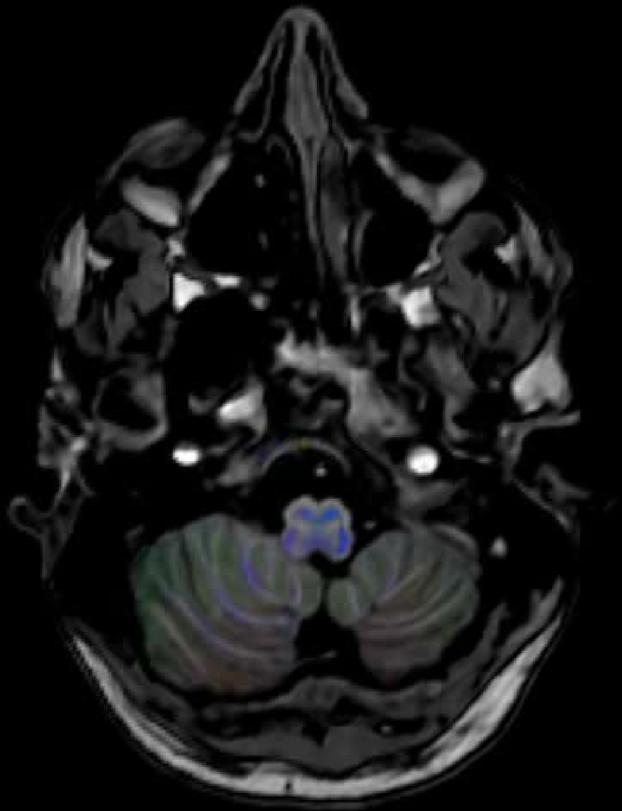
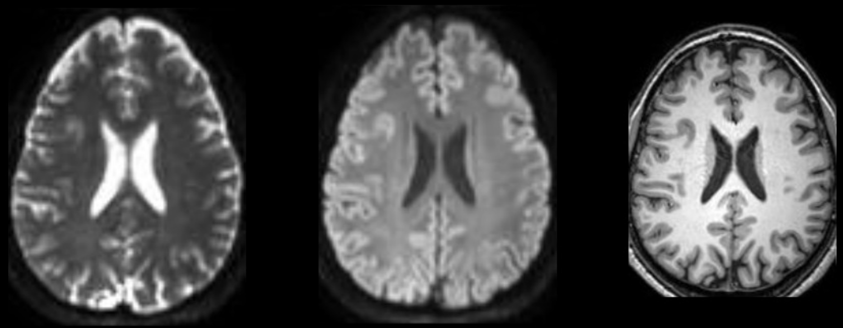
Diffusion Tensor Imaging (DTI) and Tractography



Acknowledgements and Special Thanks to



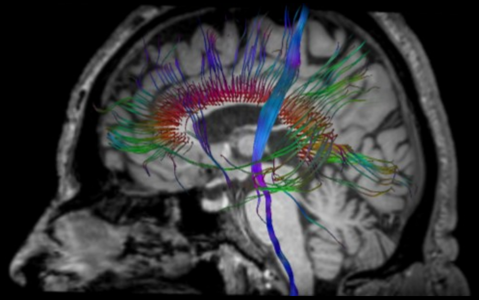
3T Philips Achieva TX MRI Scanner,
30-dir DTI, High-Resolution T1-3D

Radiology & Medical Imaging Research Unit

2nd Dpt of Radiology, Medical School, NKUA, GR

P. Toulas (MD), G. Velonakis (MD)

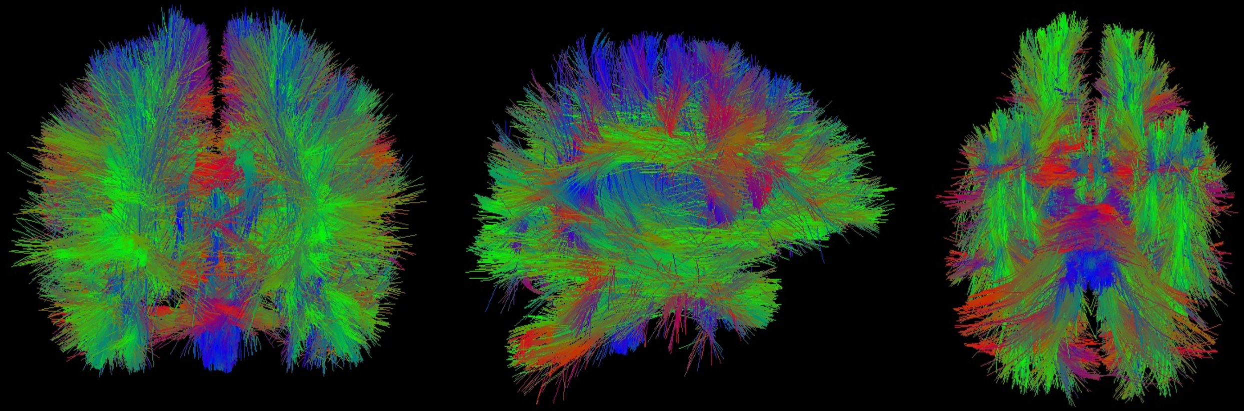
Director: Prof. N.L. Kelekis



PHILIPS

Extended MR WorkSpace

FiberTrak



Brainance

A web-based post processing and 3D visualization MRI software

Eindhoven, NL + 30 6945774570 info@advantis.io

ADVANTIS
MEDICAL IMAGING

Presentation Outline

- Introduction to Diffusion Tensor Imaging and Tractography
- In Vivo White Matter Visualization Through DTI Tractography
- Challenges / Pitfalls / Solutions
- Presurgical MRI/DTI scanning and tractography of WM eloquent tracts

Presentation Outline

- **Introduction to Diffusion Tensor Imaging and Tractography**
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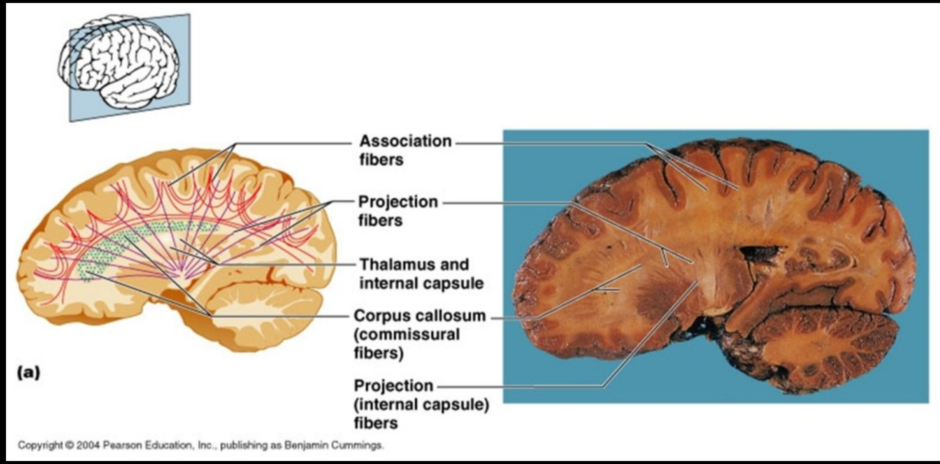
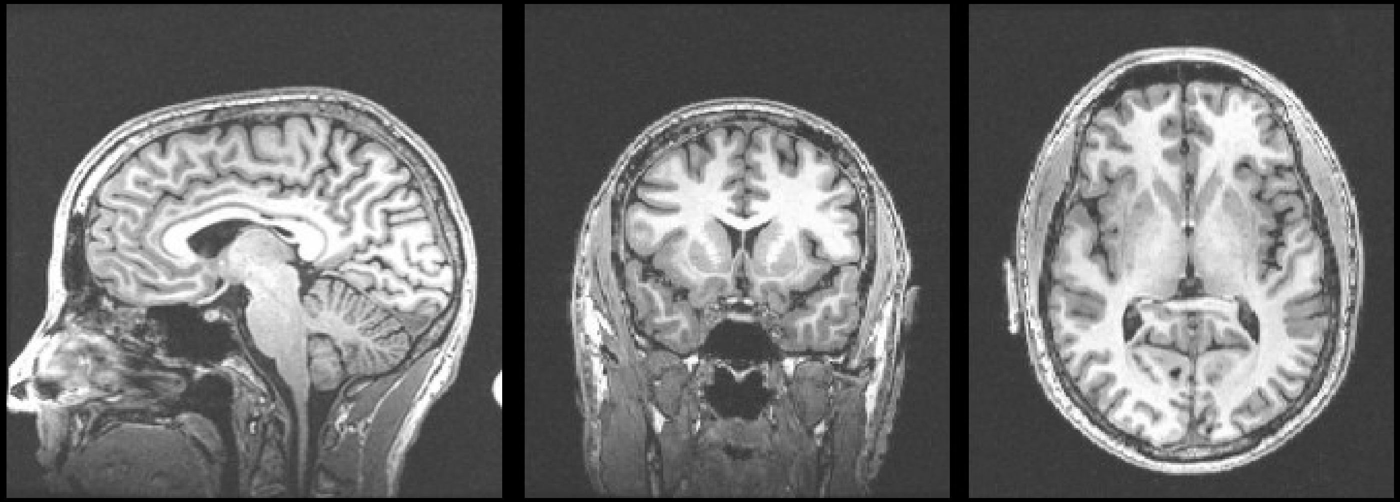
White Matter

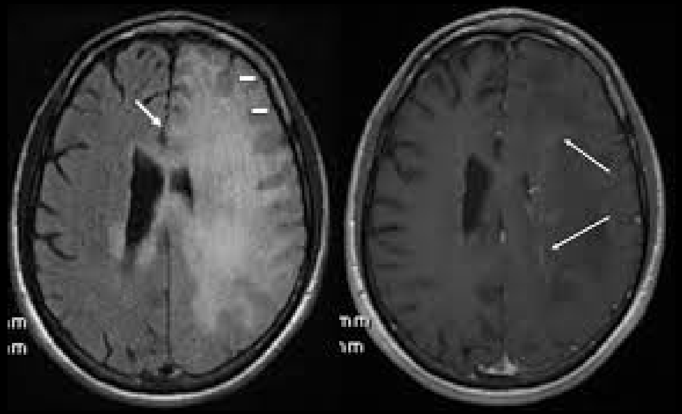


”[…] it is most reasonable to regard **white matter** as interacting with gray matter to distributed, multifocal neural **networks** to produce the phenomena of **human behavior**”

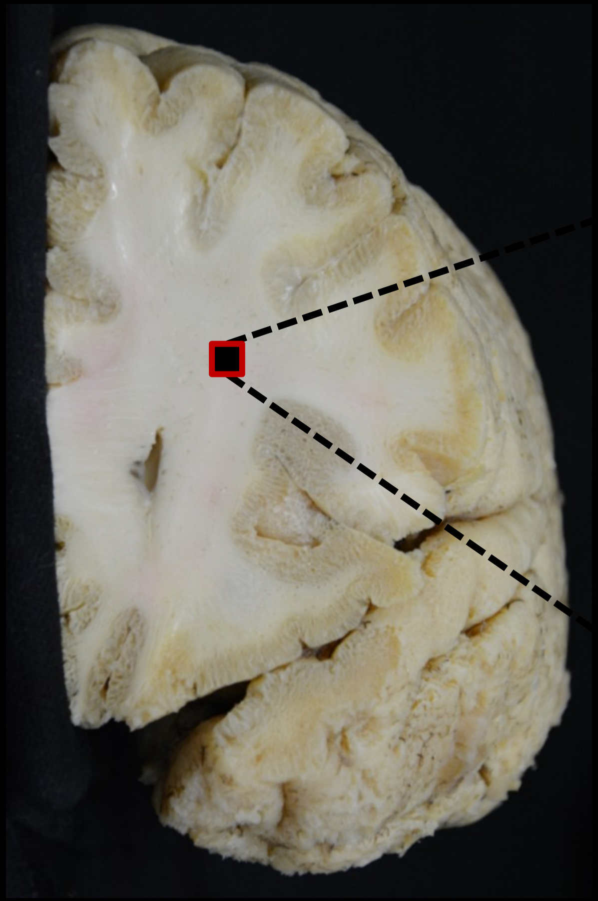
C.Filley, The Behavioral Neurology of White Matter, p. xiv, OUP, 2012.

White Matter



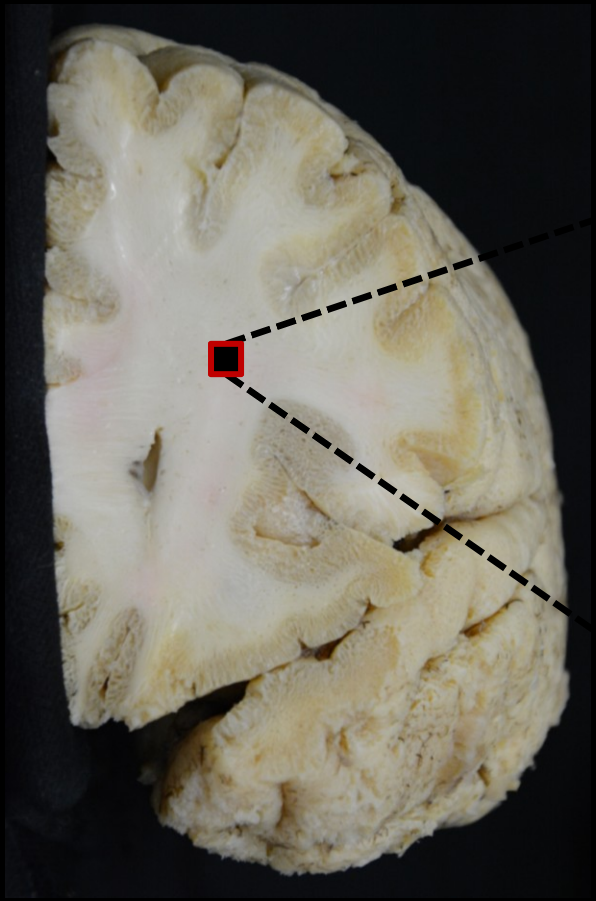


White Matter

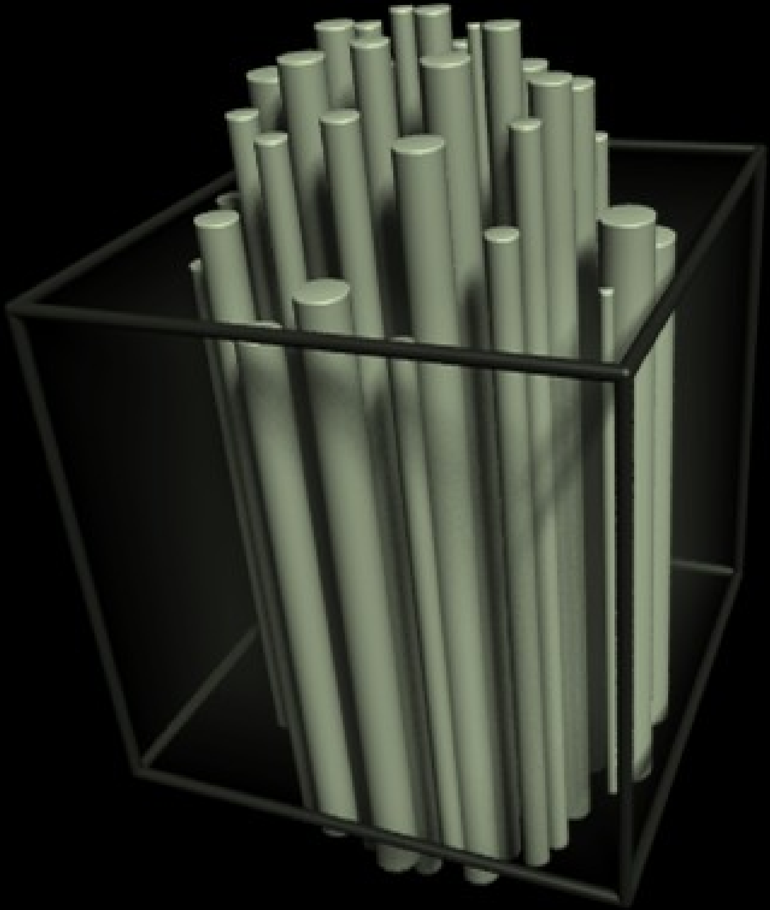


Athens Microneurosurgery Laboratory

White Matter

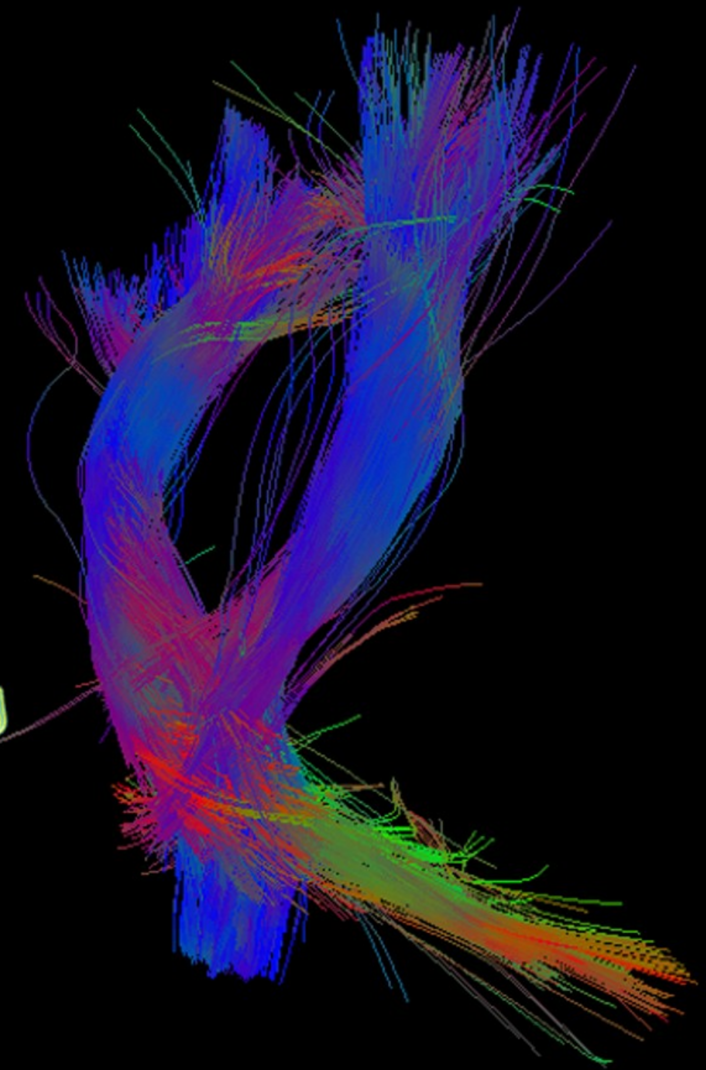


Athens Microneurosurgery Laboratory

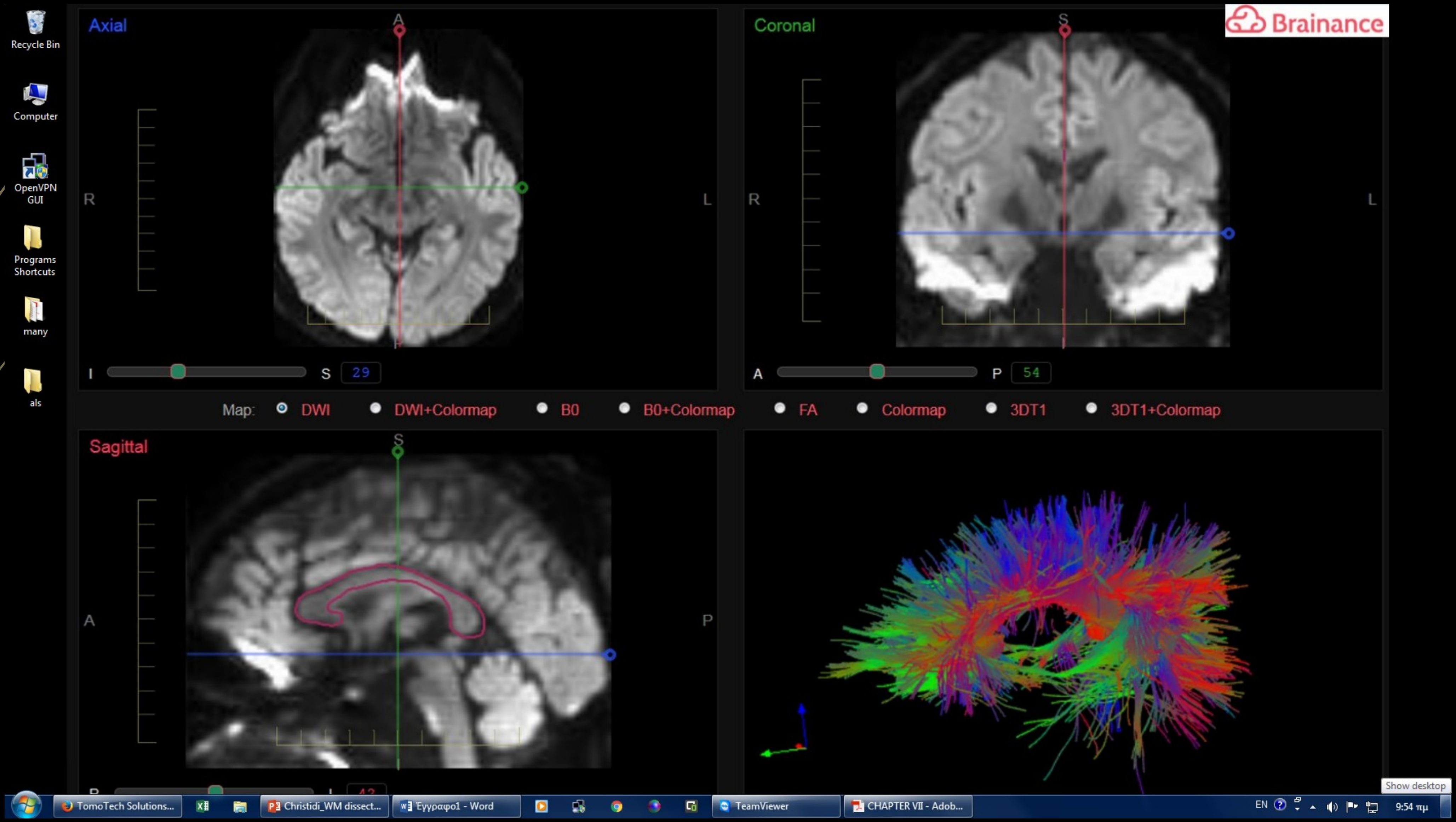


In Vivo Study of WM: Advanced Neuroimaging Techiniques

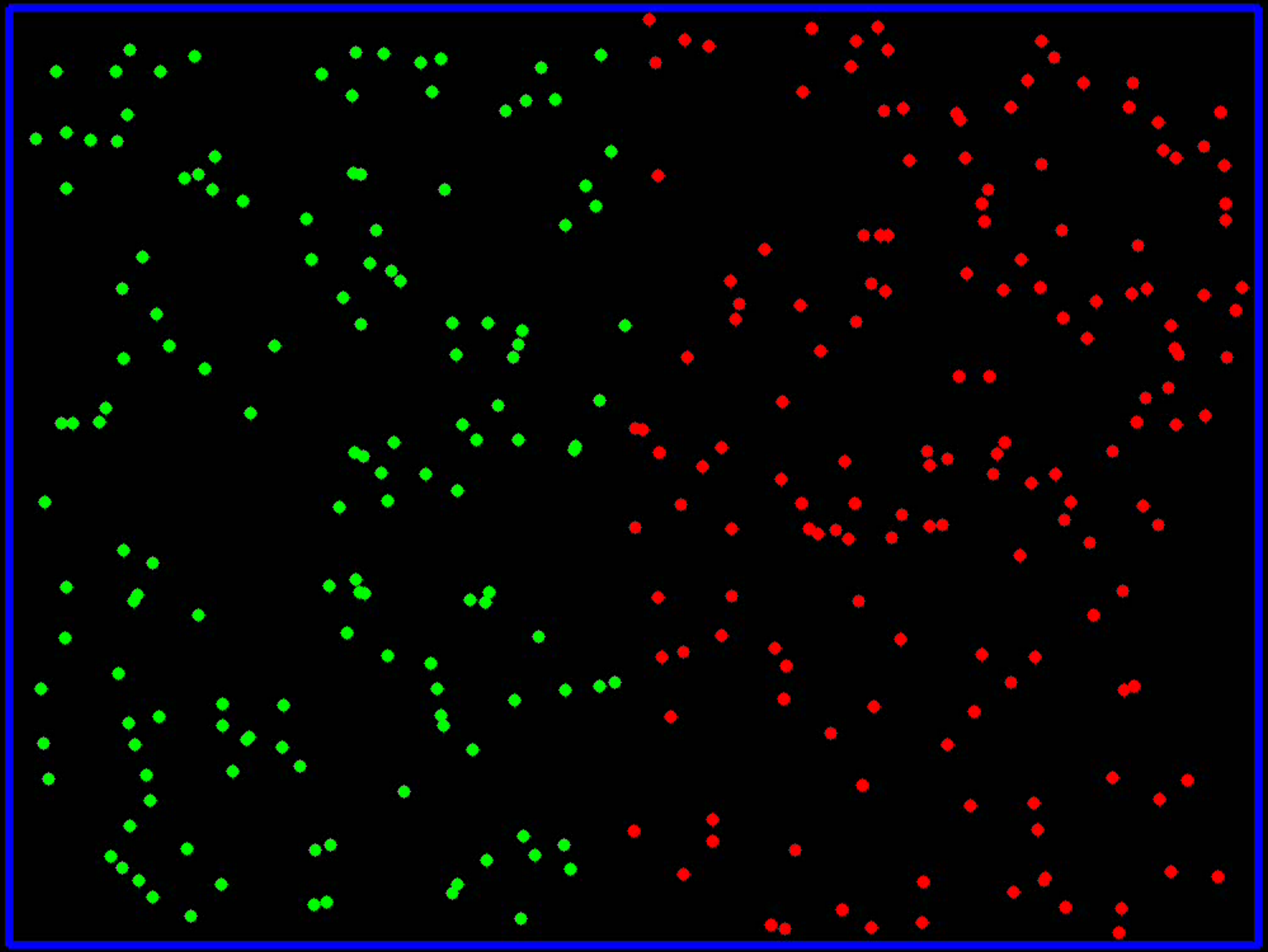
Diffusion Tensor Imaging
Tractography



In Vivo Study of WM: Advanced Neuroimaging Techiniques



Diffusion MRI



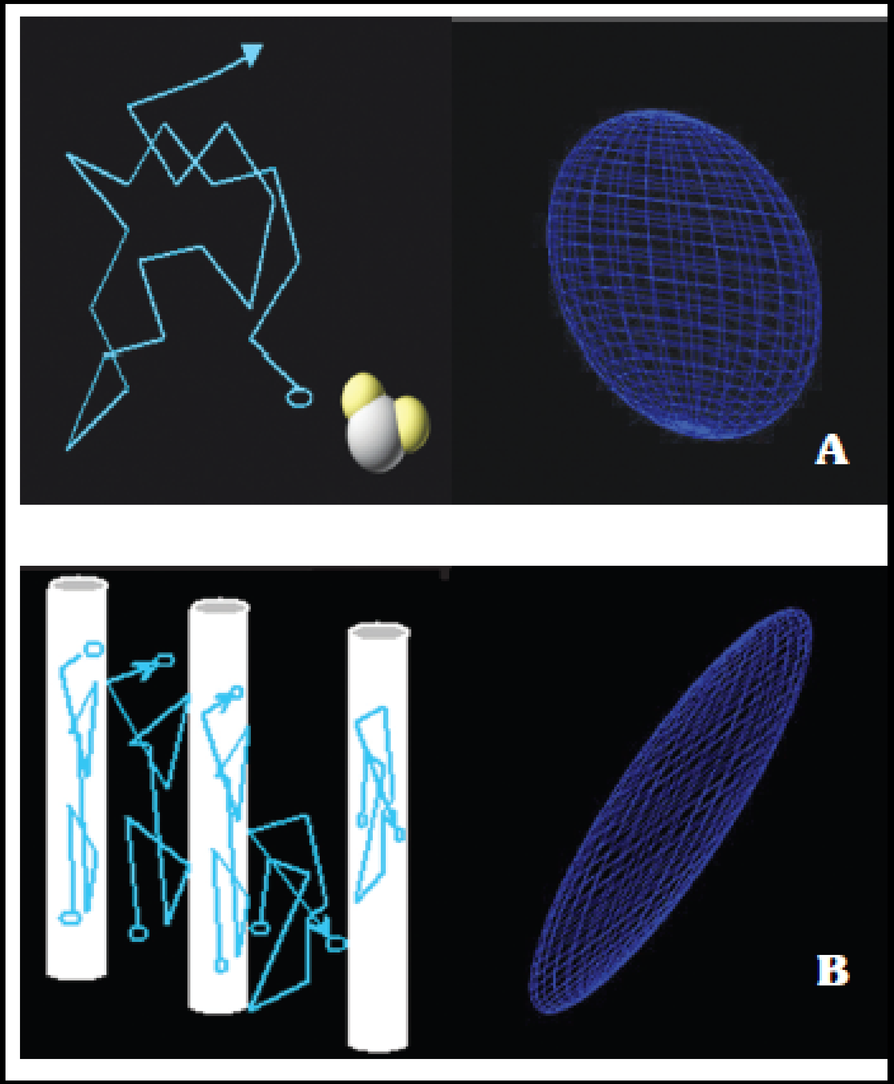
- Diffusion refers to the random, thermally included mobility (Brownian motion) of a molecule over time.
- The diffusing water molecule samples and interacts with the local environment, and thus, by measuring the degree and direction of water motion, the structure can be inferred.

Brown R., Philosoph Mag (1828); Einstein A., Annal Phys (1905)

Diffusion Tensor Imaging (DTI)

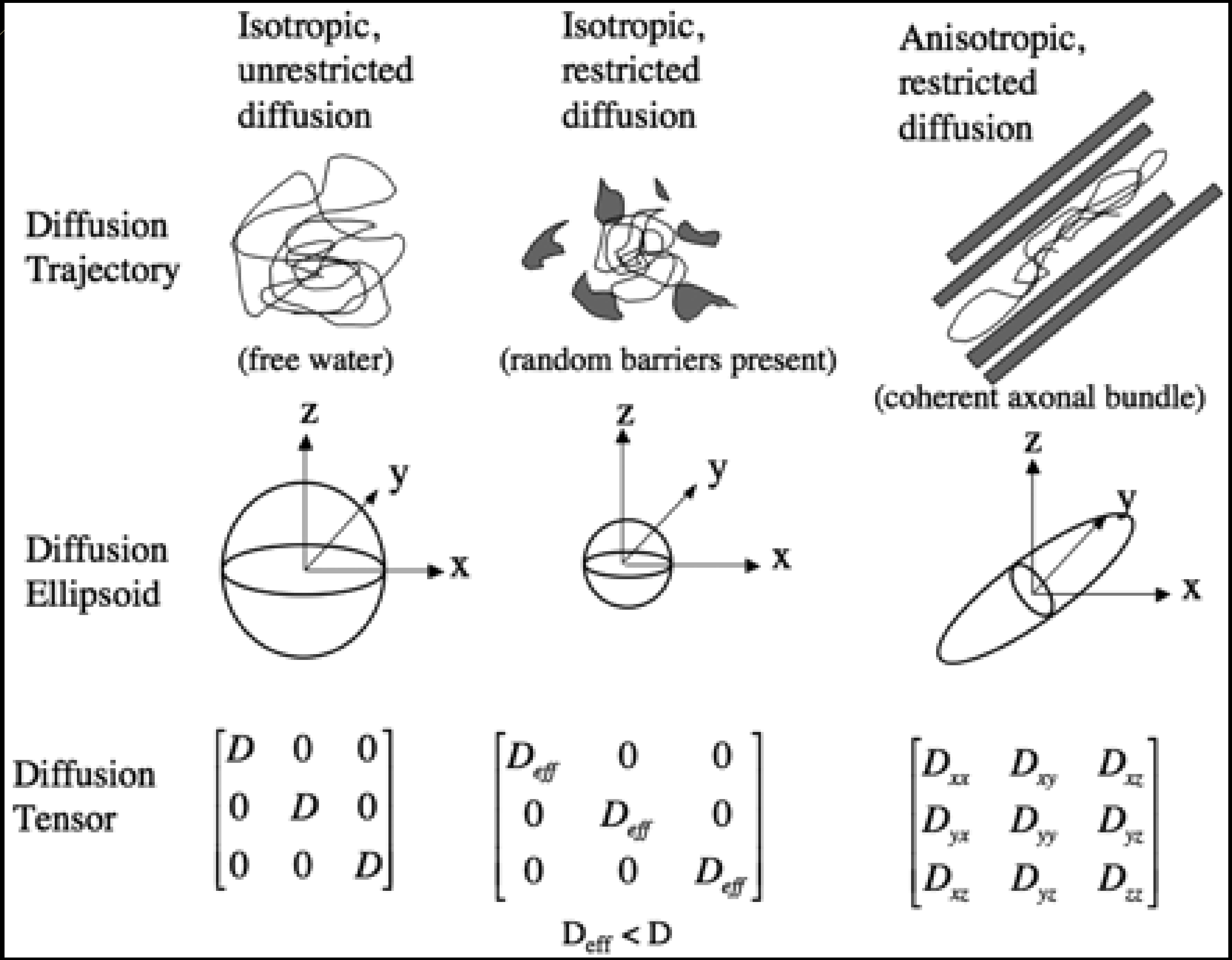
Isotropic Diffusion

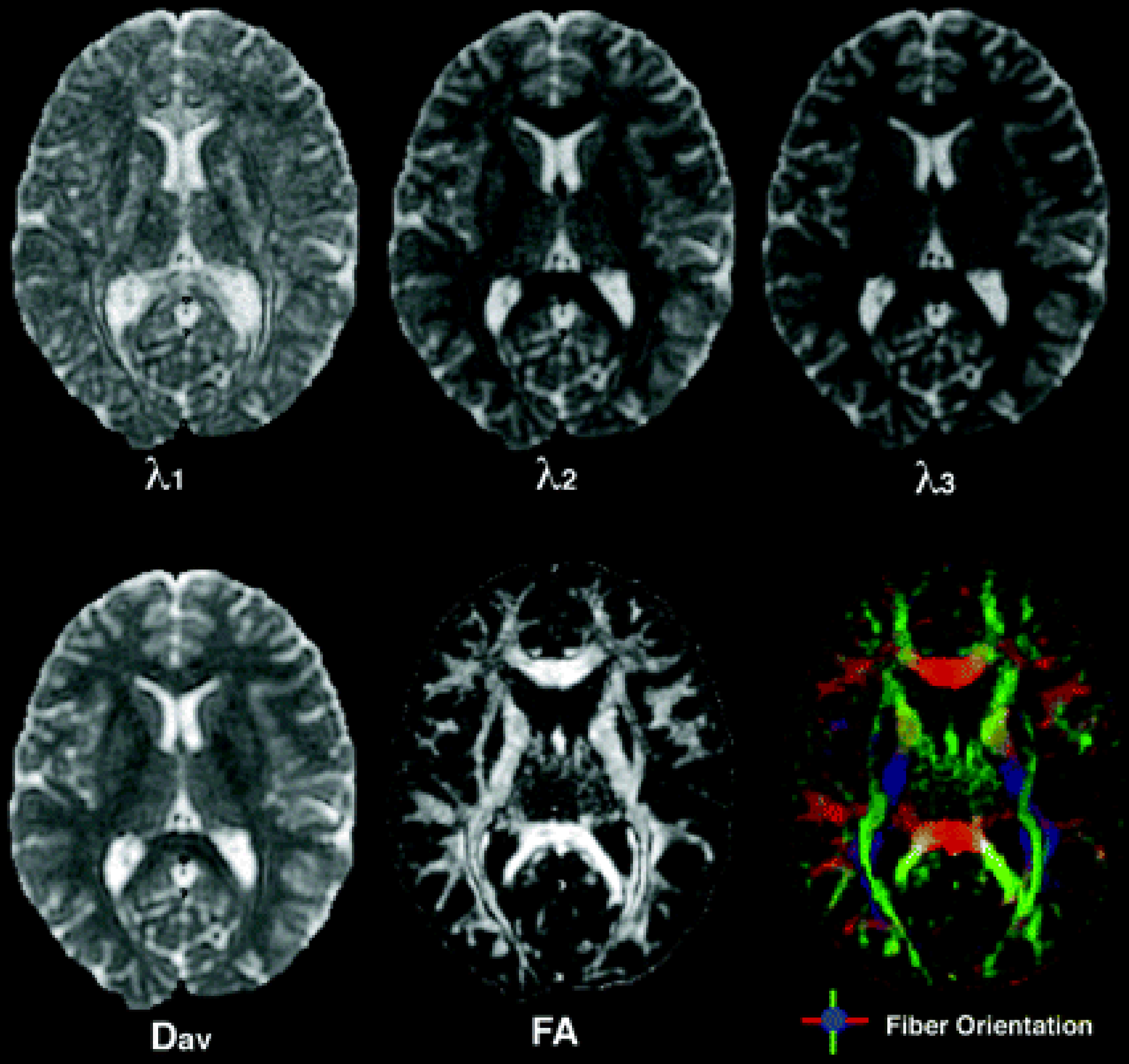
Anisotropic Diffusion



- Molecules can be either diffuse equally in all directions (**isotropic diffusion**), or they can diffuse preferentially along a particular direction or axis (**anisotropic diffusion**).
- Isotropic diffusion occurs if there are no barriers to diffusion or if the barriers are randomly oriented,
- Anisotropic diffusion occurs when there are barriers that impede diffusion in certain directions while favoring moving of water along others

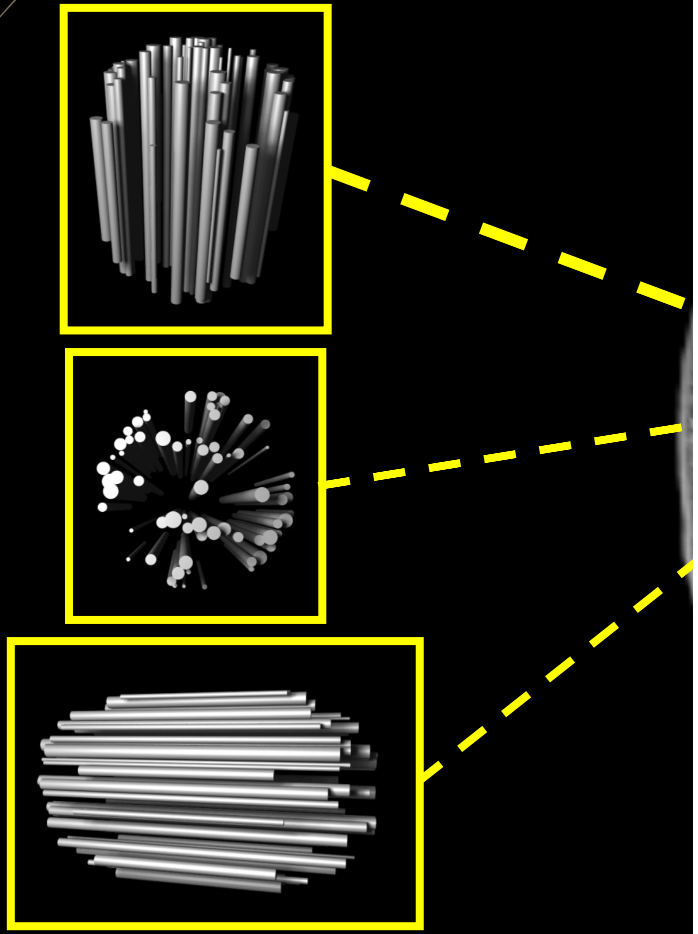
Diffusion ellipsoids and tensors

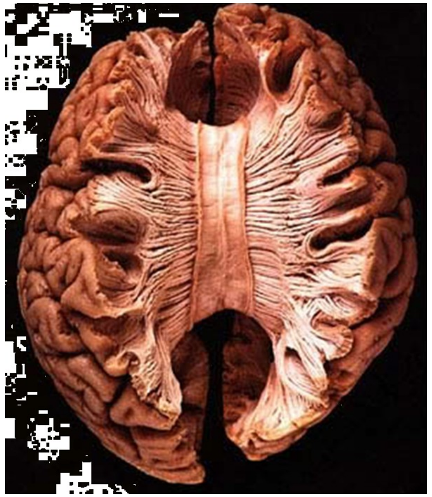




Top row: The first, second, and third eigenvalues are shown with the same intensity scaling. Note that the eigenvalues are always ordered in descending order of intensity with the first eigenvalue being the greatest.
Bottom left: The directionally averaged diffusivity is the mean of the 3 eigenvalues.
Bottom middle: The FA indicates the coherence of white matter bundles.
Bottom right: The FA map can be colorized to show the orientation of the primary eigenvector with left-to-right oriented axonal fibers green, anterior-to-posterior fibers red, and inferior-to-superior fibers blue. Colors are additively mixed to represent fiber populations oriented between these 3 cardinal axes.

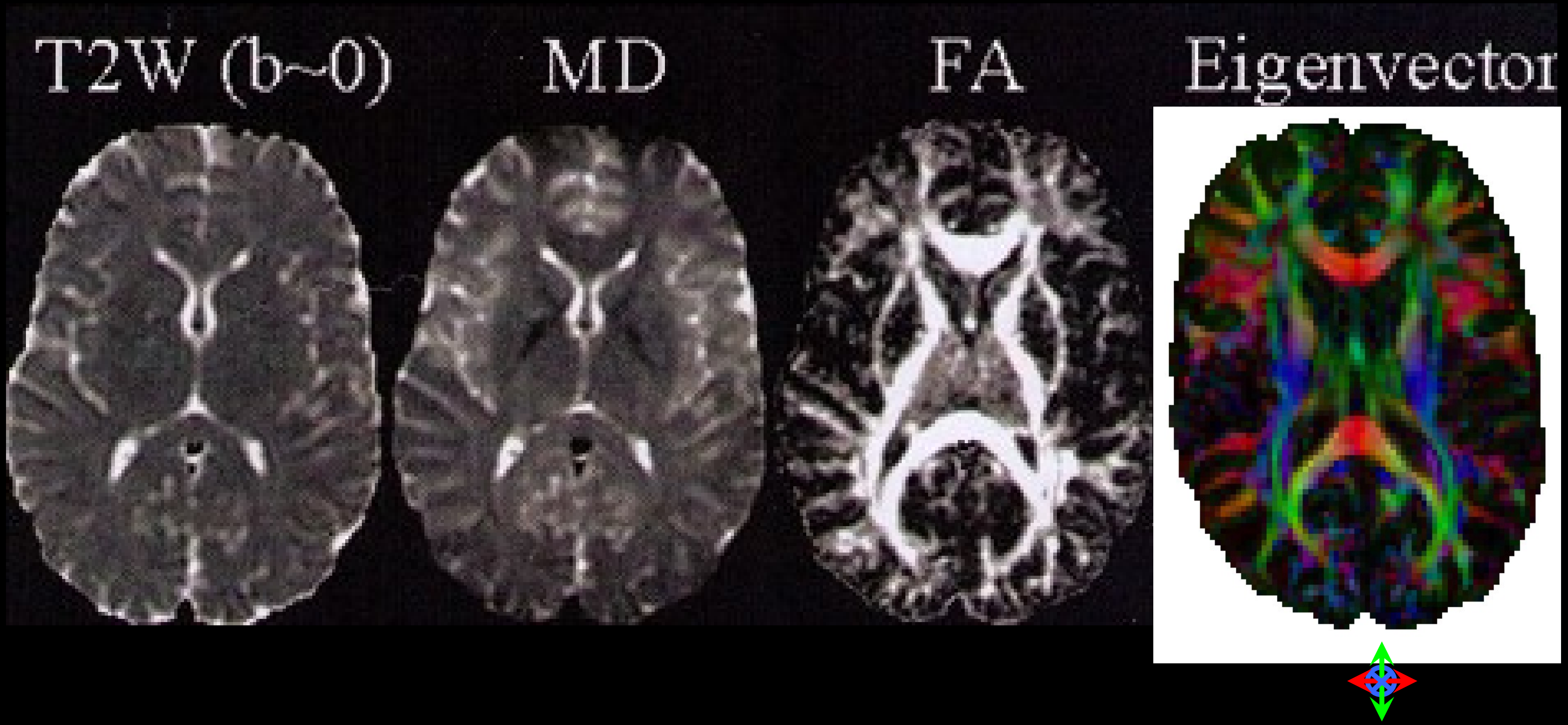
Diffusion



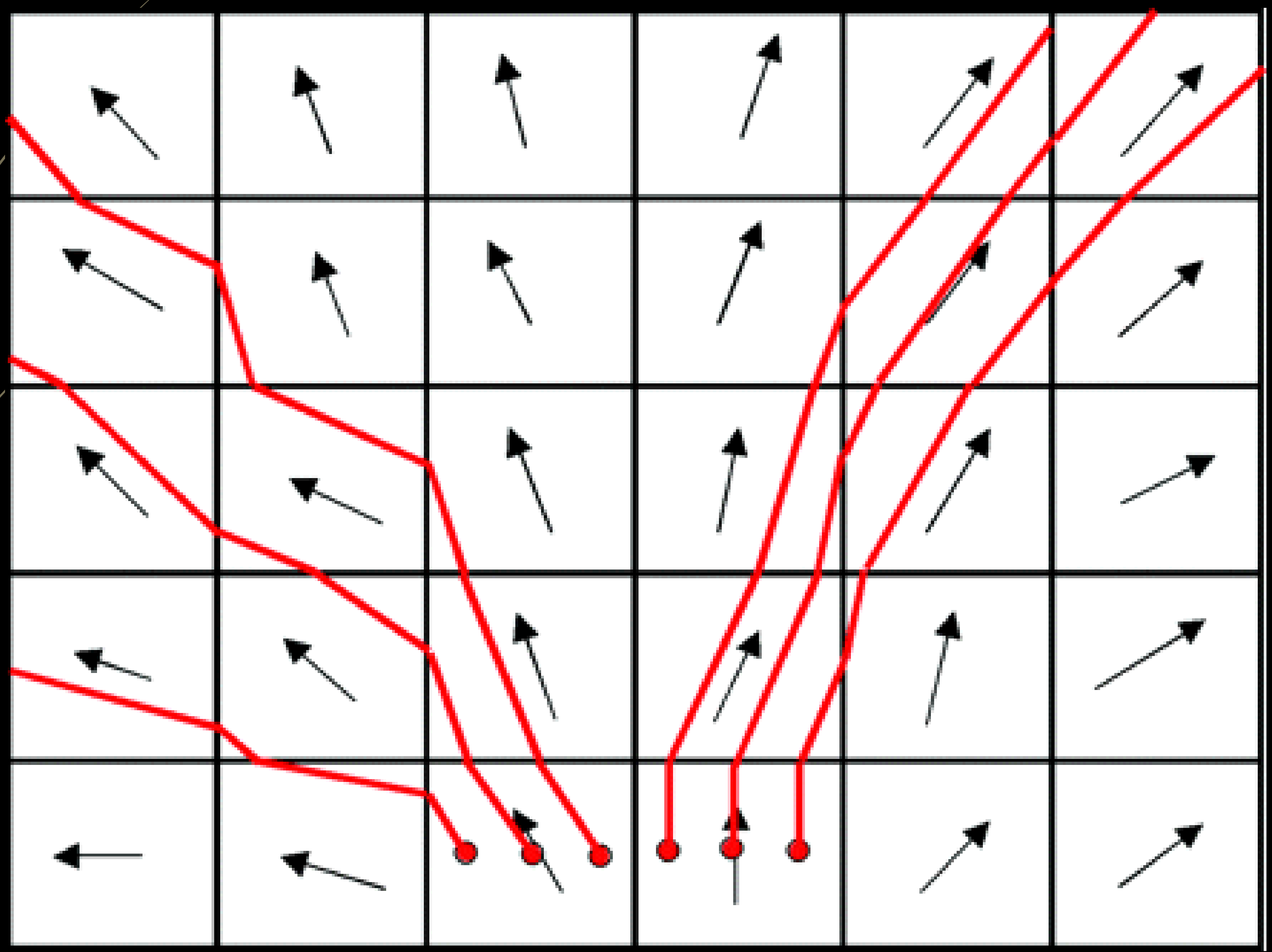


Diffusion Tesnor Imaging

Color Map RGB



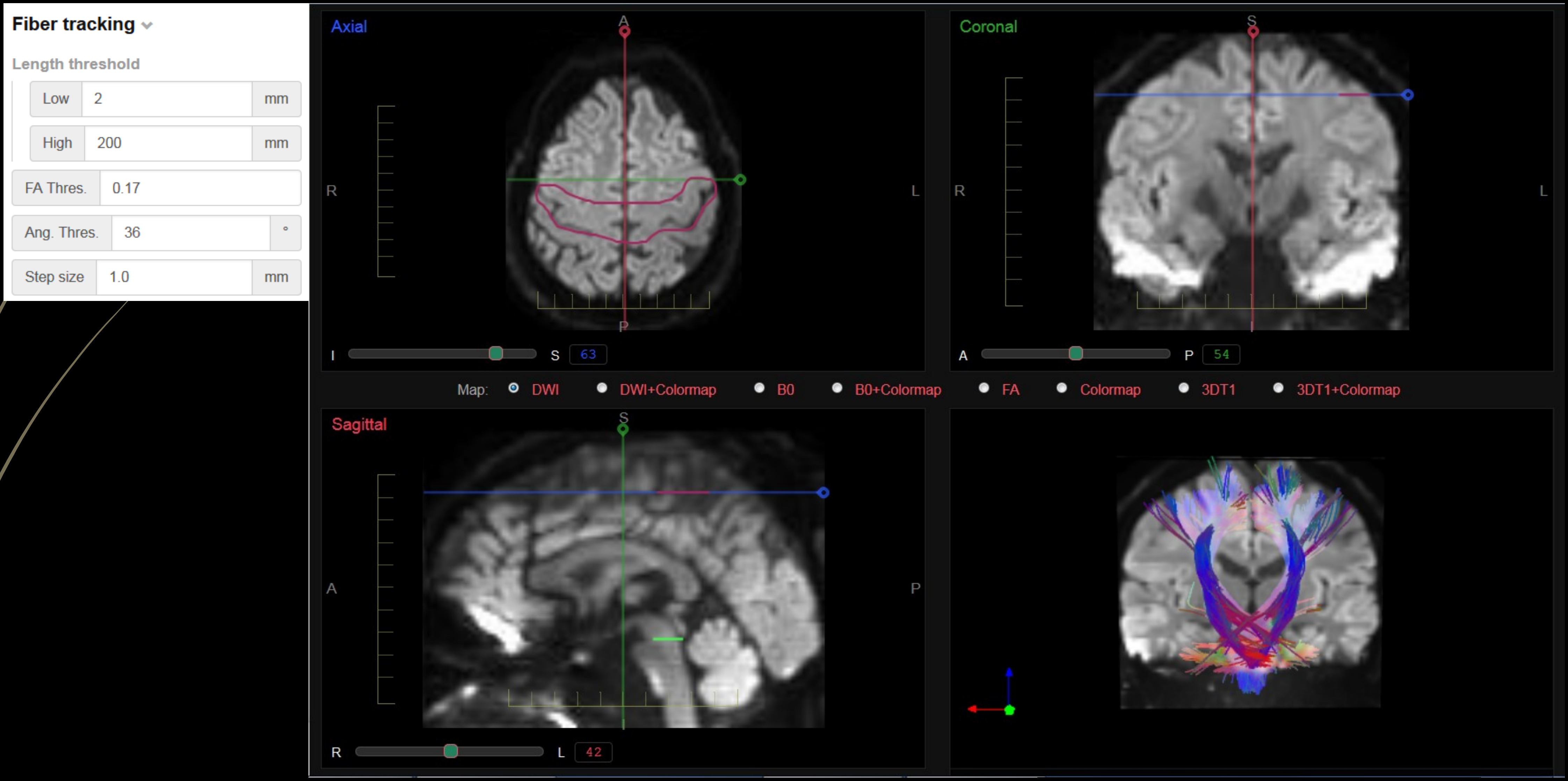
Pajevic S. & Pierpaoli C., Magn Reson Med (1999)



Schematic demonstrating the FACT algorithm. Arrows represent primary eigenvectors in each voxel. Red lines are FACT trajectories.

