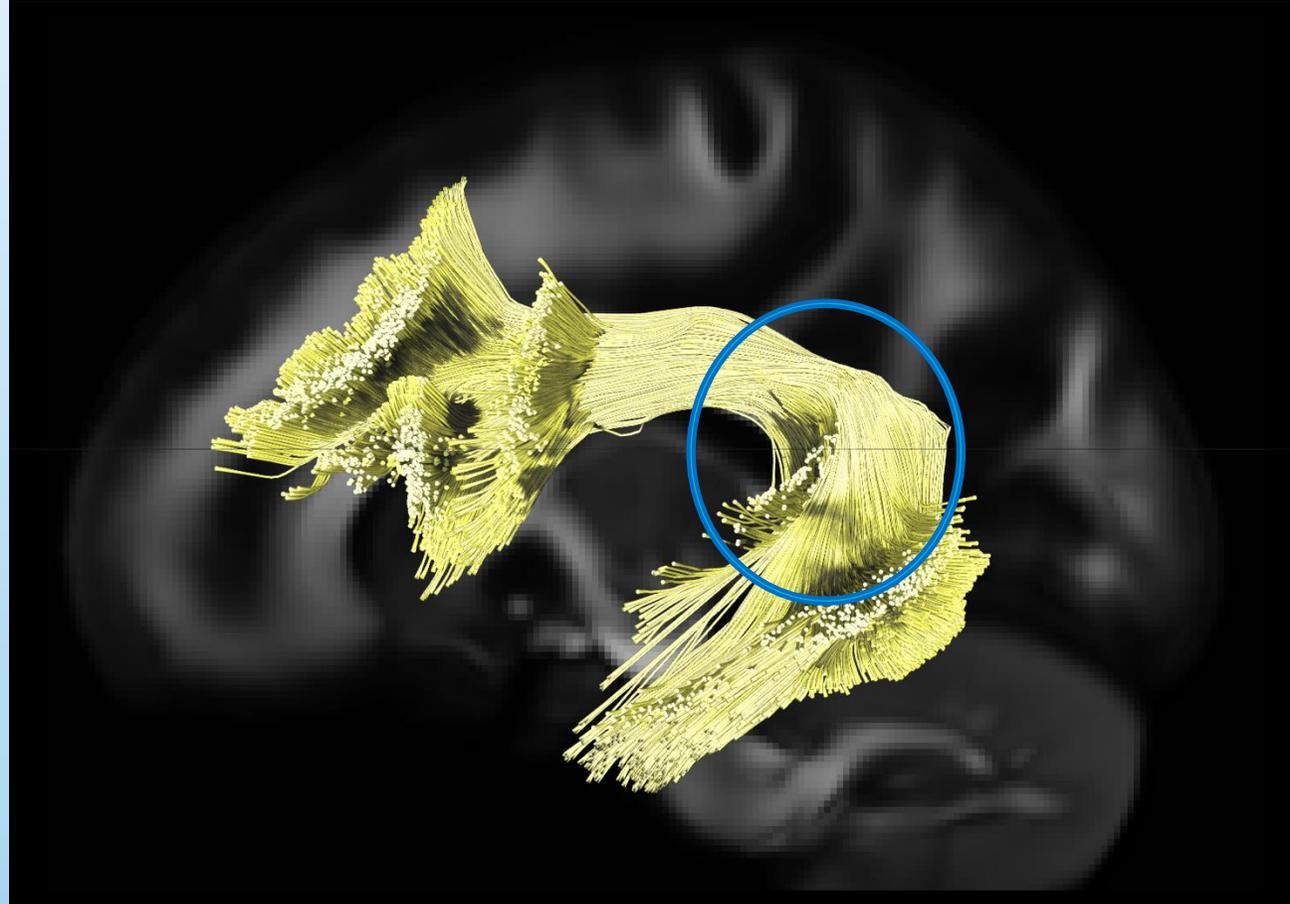# Examples of Various Uses For Tractography Continued