Starting from a seed voxel the tractography propagates, voxel by voxel, a streamline by piecing together neighbouring eigenvectors, considering specific assumptions (thresholds), i.e. minimum FA, max angle degree)

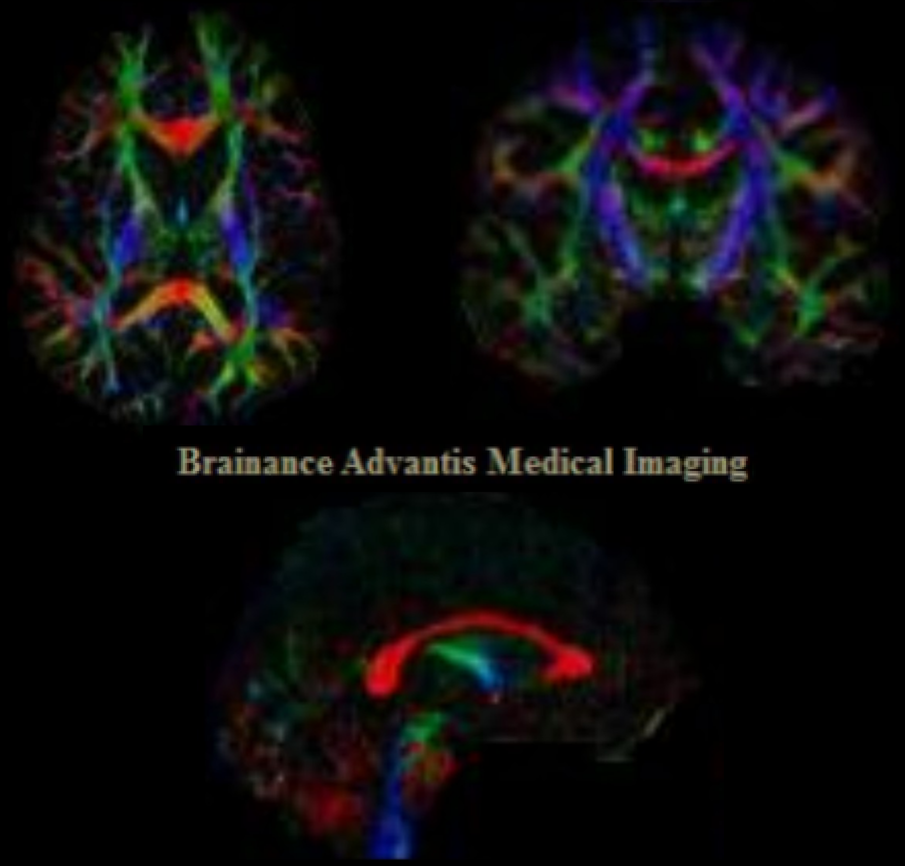
DTI Tractography



Brainance Advantis Medical Imaging

DTI Tractography

- Reconstruction and qualitative and quantitative study of WM in vivo
- Number and length of fibers
- Volume of fibers
- Quantitative indices of WM microstructural integrity:
  - fractional anisotropy (FA)
  - apparent diffusion coefficient (ADC) or mean diffusivity (MD)
  - axial diffusivity (Dax)
  - radial diffusivity (Drad)



Limitations;

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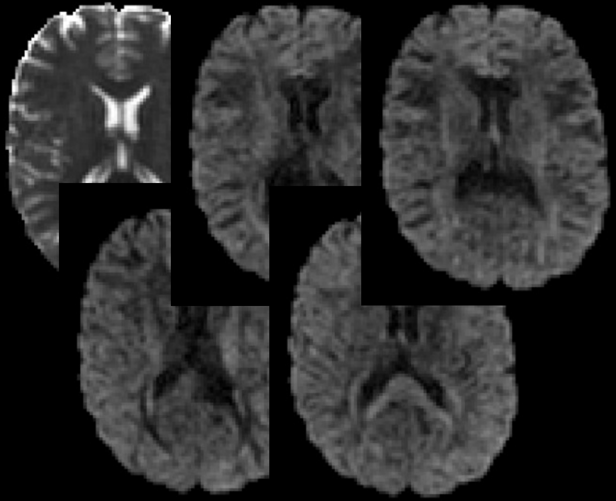
From DWI acquisition to DTI tractography



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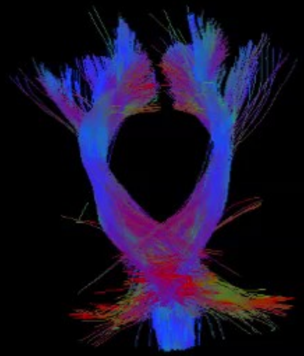
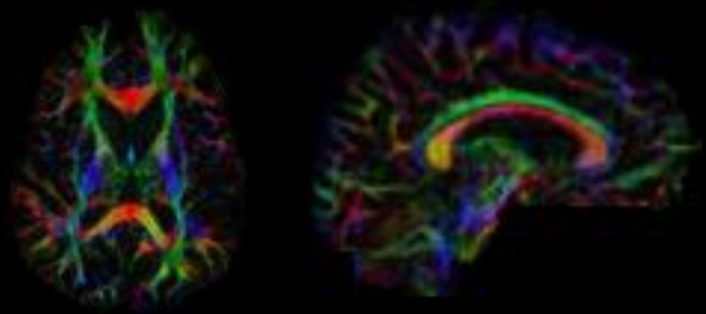
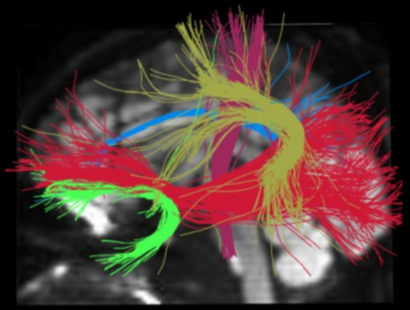
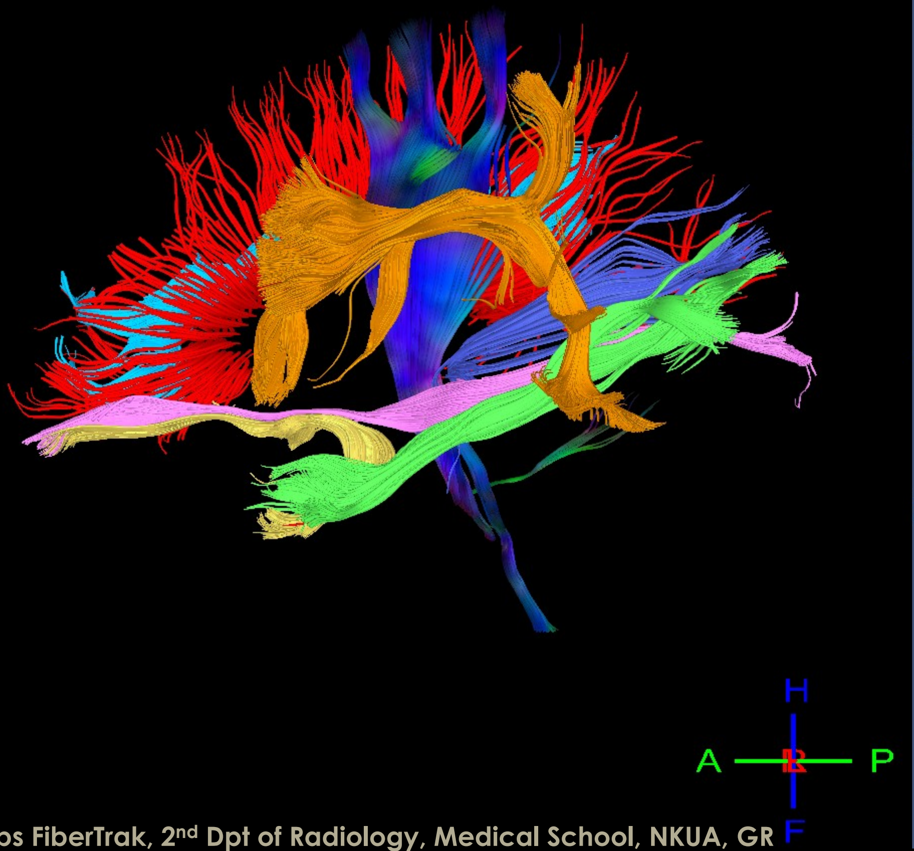


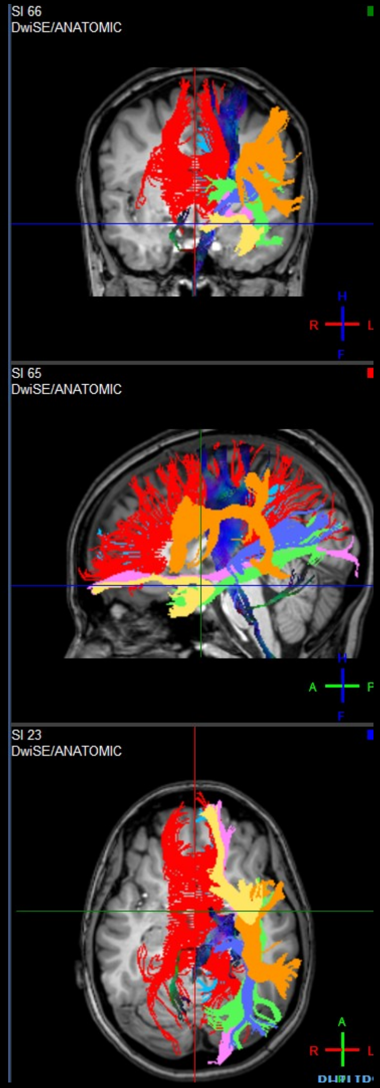
Brainance Advantis Medical Imaging





Tractography of
major commissural, projection and associative pathways





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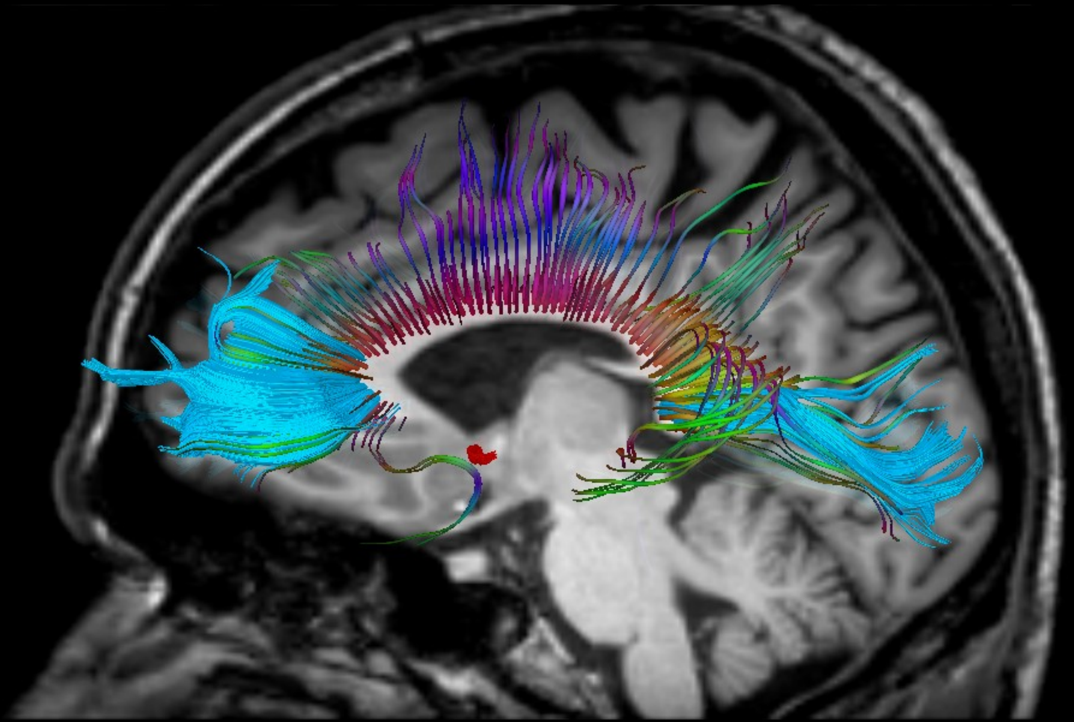
Commissural fiber system



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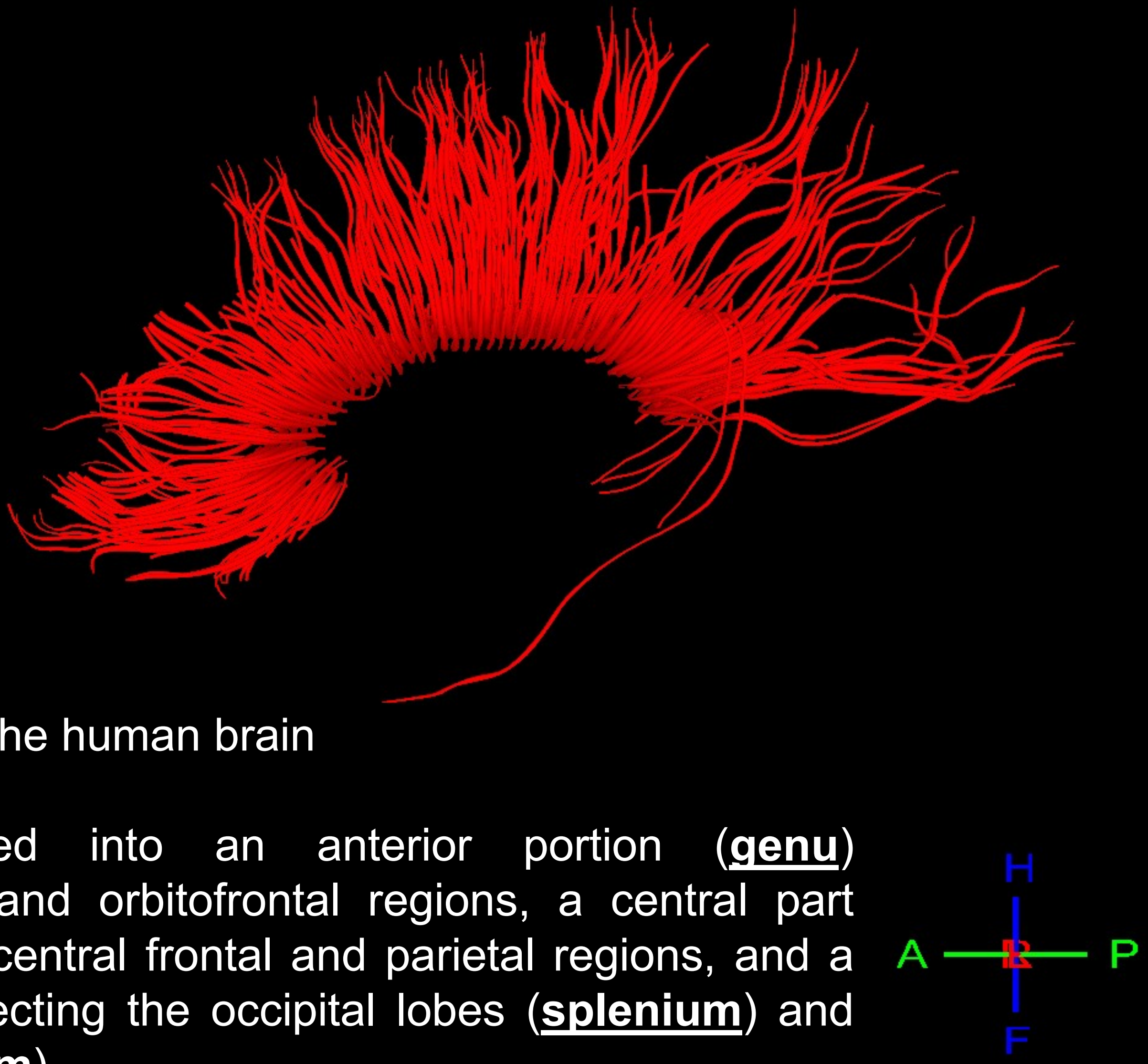
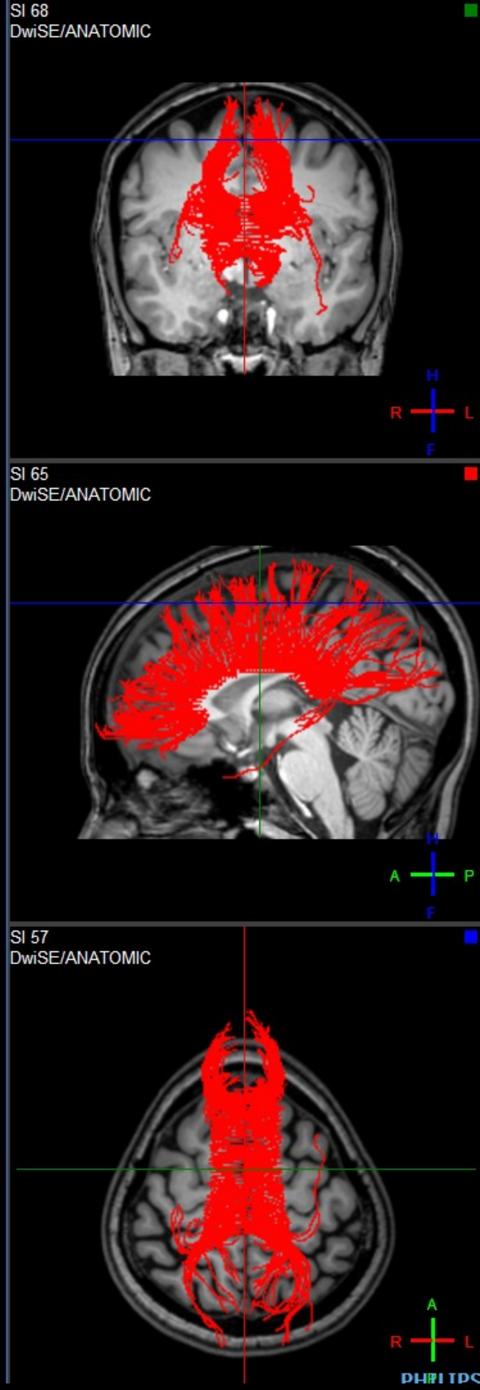
Corpus Callosum

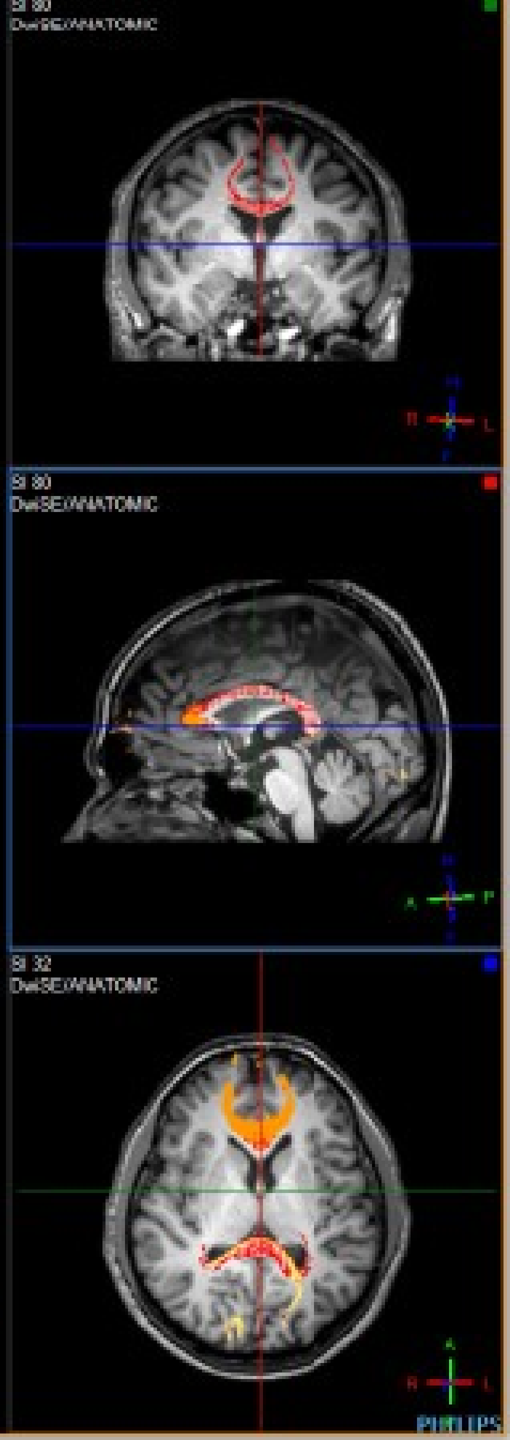




•The largest bundle of the human brain

•Conventionally divided into an anterior portion (**<u>genu</u>**) connecting prefrontal and orbitofrontal regions, a central part (**<u>body</u>**) connecting precentral frontal and parietal regions, and a posterior portion connecting the occipital lobes (**<u>splenium</u>**) and temporal lobes (**<u>tapetum</u>**)

Corpus Callosum / Fmajor & Fminor



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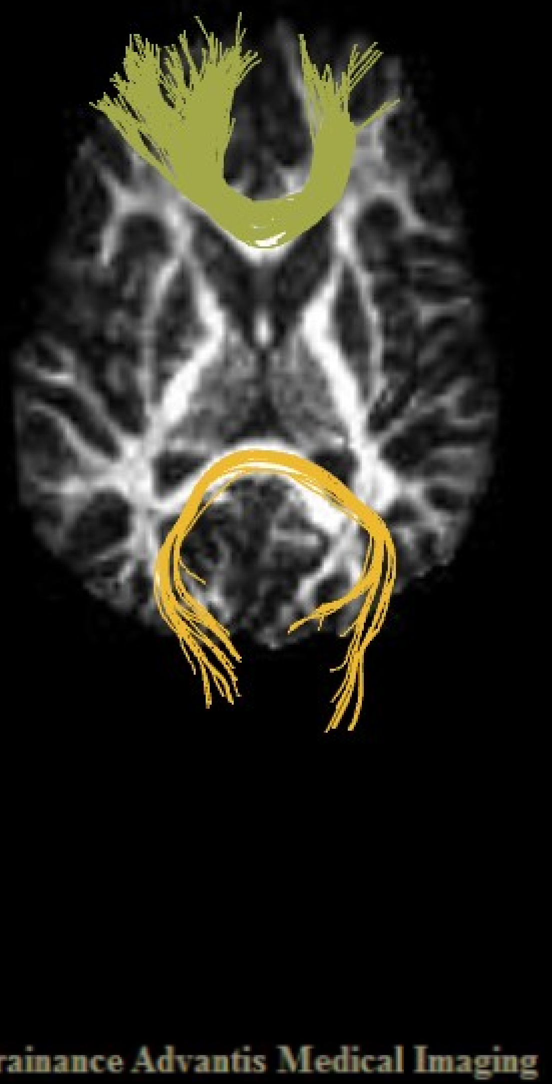
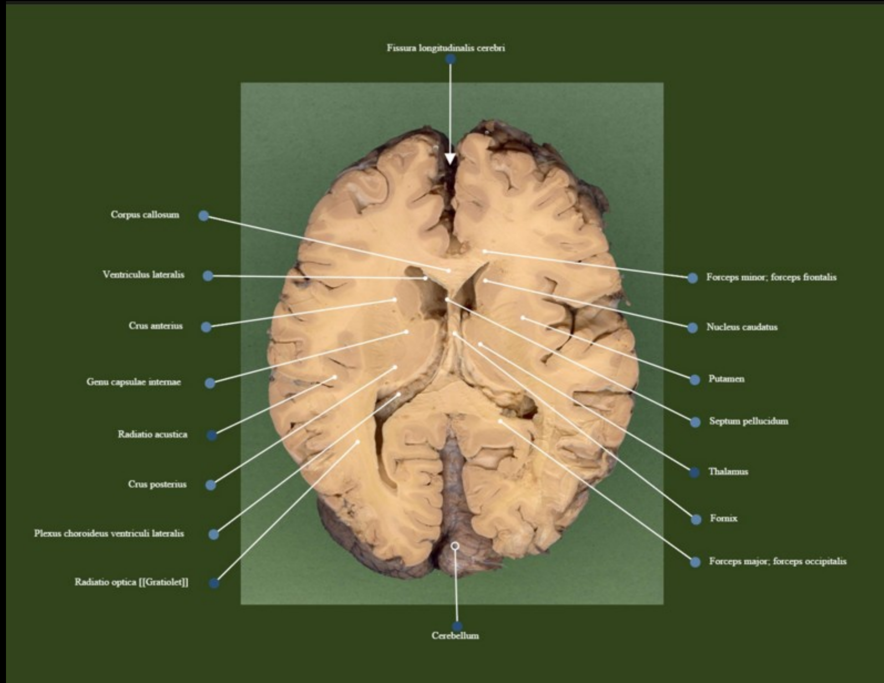
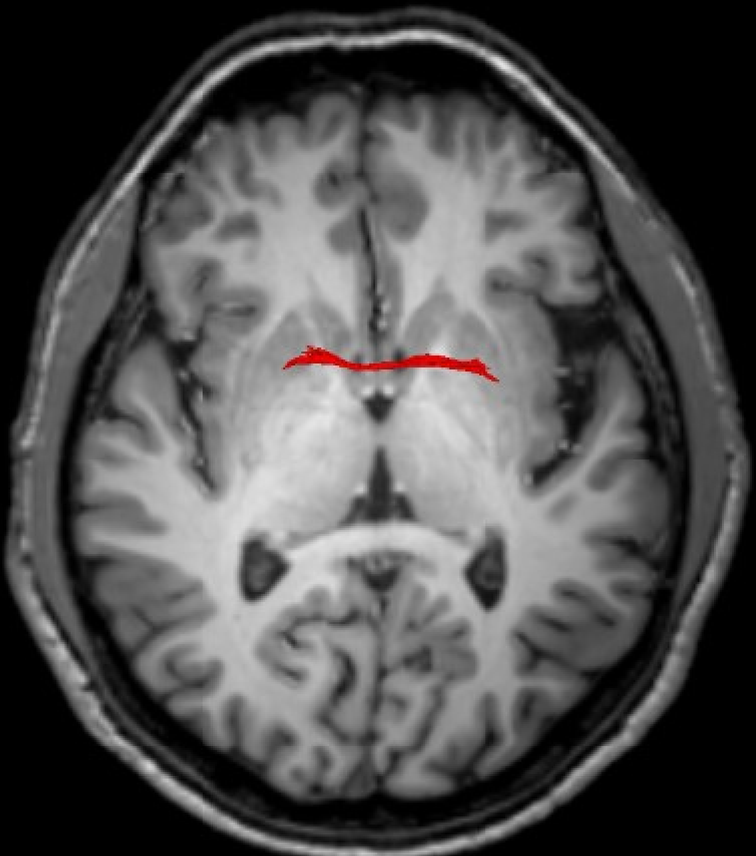
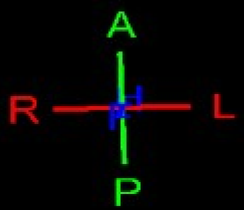
Callosal Radiations / Fmajor & Fminor

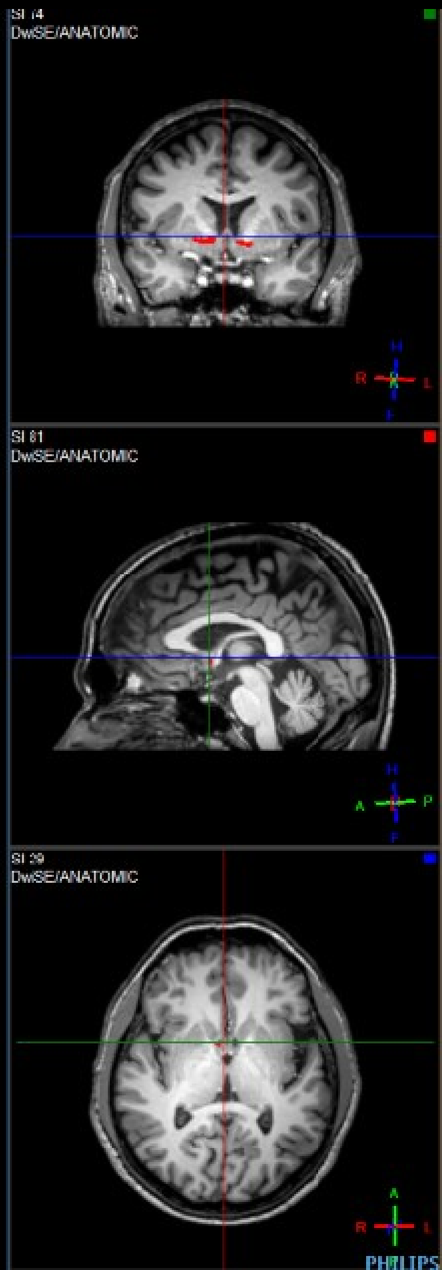




Anterior Commissure







•Connects the anterior ventral temporal lobes (including the amygdala)

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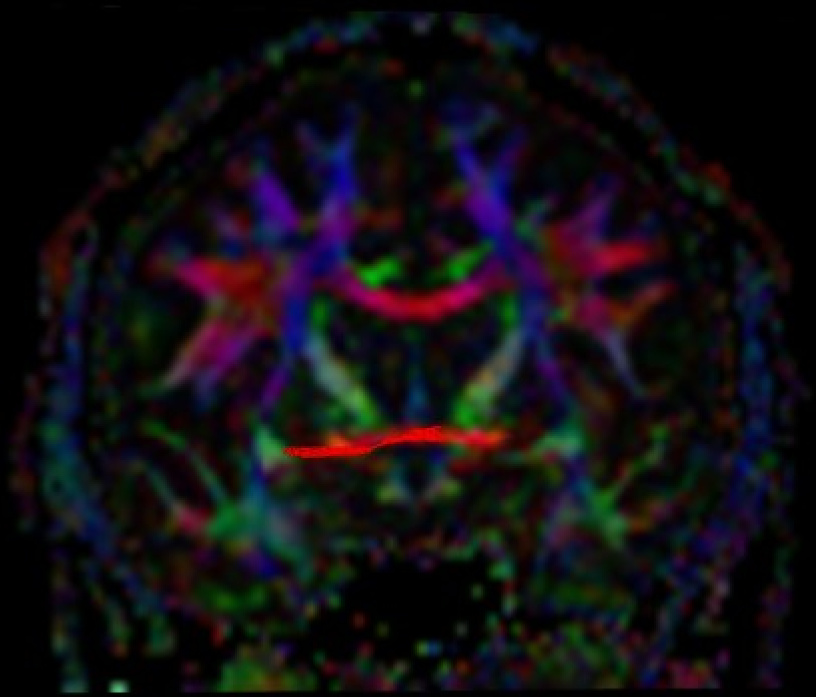
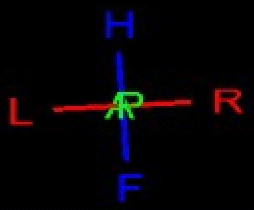
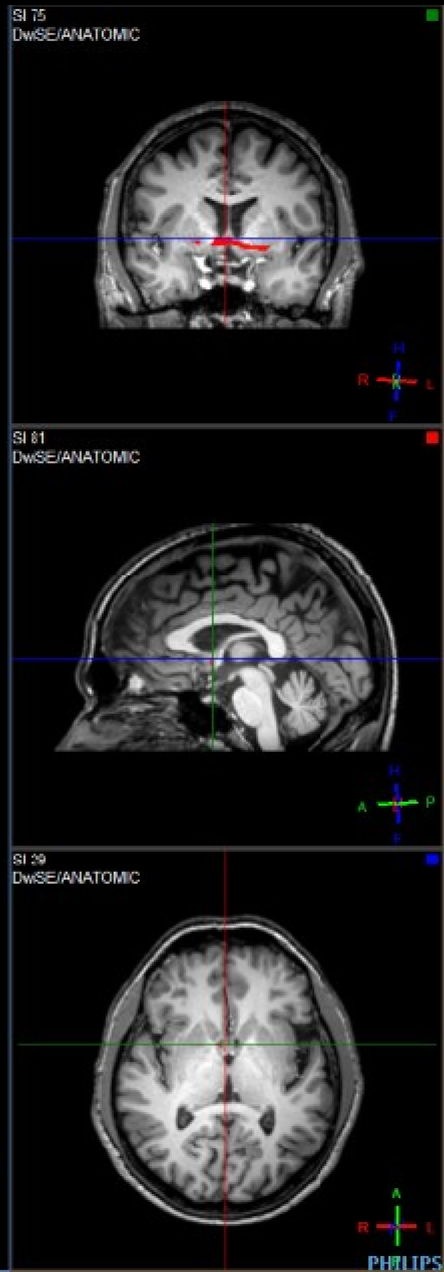
Anterior Commissure







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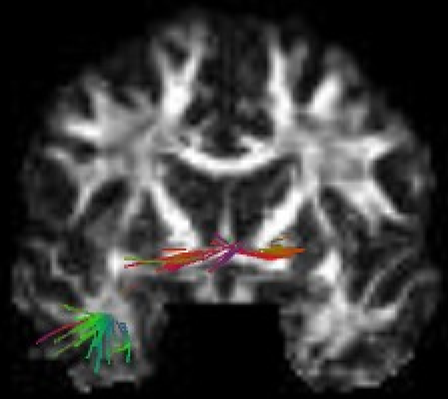
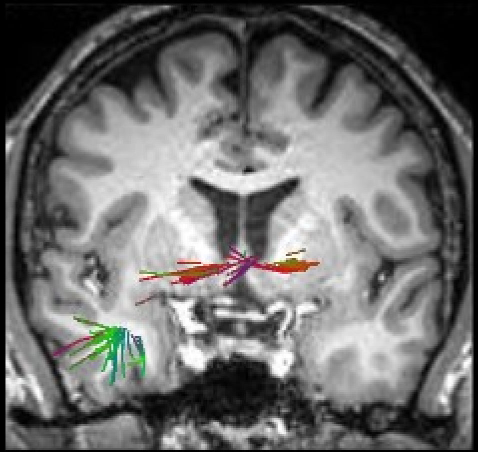
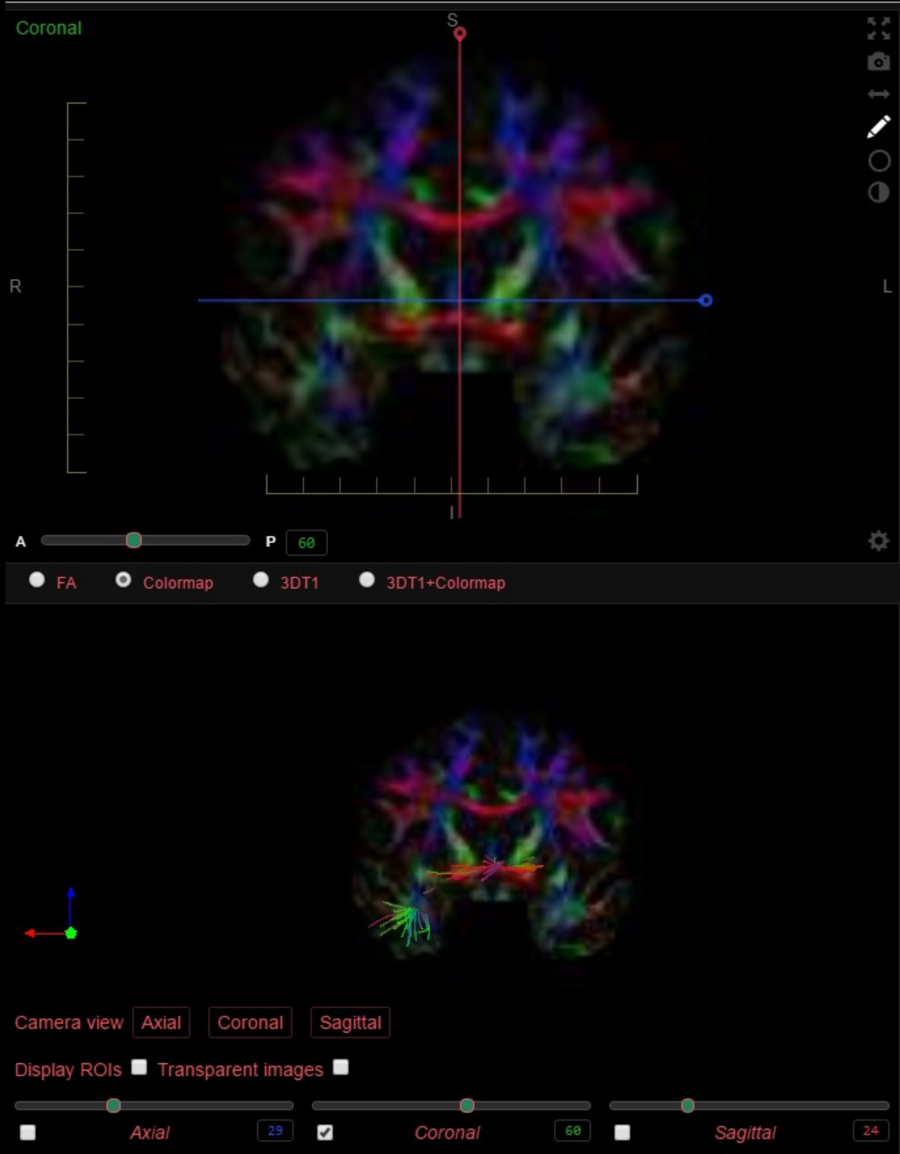
Anterior Commissure

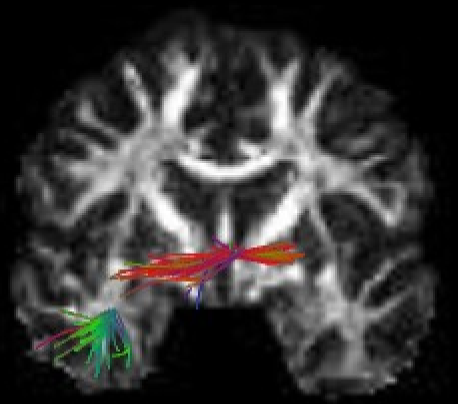


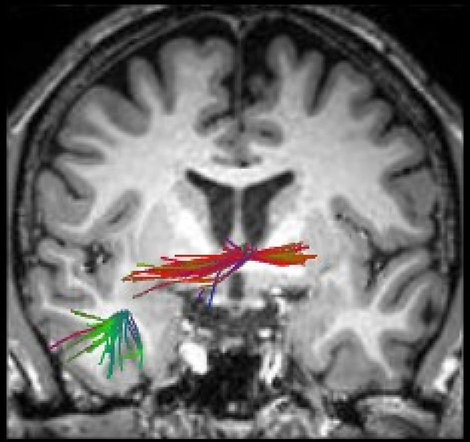


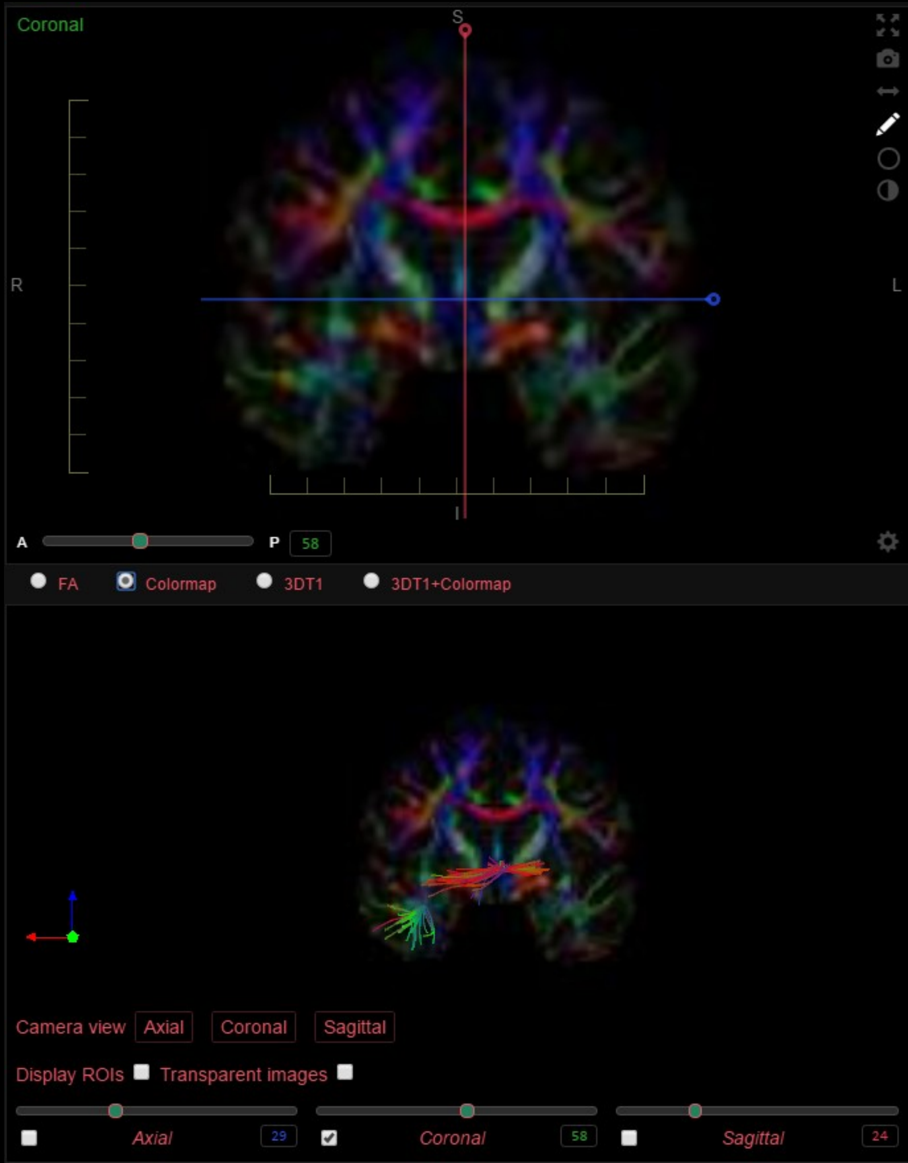


•Fibers medial to the fibers of the external/extreme capsule, ventral to the most anterior part of the body of fornix, and anterior to the cerebral peduncles

Anterior Commissure

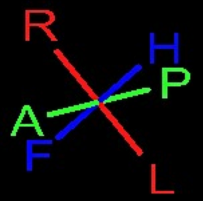


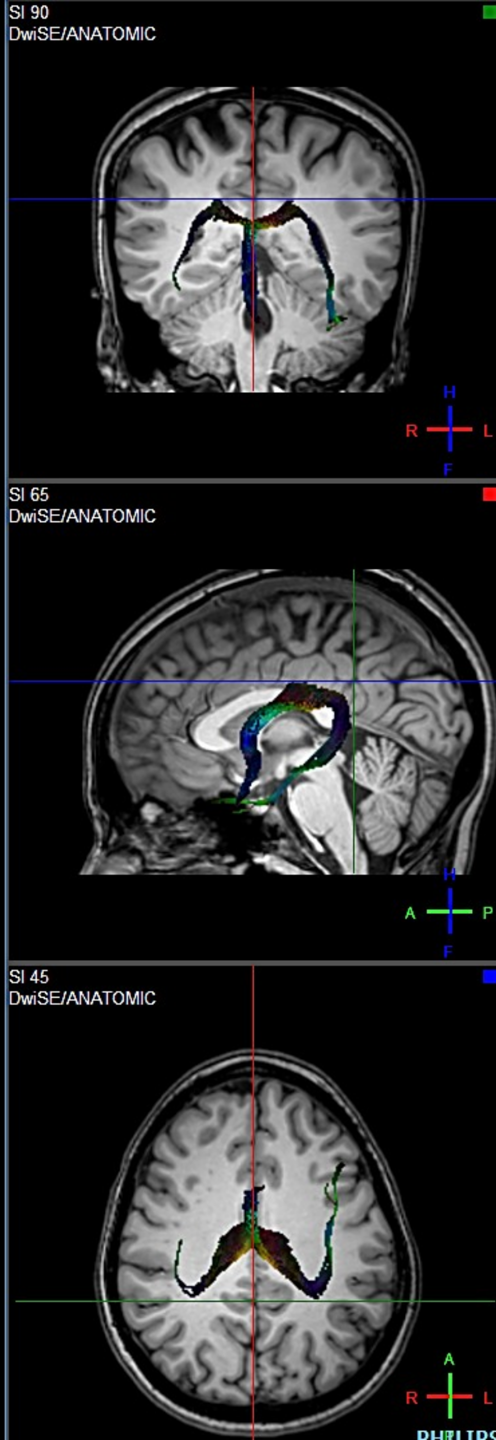




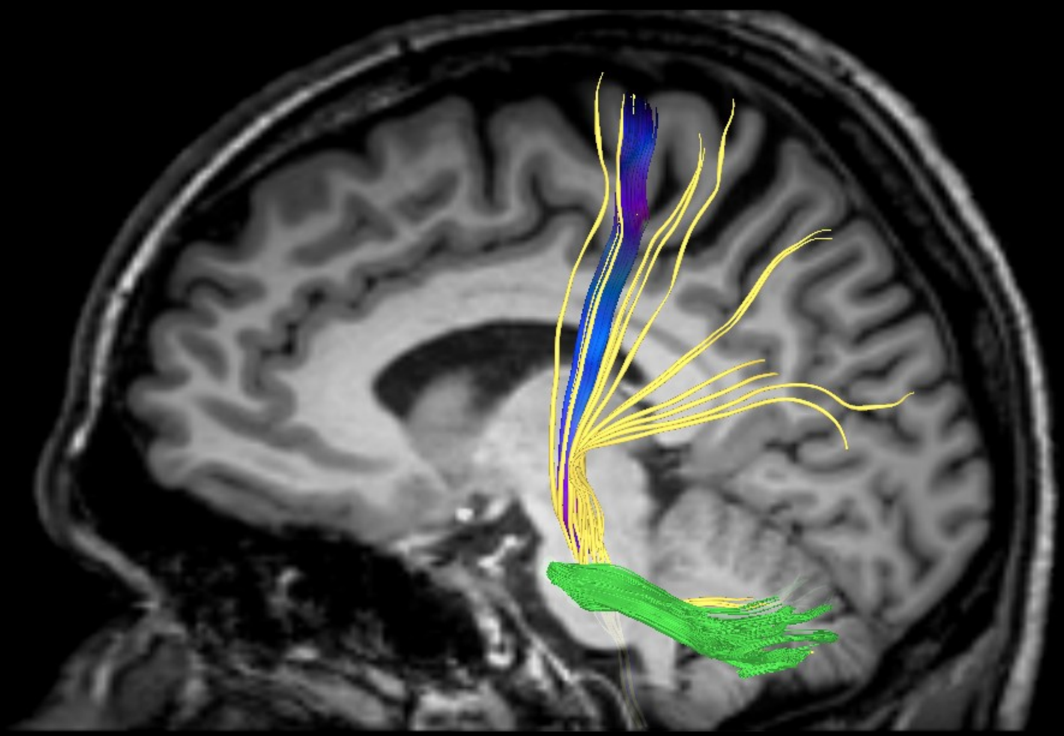
Fornix

- Fx body: runs longitudinally along the midsagittal line of the CC
- Fx anterior: bends downwards and crosses the anterior commissure after splitting into an anterior and posterior column of each side
- Fx posterior: splits into l/r branch (fimbriae), arching around the thalamus and continuing along medial occipitotemporal lobe to terminate in the hippocampus





Projection fiber system



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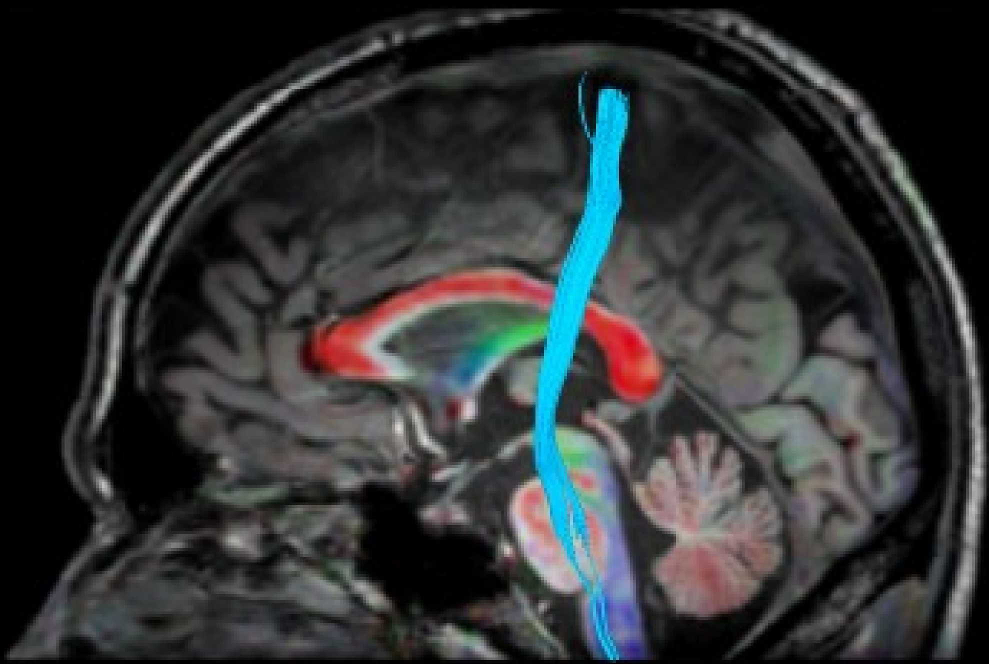
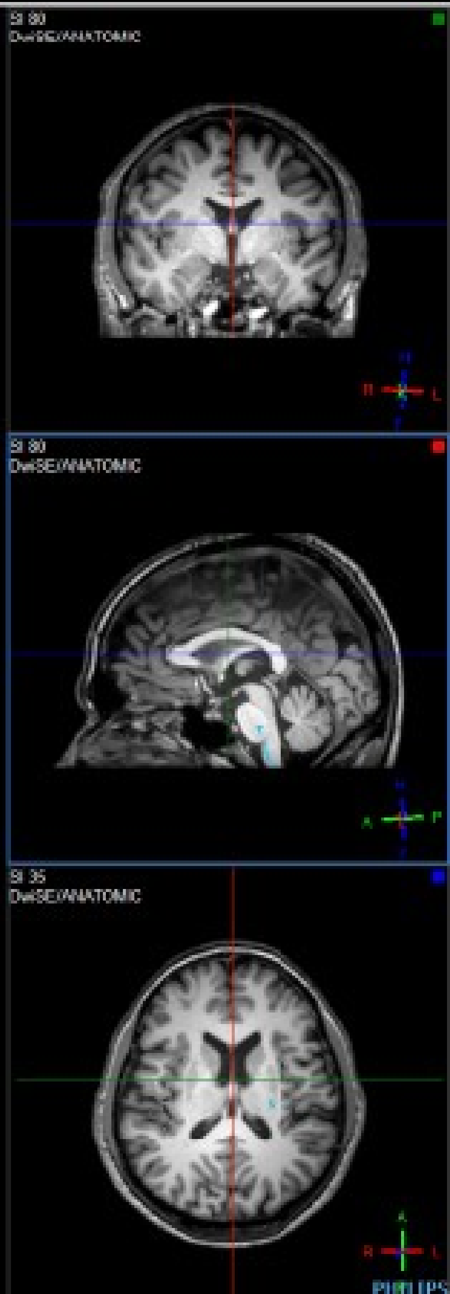
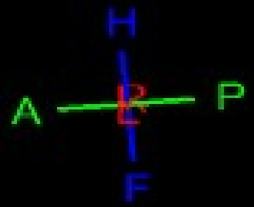
Corticospinal Tract

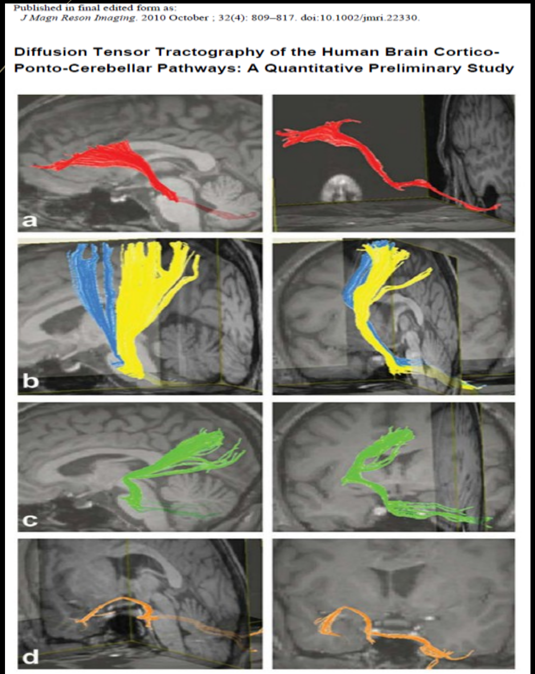




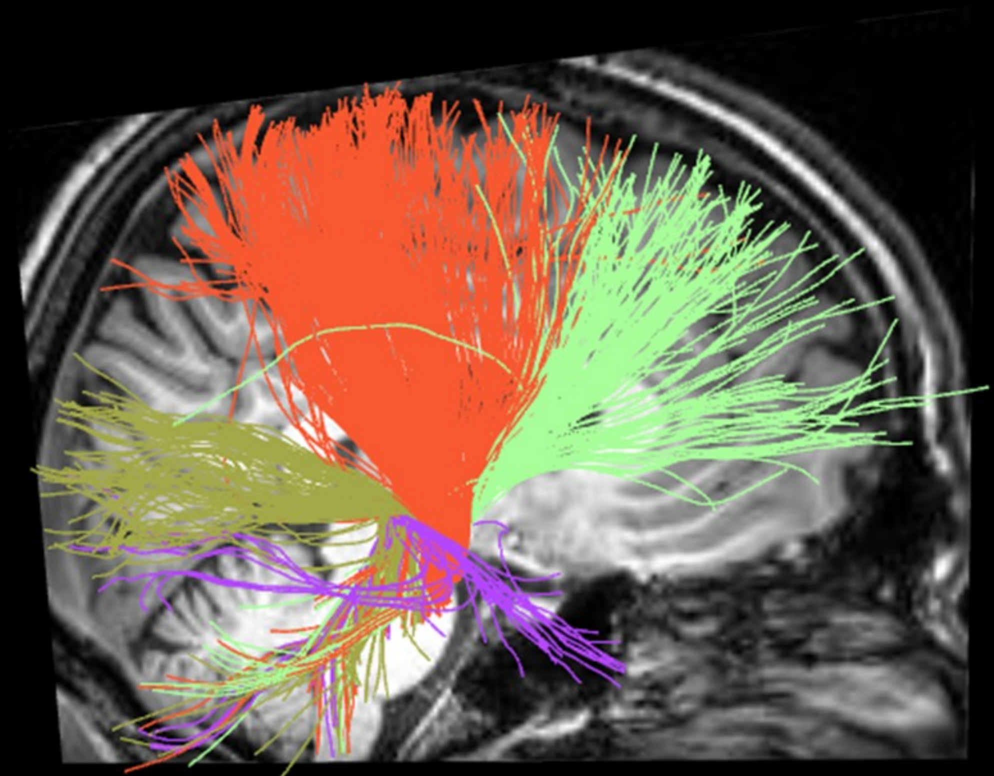


- Efferent projection fibers connecting motor cortex to the brain stem and spinal cord
- Converges into the corona radiata and continues through the PLIC to the cerebral peduncle on their way to the lateral funiculus

Cortico-ponto-cerebellar tracts



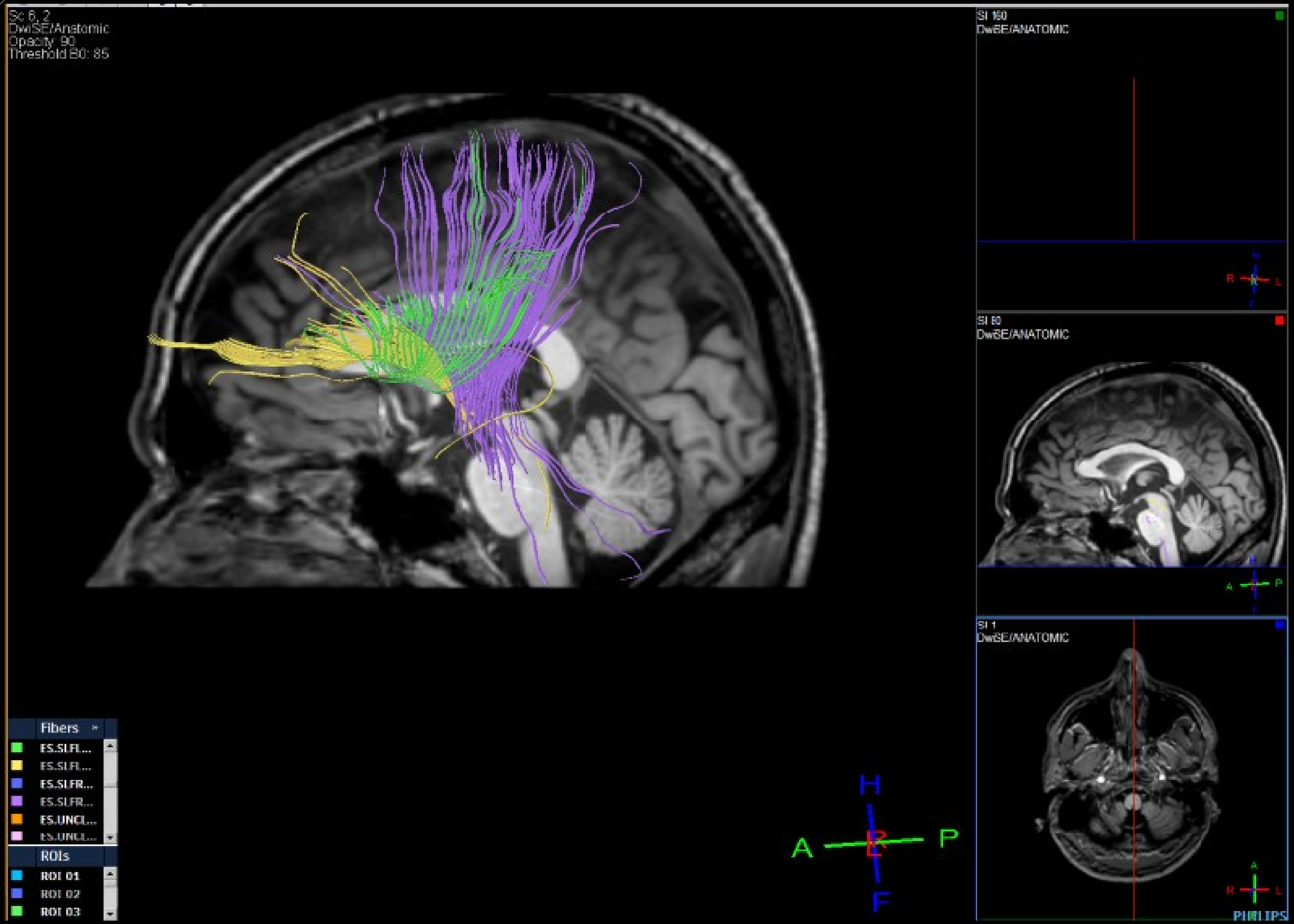
- Afferent fibers enter the cerebellum mostly through the brachium pontis or middle cerebellar peduncle (MCP) which receives fibers originated in the contralateral pontine nuclei with some additional tegmental fibers;
- make up mostly for the cortico-ponto-cerebellar (CPC) tract, bringing information from the cerebral cortex



Cortico-ponto-cerebellar tracts reconstructed using Brainace (Advantis Medical Imaging)

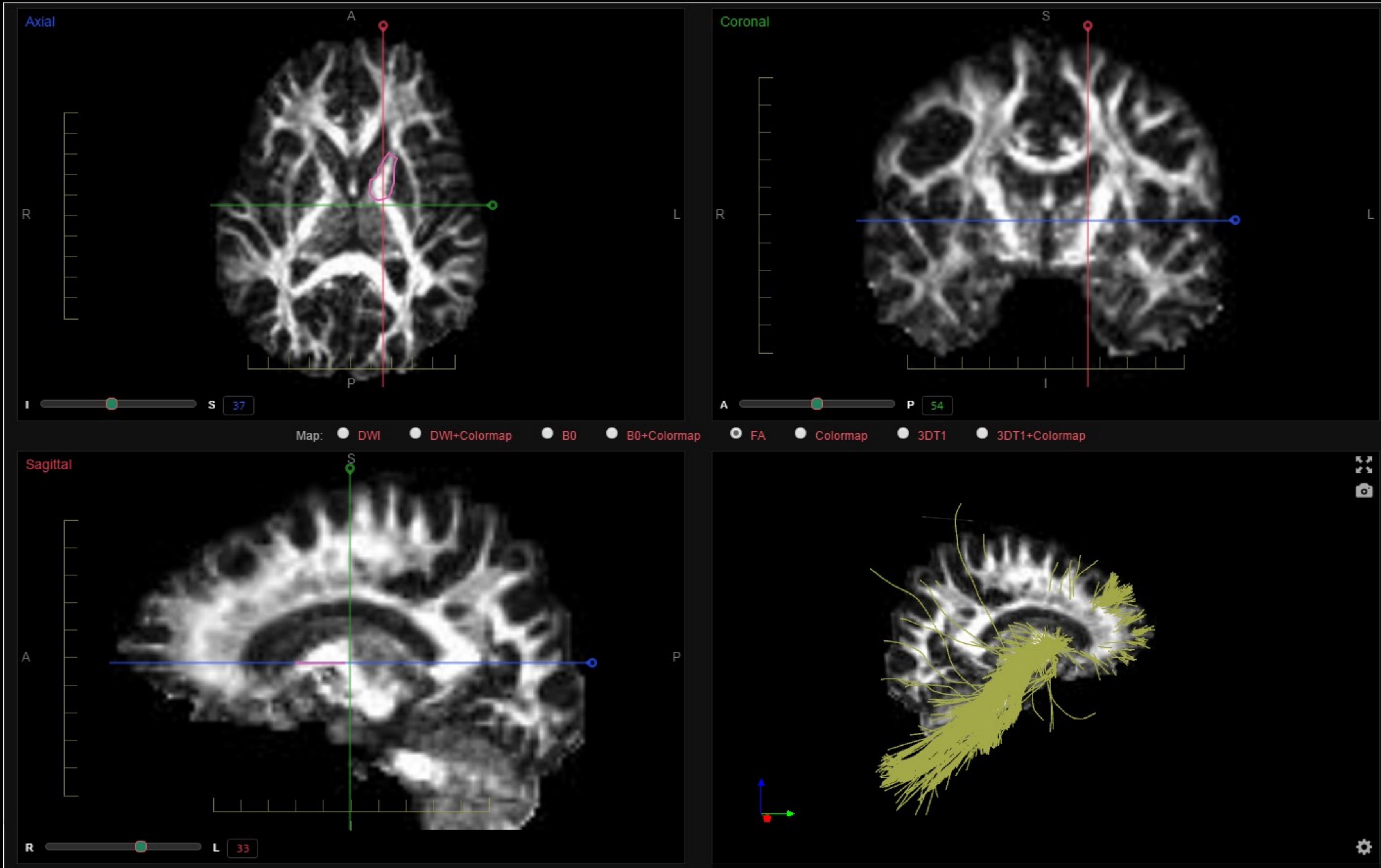
Fronto-ponto-cerebellar tract
Parieto-ponto-cerebellar tract
Occipito-ponto-cerebellar tract
Temporo-ponto-cerebellar tract

ALIC / PLIC / External Capsule



ALIC

- Medial and anterior to the lenticular nucleus and lateral and posterior to the head of the caudate nucleus



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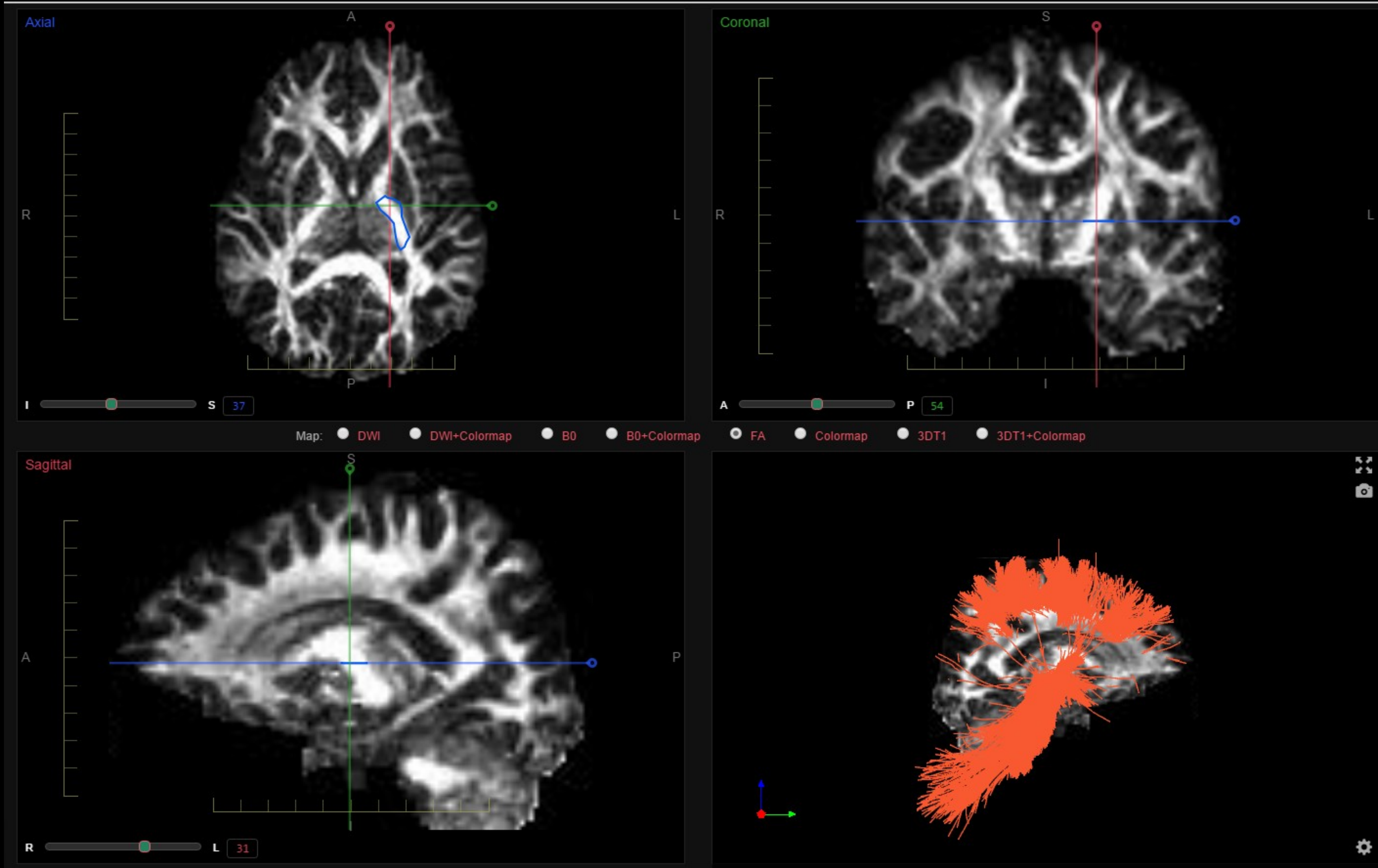
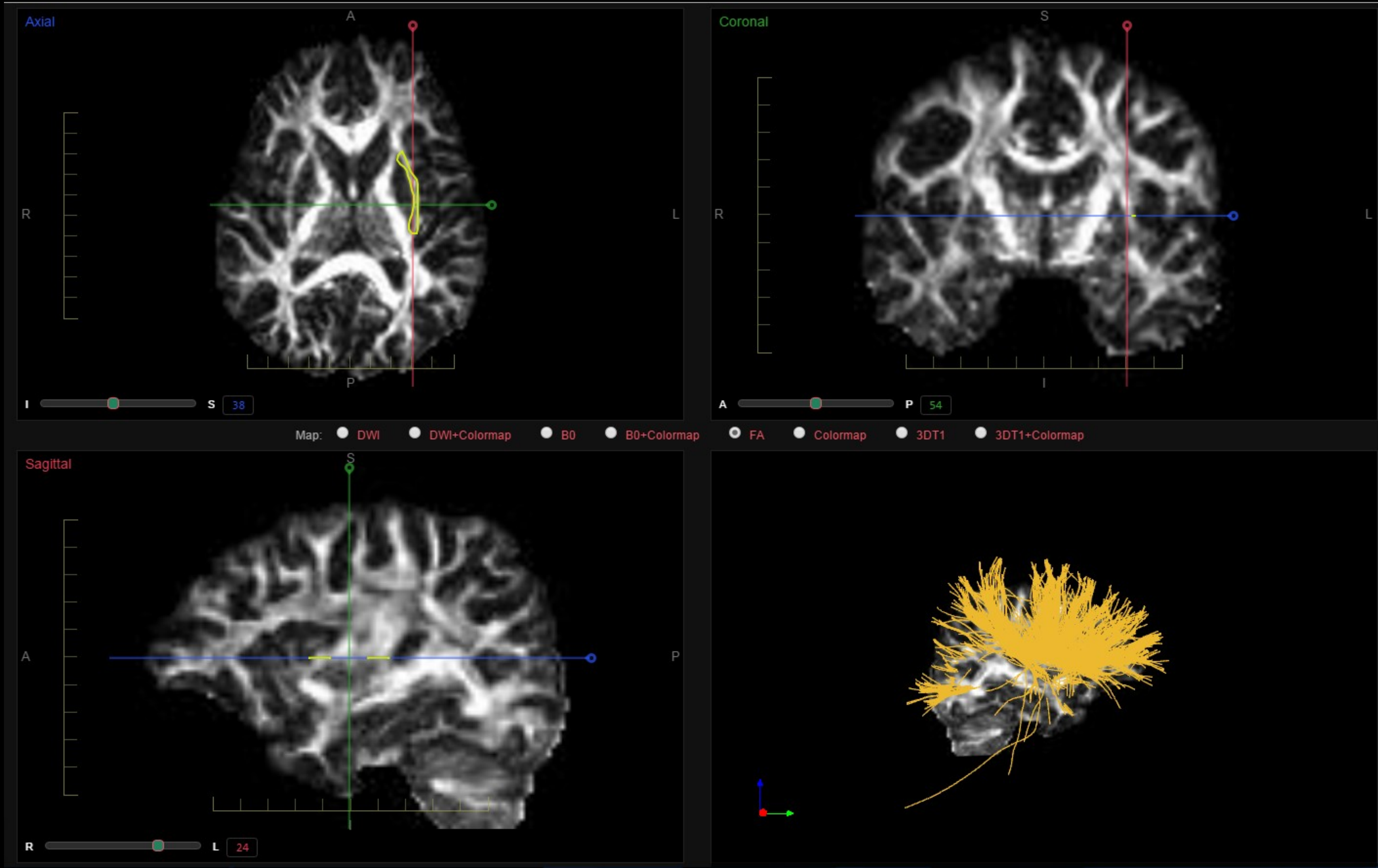
PLIC

- Medial and posterior to the lenticular nucleus and anterior and lateral to the thalamus

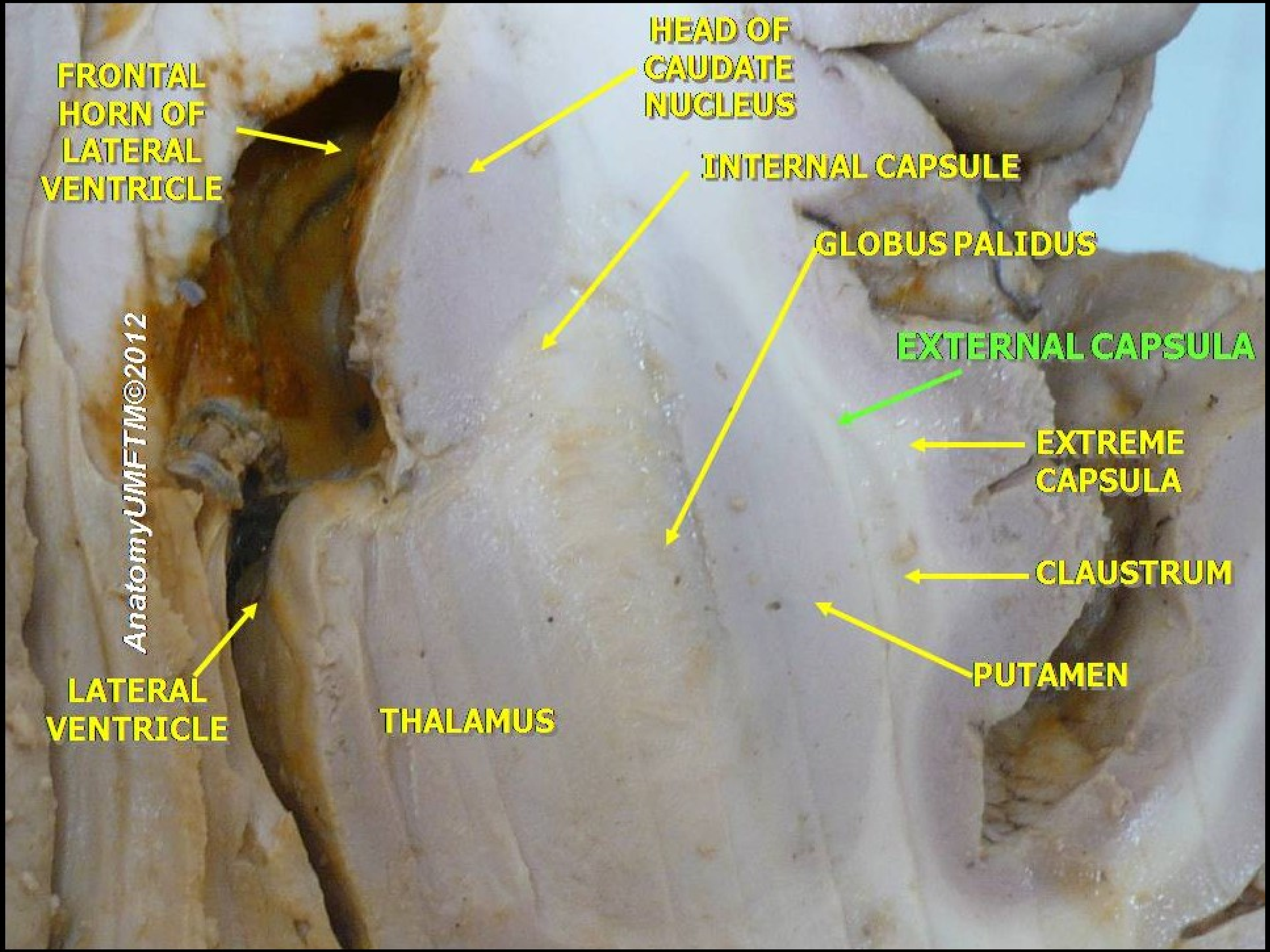


External Capsule

- thin lamina separating the claustrum from the putamen



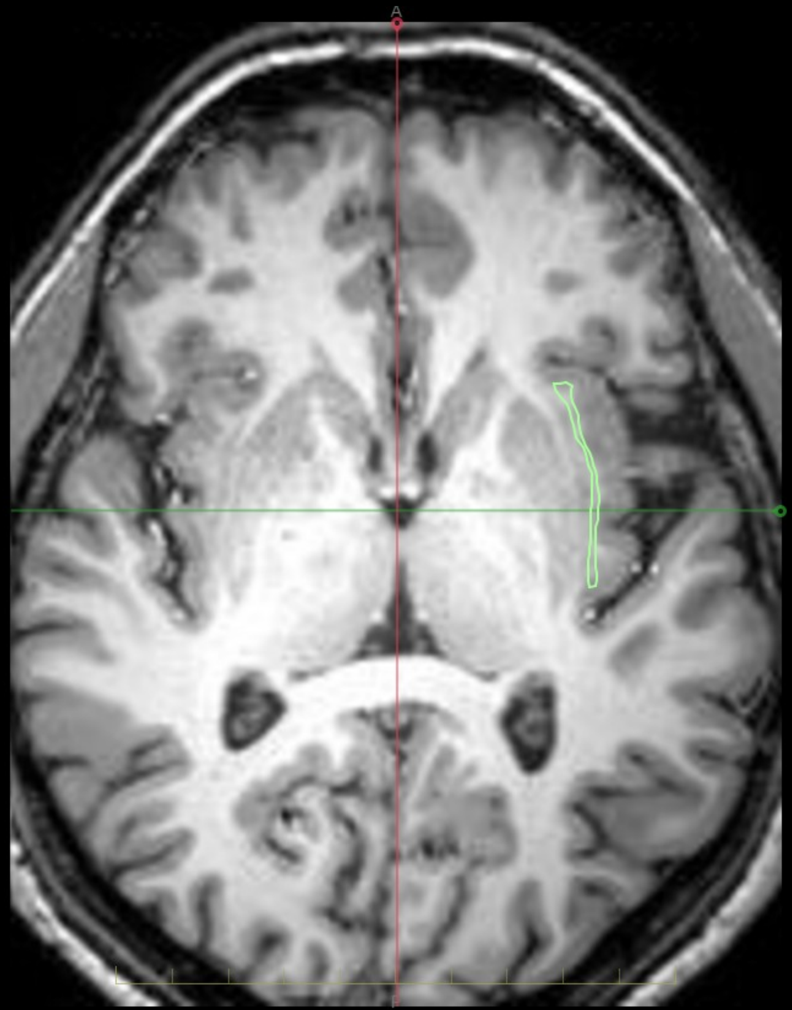
Extreme Capsule

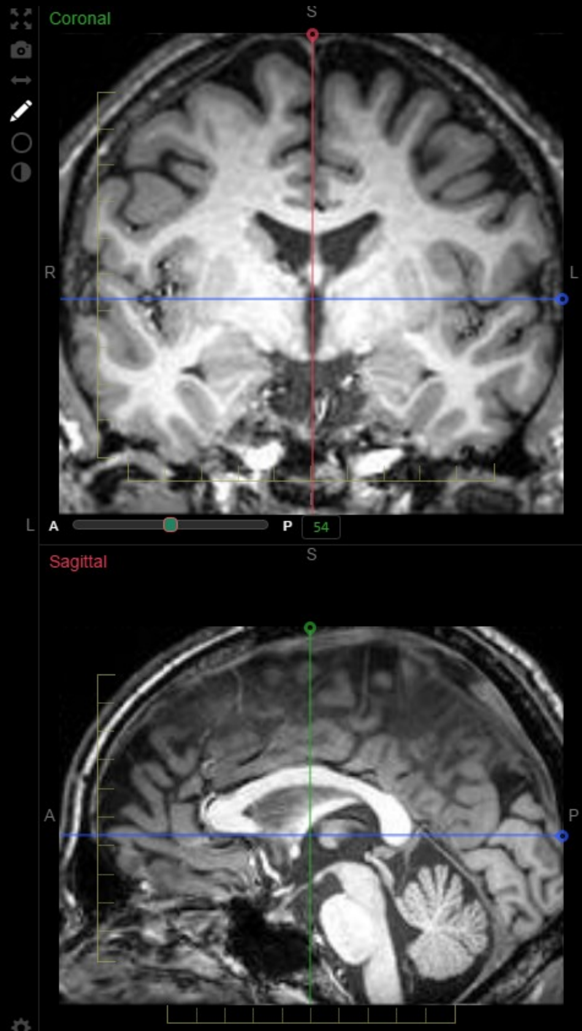


Brainance Advantis Medical Imaging

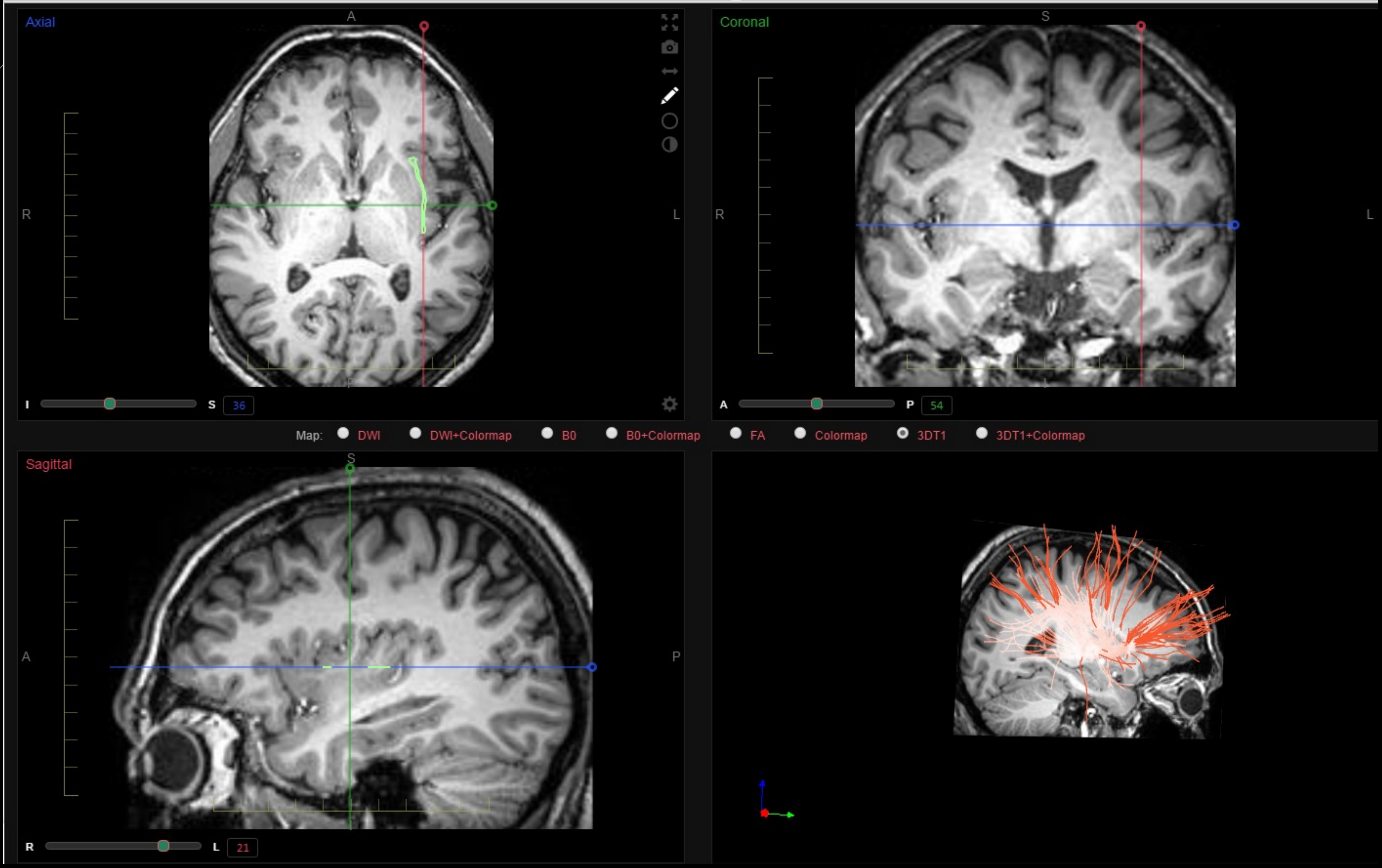
Extreme Capsule

•extremely thin lamina separating the claustrum from the insula cortex

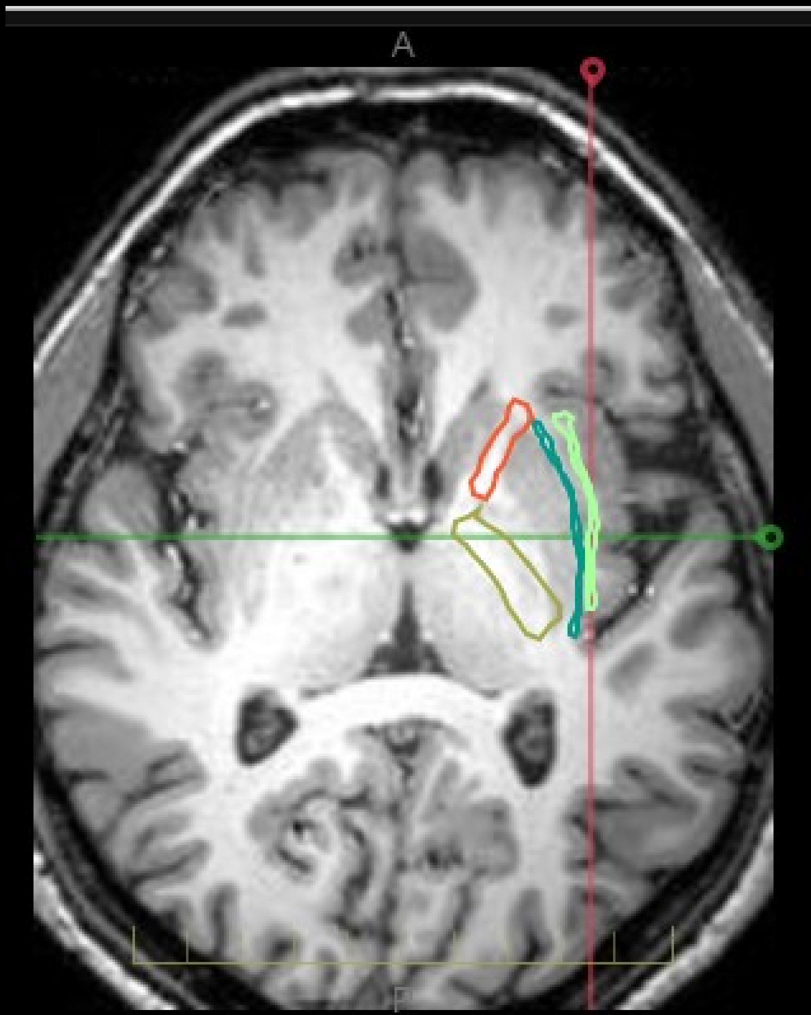




Extreme Capsule

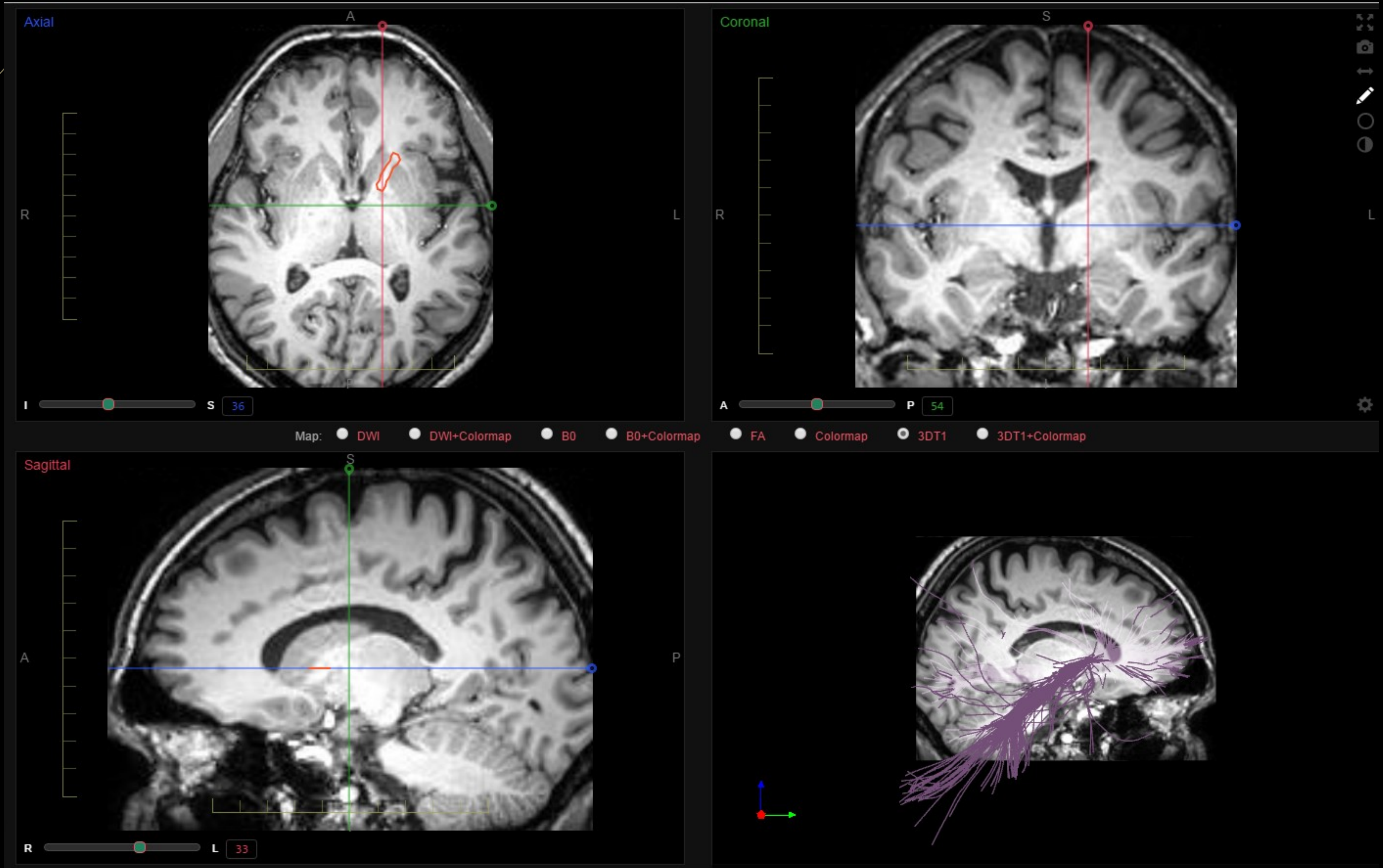


ALIC / PLIC / External C. / Extreme C.



ALIC / PLIC / External C. / Extreme C.