Examples of Various Uses For Tractography Continued

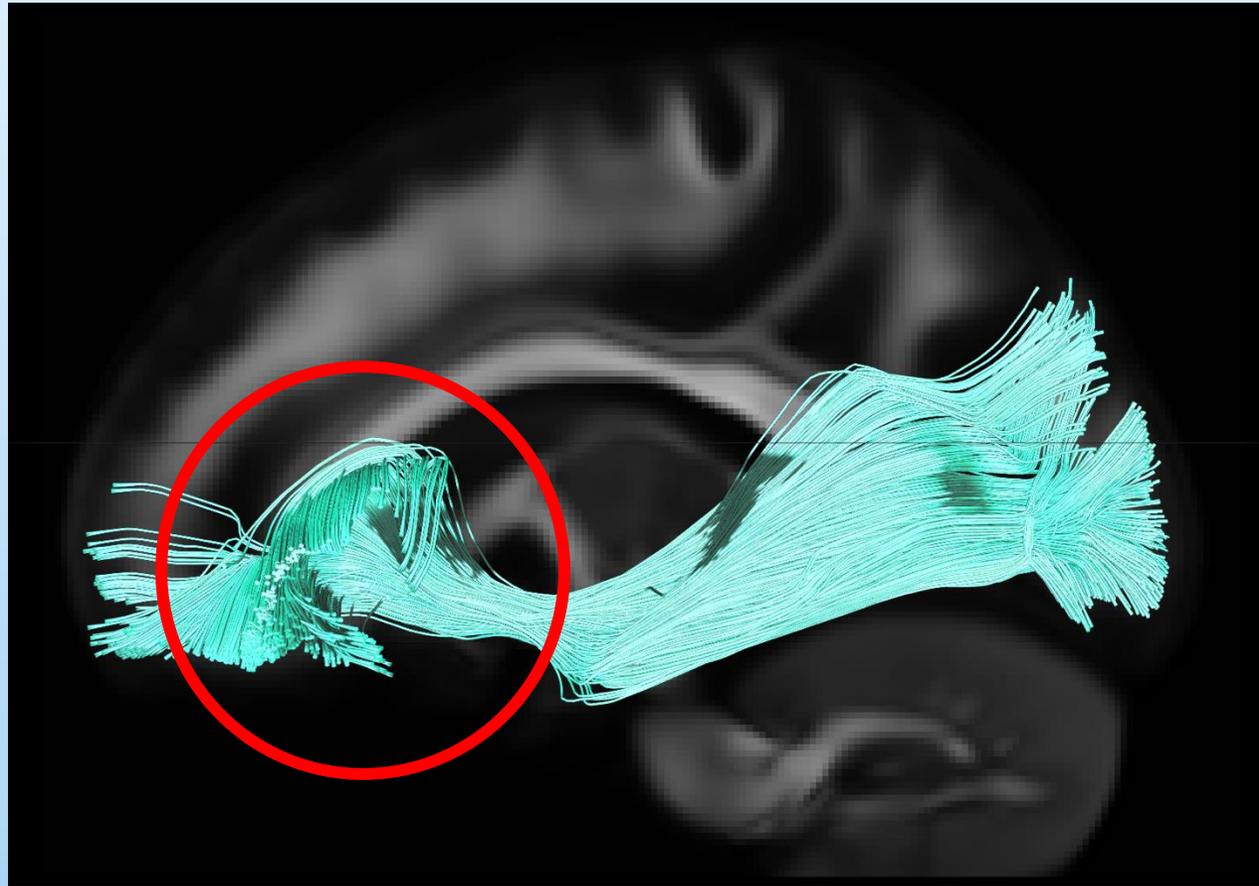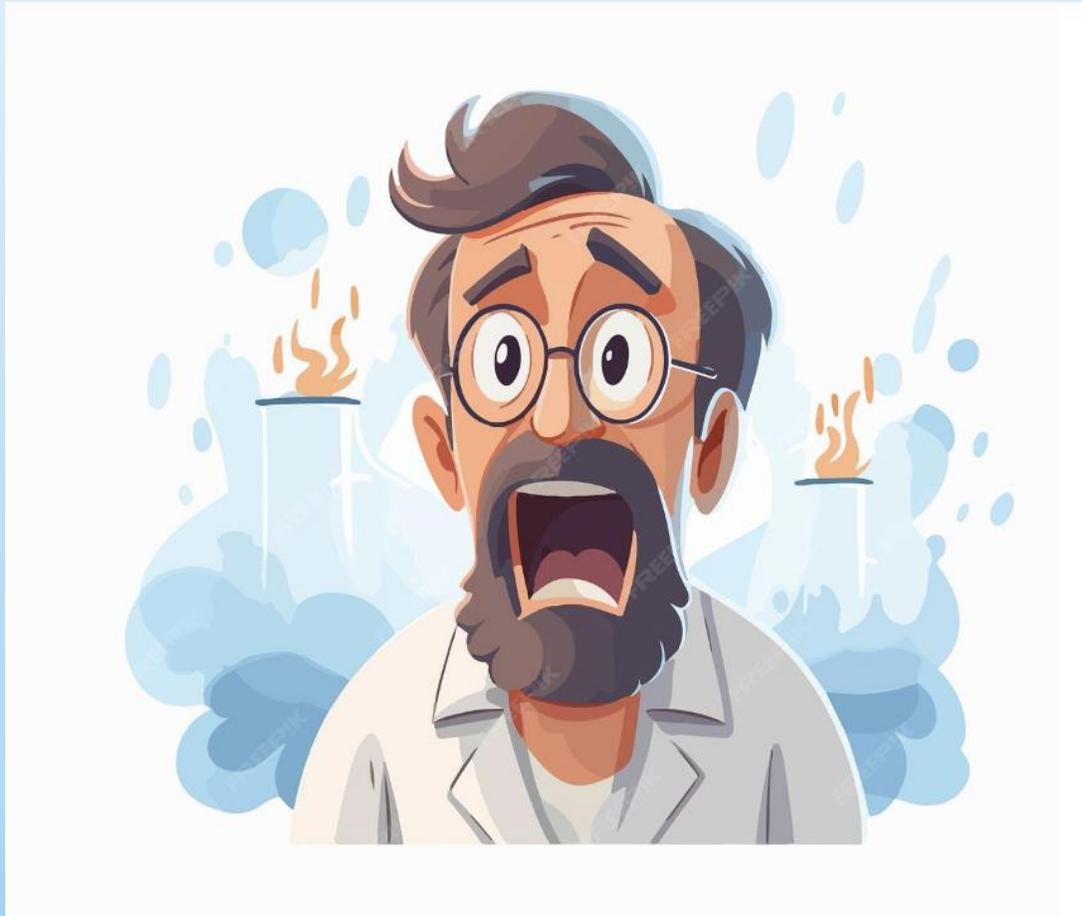# Examples of Various Uses For Tractography Continued

Examples of Various Uses For Tractography Continued

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Integrating the Neuropsychologist into the Neurosurgical Team

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Make sure you know what you're doing!

Understand that you are there to provide support for the team – that support is typically in the form of information.

Understand that the ultimate responsibility falls on the neurosurgeon and support that.

If you build it, they will come! (In other words, if you provide a good product, you will have customers).

Final Thoughts

- There is a considerable need for consensus in how to train neuropsychologists on the use of neuroimaging in the context of neurosurgery.

- Neuroimaging training needs to start early.

- Training in research-based fMRI is not enough.

- Training should include both neuroimaging and cortical stimulation mapping.

"Whoa! *That* was a good one! Try it, Hobbs — just poke his brain right where my finger is."

Acknowledging My Wonderful Team!