ALIC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Map:
DWI
DWI+Colormap
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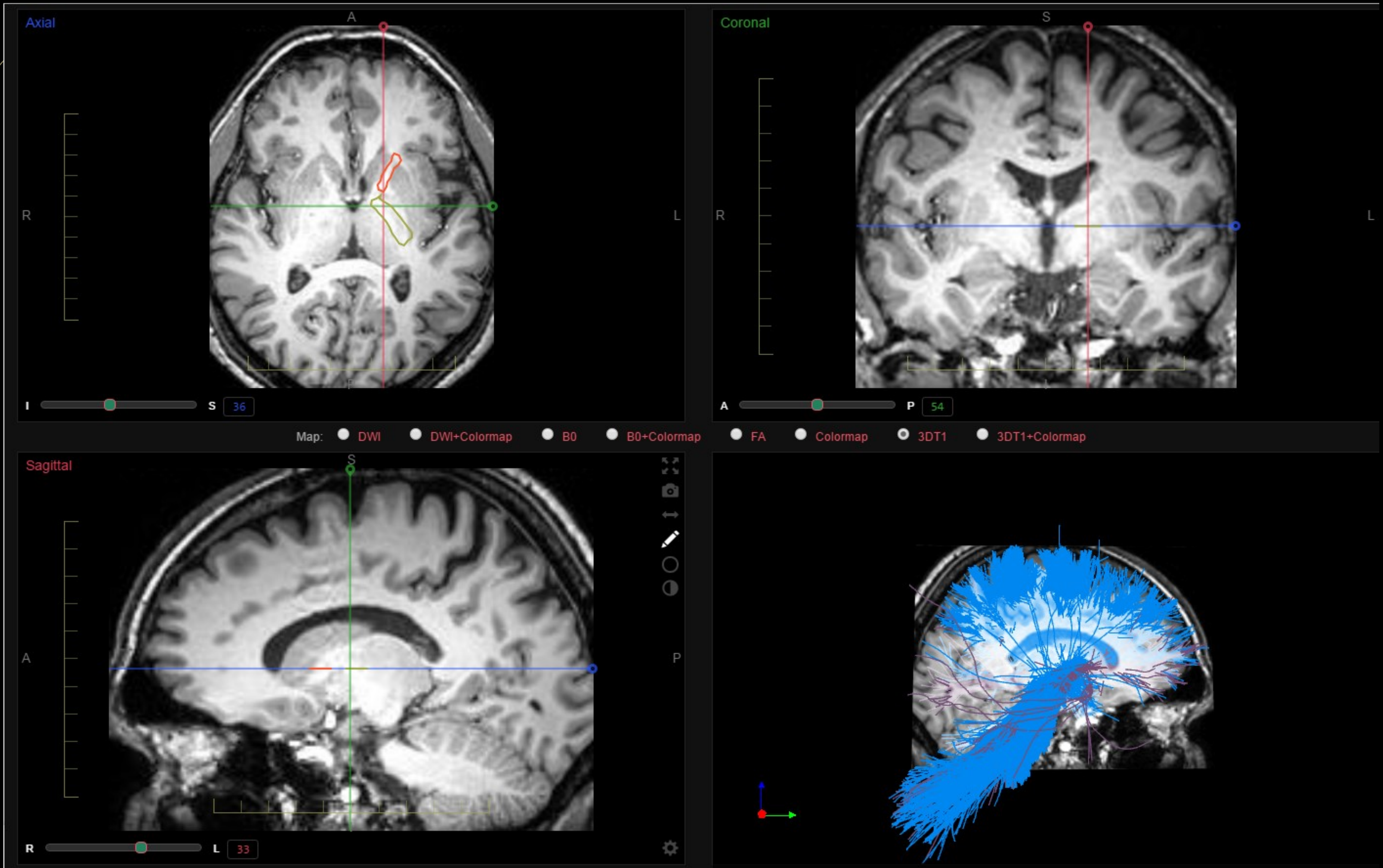
33

ALIC / PLIC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Map:
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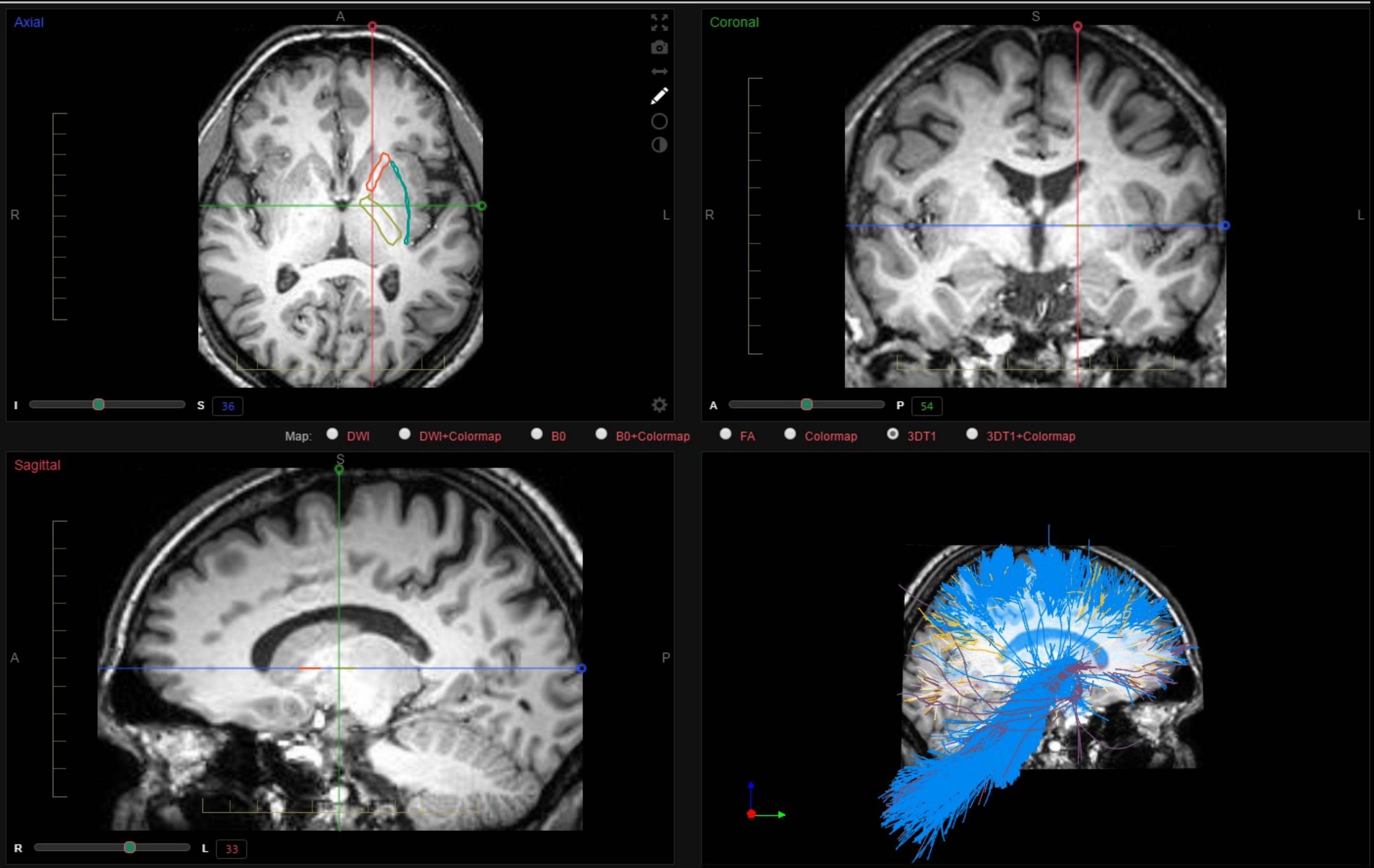
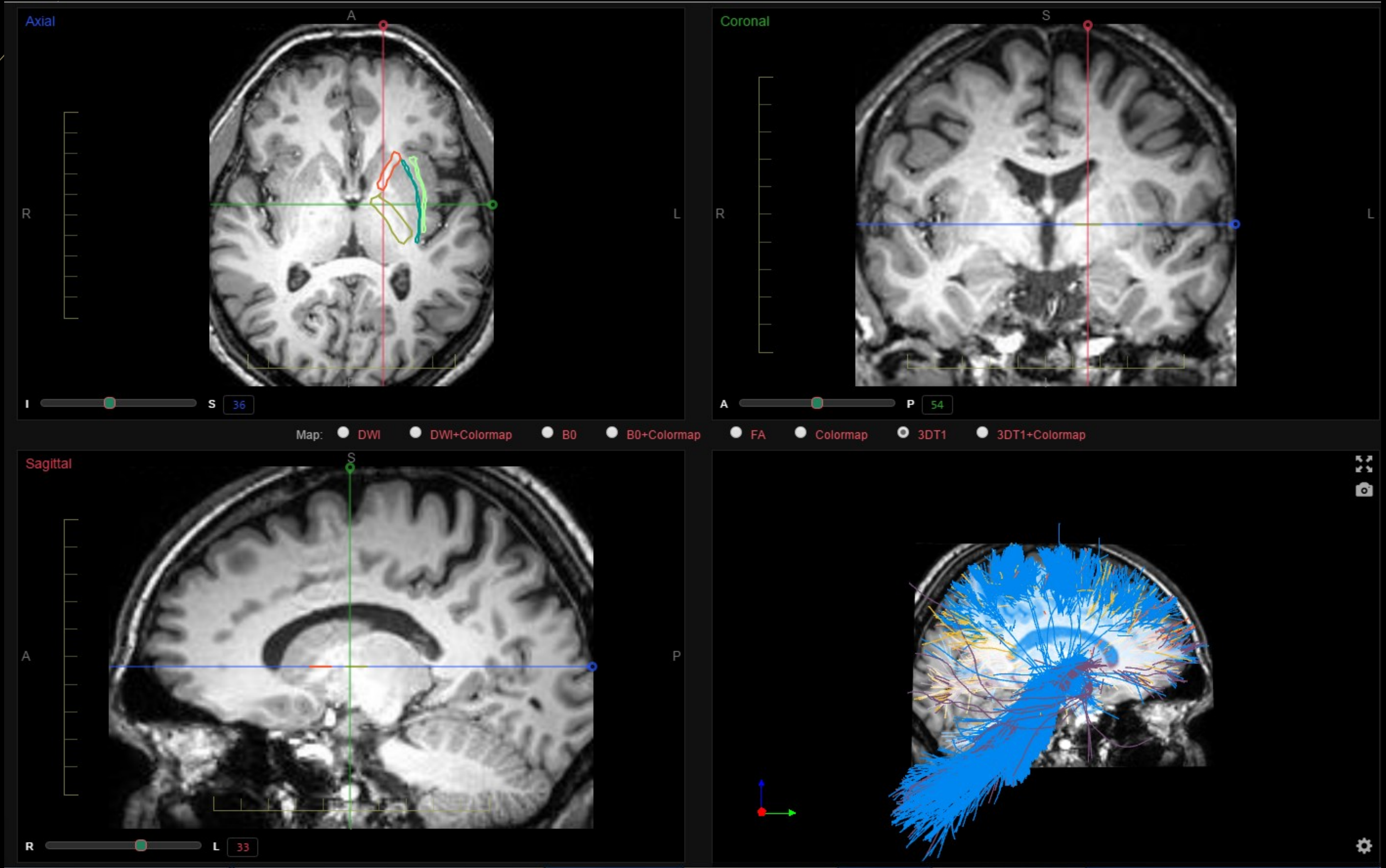
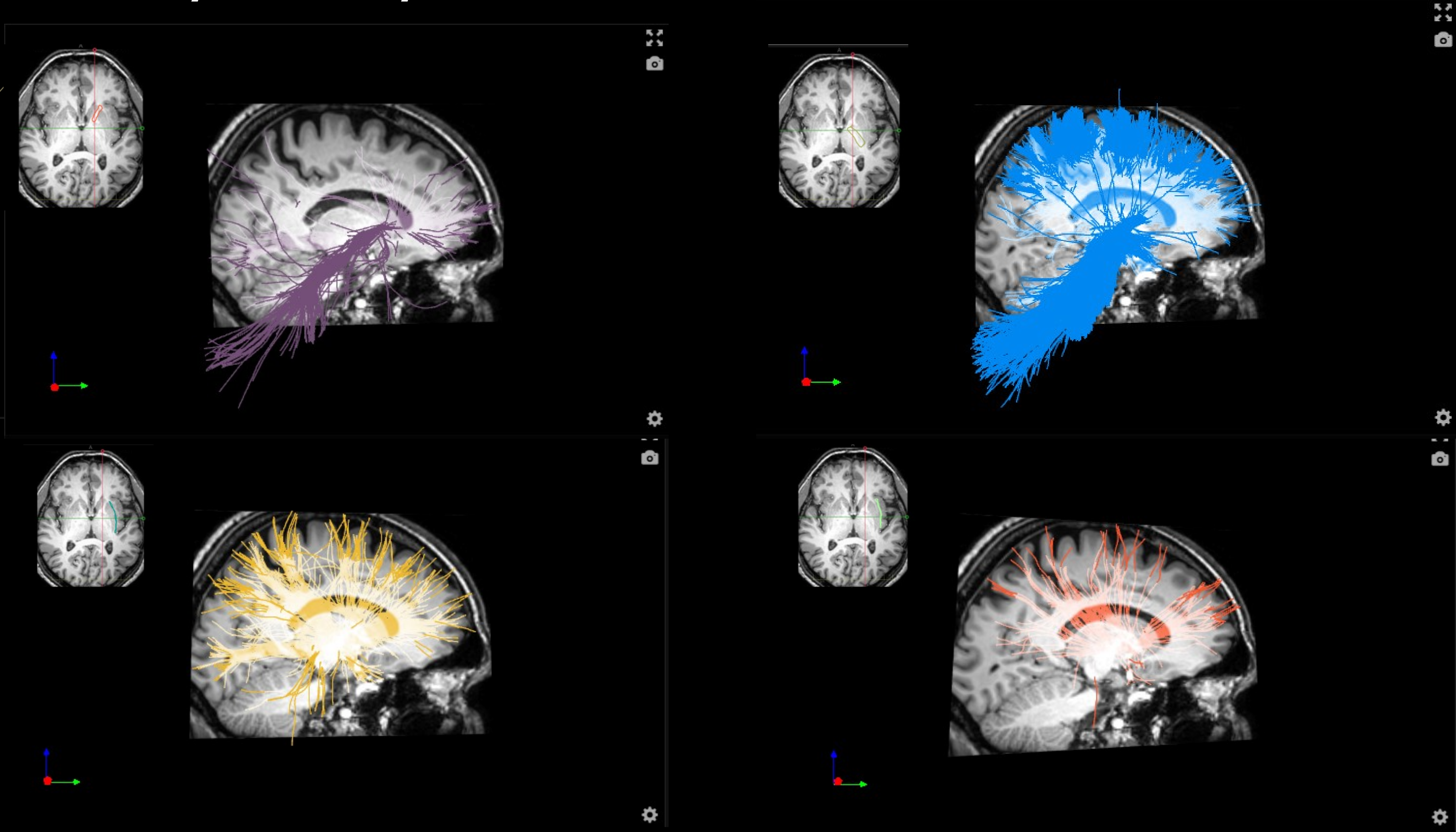
ALIC / PLIC / External C.



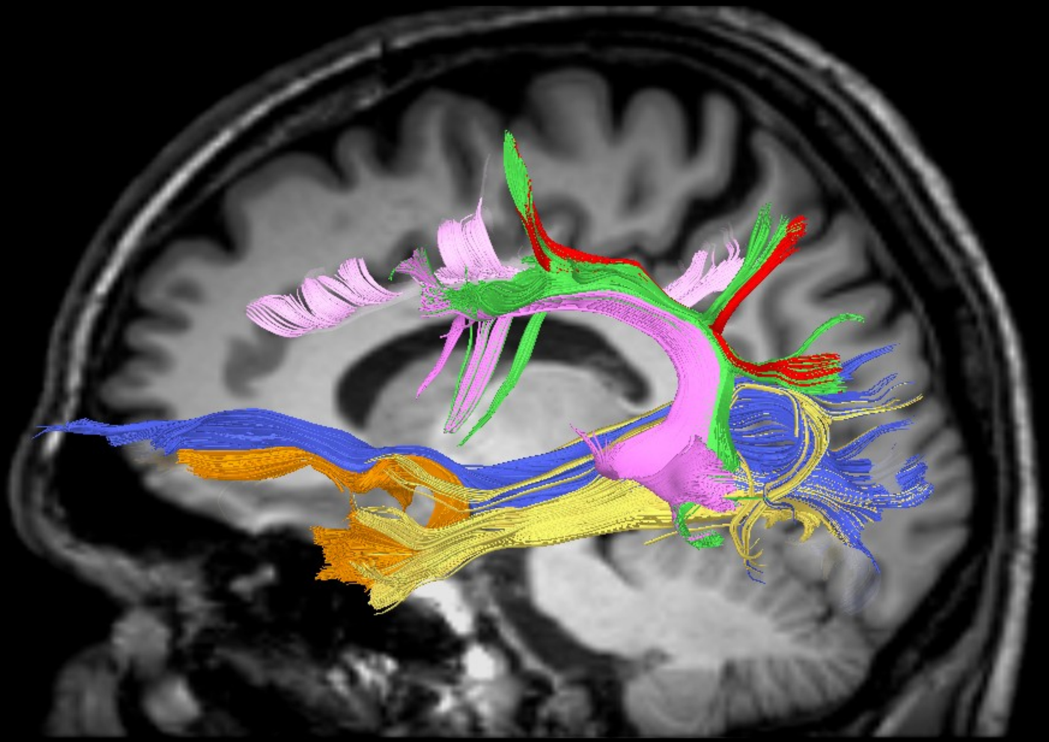
ALIC / PLIC / External C. / Extreme C.



ALIC / PLIC / External C. / Extreme C.



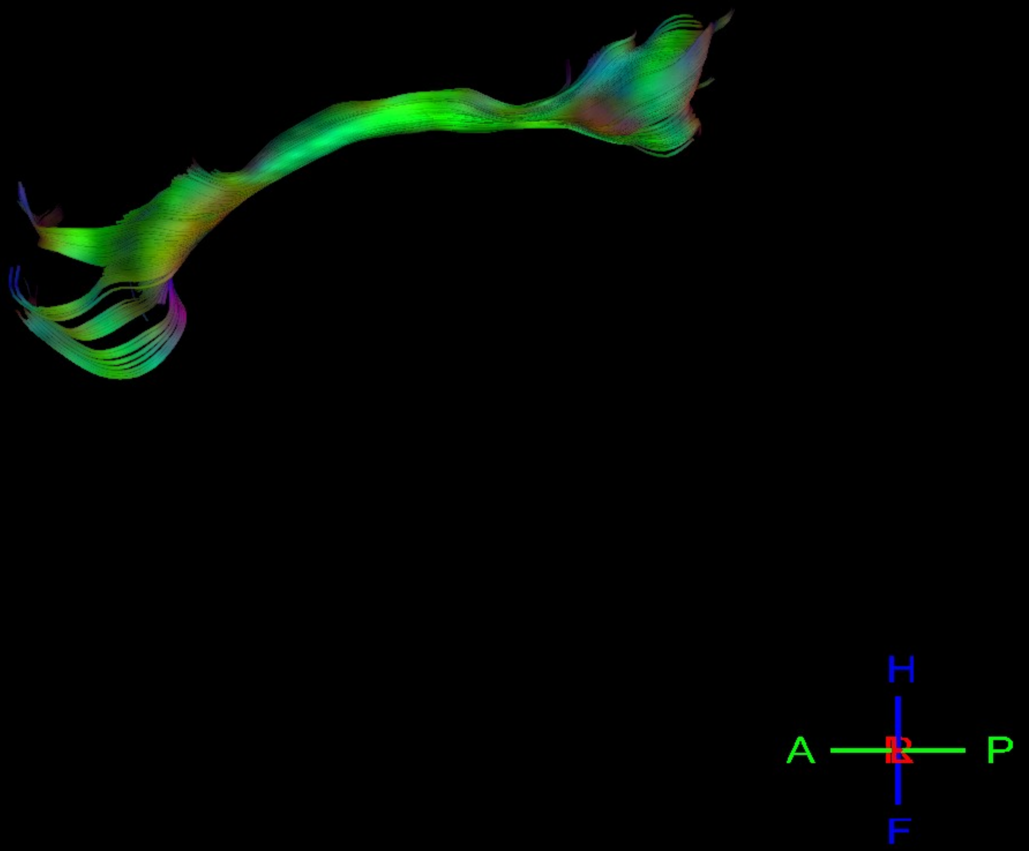
Major Perisylvian and Associative Pathways

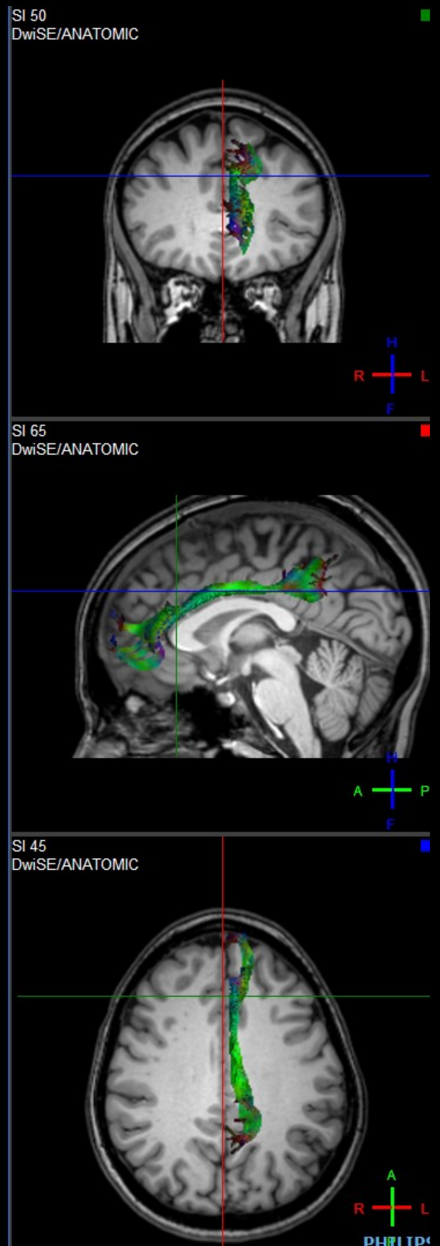


Philips FiberTrak, 2nd Dpt of Radiology, Medical School, NKUA, GR

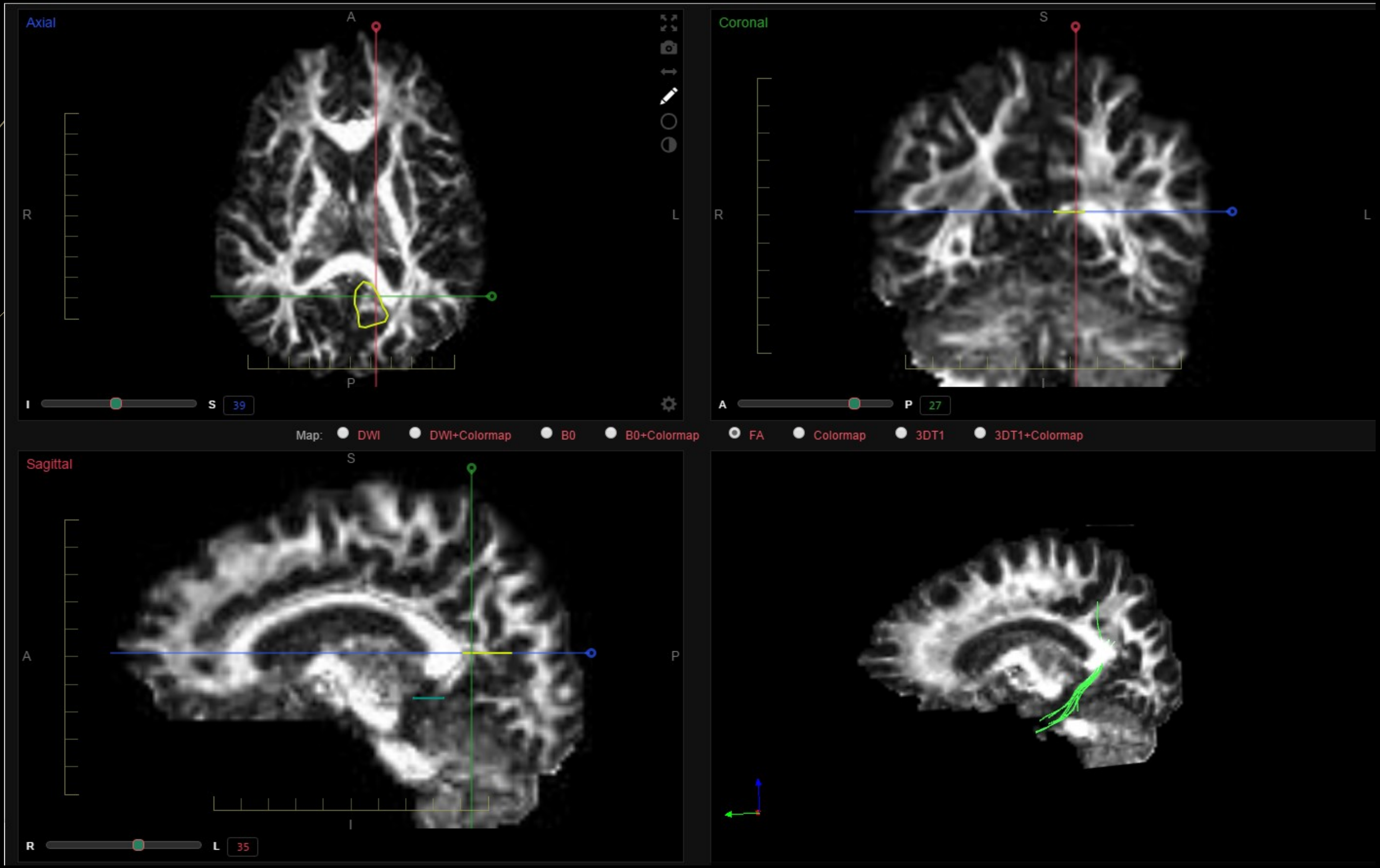
Cingulum Bundle

•Begins in the parolfactory area below CC rostrum, courses within the cingulate gyrus, arches around the entire CC, extends forward into the parahippocampal gyrus and uncus.

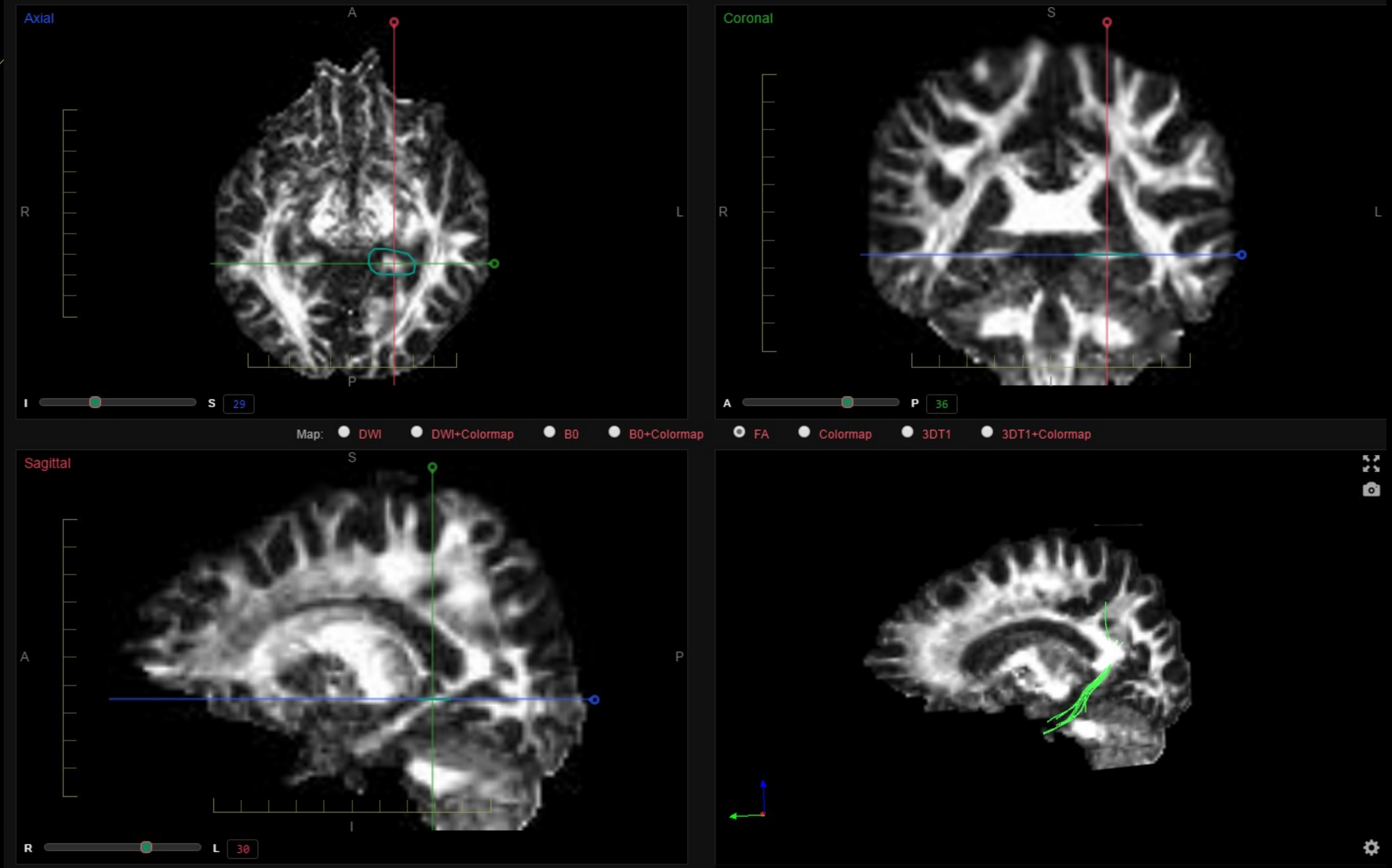




Posterior Cingulum – Hippocampus Fiber Connection

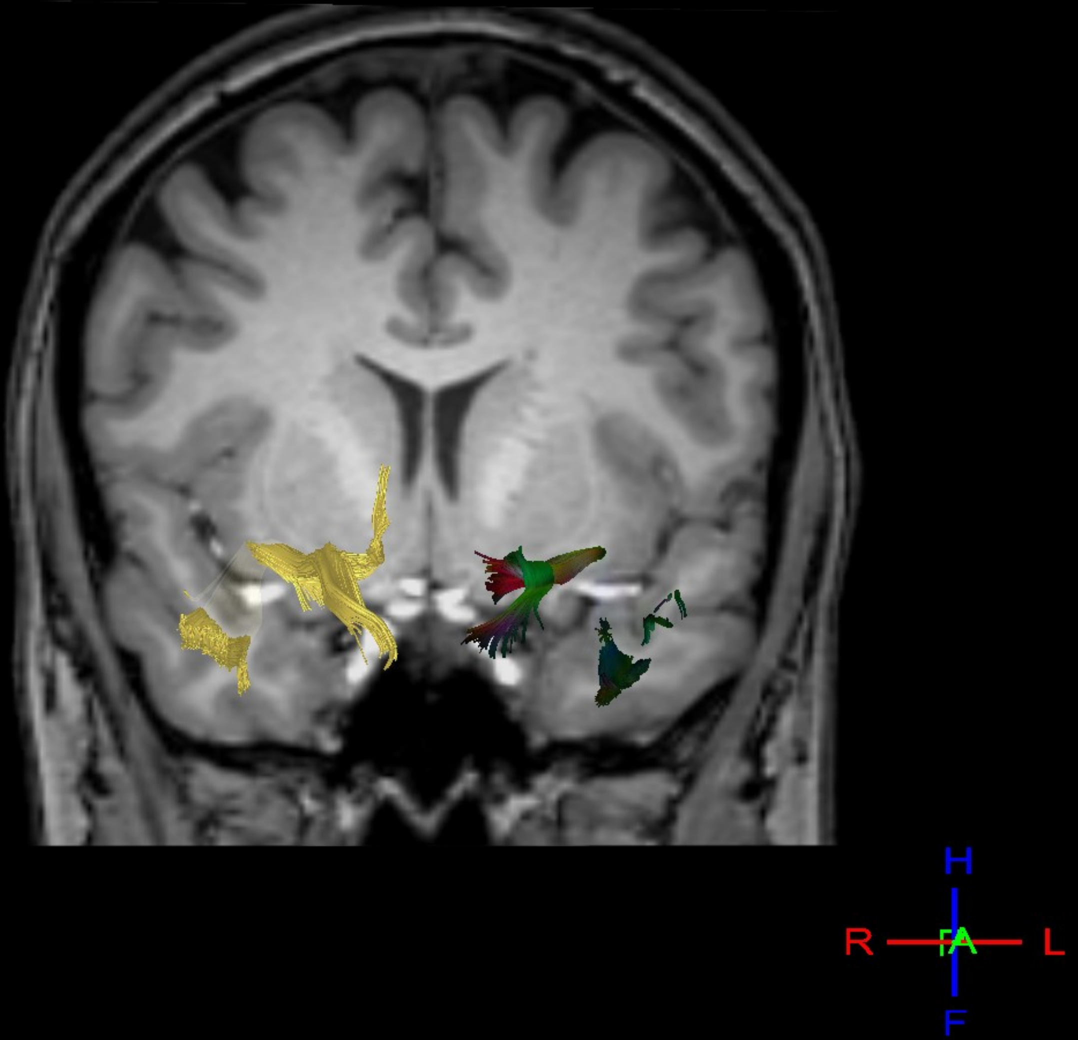


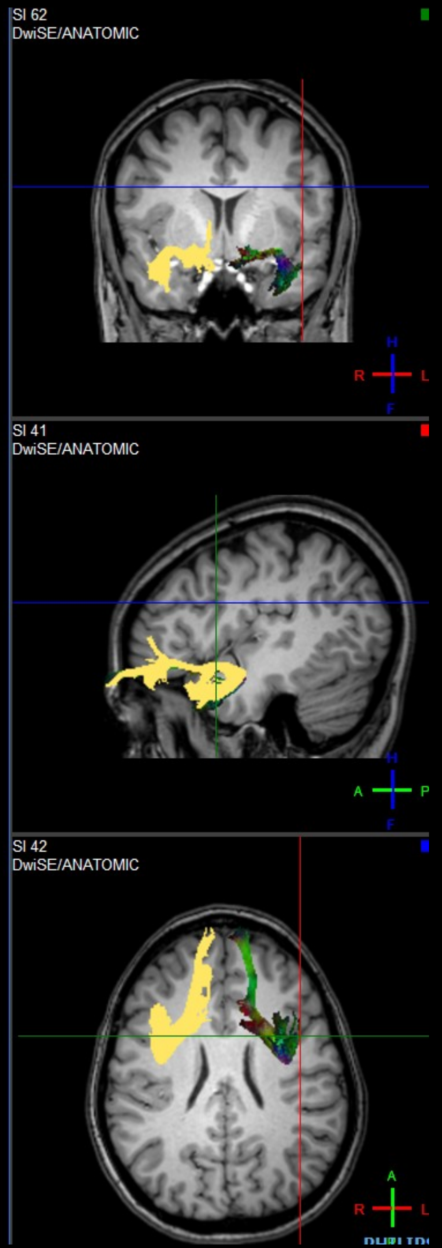
Posterior Cingulum – Hippocampus Fiber Connection



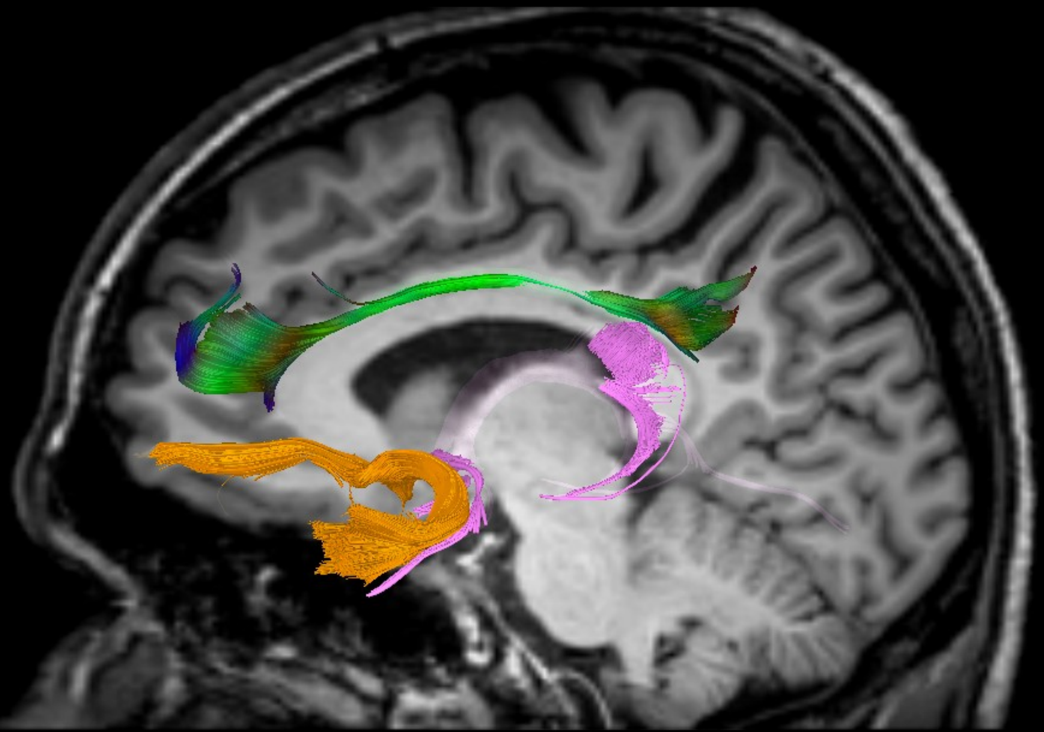
Uncinate Fasciculus

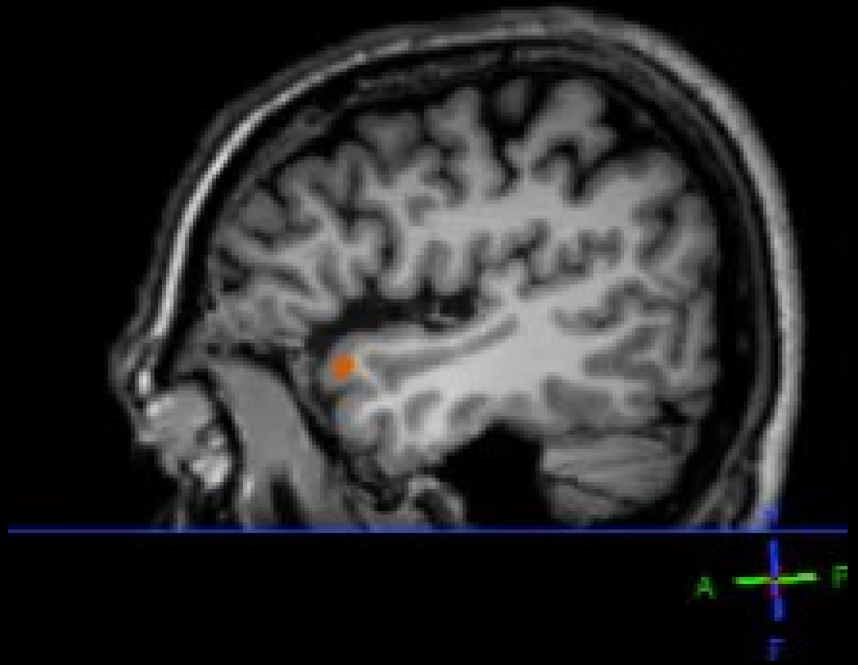
- Hooks around the lateral fissure connecting anterior temporal lobe with medial and lateral orbitofrontal cortex
- Temporal UF: medial and anterior to the ILF
- Frontal UF: lies inferomedial to the IFOF





Major Limbic Pathways

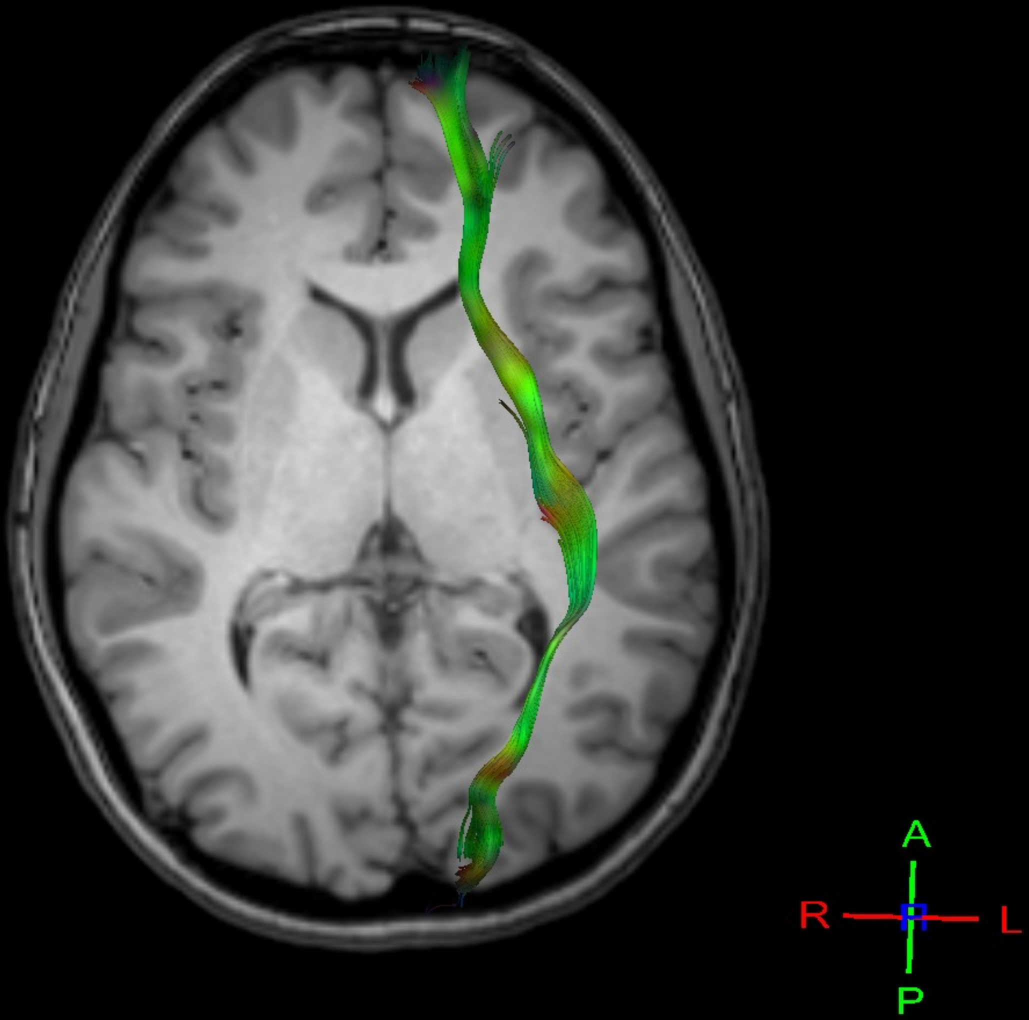


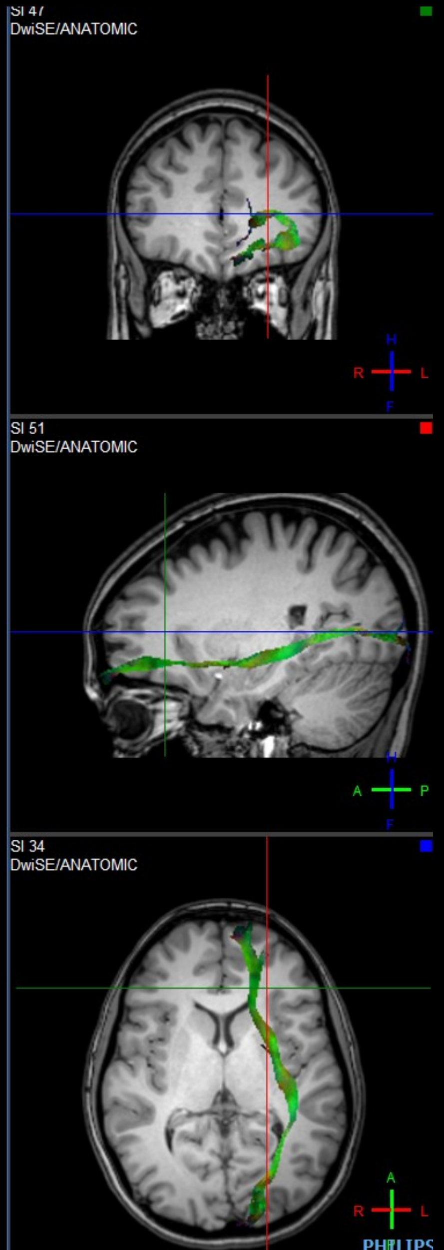


Philips FiberTrak, 2nd Dpt of Radiology, Medical School, NKUA, GR

Inferior Fronto-Occipital Fasciculus

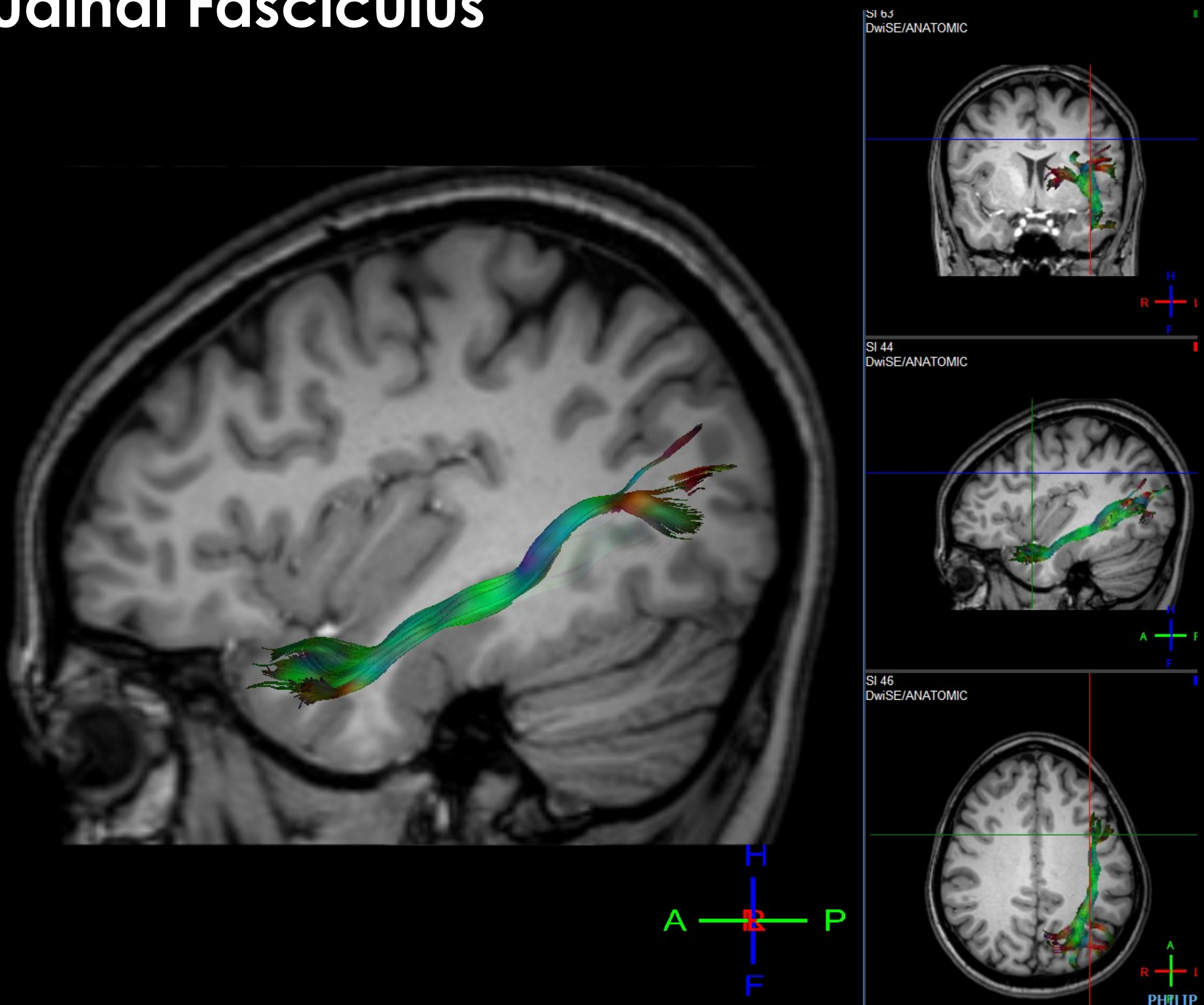
- Runs in the ventral and medial part of the occipital and temporal lobes and in the anterior floor of the external capsule (along the inferolateral edge of the claustrum), and the orbitofrontal region





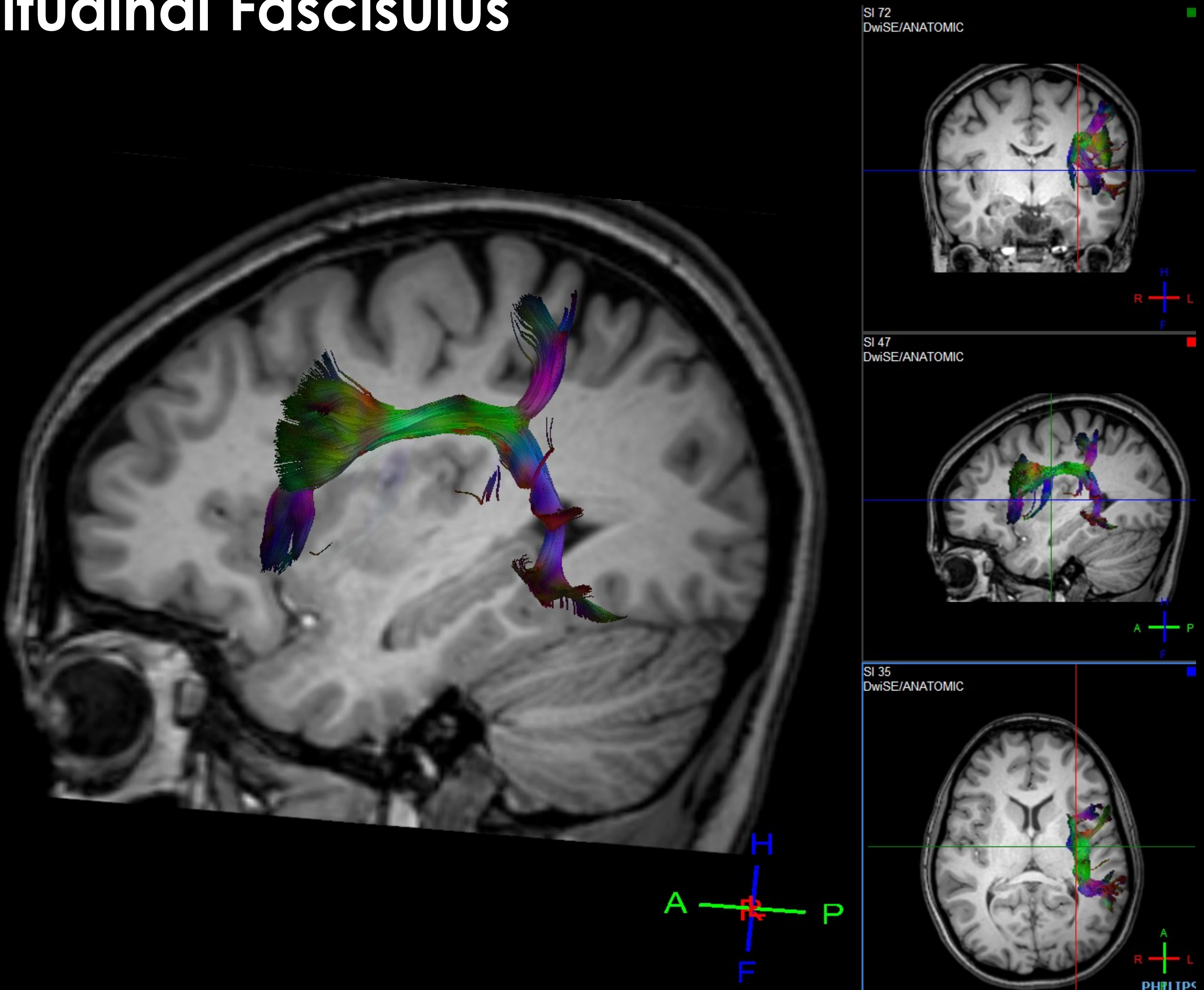
Inferior Longitudinal Fasciculus

- Transverses the length of the temporal lobe and joins the IFOF, the inferior aspect of the SLF and the optic radiations

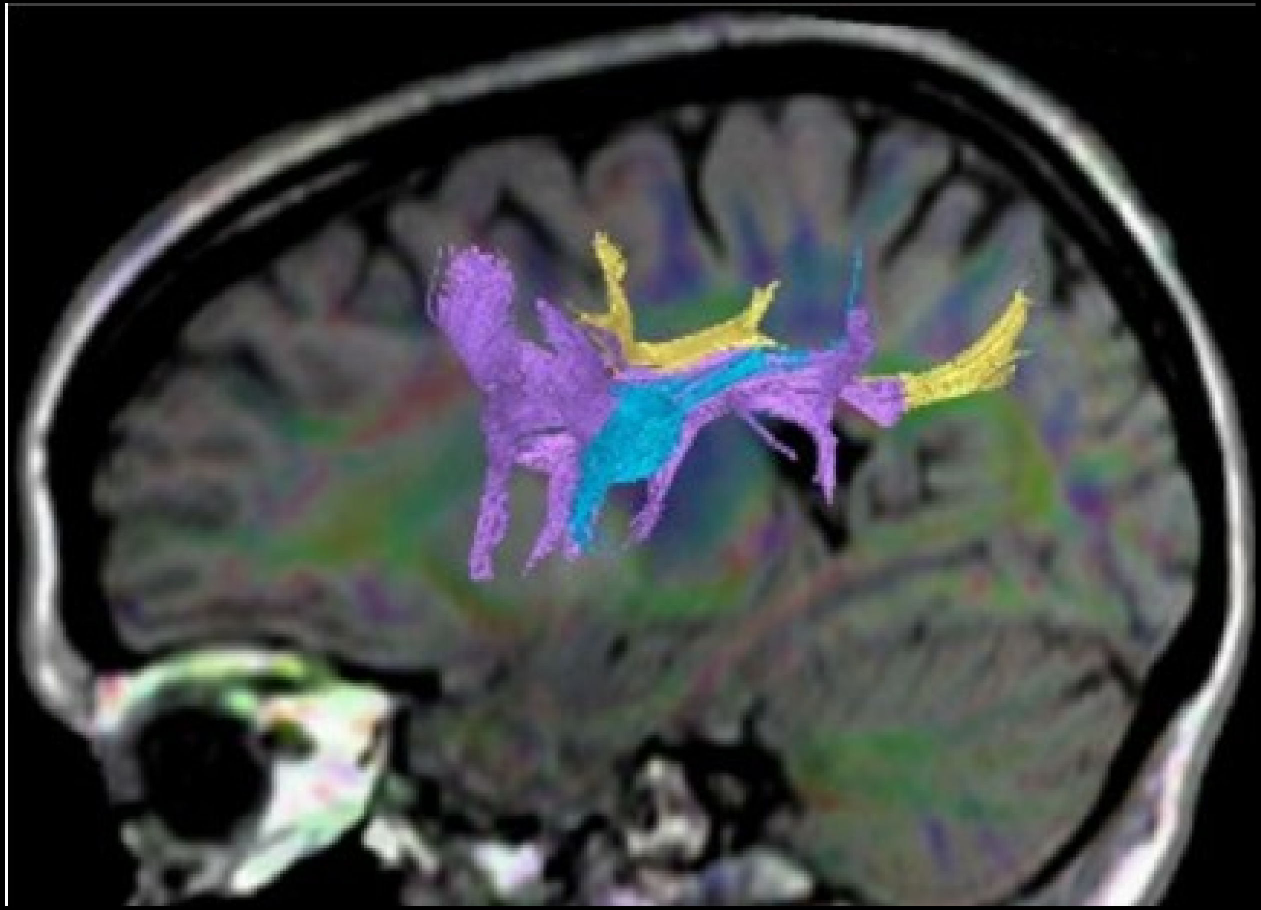


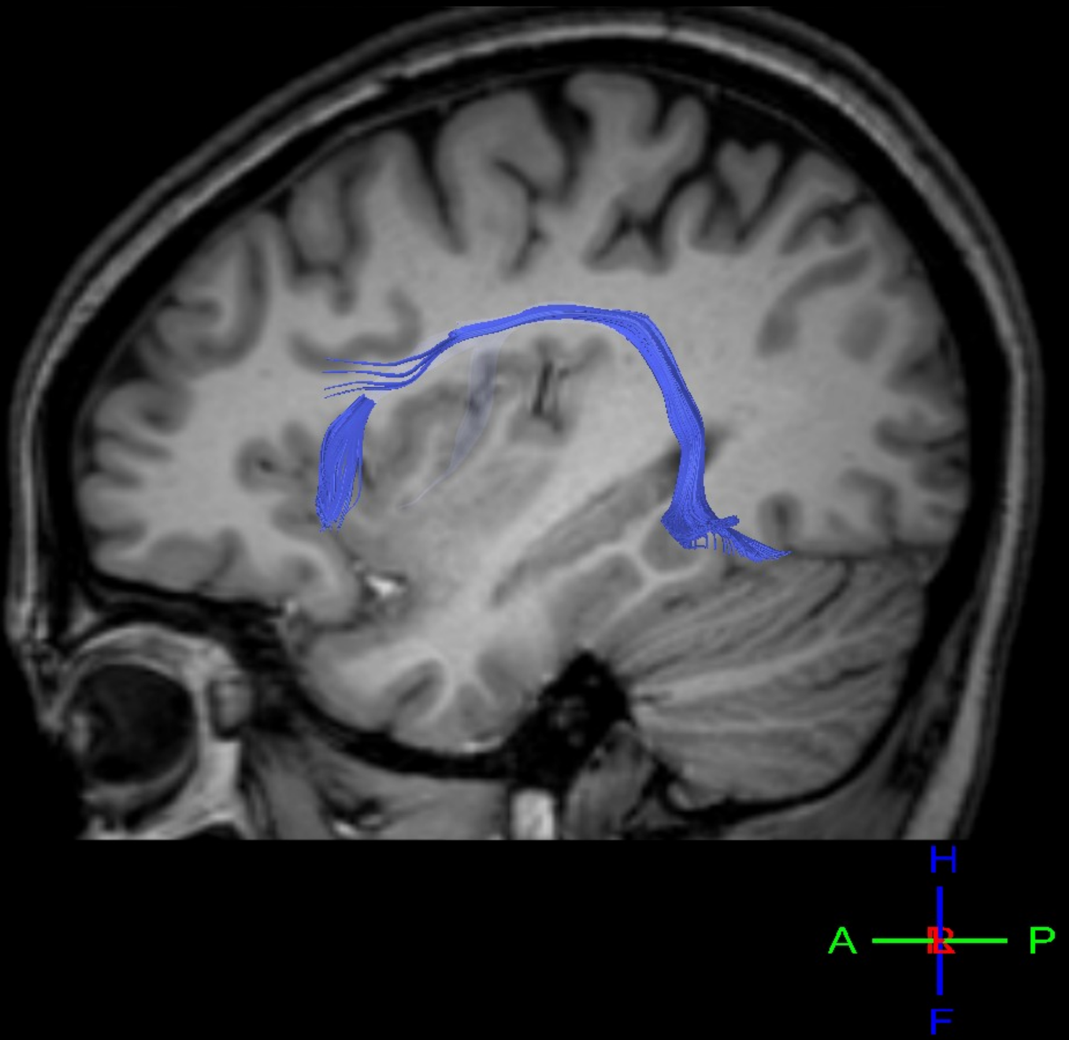
Superior Longitudinal Fascisulus

•Sweeps along the superior margin of the insula in a great arc, gathering and shedding fibers along the way to connect frontal cortex to parietal, temporal and occipital lobe



Superior Longitudinal Fascisulus

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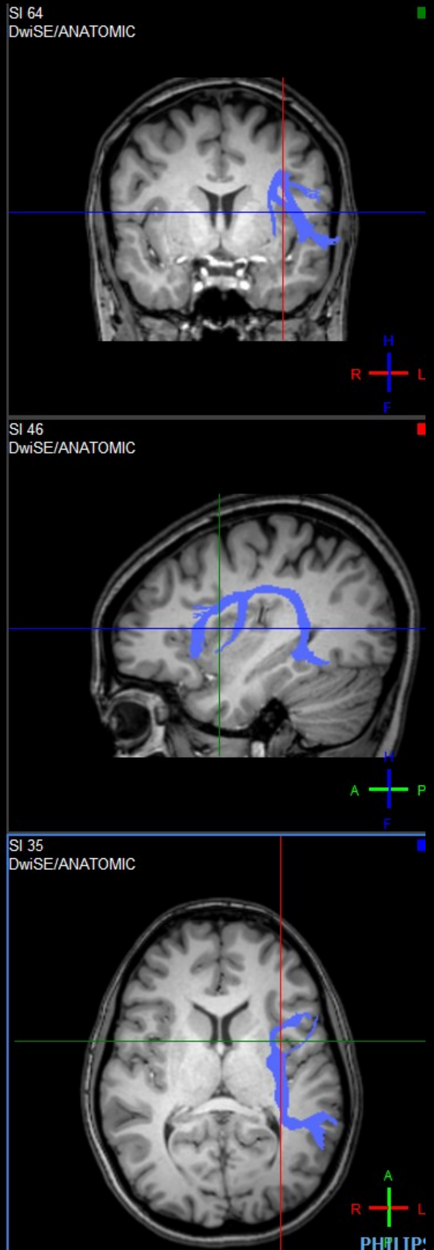
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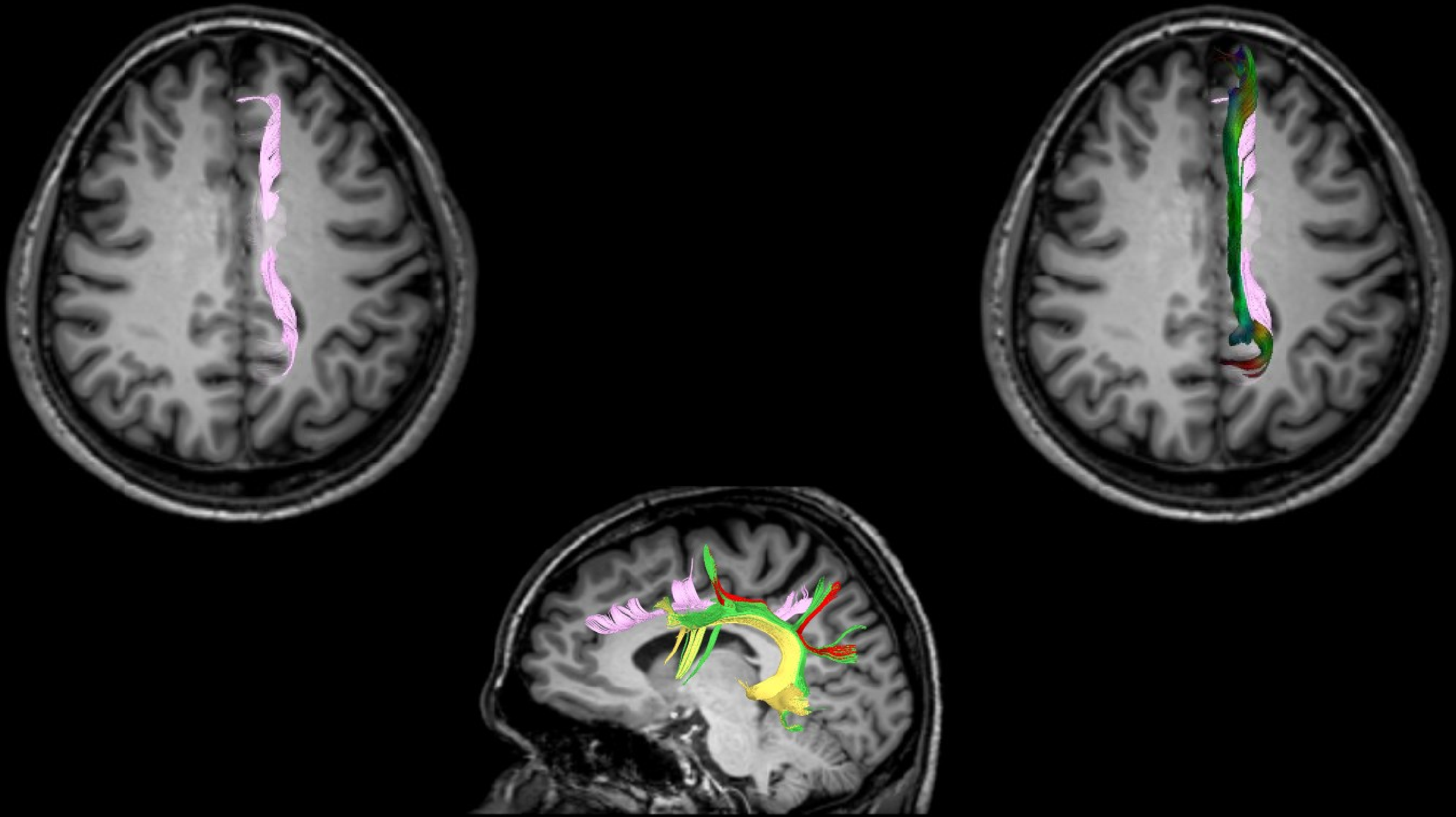
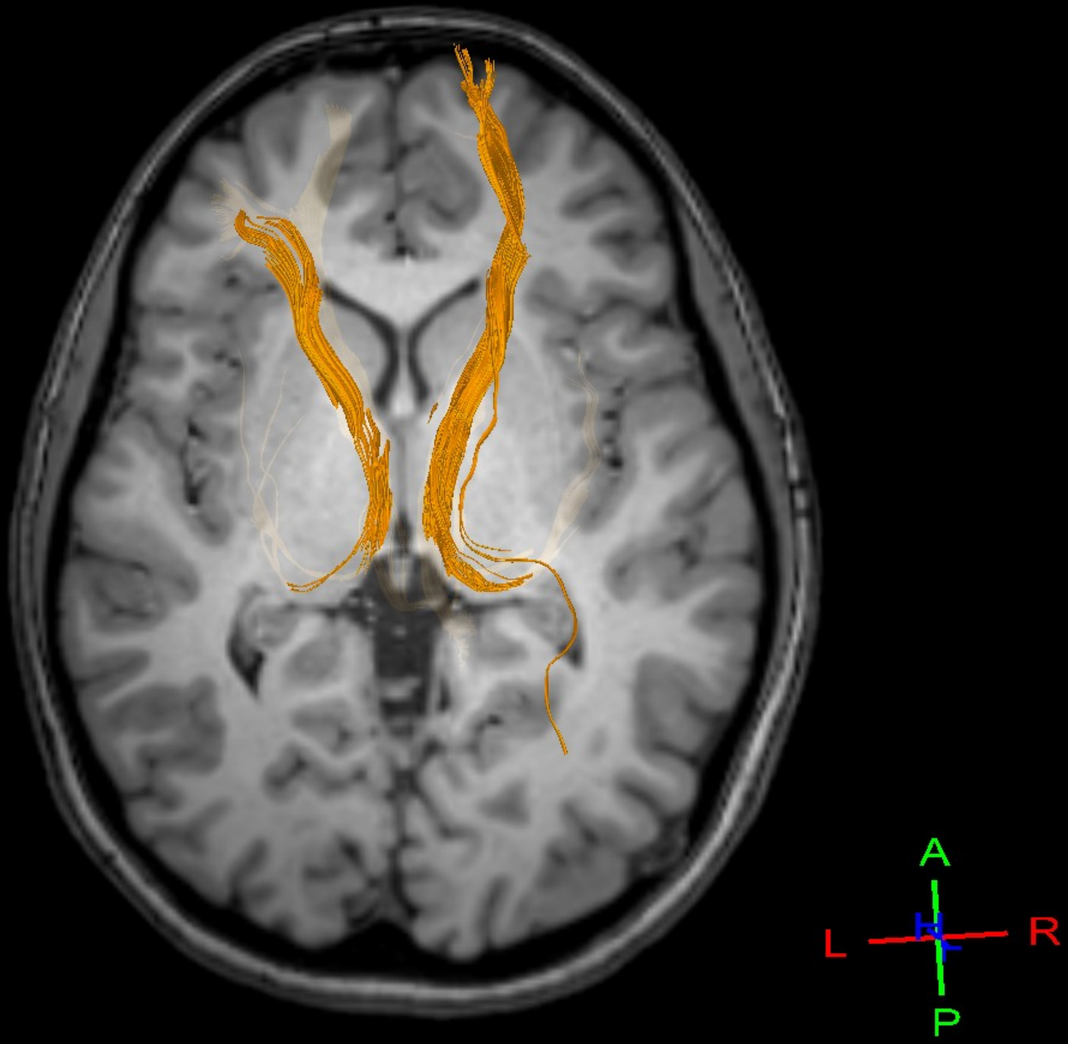
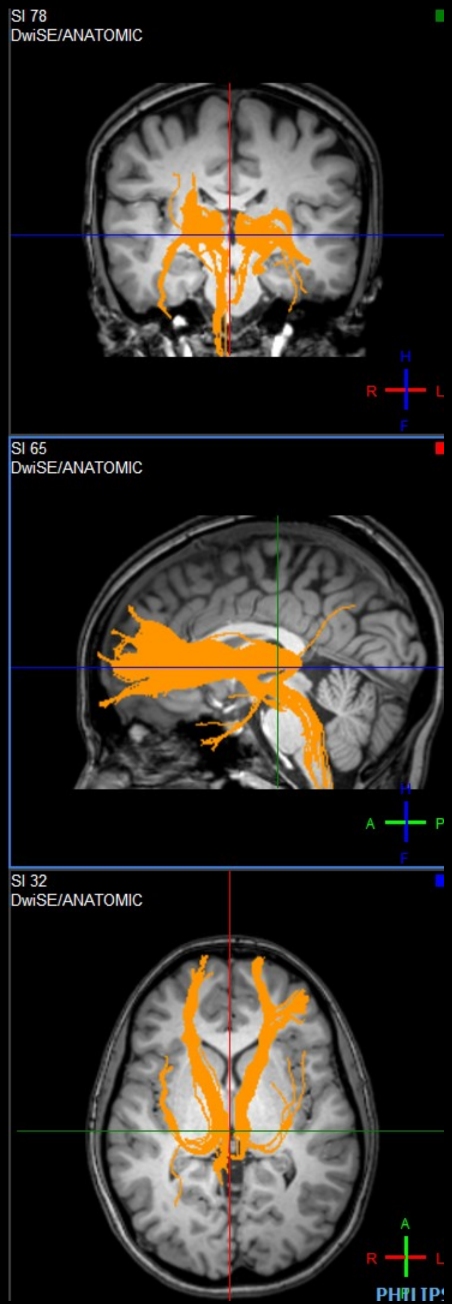
SLF & Cingulum Bundle



Anterior Thalamic Radiation





Major Optic Fiber System (OR/Meyer Loop)

- Connecting lateral geniculate nucleus to primary visual cortex

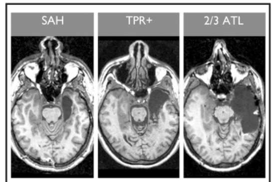
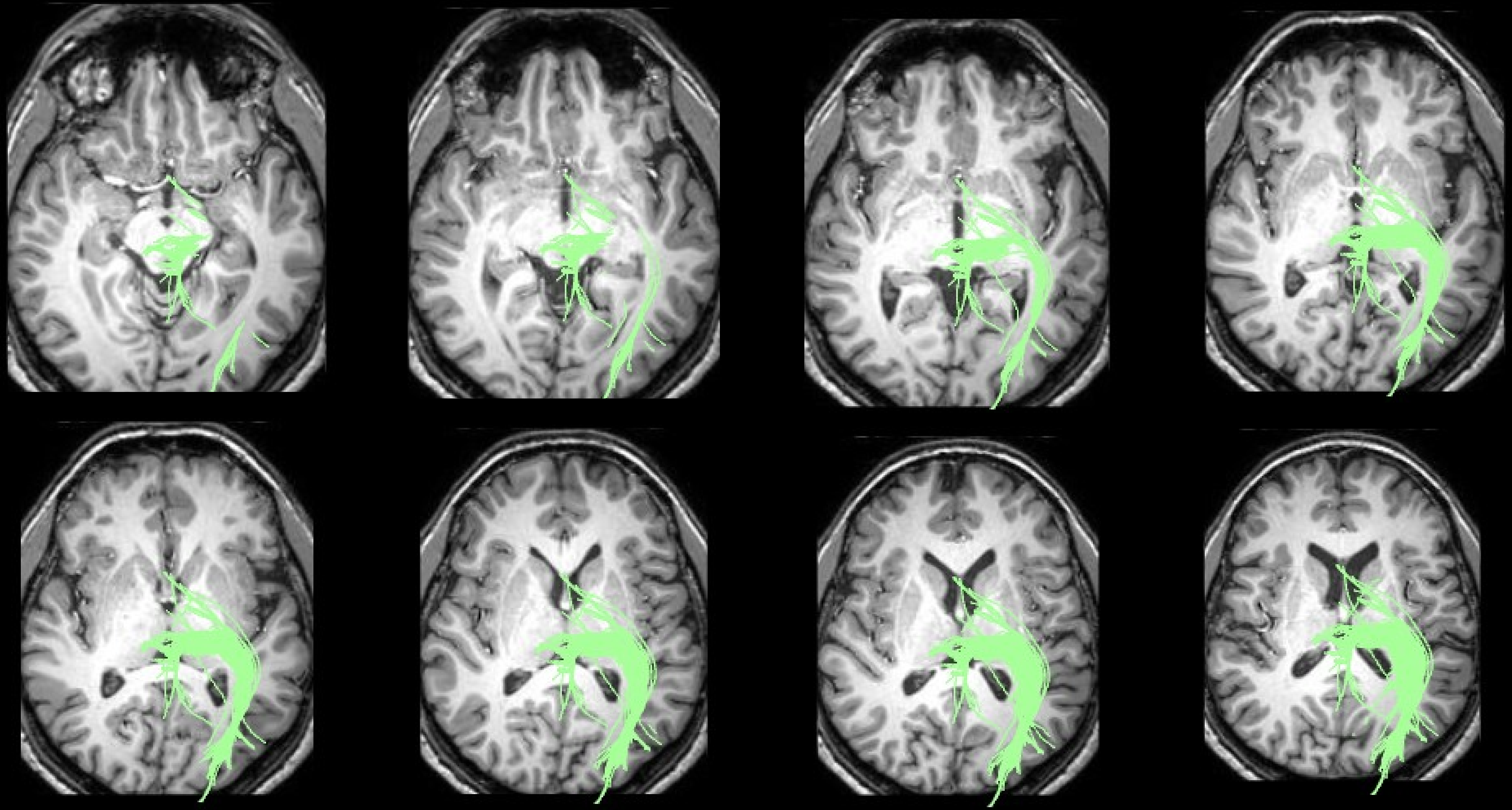
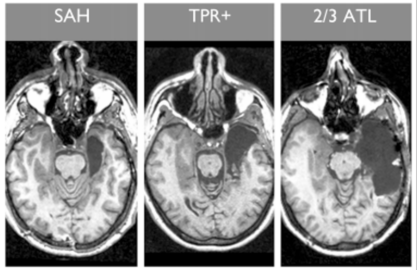


Figure 1.
Resection extent in selective amygdalohippocampectomy (SAH) and temporal pole resection (TPR+) as compared to two-thirds anterior temporal lobectomy (2/3 ATL) on transverse MRI images.
Epilepsia © ILAE



Major Optic Fiber System (OR/Meyer Loop / ILF / IFOF)



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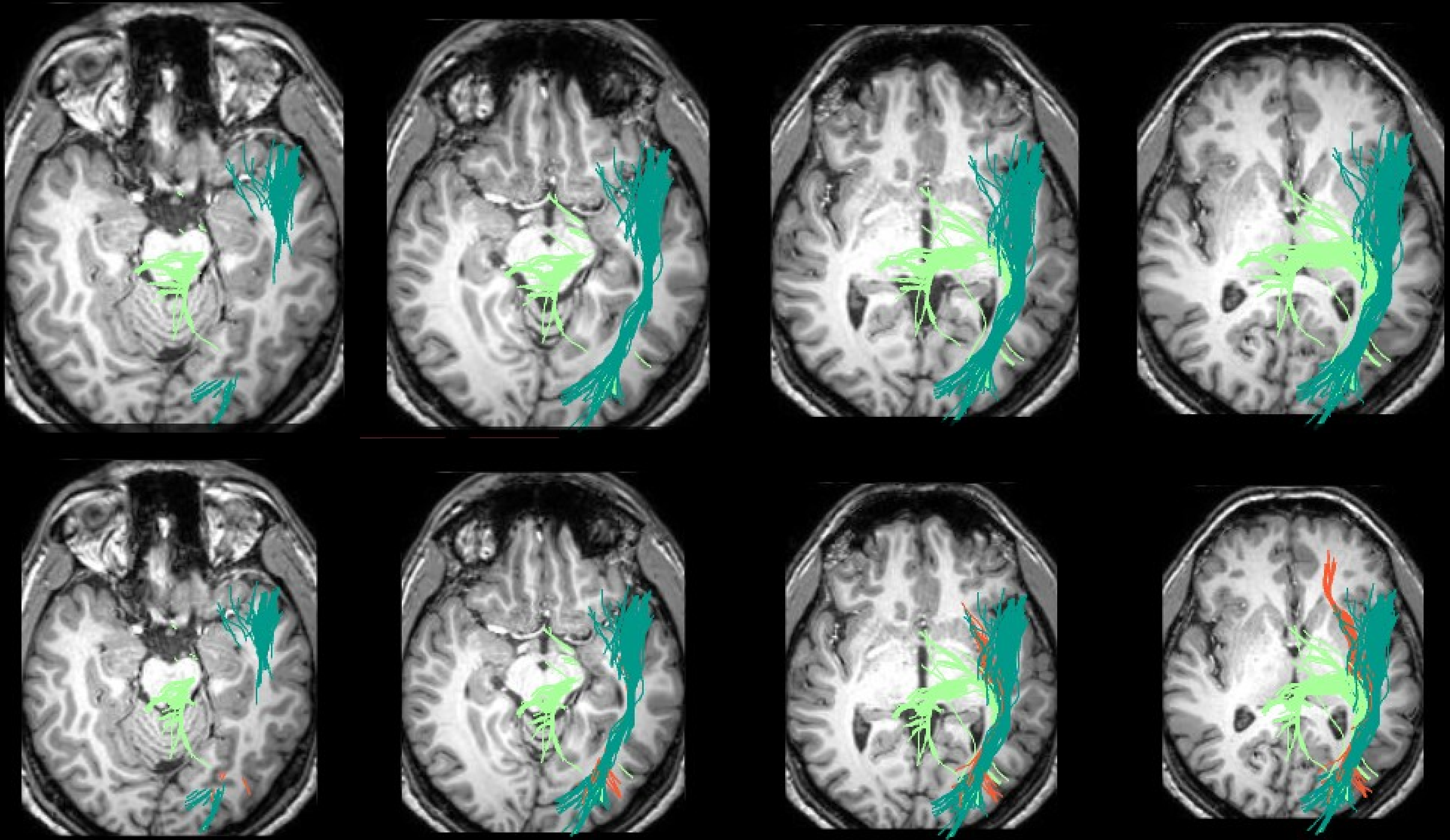
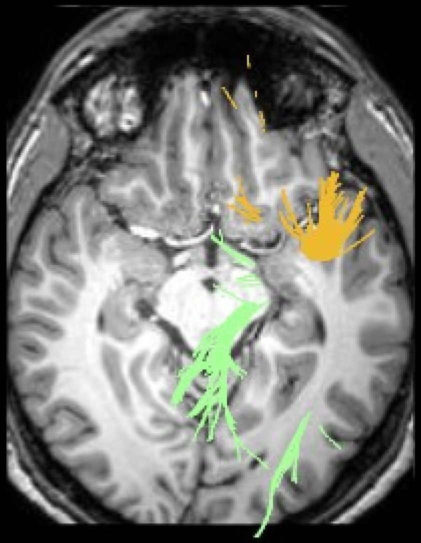
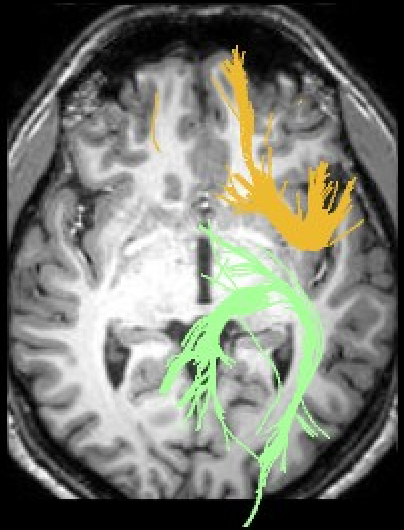
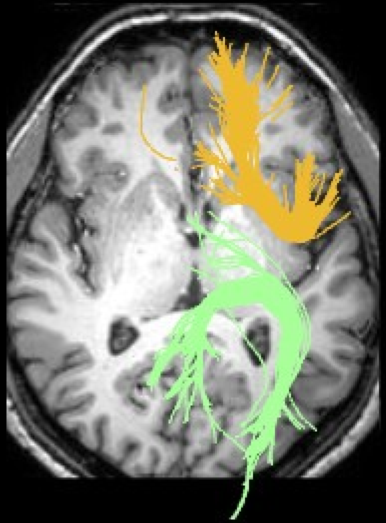


Major Optic Fiber System (OR/Meyer Loop / UF)







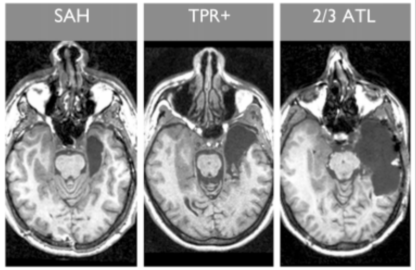
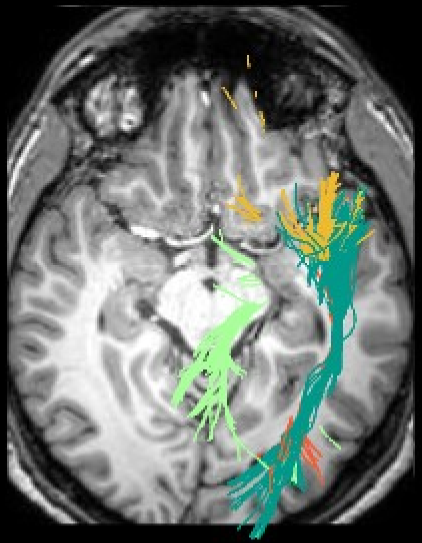
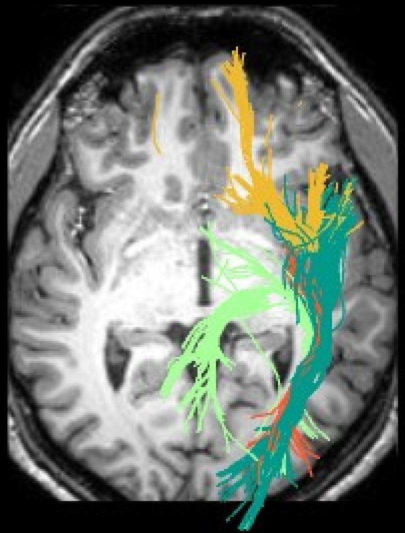
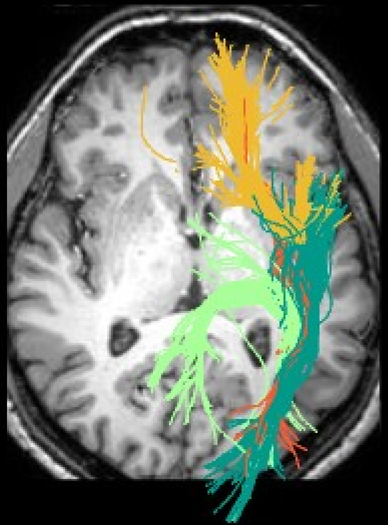


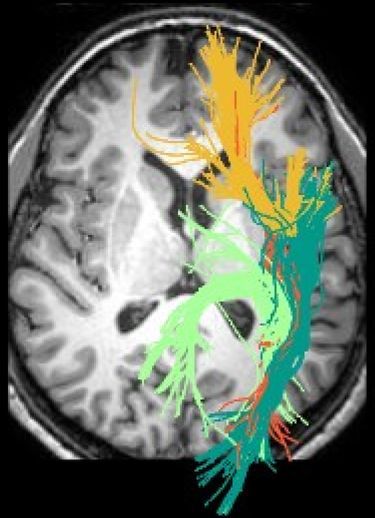
Figure 1.
Resection extent in selective amygdalohippocampectomy (SAH) and temporal pole resection (TPR+) as compared to two-thirds anterior temporal lobectomy (2/3 ATL) on transverse MRI images.
Epilepsia © ILAE

Major Optic Fiber System (OR/Meyer Loop / ILF / IFOF / UF)









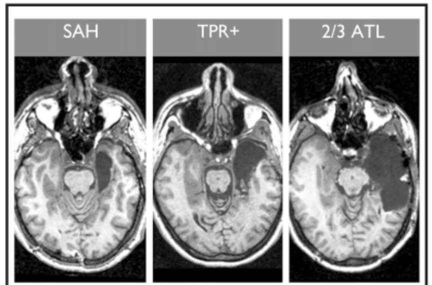


Figure 1.
Resection extent in selective amygdalohippocampectomy (SAH) and temporal pole resection (TPR+) as compared to two-thirds anterior temporal lobectomy (2/3 ATL) on transverse MRI images.
Epilepsia © ILAE

Τα δίκτυα της μνήμης και του λόγου

Τα δίκτυα και τα δίχτυα της μνήμης

Korsakoff

Scoville
Penfield
Milner

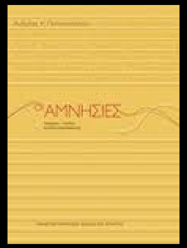
Μνήμη
που μαθαίνει, που θυμάται, που ξεχνά

Μνήμη Κατηγορίες μνημονικών αναμνήσεων

Δηλωτική (declarative/explicit)		
Βιωματική (episodic memory)	**Μνήμη προέλευσης (source memory)**	**Προοπτική μνήμη (prospective memory)**
Γνωσιακή (semantic memory	**Γνώσεις, γενικές έννοιες, σύμβολα**	
Άδηλη (non-declar./implicit)	**Αντιληπτική**	**Διαδικαστική**

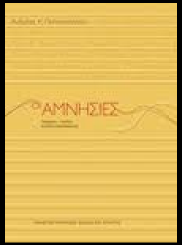
Λεκτική & Οπτική μνήμη

Αυτοβιογραφική	**Βιωματικές αναμνήσεις**	**Γνώσεις**	**Άδηλες αναμνήσεις**

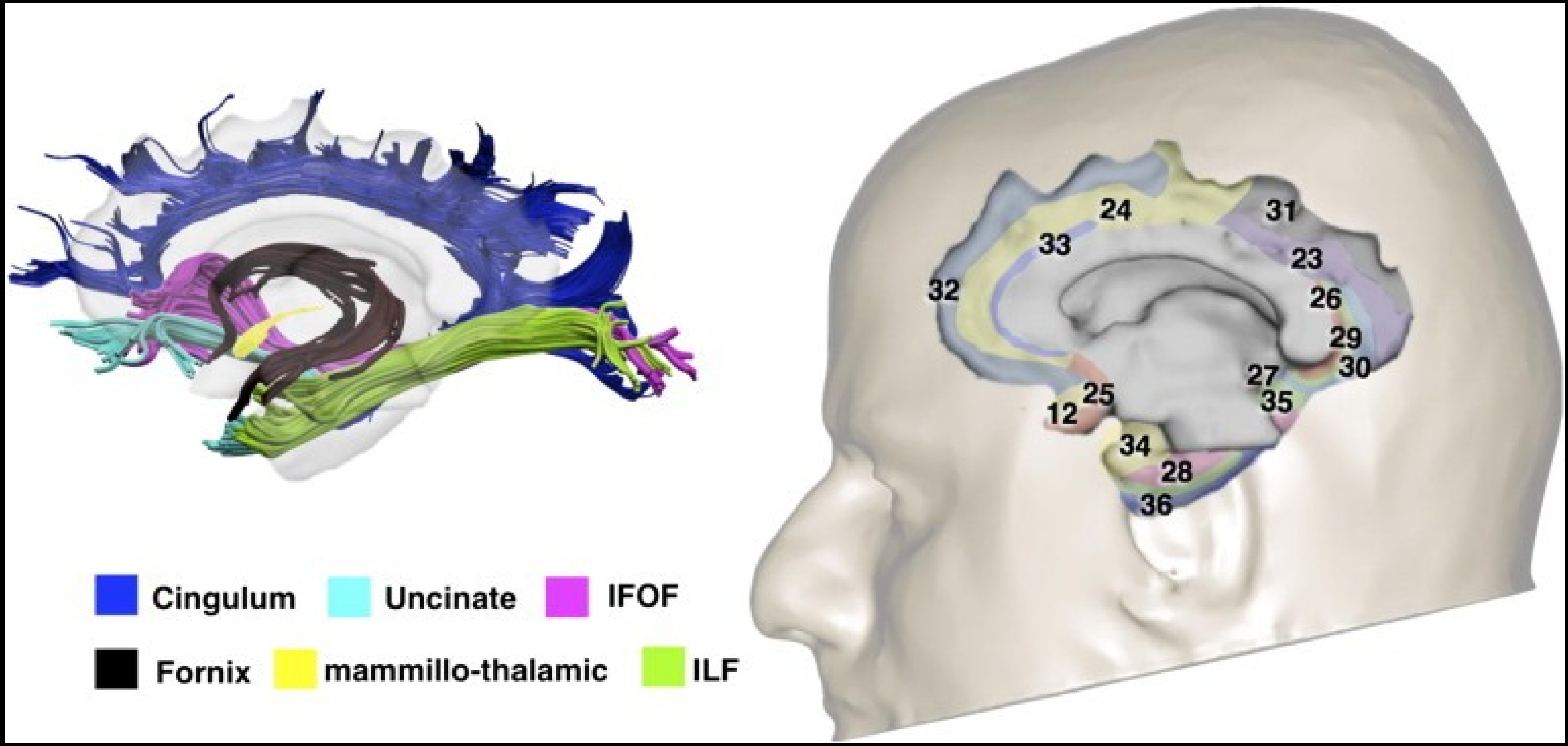


Μνήμη
που μαθαίνει, που θυμάται, που ξεχνά

Μνήμη	Κατηγορίες μνημονικών συστημάτων με διακριτές λειτουργίες/διεργασίες και εγκεφαλικούς μηχανισμούς	
Πρωτογενές Σύστημα	**Βραχύχρονη**	**Αυθόρμητη, αβίαστη κωδίκευση και ανάκληση**
	Ενεργός	**Εσκεμμένη, κοπιώδης κωδίκευση, νοητική επεξεργασία και ανάκληση**
Δευτερογενές Σύστημα	**Μακρόχρονη**	**Παγίωση και αποθήκευση**



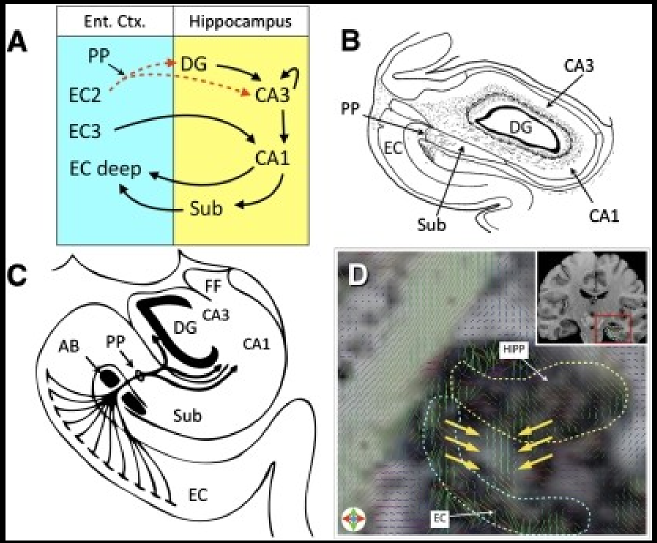
Τα δίκτυα και τα δίχτυα της μνήμης

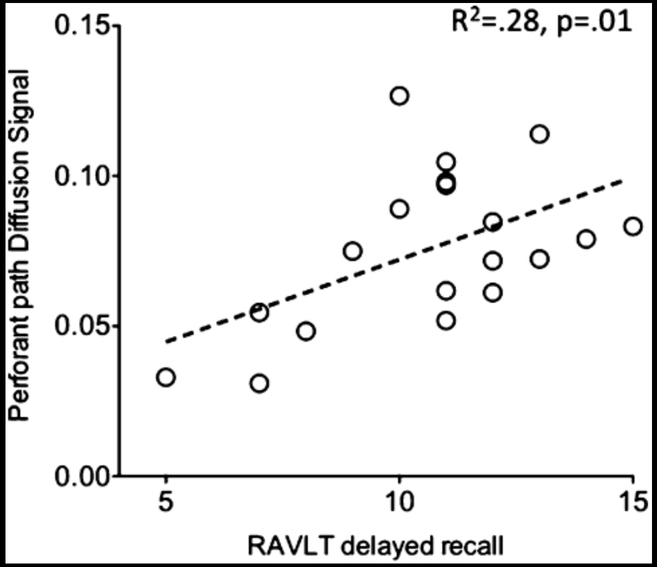


http://neuropsychologie.wordpress.com/

Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στη φυσιολογική γήρανση

Χρησιμοποιώντας υψηλής ευκρίνειας απεικόνιση τανυστή διάχυσης στη μελέτη της μνημονικής λειτουργίας στη φυσιολογική γήρανση, αναδείχθηκε in vivo η εκφύλιση της **διατιτραίνουσας οδού** (ενός μικρού δεματίου λευκής ουσίας που συνδέει το ενδορρινικό φλοιό και τον ιππόκαμπο) στη φυσιολογική γήρανση και η σχέση του βαθμού εκφύλισης με την επίδοση σε κλασικές δοκιμασίες εκμάθησης και καθυστερημένης ανάκλησης λίστας λέξεων



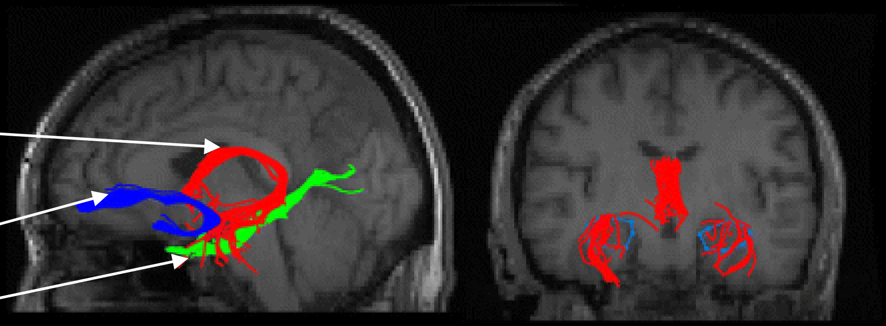


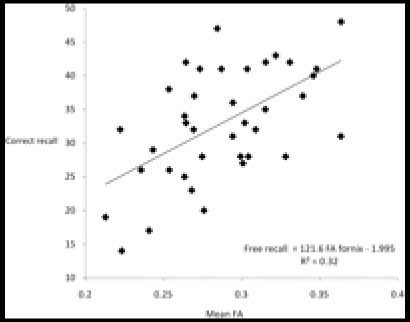
Yassa et al., 2010

Τα δίκτυα και τα δίχτυα της μνήμης

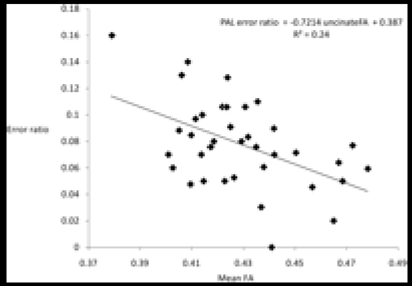
Μελέτες στη φυσιολογική γήρανση

Σε ενήλικες άνω των 50 ετών, η ηλικία συσχετίζεται με μικροδομικές μεταβολές στην ψαλίδα που συνδέει της έσω κροταφικές περιοχές με προμετωπιαίες και υποφλοιώδεις περιοχές, την αγκιστροειδή δεσμίδα και το δεμάτιο που συνδέει την έλικα προσαγωγίου-παραϊποκκάμπειο έλικα.





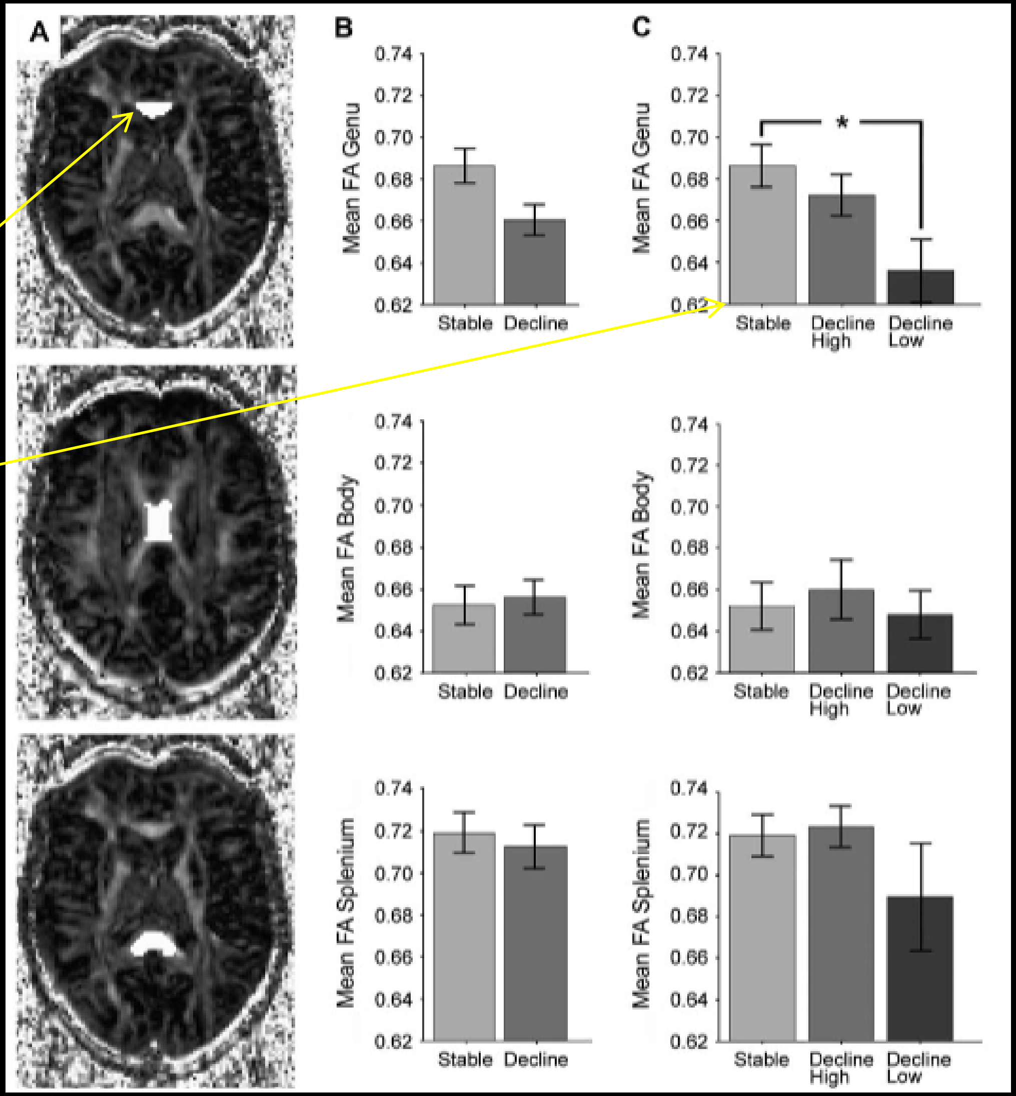
Η φυσιολογική μεταβολή στη βιωματική μνήμη σχετίζεται με μεταβολές στην **ψαλίδα**, ενώ οι δείκτες της **αγκιστροειδούς δεσμίδας** σχετίζονται με την ικανότητα ελέγχου του λάθους (error monitoring) σε δοκιμασία οπτικής αναγνώρισης θέσης αντικειμένου.



(Metzler-Baddeley et al., 2011).

Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στη φυσιολογική γήρανση

Σε μία διαχρονική μελέτη σε υγιείς ηλικιωμένους, η μείωση της μνημονικής επίδοσης συσχετιζόταν με ελάττωση του όγκου του ιπποκάμπου και μείωση του δείκτη FA στο πρόσθιο τμήμα του μεσολοβίου



(Persson et al., 2006)

Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στη φυσιολογική γήρανση, MCI και AD

Μελέτες με απεικόνιση τανυστή διάχυση στο MCI και στο AD παρέχουν ενδείξεις υπερ της διακριτικής ικανότητας των δεικτών του DTI στη διαφοροποίηση μεταξύ της φυσιολογικής γήρανσης, του MCI και του AD αλλα και αναδεικνύουν τη σχέση μεταξύ μικροδομικών αλλαγών και μνημονικής επίδοσης

(Bosch et al., 2012; Bozzali et al., 2012; Fellgiebel et al., 2008; Fellgiebel et al., 2005; Fujie et al., 2008; Kalus et al., 2006; Nakata et al., 2009; Rogalski et al., 2009; Yoshiura et al., 2002; Zhou et al., 2008; Huang et al., 2012; Yakushev et al., 2011)

- Ο δείκτης FA του προσαγωγίου αποτελεί ισχυρό διακριτικό δείκτη μεταξύ AD και μαρτύρων, και του προσαγωγίου-παραϊπποκάμπειας έλικας μεταξύ MCI και μαρτύρων. Ο δείκτης μέσης διάχυσης (mean diffusivity-MD) στον ιππόκαμπο αναδεικνύει τη μεγαλύτερη διαφορά μεταξύ AD και μαρτύρων, καθώς και μεταξύ MCI και μαρτύρων (Clerx et al, 2012)

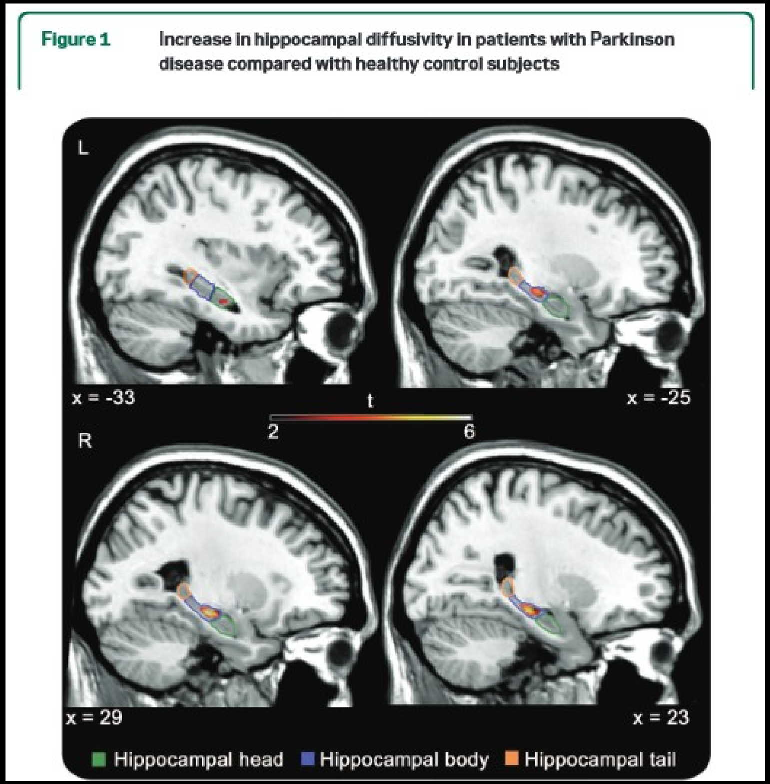
- Η πρώτη μελέτη της διατιτραίνουσας οδού στο MCI και στο AD, αναφέρει μειωμένη συνοχή στη ζώνη της διατιτραίνουσας οδού στους ασθενείς με MCI και AD σε σχέση με τους μάρτυρες, με τις μικροδομικές αλλαγές να συσχετίζονται σημαντικά με την επίδοση σε δοκιμασία καθυστερημένης ανάκλησης.
- Ο βαθμός συνοχής της διατιτραίνουσας οδού ήταν ο μόνος δείκτης διάκρισης μεταξύ των MCI και μαρτύρων (Kalus et al., 2006).

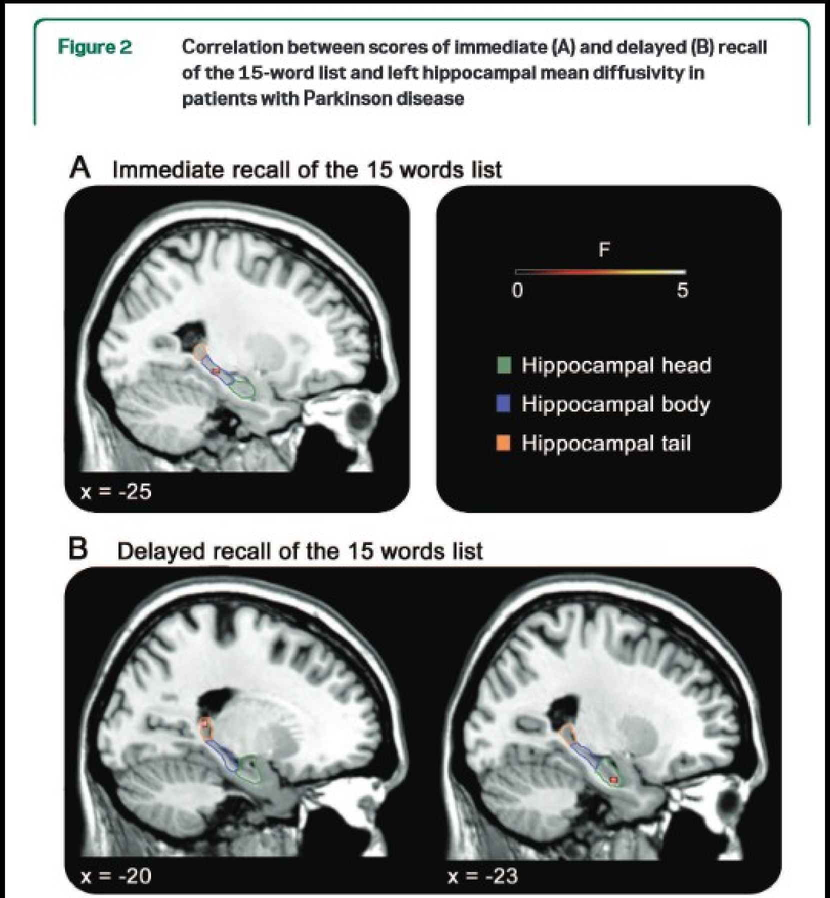
Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στη φυσιολογική γήρανση, MCI και AD

- Η ψαλίδα παρουσιάζει μικροδομικές αλλαγές (μειωμένο FA, αυξημένο MD) σε ασθενείς με AD in AD (Kantarci et al., 2010; Mielke et al., 2009) αλλά όχι στο MCI (Mielke et al., 2009).
- Ο δείκτης FA στην ψαλίδα συσχετίζεται με τη μνημονική επίδοση σε ασθενείς με αμνησικού τύπου MCI, τη μελλοντική μνημονική εξασθένηση και τη μετάπτωση σε AD (Mielke et al., 2012).

- Συνδέσεις μεταξύ του θαλάμου (κυρίως πρόσθια τμήματα) και έσω κροταφικών δομών (κυρίως ιπποκάμπου) παρουσιάζουν ελάττωση σε ασθενείς με AD (Damoiseaux et al., 2009; Fellgiebel et al., 2004; Zarei et al., 2010), ενισχύοντας την άποψη για συμμετοχή των συνδέσεων στα μνημονικά ελλείμματα στην AD (Di Paola et al., 2007).

Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στην νόσο Parkinson

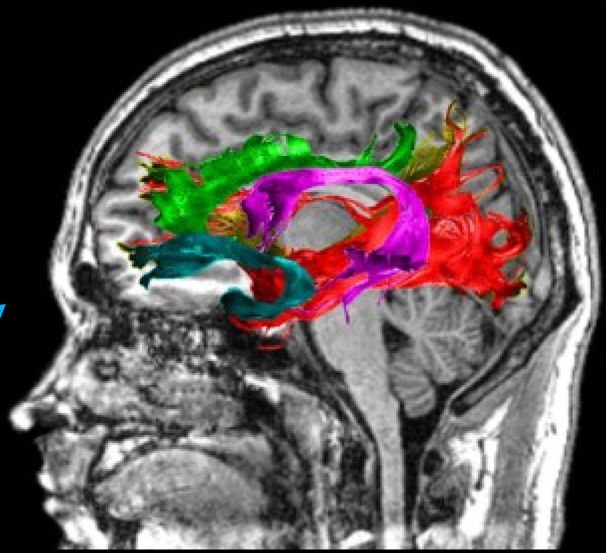




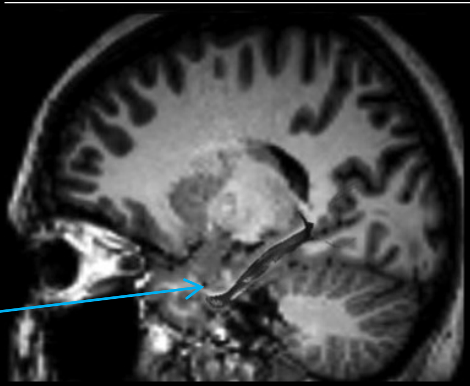
Μικροδομικές αλλαγές στον ιππόκαμπο (αυξημένο MD) έχουν συσχετισθεί με μειωμένη μνημονική επίδοση σε ασθενείς με PD χωρίς άνοια, χωρίς να παρατηρείται συσχέτιση με τον όγκο του ιπποκάμπου (Carlesimo et al., 2012).

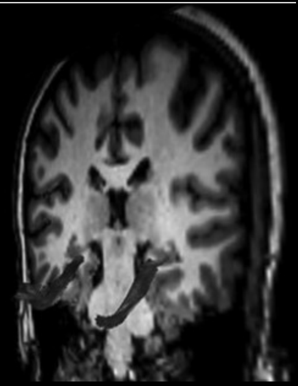
Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτες στην ΚΕΚ

Αυξημένο MD στον ιπποκάμπειο σχηματισμό, στο οπίσθιο προσαγώγιο, σε κροταφικές, μετωπιαίες και ινιακές περιοχές σχετίζεται με τη ικανότητα εκμάθησης και ανάκλησης (Salmond et al., 2006).



Μικροδομικές αλλαγές ανιχνεύονται στα βασικά δεμάτια του κροταφικού λοβού (ILF, IFOF, UF, AF) και σχετίζονται με την επίδοση σε λεκτικές και οπτικές δοκιμασίες μνήμης στην ΚΕΚ (Bigler et al., 2010).

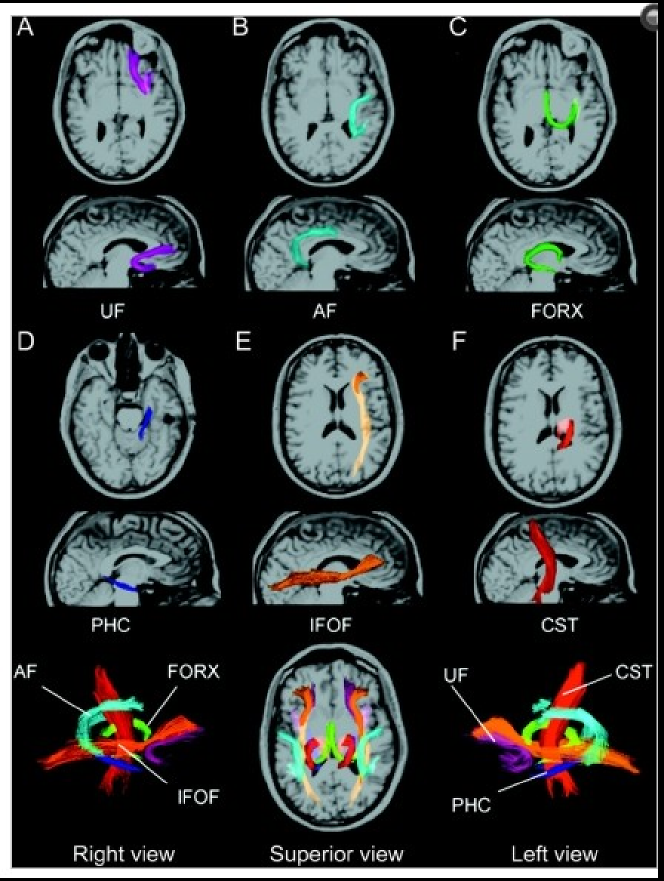




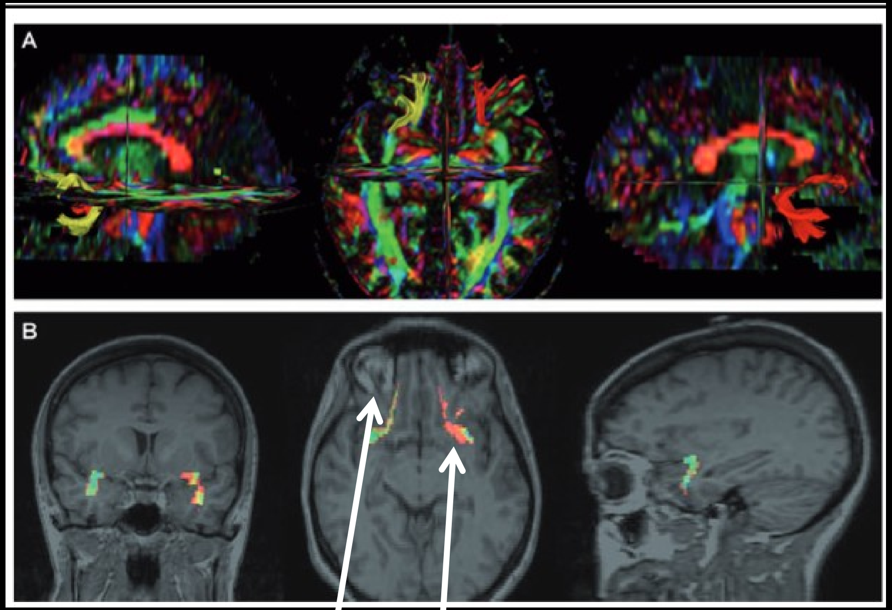
Πρόσφατα, μέσω του DTI ανιχνεύτηκαν οι μικροδομικές αλλαγές στη διατιτραίνουσα οδό του ιπποκάμπου με υψηλή συσχέτιση με τα μνημονικά ελλείμματα των ασθενών με ΚΕΚ (Christidi et al., 2011).

Τα δίκτυα και τα δίχτυα της μνήμης

Μελέτες στην κροταφική επιληψία



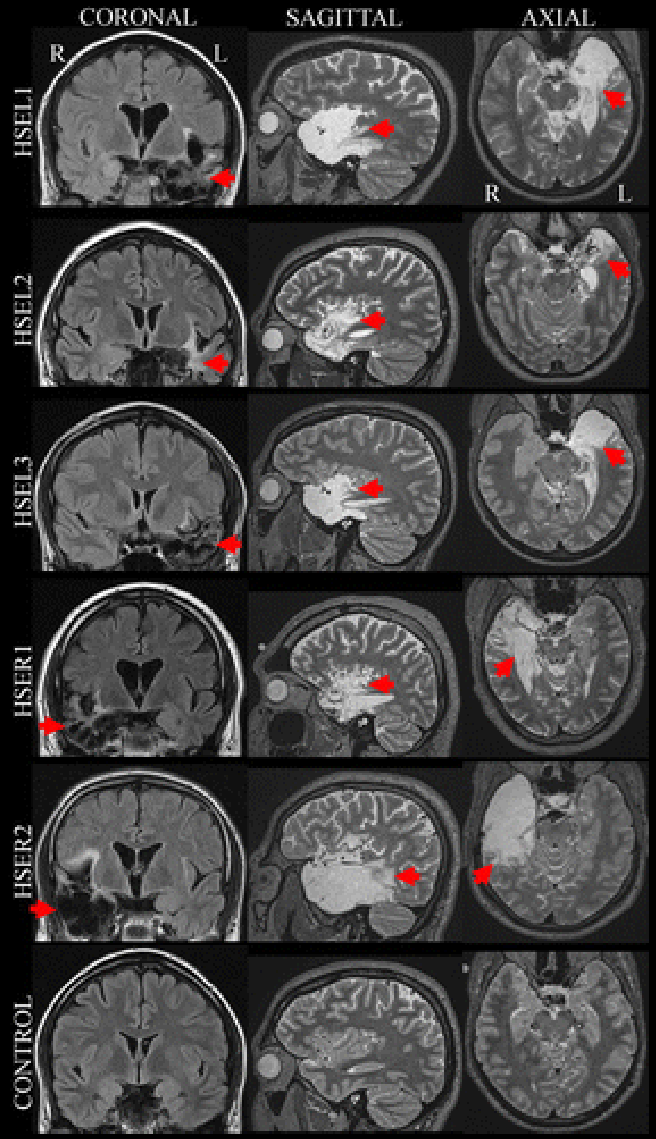
Μετά από έλεγχο για τον όγκο του ιπποκάμπου, τα μικροδομικά χαρακτηριστικά δεματίων όπως AF, UF, IFOF, αποτελούν ανεξάρτητους προβλεπτικούς παράγοντες για τη μνημονική επίδοση (McDonald et al., 2008).



- ΑΡ Κροταφική Επιληψία (Diehl et al., 2008)
  - ΑΡ Αγκιστροειδής & Ανάκληση (άμεση & καθυστερημένη) λεκτικού υλικού
  - ΔΕ Αγκιστροειδής & Ανάκληση (καθυστερημένη) οπτικού υλικού

Τα δίκτυα και τα δίχτυα της μνήμης
Μελέτη στην ερπητική εγκεφαλίτιδα

Σε μικρό αριθμό ασθενών με μονόπλευρη βλάβη στον έσω κροταφικό λοβό στην MRI και σοβαρά τόσο μνημονικά ελλείμματα τόσο σε λεκτικές όσο και οπτικές δοκιμασίες, η DTI αποκάλυψε σημαντικές μεταβολές σε πολλά δεμάτια λευκής ουσίας που συνδέουν τις κροταφικές περιοχές με άλλες περιοχές αντίπλευρα της βλάβης (χωρίς να υπάρχει σημαντική μεταβολή στον όγκο του ιπποκάμπου ή φλοιϊκή ατροφία και χωρίς ευρήματα στην τυπική MRI) (Grydeland et al., 2010).



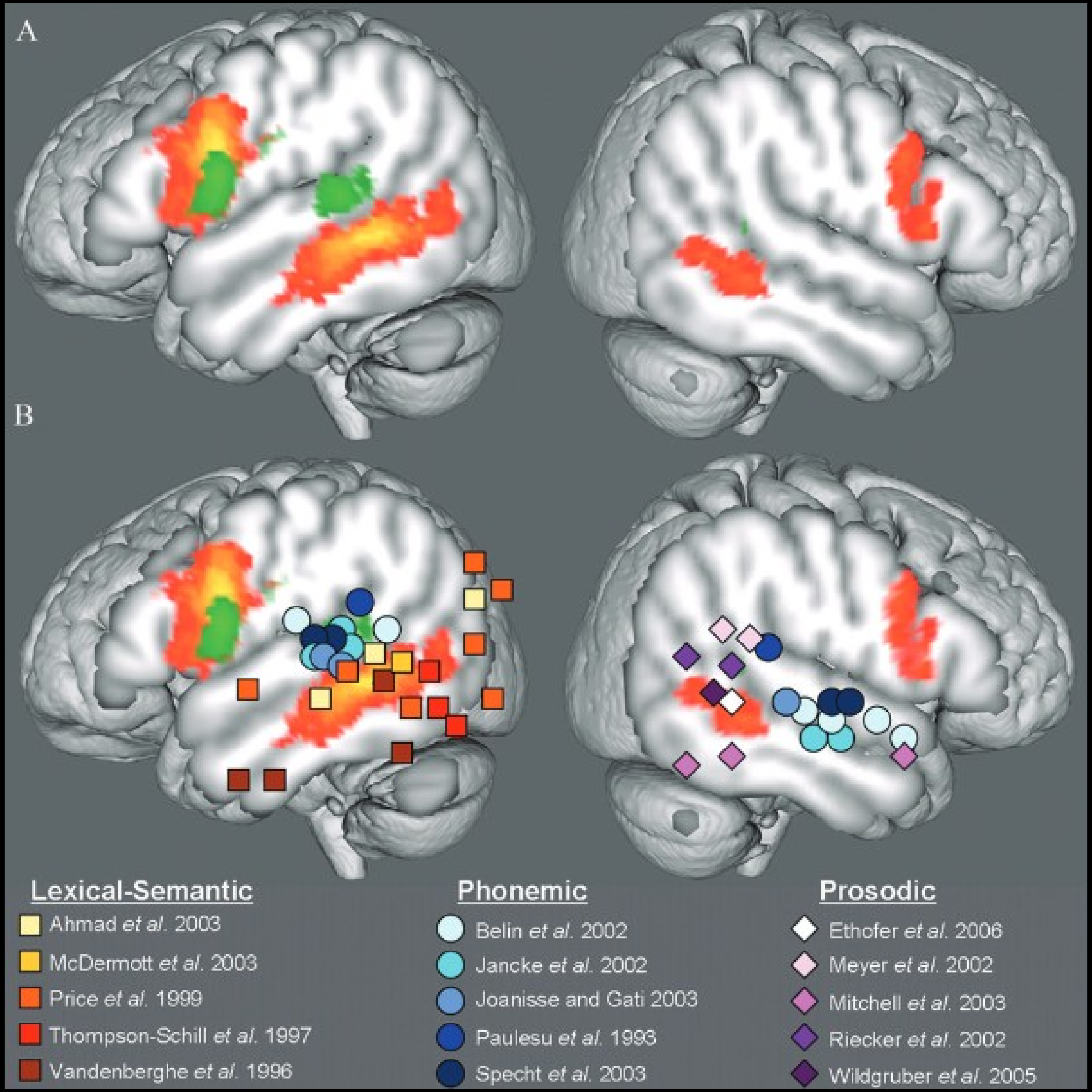
Τα δίκτυα και τα δίχτυα της μνήμης

ανάδειξη μικροδομικών αλλαγών και ερμηνεία μνημονικών ελλειμμάτων

- Μικροδομικές μεταβολές στην ψαλίδα και άλλες δεμάτια λευκής ουσίας του μεταιχμιακού συστήματος, σε ασθενή με παλαιά ΚΕΚ, ευρήματα ΑΡ μετωπιαίας βλάβης στην κλασική MRI, αλλά εμμένοντα μνημονικά ελλείμματα 14 χρόνια μετά την ΚΕΚ (Papanicolaou et al., 2007)

- Η χρήση του DTI και κλασικής MRI σε ασθενή με εμπροσθόδρομη και οπισθόδρομη αμνησία συνέπεια έμφρακτου στην πρόσθια ψαλίδα άμφω ερμηνεύει το πρότυπο μνημονικών ελλειμμάτων και τα εμμένοντα ελλείμματα 1 χρόνο μετά το έμφρακτο χωρίς περαιτέρω αλλαγές στην MRI. (Renou, Ducreux, Batouche, & Denier et al., 2008)

Τα δίκτυα του λόγου



Cerebral Cortex November 2008;18:2471–2482
doi:10.1093/cercor/bhn011
Advance Access publication February 14, 2008

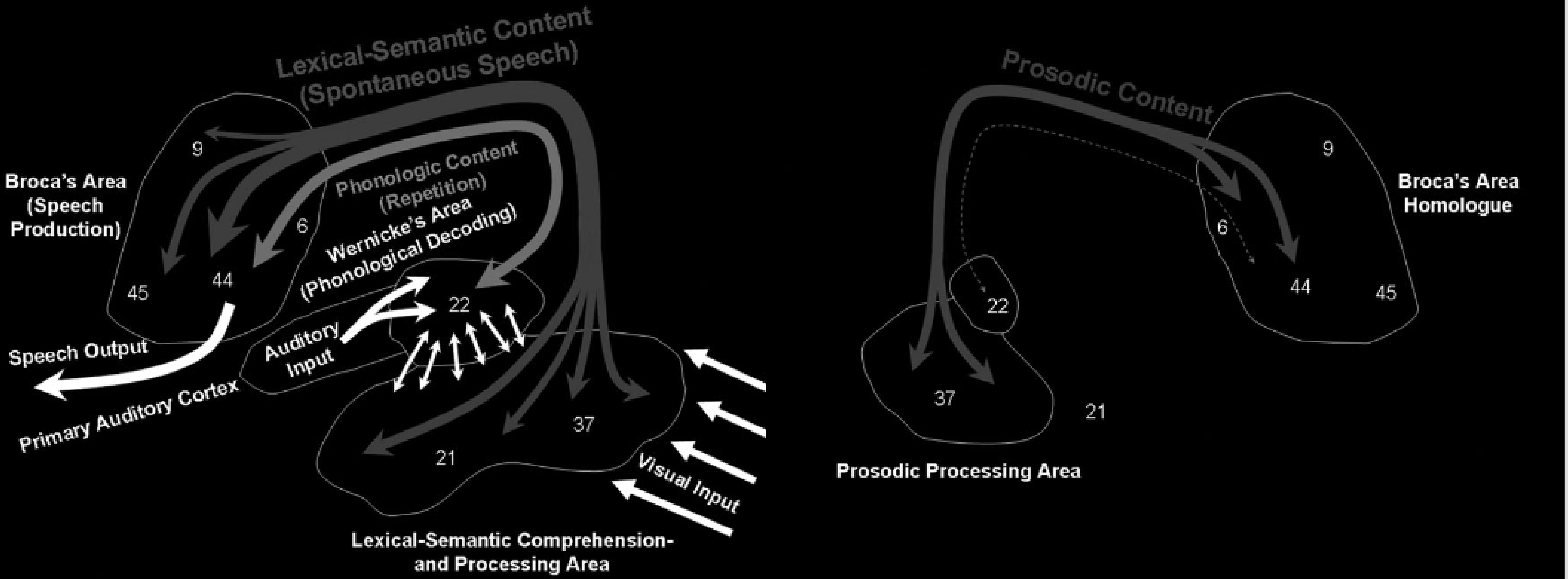
FEATURE ARTICLE
DTI Tractography of the Human Brain's Language Pathways

Matthew F. Glasser[1] and James K. Rilling[1,2,3,4]

[1]Department of Anthropology, [2]Department of Psychiatry and Behavioral Sciences, [3]Center for Behavioral Neuroscience and [4]Yerkes National Primate Research Center, Emory University, Atlanta, GA 30322, USA

Figure 1.
(A) Average arcuate fasciculus tractography results for the 20-subject data set. Connections linking the STG with the frontal lobe are colored green. Connections linking the regions below the superior temporal sulcus with the frontal lobe are colored orange. Average pathways were thresholded to include voxels in which at least 2 subjects had a pathway.
(B) Functional activations overlaid on average tractography results, in standard space. Each study in each hemisphere is represented by a different color. Lexical--semantic tasks are represented as squares, phonemic tasks are represented as circles, and prosodic tasks are represented as diamonds

Τα δίκτυα του λόγου



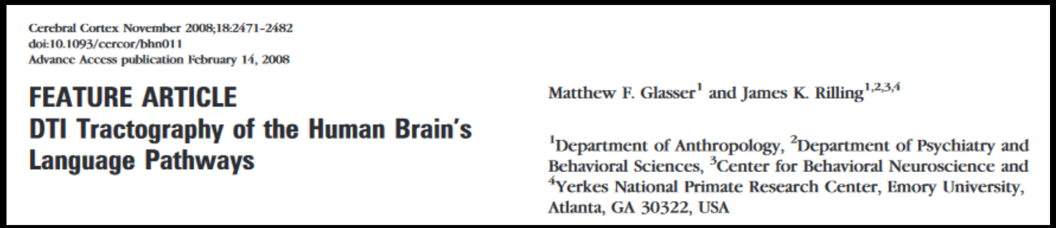


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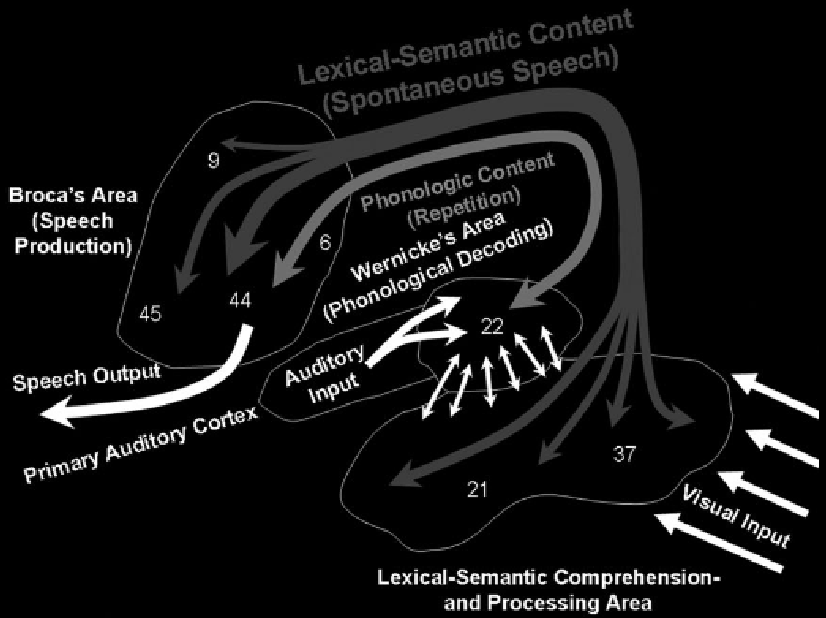
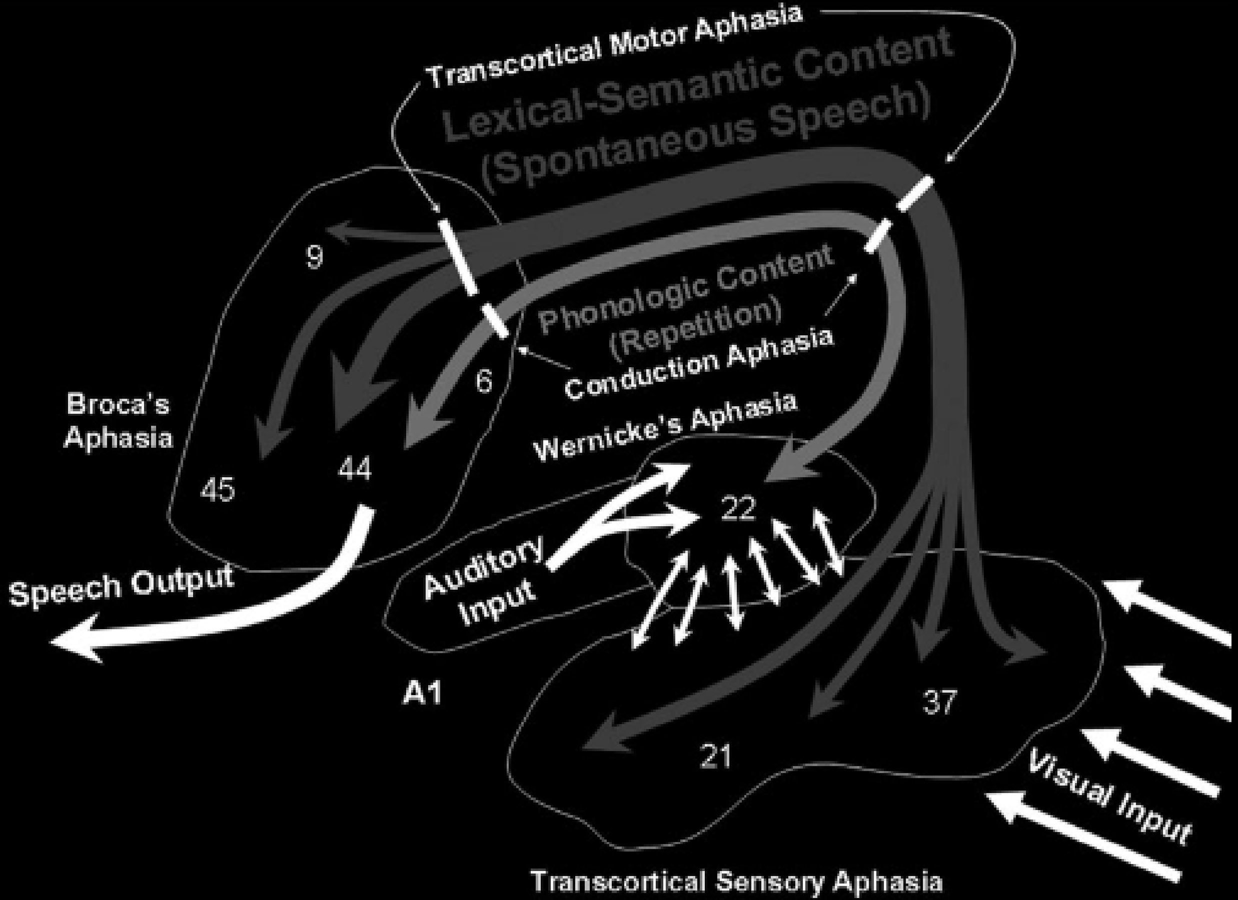
Figure 3.
The functions of the STG and MTG pathways according to the model of Hickok and Poeppel (2004) and Price (2000) in the left hemisphere and the right hemisphere

Τα δίκτυα του λόγου





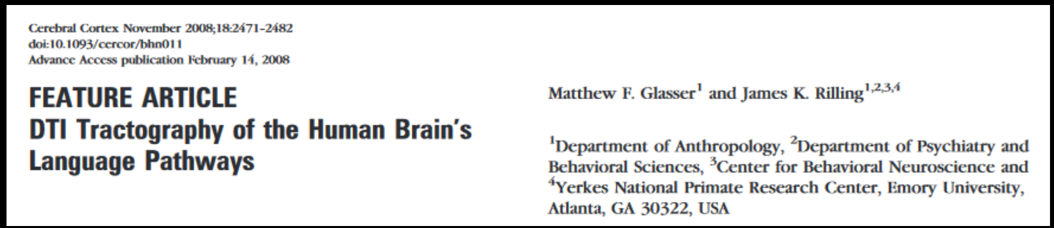


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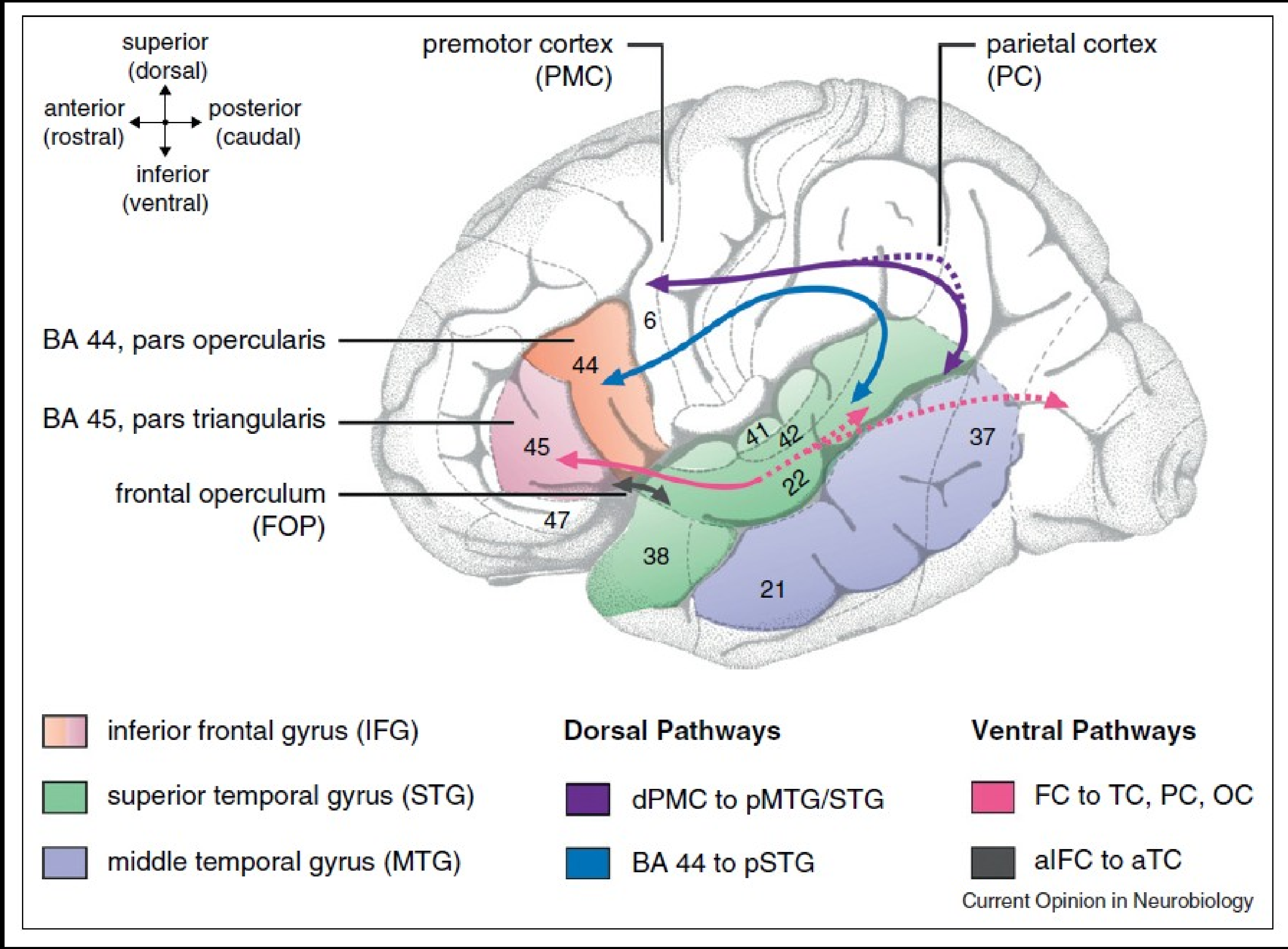
Figure 5.
Common locations of the aphasias

Τα δίκτυα του λόγου

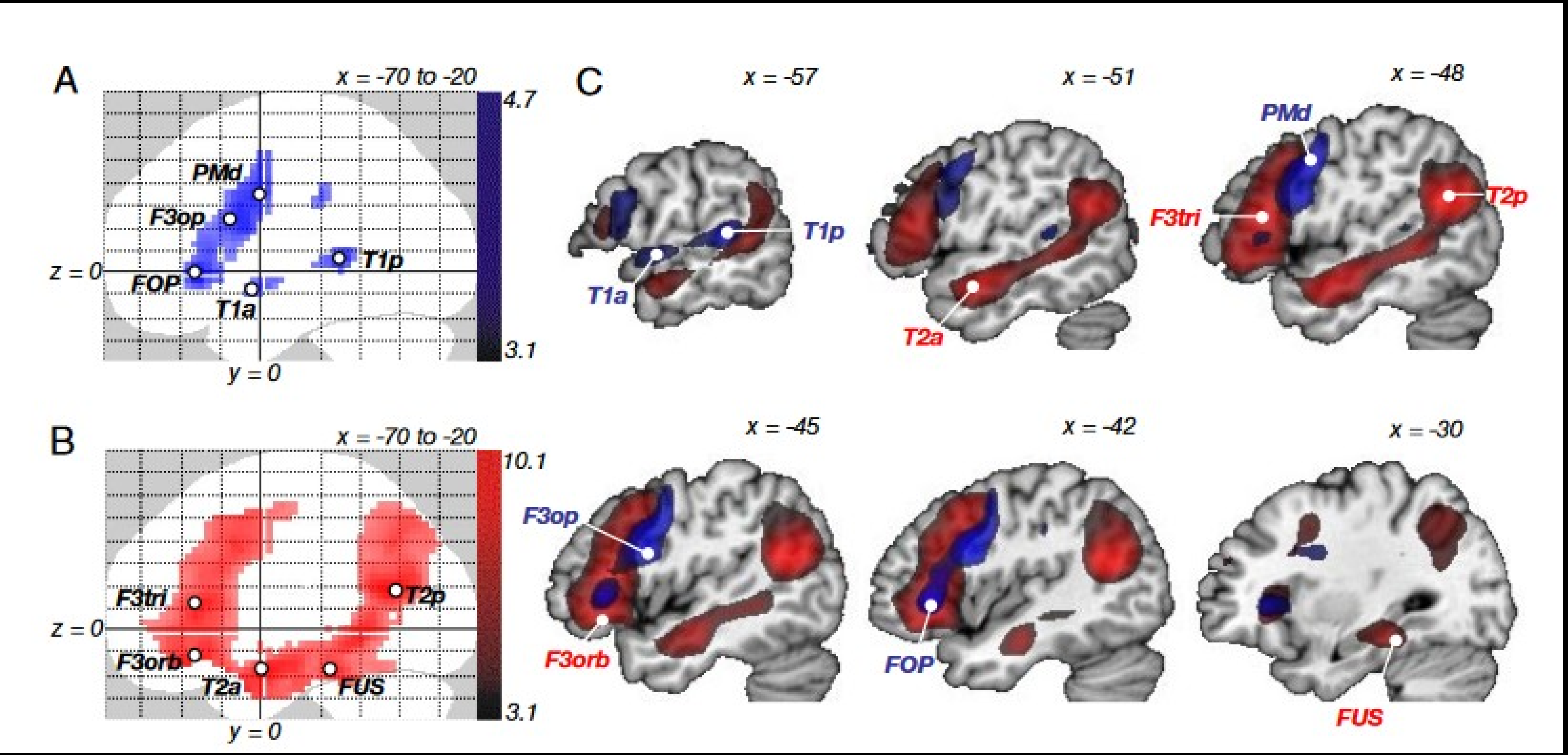


The language network
Angela D Friederici and Sarah ME Gierhan
Current Opinion in Neurobiology 2012, **23**:1–5

Language-relevant brain regions and fiber tracts (schematic and condensed view of the left hemisphere).

The **dorsal pathway** connecting dorsal premotor (dPMC) with posterior temporal cortex (pMTG/STG) involves the **SLF III** and/or the **SLF II** and **the SLF-tp**; the dorsal pathway connecting BA44 with the posterior STG involves the **AF**.
The **ventral pathway** connecting the frontal cortex (FC), that is, BA 45 and others, with the temporal (TC), the parietal (PC), and the occipital (OC) cortex, involves the **IFOF** (also called the ECFS); the ventral pathway connecting the anterior inferior FC (aIFC), that is, BA 47 and others, and the FOP, with the anterior TC (aTC), involves the **UF**.

Τα δίκτυα του λόγου



PNAS | November 18, 2008 | vol. 105 | no. 46 | 18035–18040

Fig. 1.
fMRI results. Functional networks involved in (A) repetition (of pseudowords compared with words) and (B) comprehension (listening to normal sentences compared to meaningless pseudo sentences), analyzed in two random effects analyses (no.33).
Activations are overlaid as maximum intensity projections on a canonical brain. Peak voxels within each cluster defined the nodes of the networks, which served as seed regions for the probabilistic fiber tracking.
(C) Both contrasts (repetition, blue; comprehension, red) displayed along the x coordinate of the seed regions.
T1a/p, anterior/posterior superior temporal gyrus; T2a/p, anterior/posterior middle temporal gyrus; FUS, fusiform gyrus; F3orb/tri/op, pars orbitalis/triangularis and opercularis of the inferior frontal gyrus; FOP, deep frontal operculum; PMd, dorsal premotor cortex.

Τα δίκτυα του λόγου

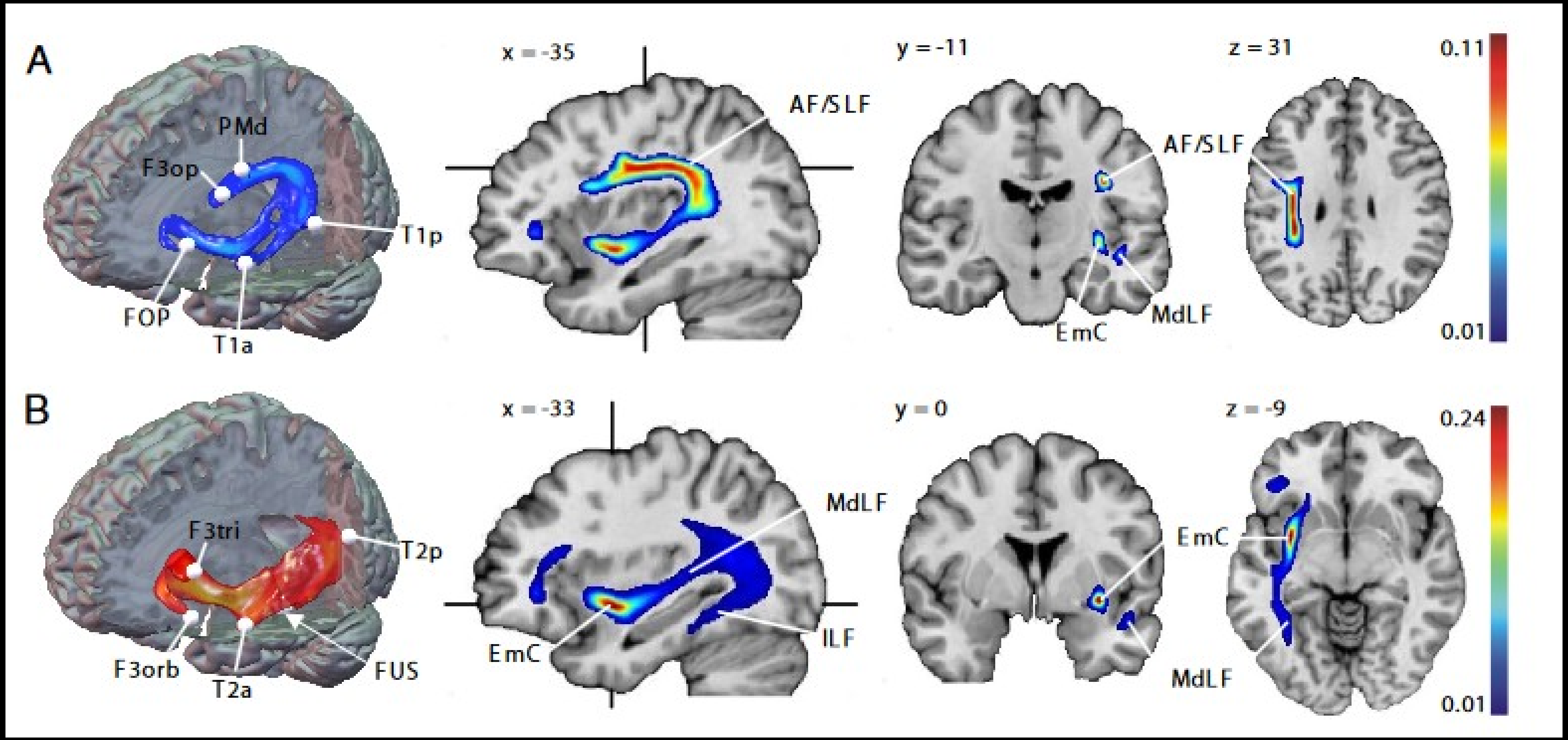


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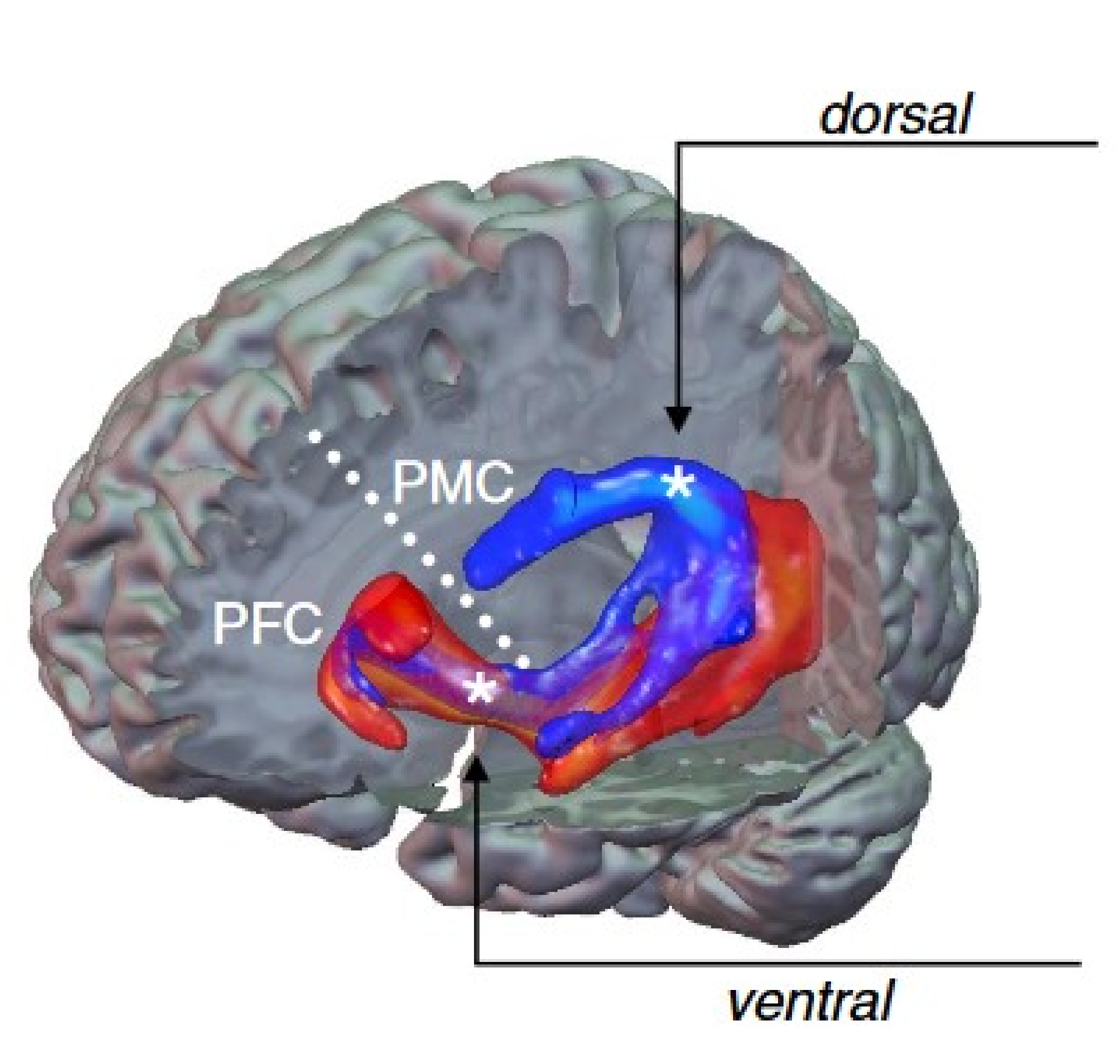
Fig. 2.
Fiber tracking results. Composite fiber networks subserving repetition (A) and comprehension (B) computed by averaging the pairwise connections of 33 subjects defined in the repetition and comprehension experiment, respectively.
Three-dimensional tractography renderings visualize the spatial orientation of both networks. Crosshairs on sagittal sections indicate the orientation of the coronal and axial sections. Maximum PIBI (probability index forming part of the bundle of interest) values are given at the top of the color bar.
EmC, extreme capsule; AF/SLF, arcuate and superior longitudinal fascicle; MdLF/ILF, middle and inferior longitudinal fascicle. Abbreviation of seed regions are as indicated in Fig. 1

Τα δίκτυα του λόγου




Ventral and dorsal pathways for language

Dorothee Saur[a,b,1], Björn W. Kreher[b,c], Susanne Schnell[b,c], Dorothee Kümmerer[a,c], Philipp Kellmeyer[a,c], Magnus-Sebastian Vry[a,c], Roza Umarova[a,c], Mariacristina Musso[a,c], Volkmar Glauche[a,c], Stefanie Abel[d], Walter Huber[d], Michel Rijntjes[a], Jürgen Hennig[b,c], and Cornelius Weiller[a,c]

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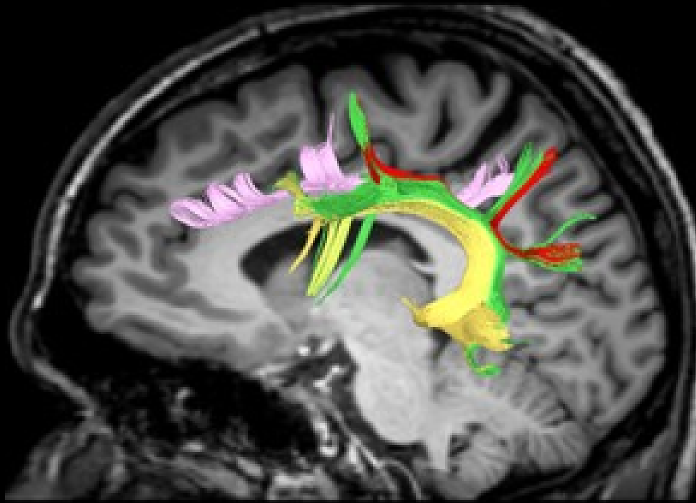

Fig. 3.
Dual pathway network for language. Composite fiber network for repetition (blue) and comprehension (red).

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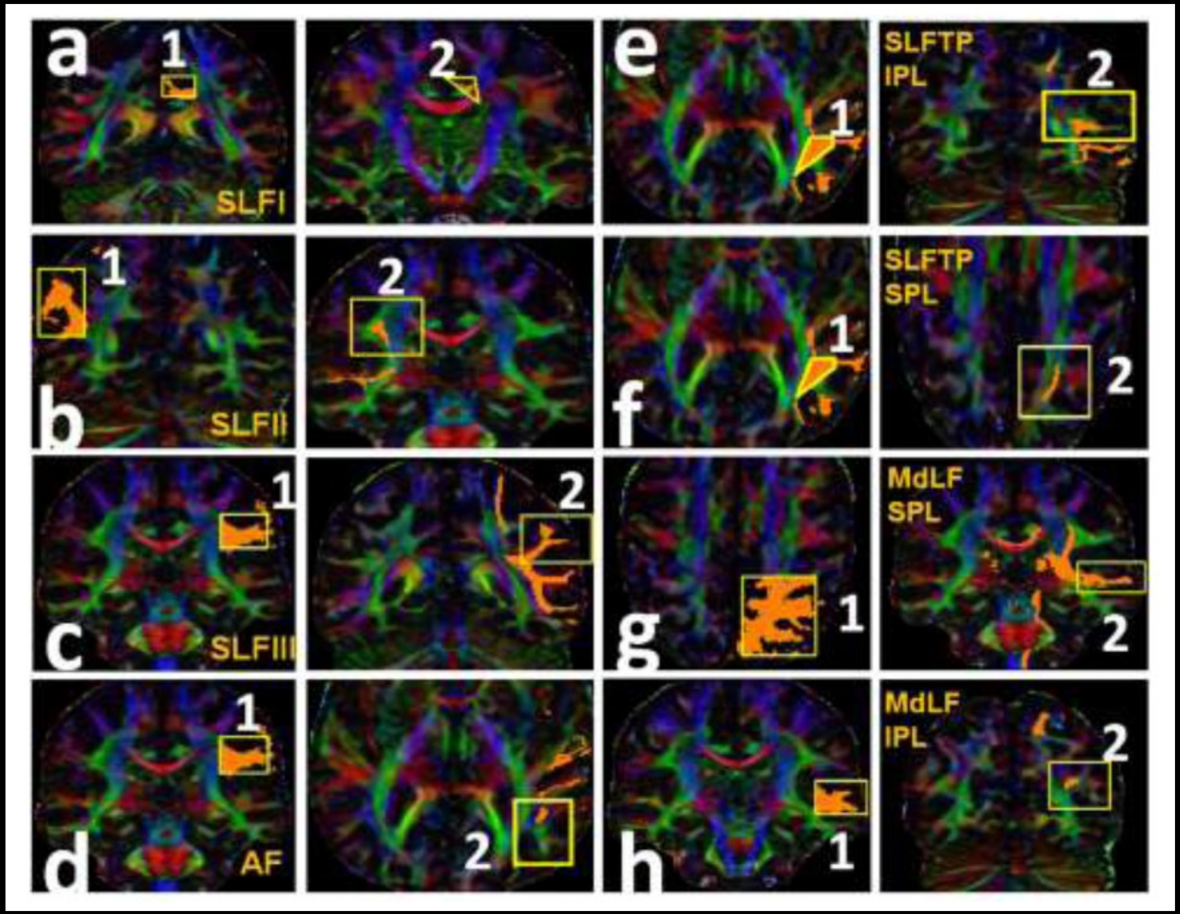

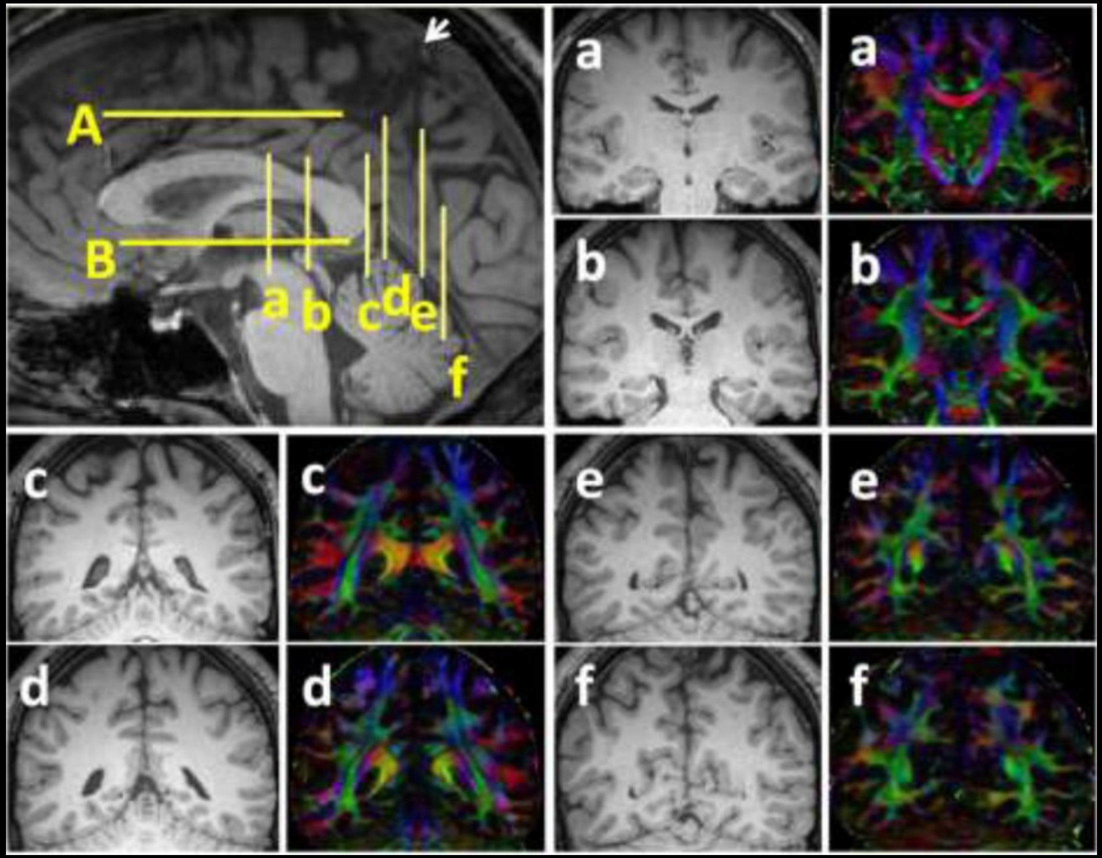

Brain Struct Funct. 2014 January ; 219(1): . doi:10.1007/s00429-012-0498-y.

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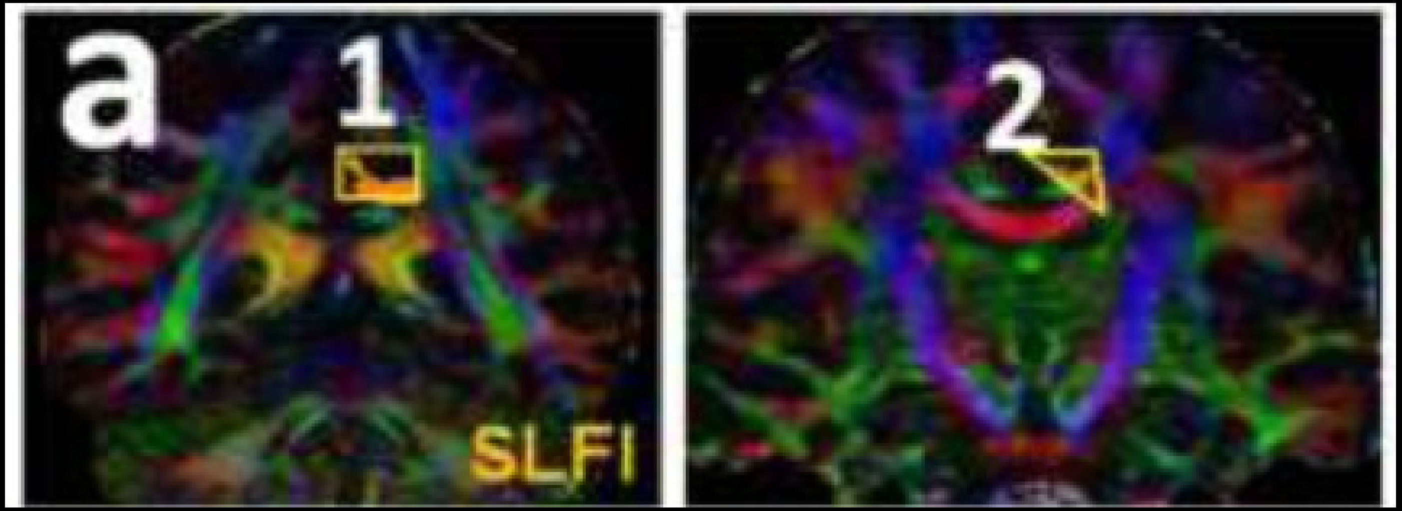
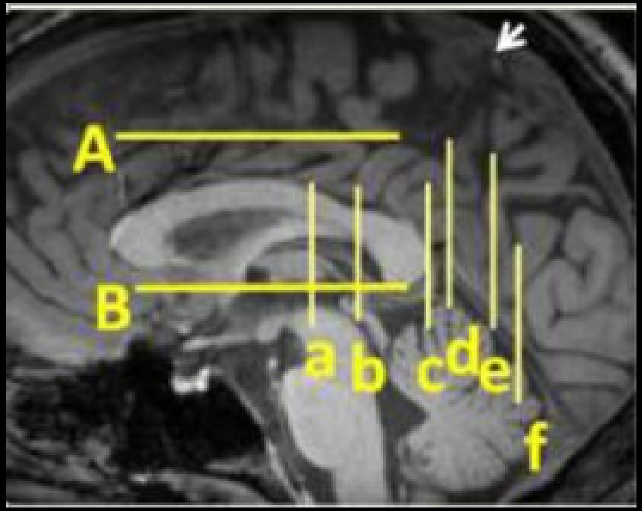
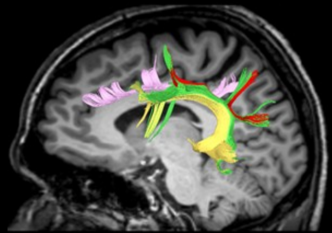
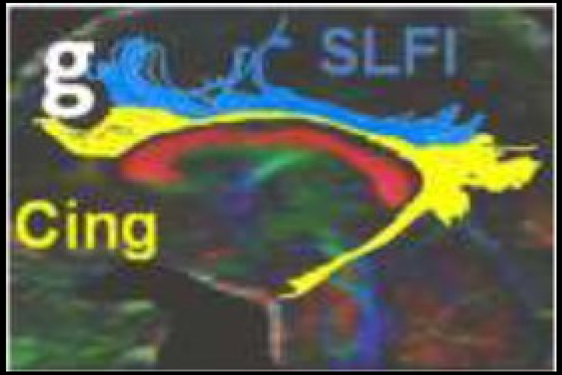




(a) SLF I: the ROI 1 is delineated over the green association bundles just superolateral to the cingulum. The ROI 2 was placed over the fibers generated on the superolateral aspect of the cingulum.





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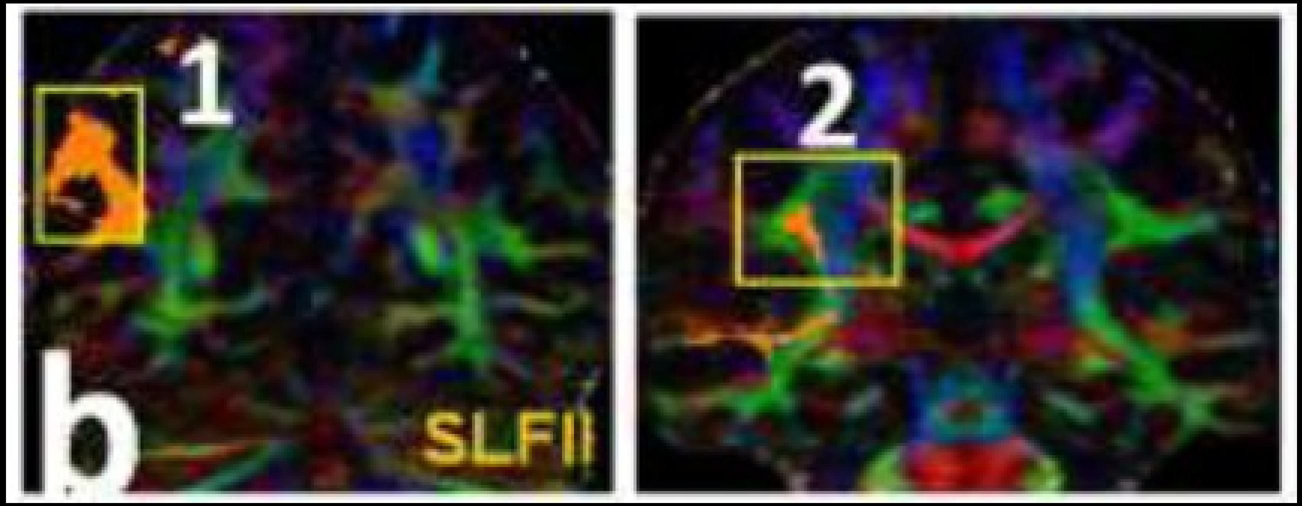
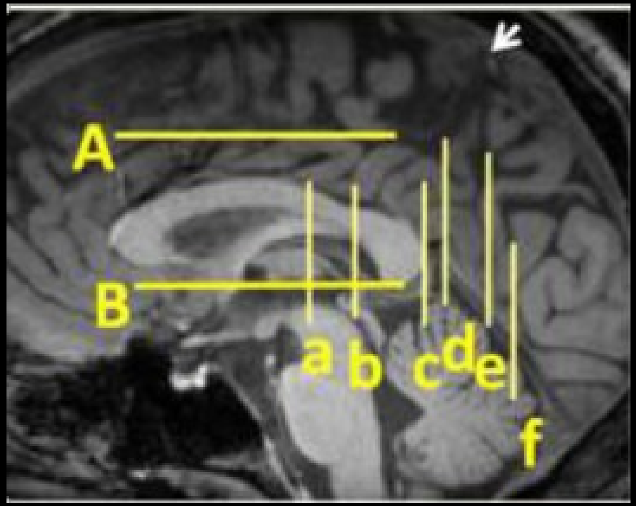
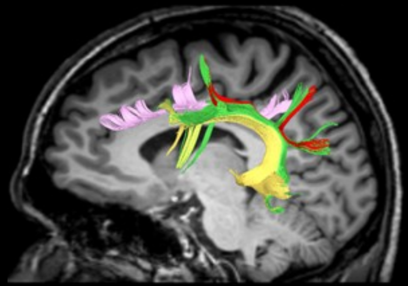
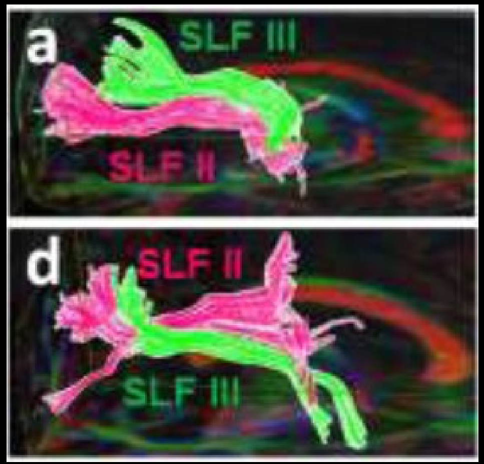




(b) SLF II: the ROI 1 is placed over the white matter of the angular gyrus (coronal plane e in Figure 2). The second ROI was placed on the fibers generated on the association green area.





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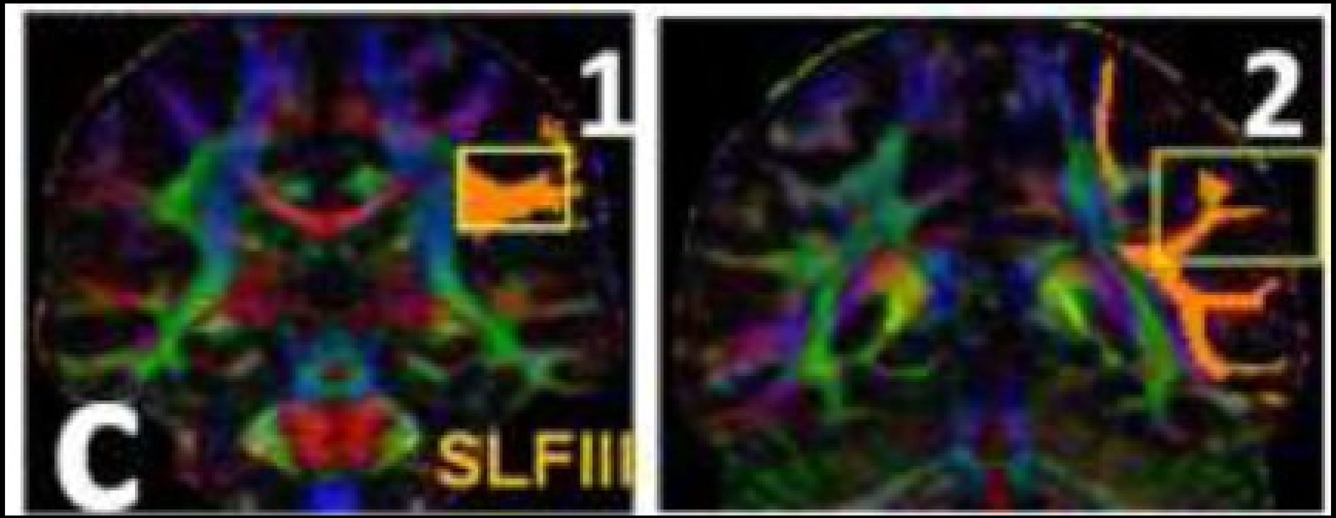
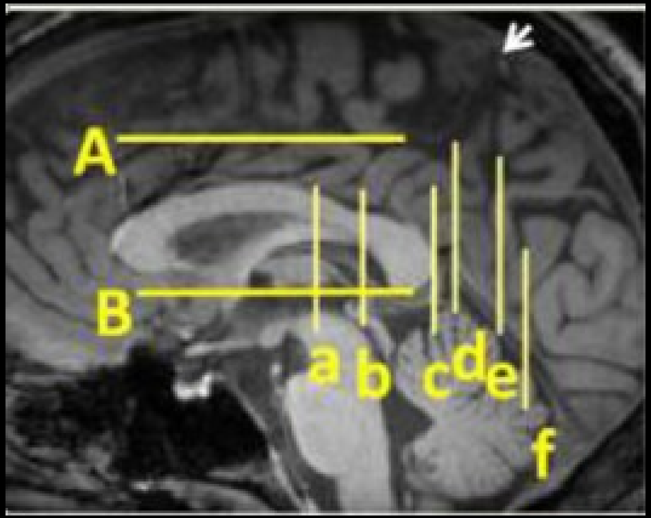
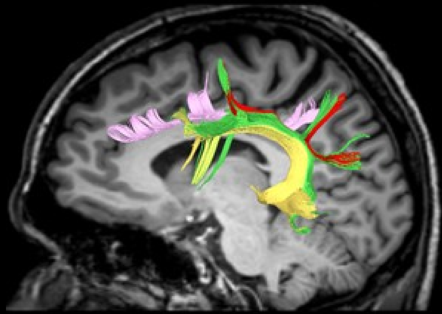
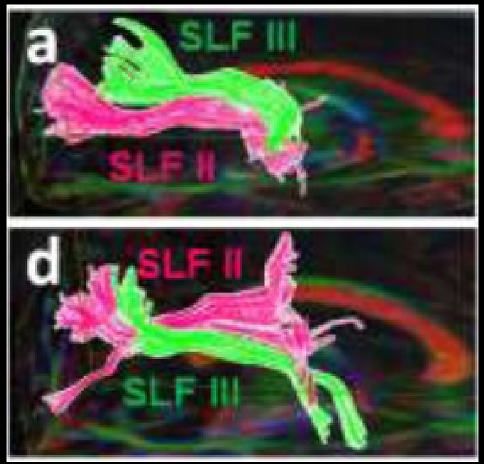




(c) SLF III: the ROI 1 is paced over the periventricular green association fibers followed by the second ROI over the fibers generated on the white matter of the supramarginal gyrus





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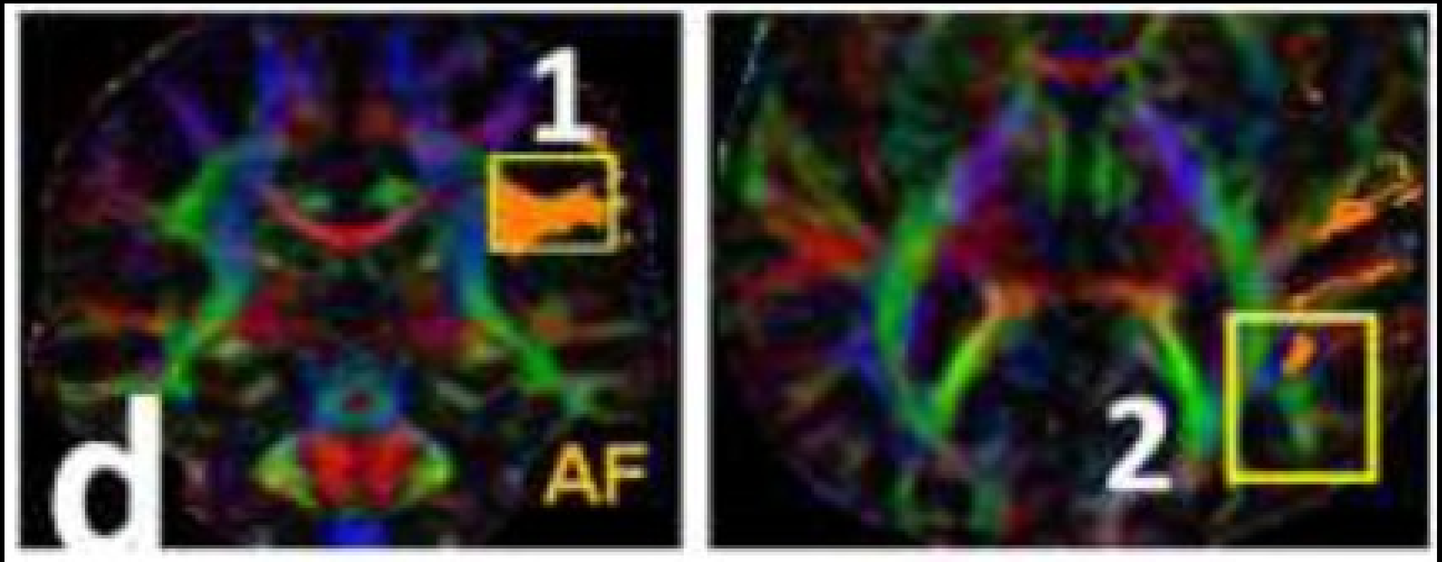
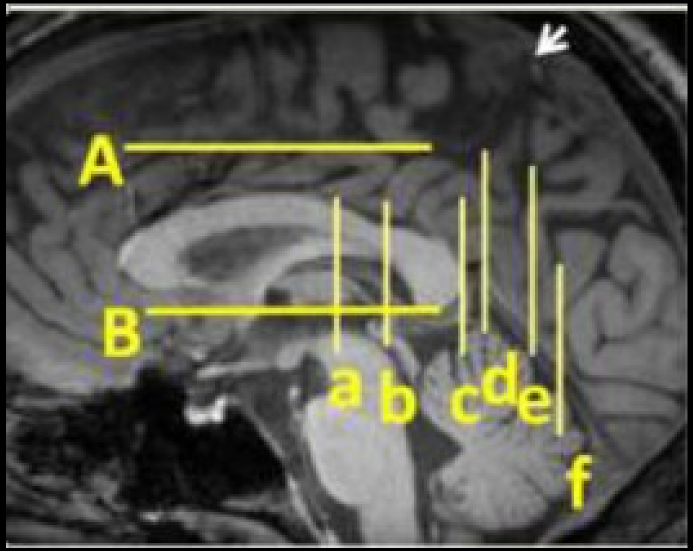
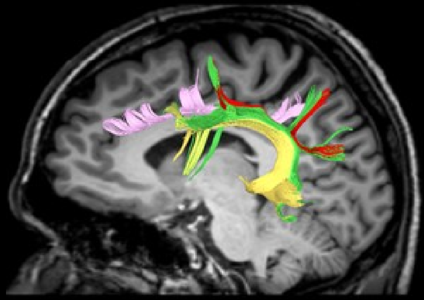


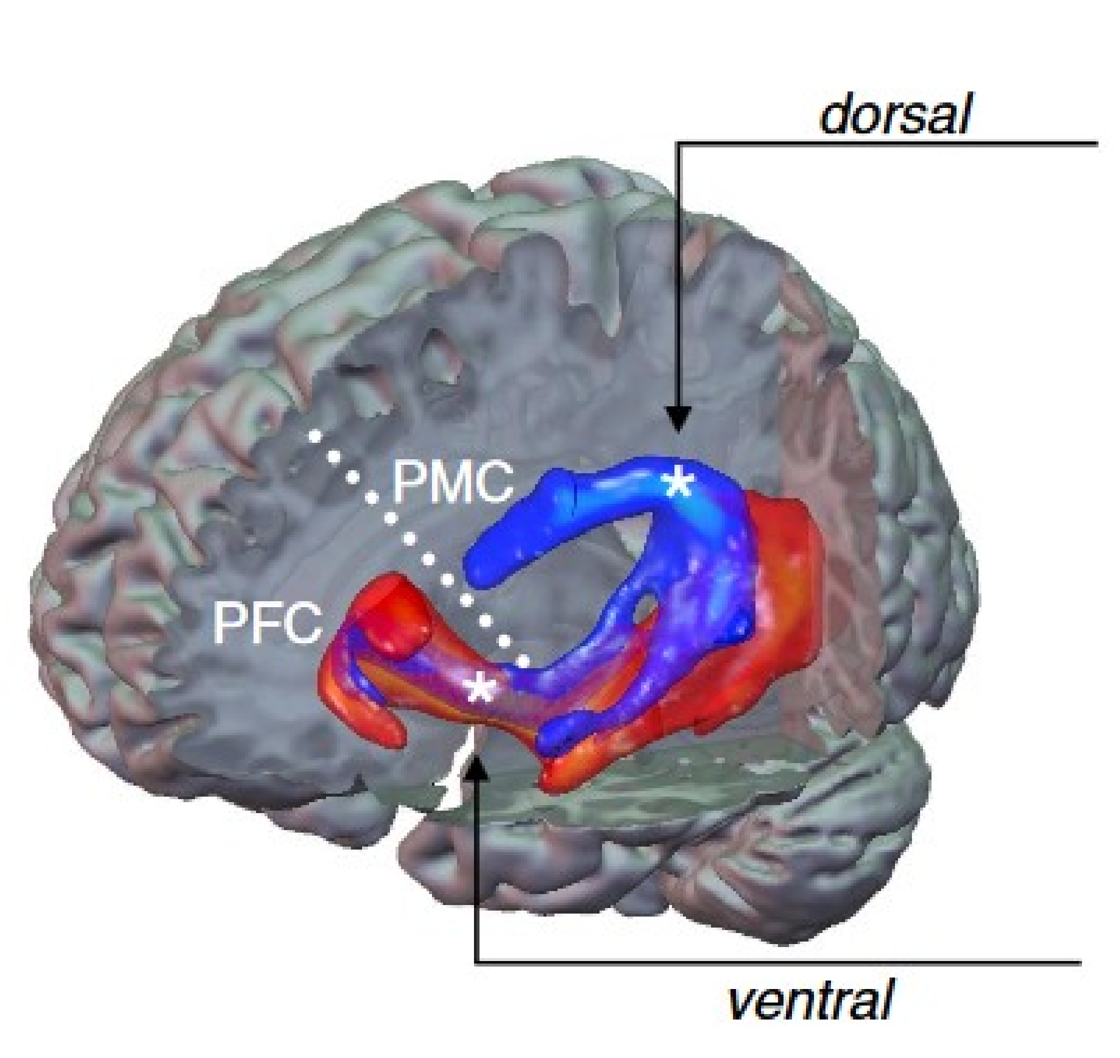


(d) AF: the first ROI is the same as ROI 1 for the SLF III. The ROI 2 is situated over the periventricular craniocaudally oriented blue fibers



Brain Struct Funct. 2014 January ; 219(1): . doi:10.1007/s00429-012-0498-y.

Τα δίκτυα του λόγου



Ventral and dorsal pathways for language

Dorothee Saur[a,b,1], Björn W. Kreher[b,c], Susanne Schnell[b,c], Dorothee Kümmerer[a,c], Philipp Kellmeyer[a,c], Magnus-Sebastian Vry[a,c], Roza Umarova[a,c], Mariacristina Musso[a,c], Volkmar Glauche[a,c], Stefanie Abel[d], Walter Huber[d], Michel Rijntjes[a], Jürgen Hennig[b,c], and Cornelius Weiller[a,c]

PNAS | November 18, 2008 | vol. 105 | no. 46 | 18035–18040

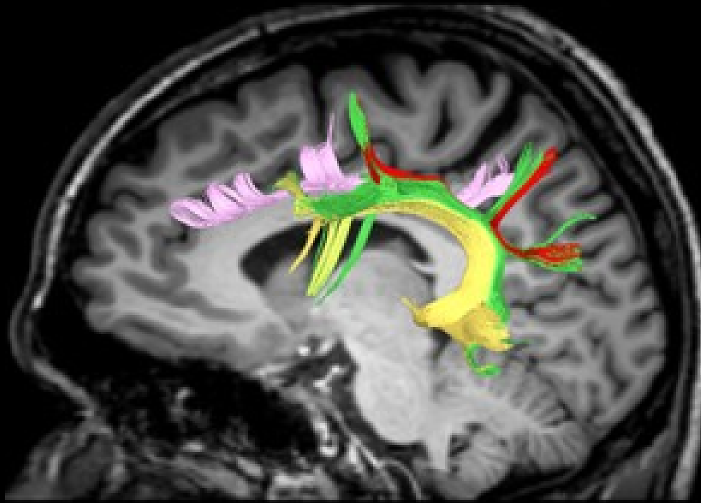


Fig. 3.
Dual pathway network for language. Composite fiber network for repetition (blue) and comprehension (red).

Τα δίκτυα του λόγου

Brain Struct Funct. 2009 February ; 213(3): 343–358. doi:10.1007/s00429-008-0199-8.

The extreme capsule in humans and rethinking of the language circuitry

Nikos Makris, M.D., Ph.D. and
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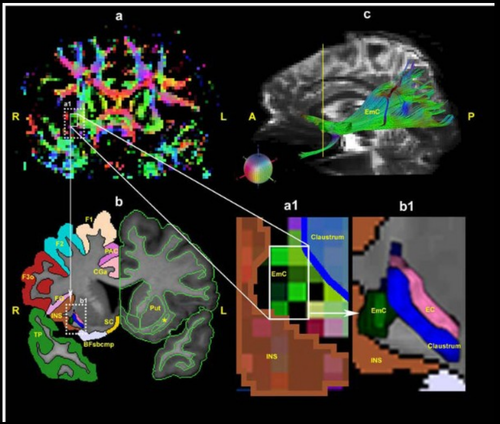
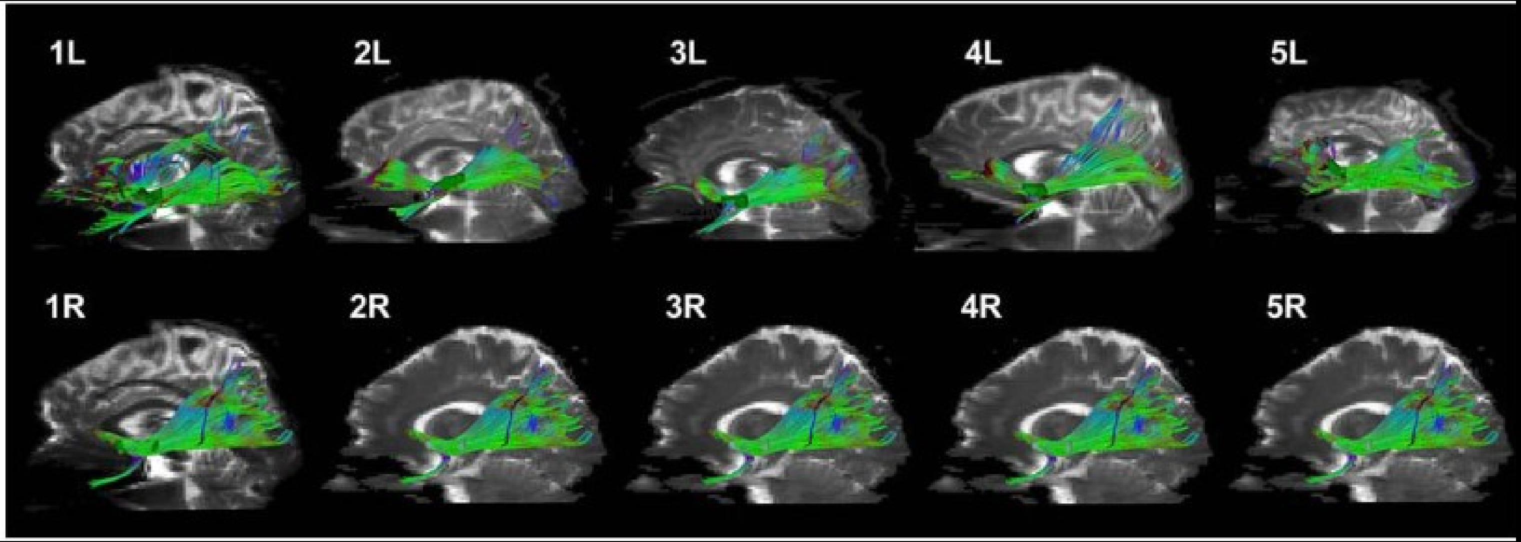
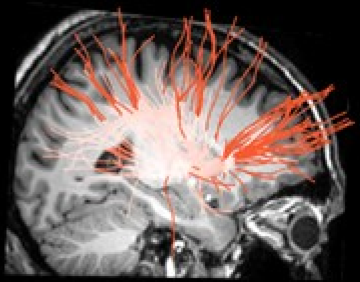
Department of Anatomy and Neurobiology, Boston University, School of Medicine, Boston, MA 02215, USA

Deepak N. Pandya, M.D.
Department of Anatomy and Neurobiology, Boston University, School of Medicine, Boston, MA 02215, USA

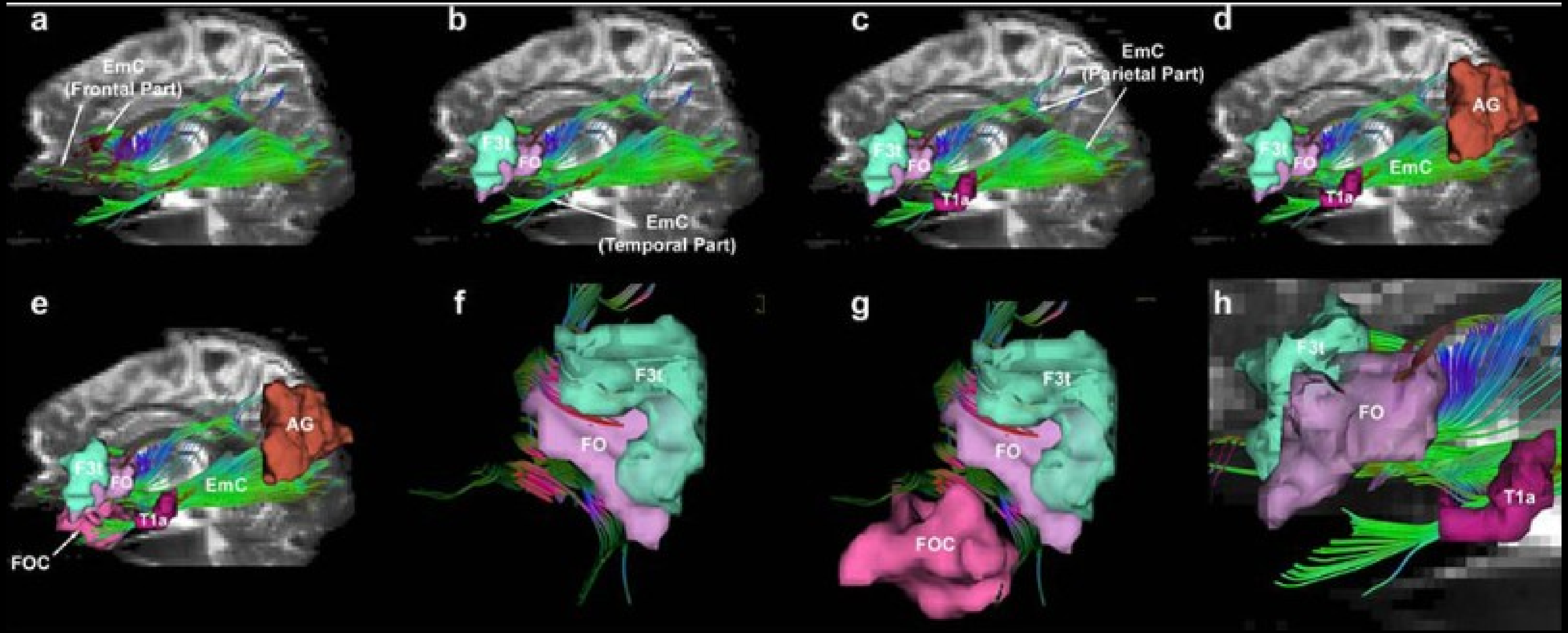




Three-dimensional renderings showing the trajectory of the EmC (extreme capsule) including the seed point, as resulted from DTMRI-based tractography in the ten hemispheres (ten hemispheres, 1L–5R) of all the subjects analyzed in the study in a lateral view. The EmC is shown in green projected on the background of a parasagittal T2-EPI section. Abbreviations: L left; R right



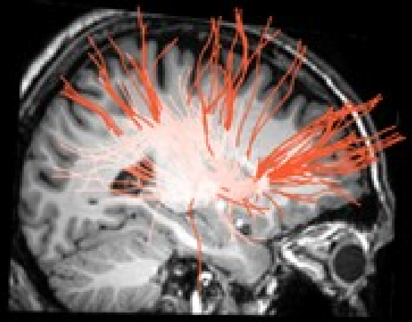
Τα δίκτυα του λόγου



The trajectory of the EmC (extreme capsule) and the cortical regions it connects are shown on a series of illustrations of a left lateral profile (a–e) in a representative subject (1L of Fig. 3). EmC resulted from DT-MRI-based tractography and is shown in green projected on the background of a parasagittal T2-EPI section. The cortical ROIs were derived using cortical parcellation (Caviness et al. 1996).

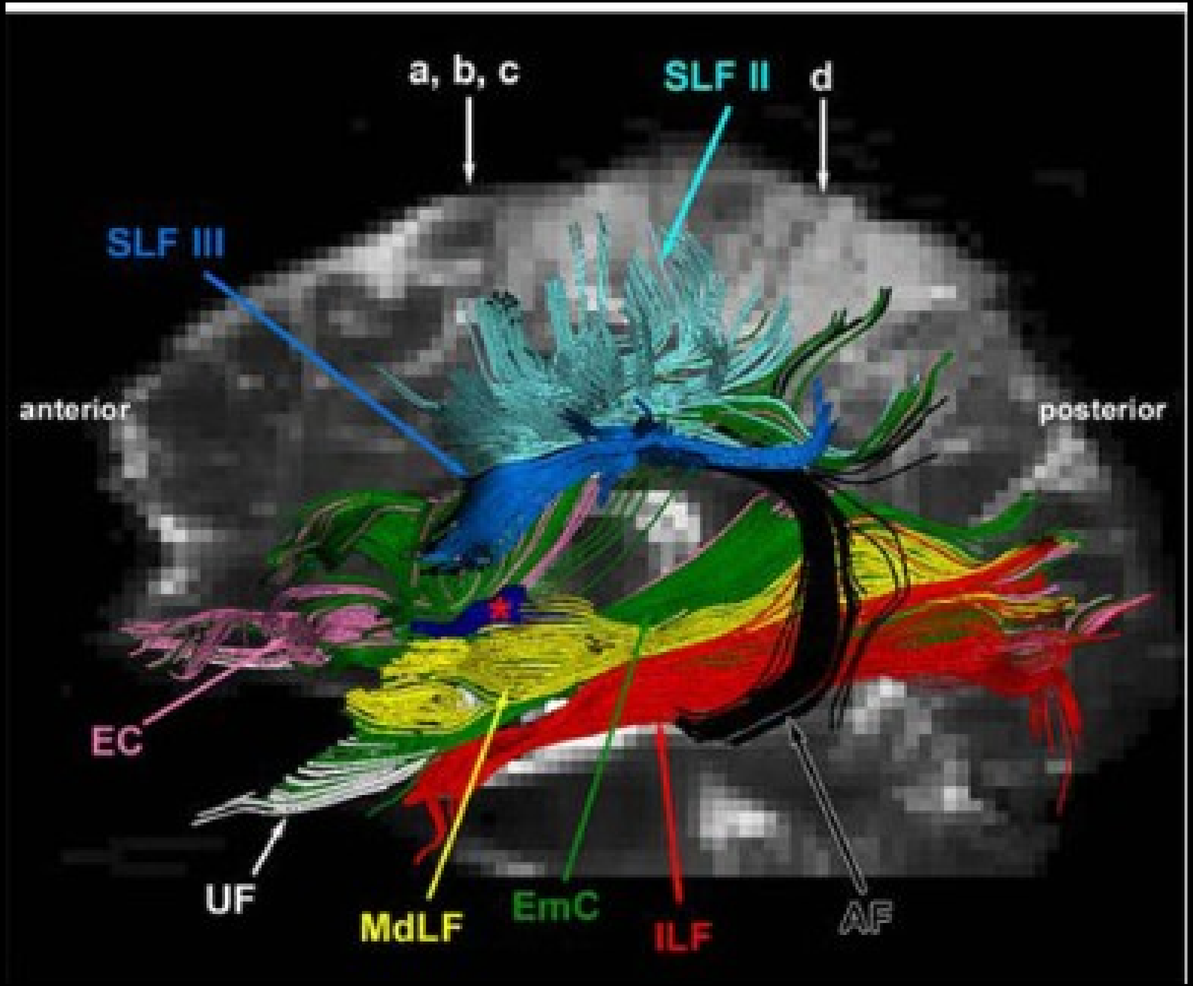
The EmC appears to have a frontal, a temporal and a parietal part (a–d).

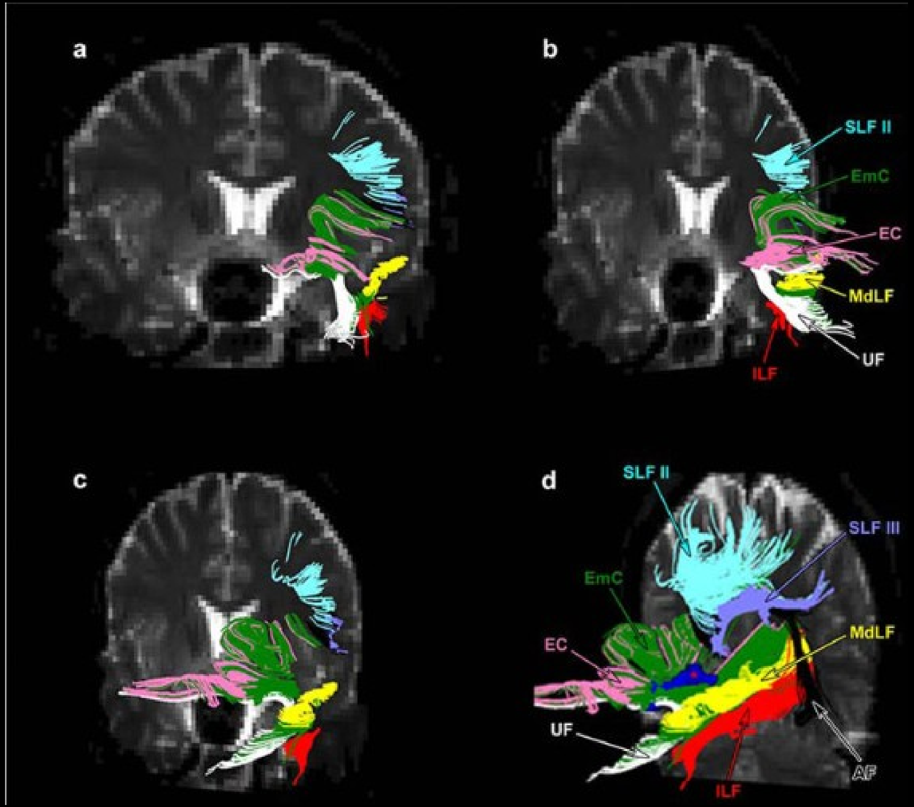
The fibers of the rostral or frontal part are shown within the cortex of the inferior frontal gyrus (F3t and FO) and the frontoorbital cortex (FOC) (b, e, f, g). The fibers of the caudal or parietal segment are shown within the inferior parietal lobule (angular gyrus, AG) (d, e). The fibers of the intermediate, lateral or temporal part are shown within the cortex of the superior temporal gyrus (T1a) (c, e, h). Abbreviations: AG angular gyrus, F3t inferior frontal gyrus, pars triangularis, FO frontal operculum, FOC frontoorbital cortex, T1a superior temporal gyrus, anterior, L left, R right



Brain Struct Funct. 2009 February ; 213(3): 343–358. doi:10.1007/s00429-008-0199-8.

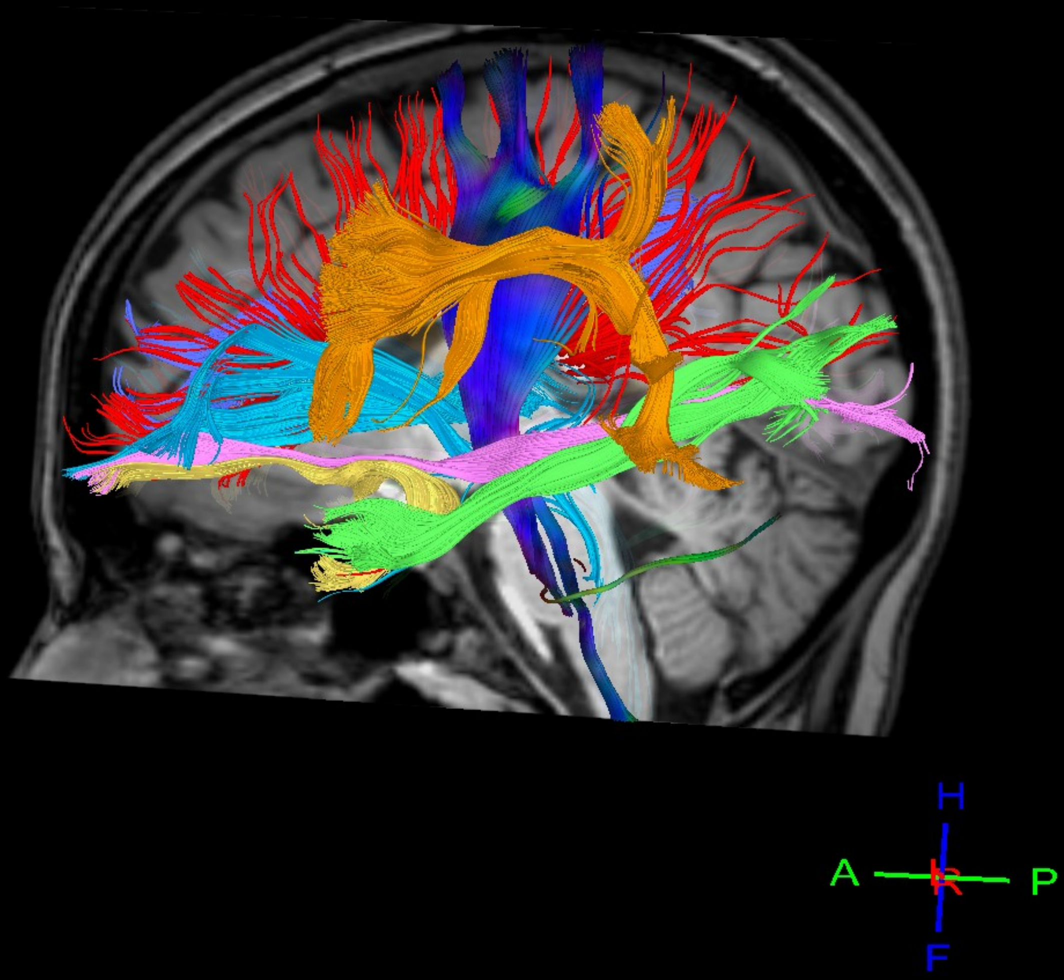
Τα δίκτυα του λόγου

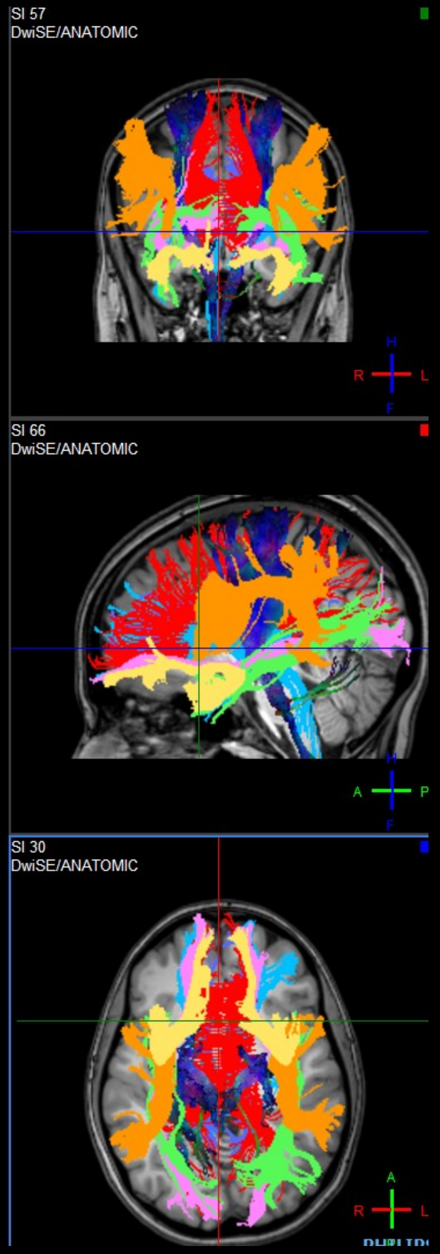




Brain Struct Funct. 2009 February ; 213(3): 343–358. doi:10.1007/s00429-008-0199-8.

Major White Matter Tracts (Lateral to Medial)



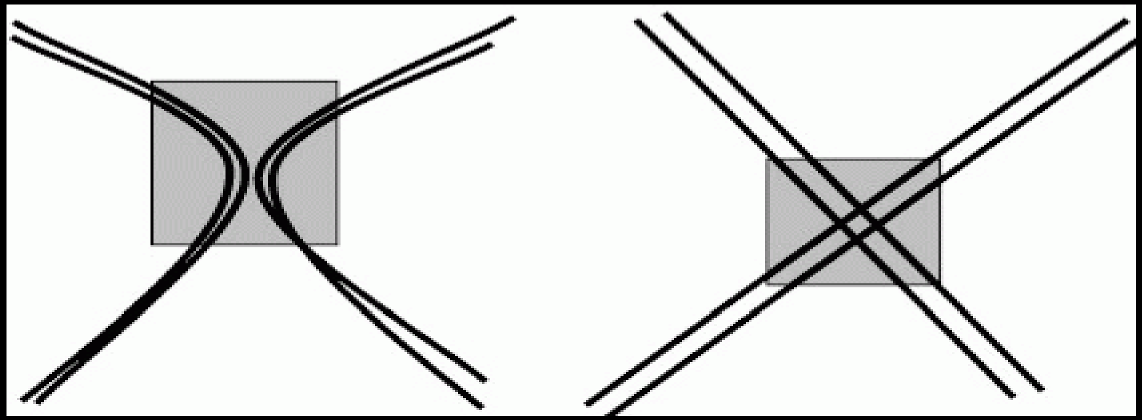


Presentation Outline

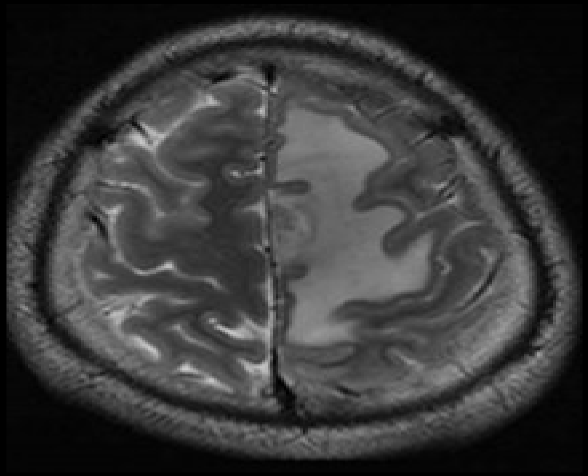
- Introduction to Diffusion Tensor Imaging and Tractography
- In Vivo White Matter Visualization Through DTI Tractography
- **Challenges / Pitfalls / Solutions**
- Presurgical MRI/DTI scanning and tractography of WM eloquent tracts

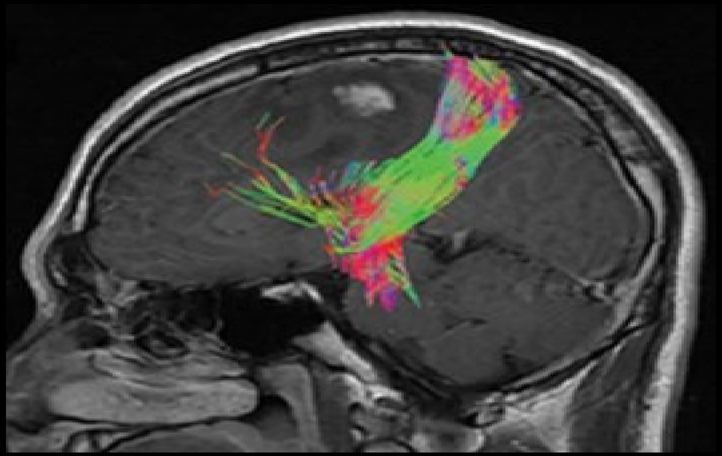
Limitations of DTI

Kissing fibers / Crossing fibers



Edema – low FA





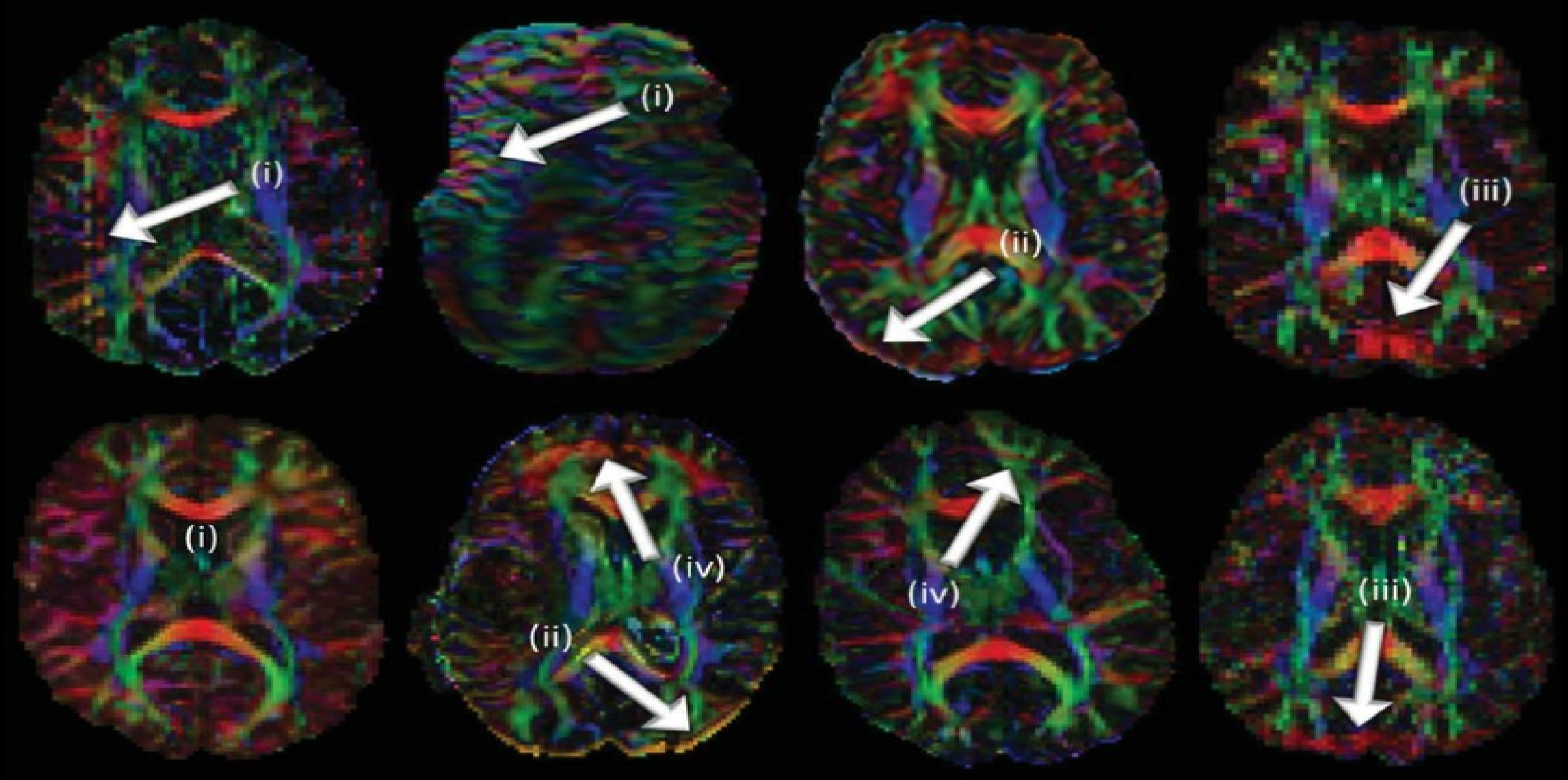
Pitfalls of DTI

Machine or patient related artifacts

Quality of data (eddy currents, motion artifacts due to patient or vibrations of hardware)

Examples of typical artifacts:

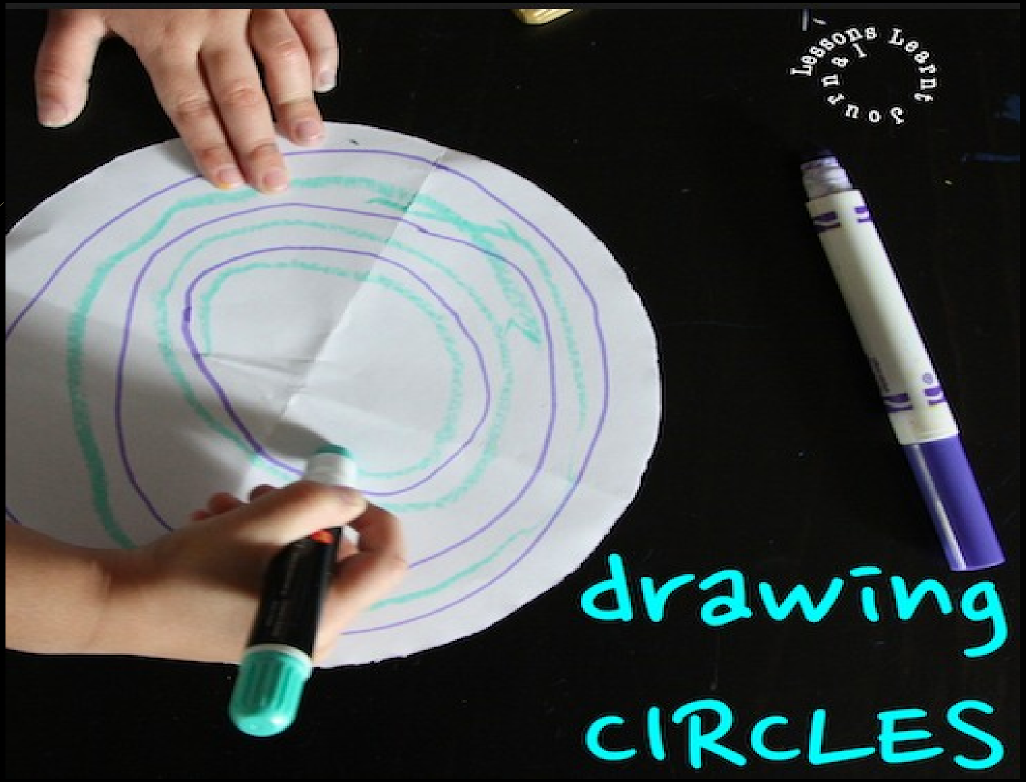
(i) signal/slice dropouts, eddy-current induced geometric distortions, (iii) systematic vibration artifacts, and (iv) ghosting (insufficient/incorrect fat suppression).

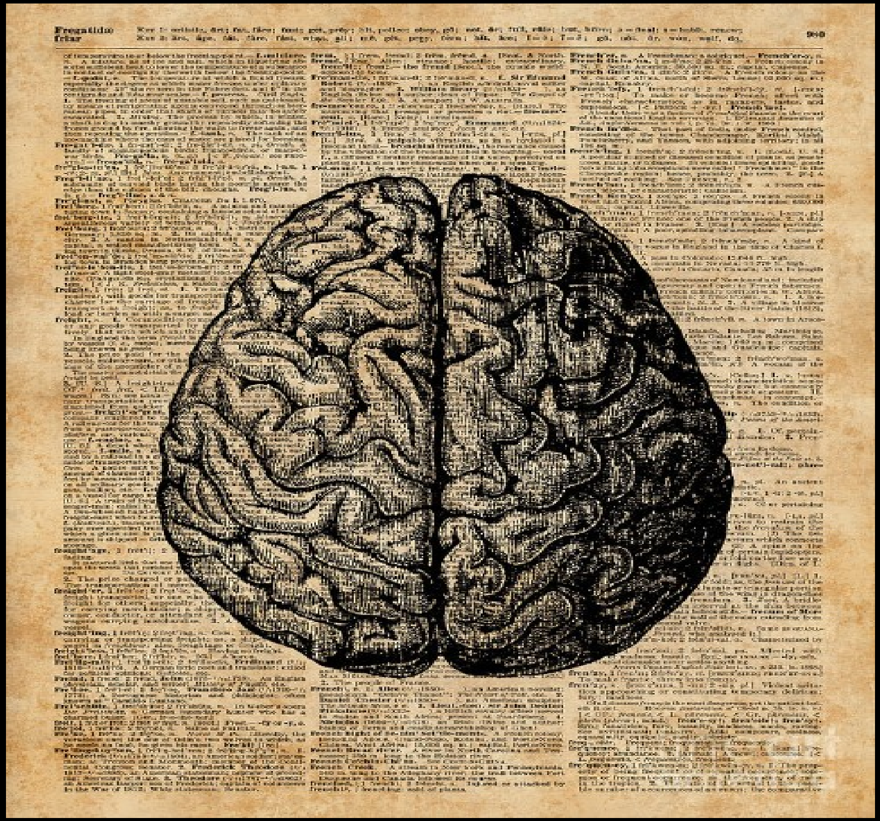


Pitfalls of DTI

User related

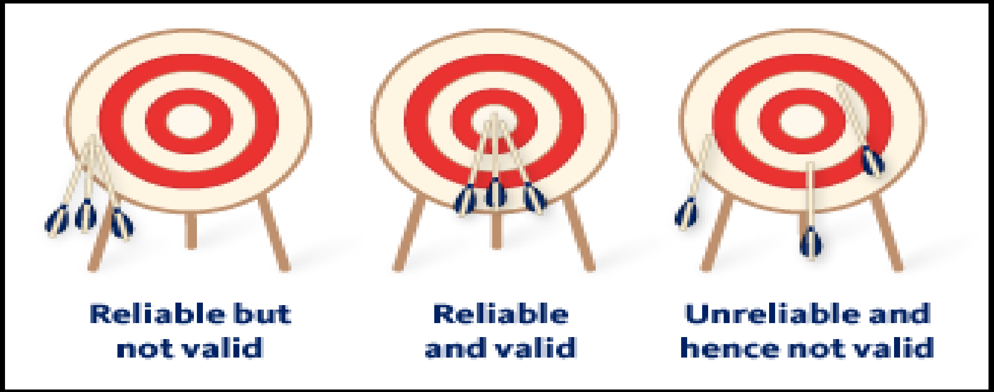
Design of ROI / knowledge of the anatomy





How to solve partially the limitation of DTI ?

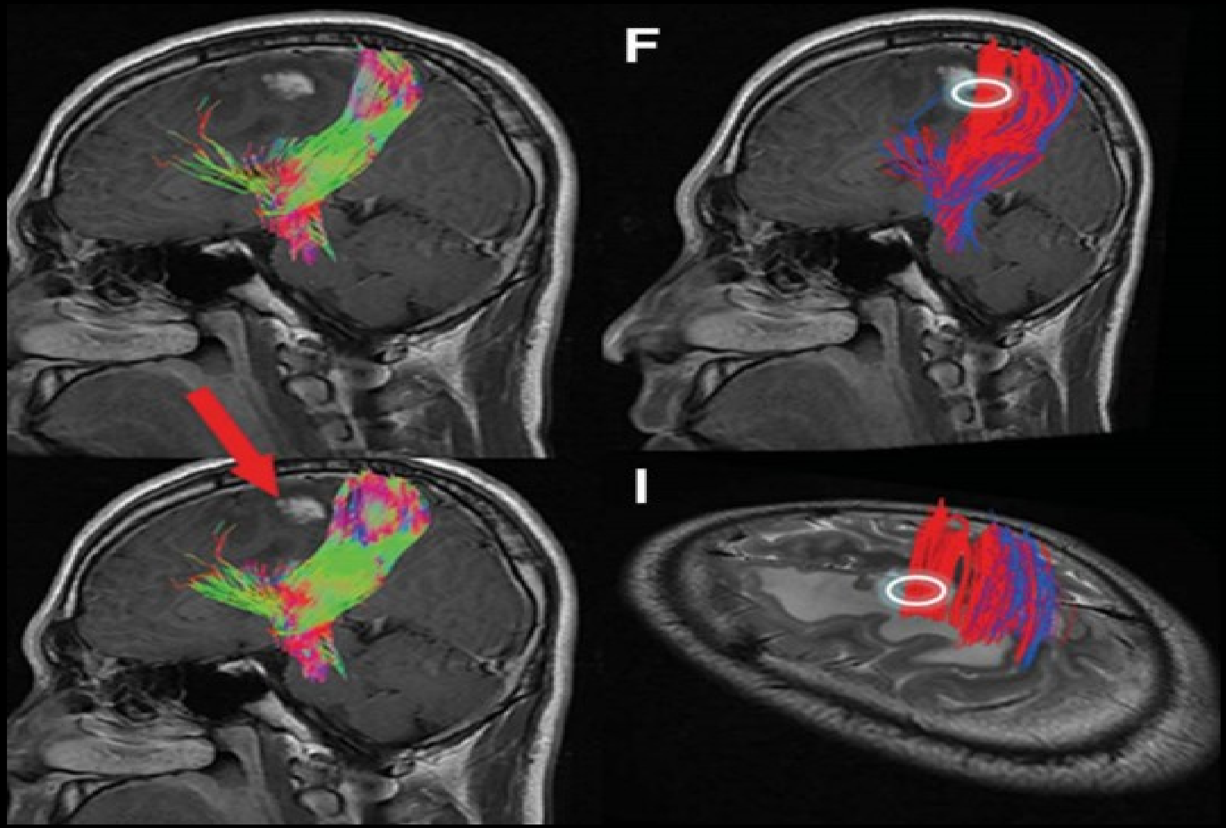
Concerning the machine and user related false positive/negative results



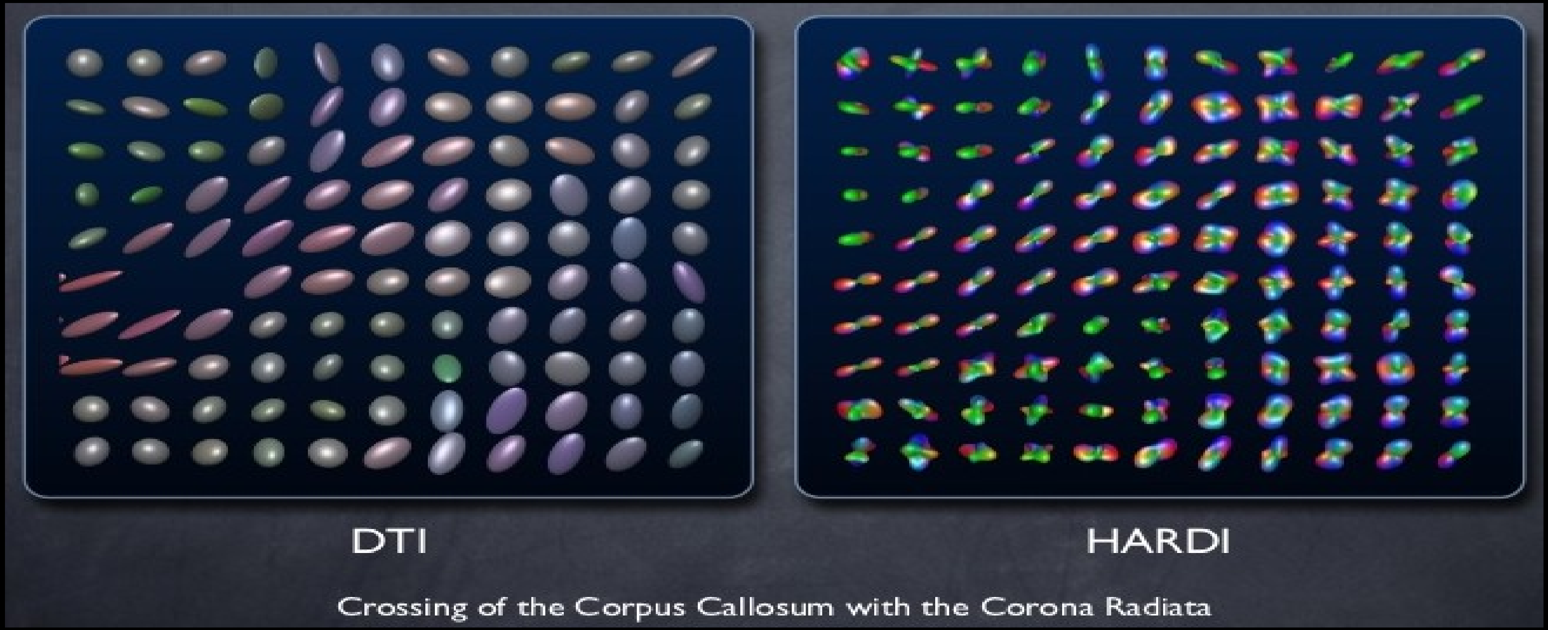
How to solve partially the limitation of DTI ?

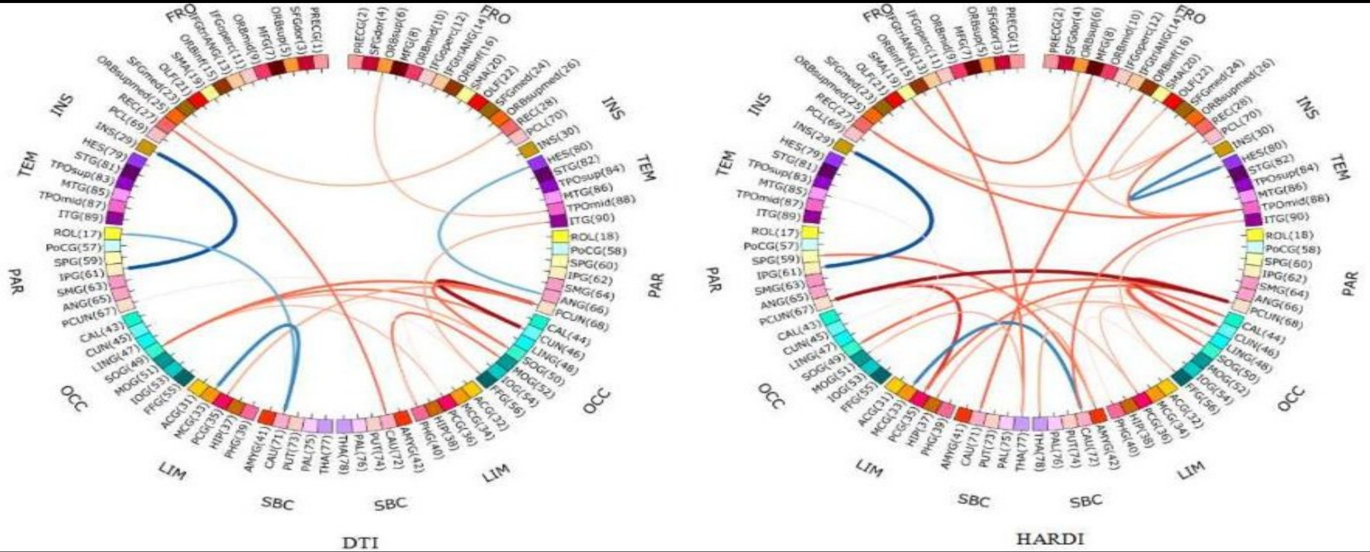
Concerning the complex fibers' anatomy

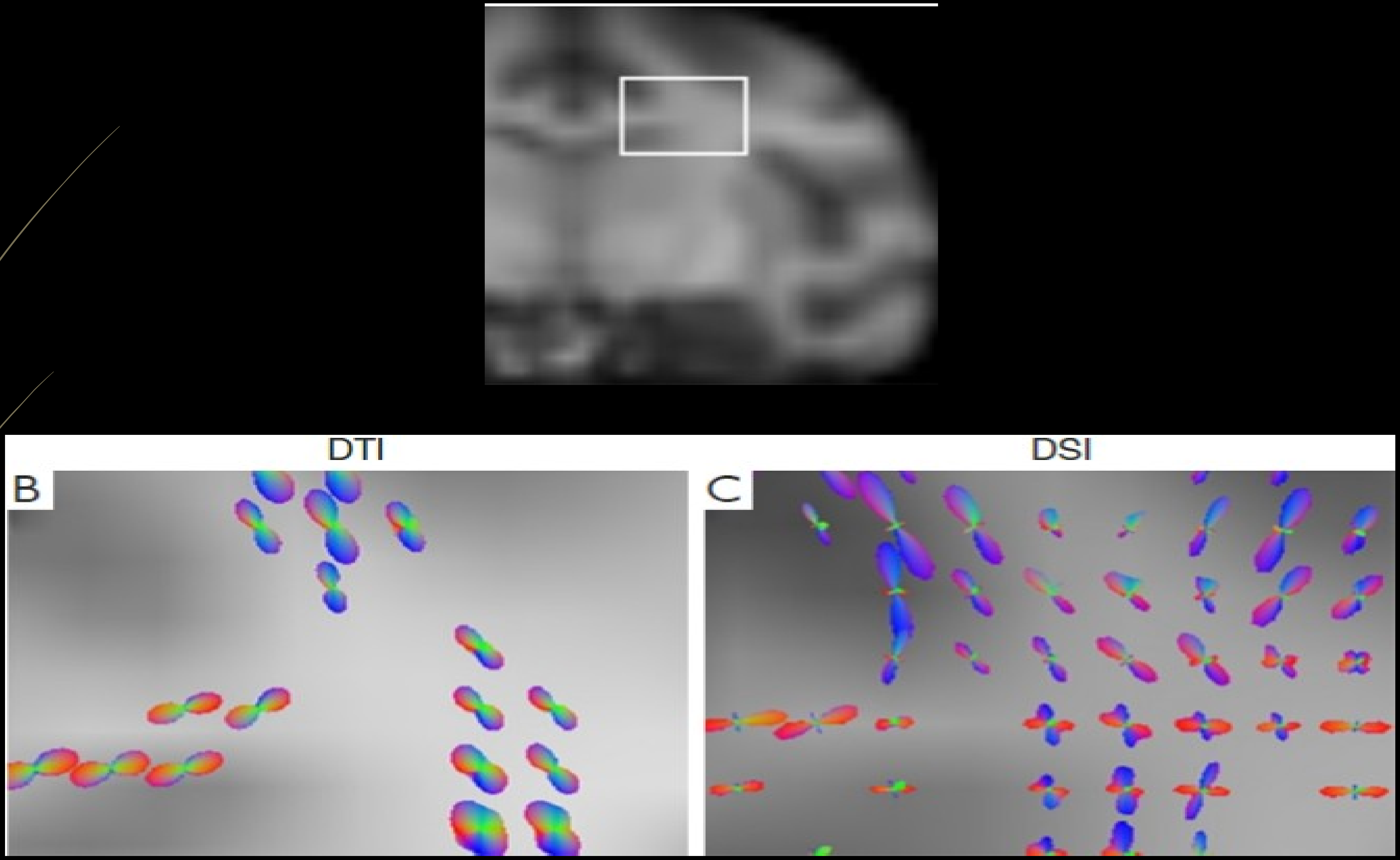
- High order deterministic algorithms
- Probabilistic tractography
- HARDI – DSI – q-Ball

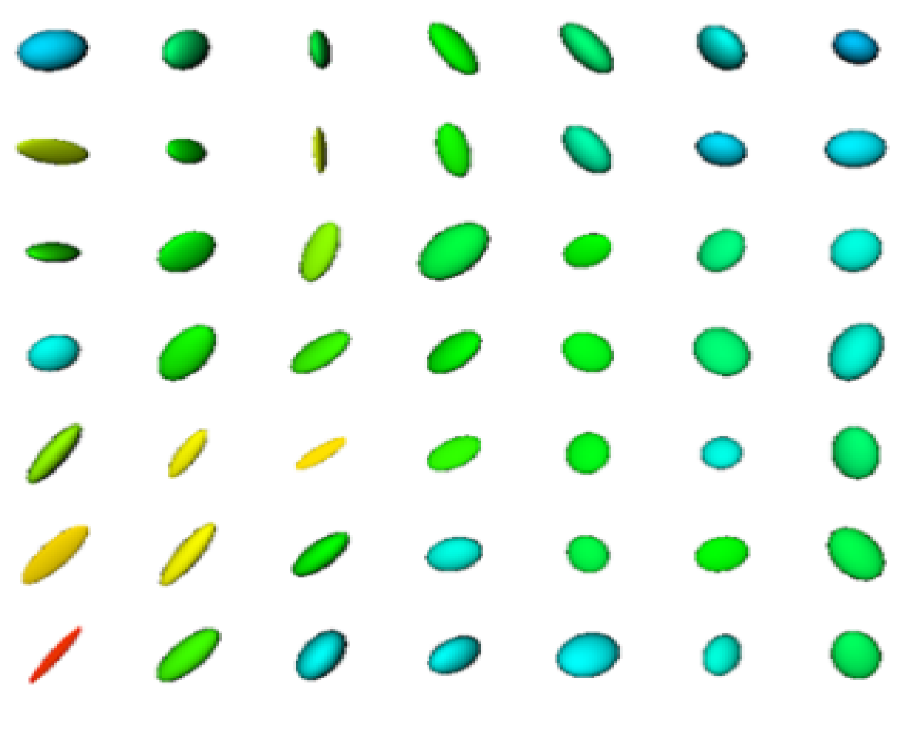


Generalized Q-sampling imaging
in edema

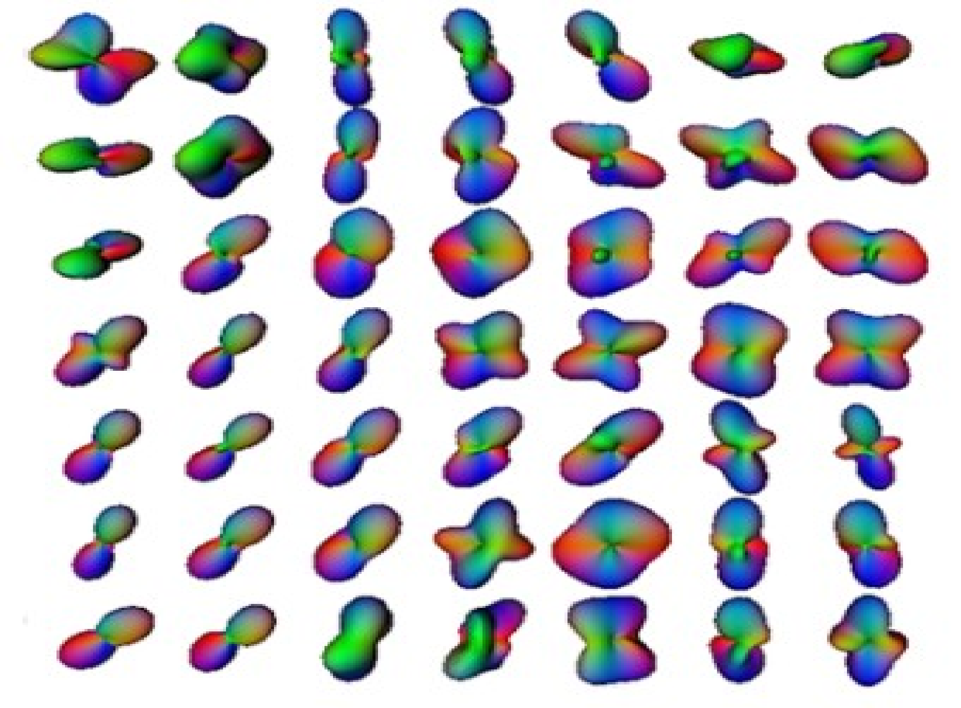

DTI
HARDI
Crossing of the Corpus Callosum with the Corona Radiata


FRO
INS
TEM
PAR
OCC
LIM
SBC
DTI
HARDI

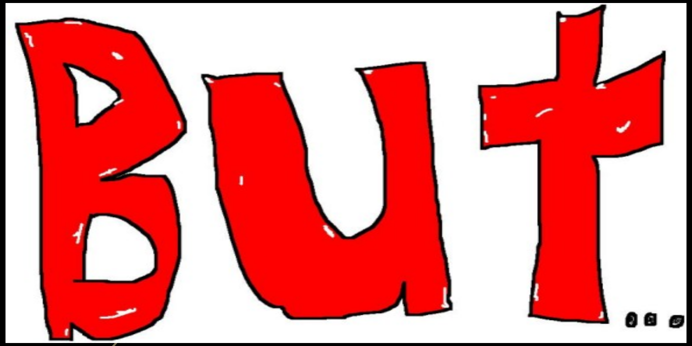

DTI
DSI
B
C



DTI



QBall



HARDI requires >90 Gradient Direction

DSI requires >90 Gradient Direction and multiple b values

Q-Ball requires >90 Gradient Direction and high b values

All of the above are time consuming

↓

Possibility of subject motion

Only

Presentation Outline

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- Challenges / Pitfalls / Solutions
- **Presurgical MRI/DTI scanning and tractography of WM eloquent tracts**

Altered states of WM resulting from cerebral neoplasms

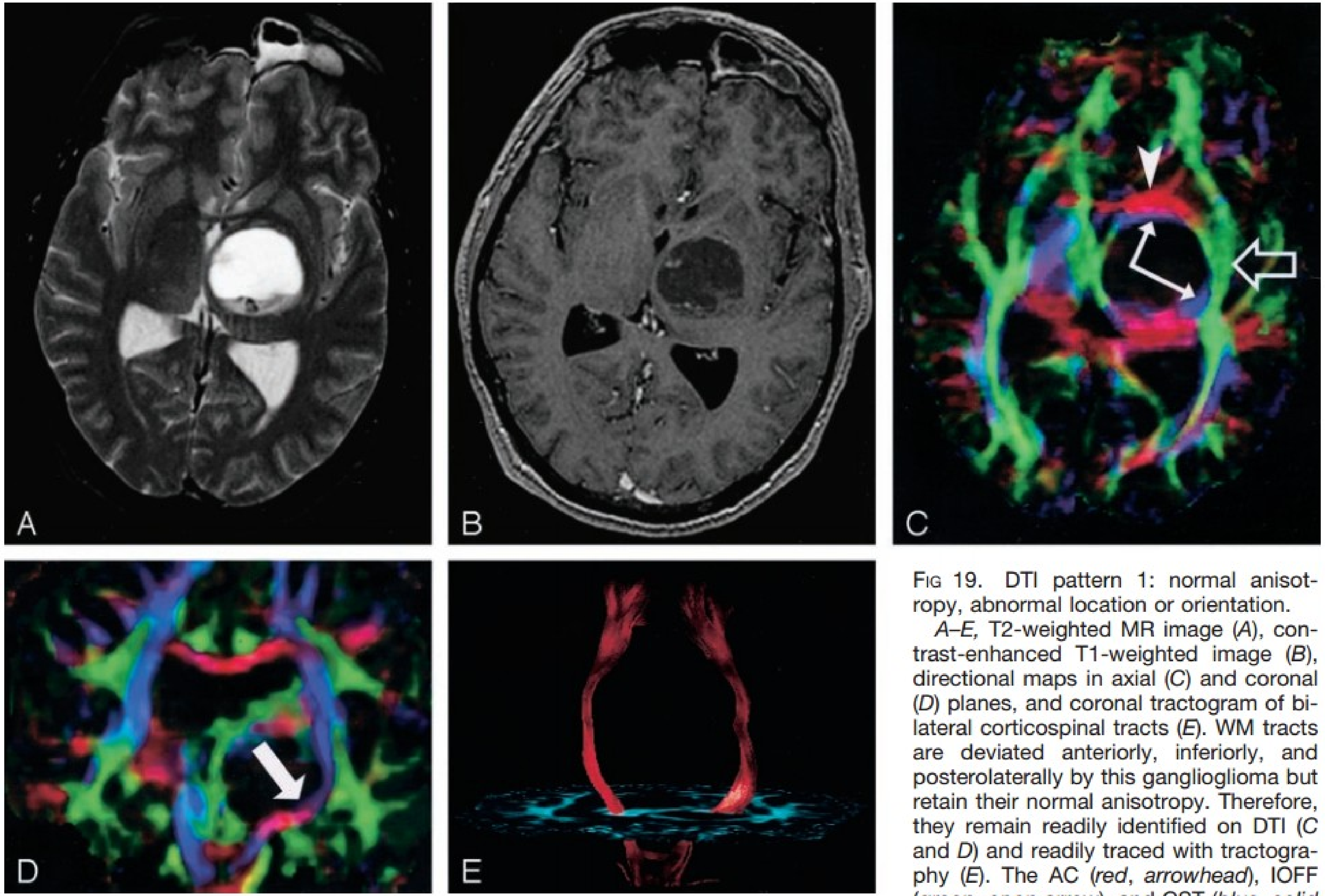


FIG 19. DTI pattern 1: normal anisotropy, abnormal location or orientation.
A–E, T2-weighted MR image (*A*), contrast-enhanced T1-weighted image (*B*), directional maps in axial (*C*) and coronal (*D*) planes, and coronal tractogram of bilateral corticospinal tracts (*E*). WM tracts are deviated anteriorly, inferiorly, and posterolaterally by this ganglioglioma but retain their normal anisotropy. Therefore, they remain readily identified on DTI (*C* and *D*) and readily traced with tractography (*E*). The AC (*red*, *arrowhead*), IOFF (*green*, *open arrow*), and CST (*blue*, *solid arrows*) are deviated. Note the blue hue of the CST change to red as it deviates toward the axial plane by the tumor (*arrow* on coronal view [*D*]).

Jellison et al., AJNR Am H Neuroradiol 2004; 25: 356-369

Altered states of WM resulting from cerebral neoplasms

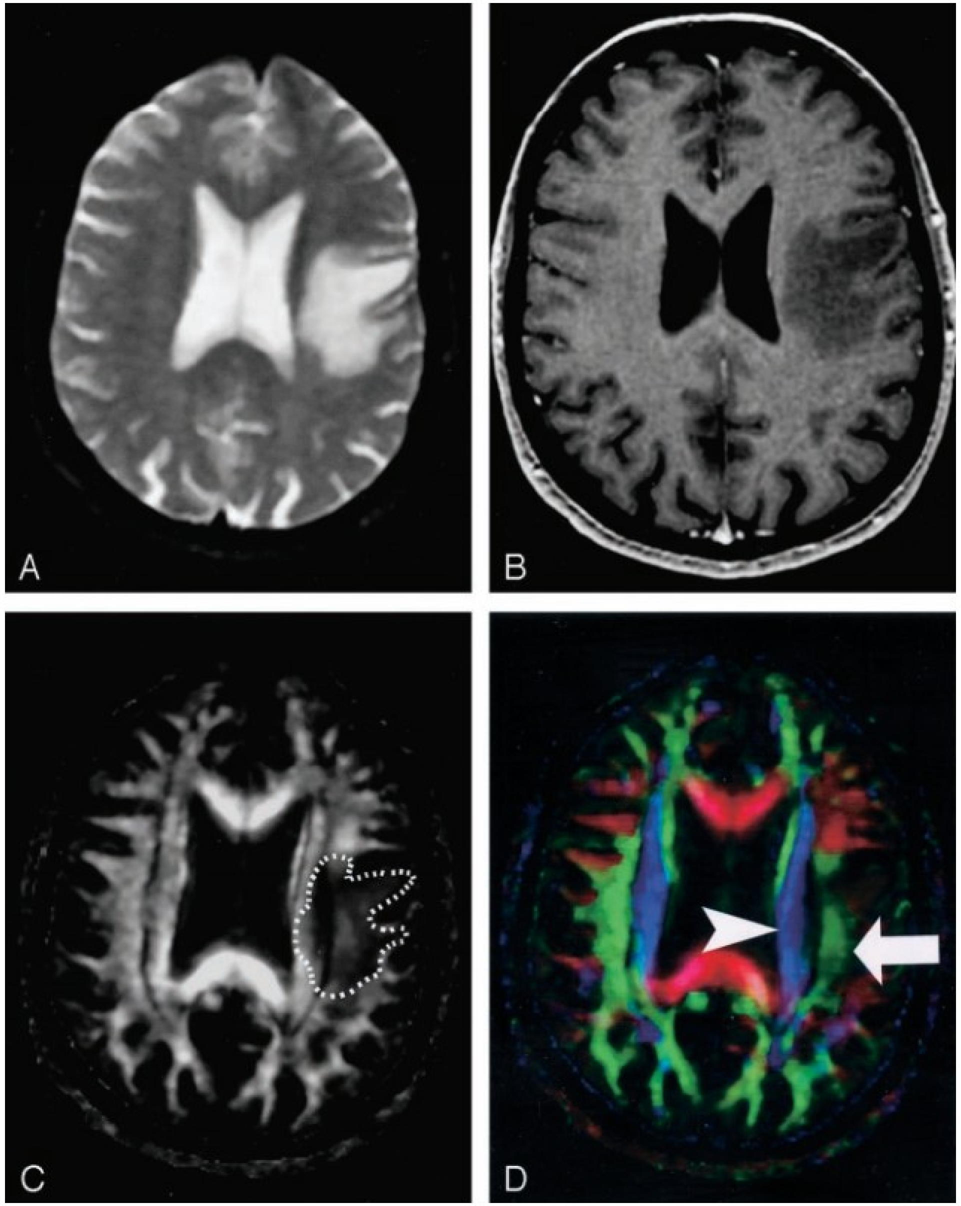


FIG 20. DTI pattern 2: abnormal (low) anisotropy, normal location and orientation. *A–D*, T2-weighted MR image (*A*), contrast-enhanced T1-weighted MR image (*B*), FA map (*C*), and directional map (*D*). The homogeneous region of hyperintensity on the T2-weighted image represents vasogenic edema surrounding a small metastasis (on another section, not shown). Despite diminished anisotropy in this region (darker region outlined on FA map) and diminished color brightness on directional map, the involved fiber tracts retain their normal color hues on the directional map (superior longitudinal fasciculus, green, arrow; corona radiata, blue, arrowhead). This preservation of normal color hues despite a substantial decrease in anisotropy is consistent with the abnormality of vasogenic edema, which enlarges the extracellular space (allowing less restricted diffusion perpendicular to axonal fibers, thus reducing the anisotropy) without disrupting cellular membranes, leaving their directional organization intact. It is not yet known to what extent this pattern is specific for edema, however.

Jellison et al., AJNR Am H Neuroradiol 2004; 25: 356-369

Altered states of WM resulting from cerebral neoplasms

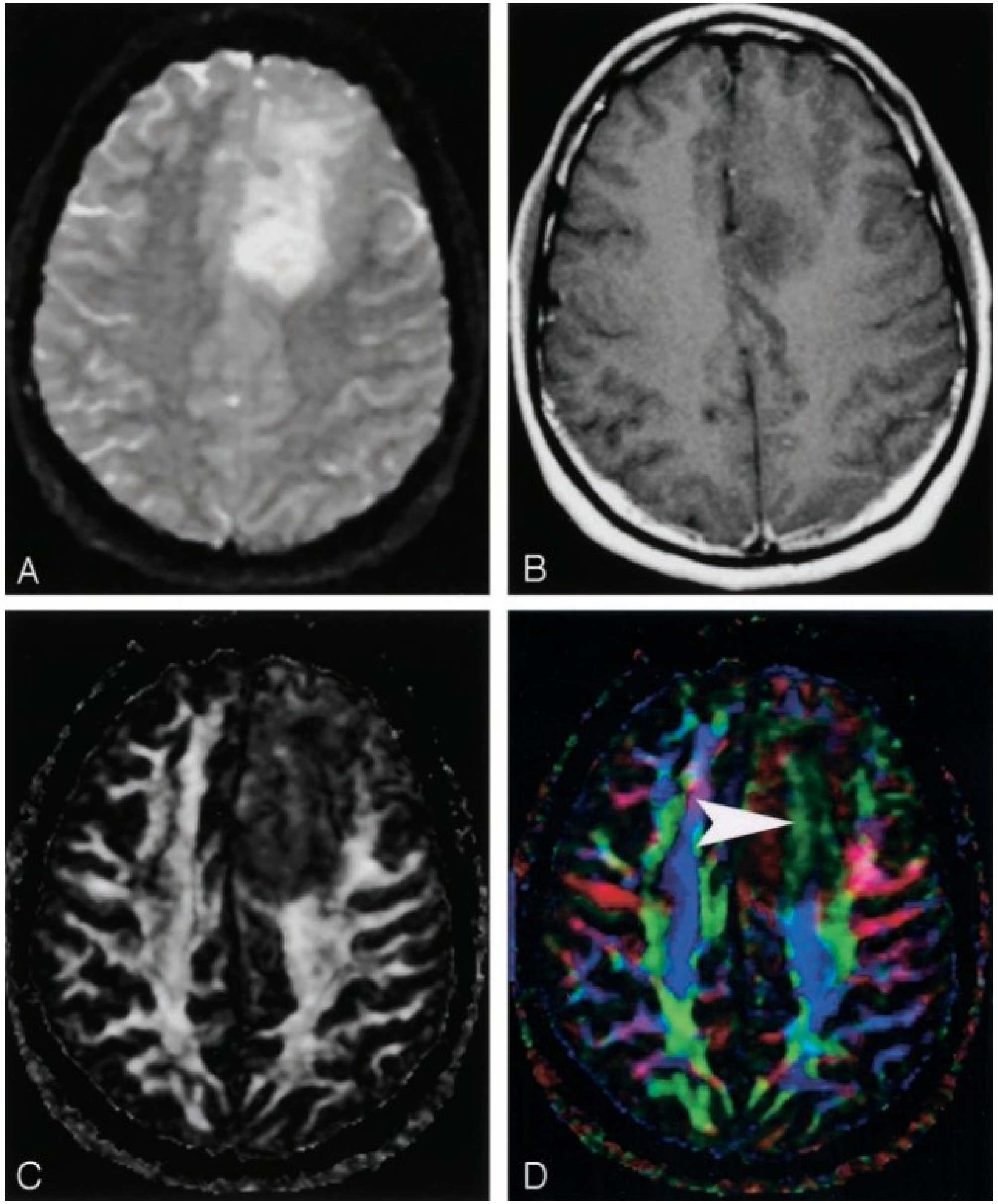


FIG 21. DTI pattern 3: abnormal (low) anisotropy, abnormal orientation.

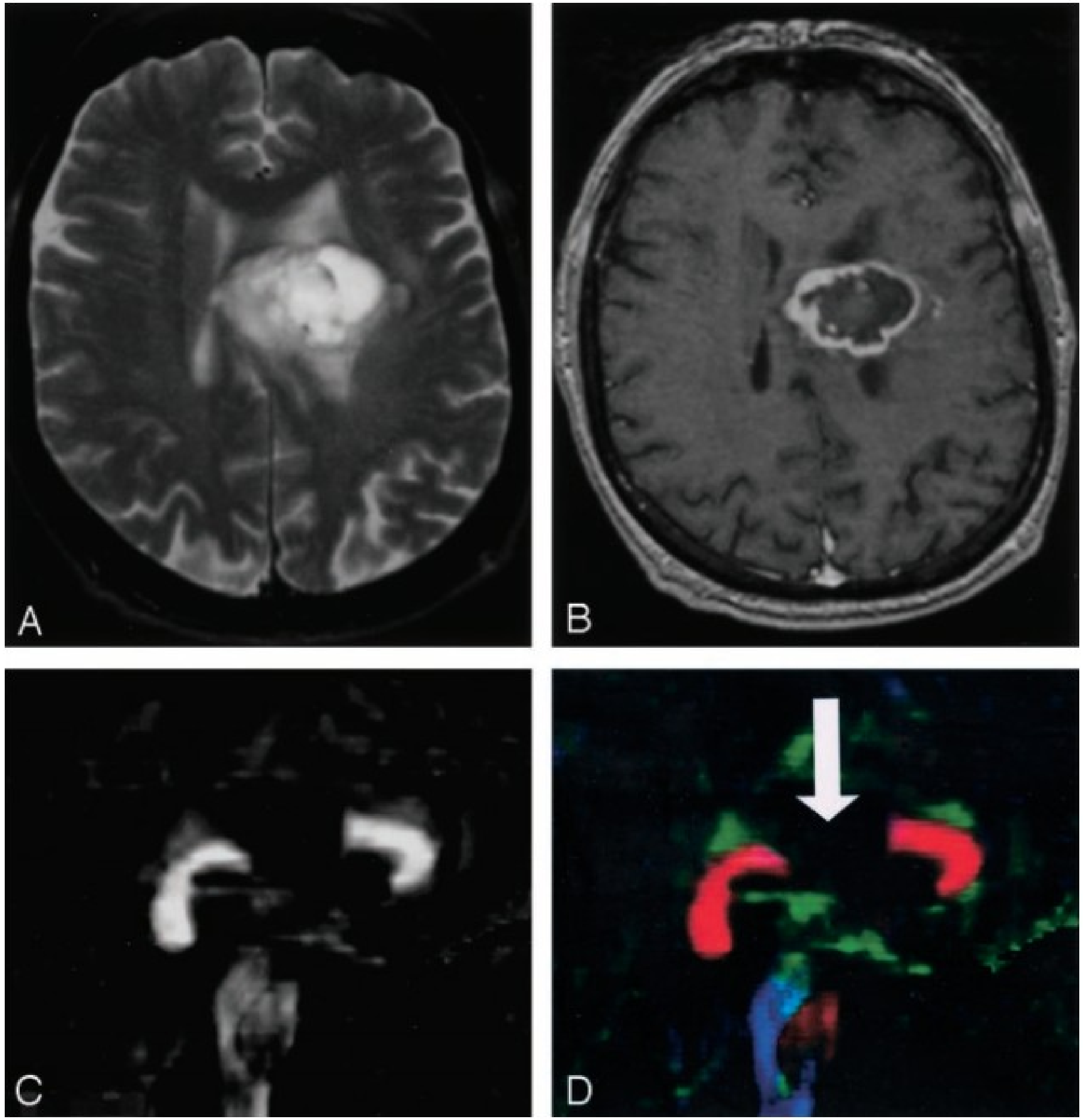
A–D, T2-weighted MR image (*A*), contrast-enhanced T1-weighted image (*B*), FA map (*C*), and directional map (*D*). This infiltrating astrocytoma is characterized by both diminished anisotropy and abnormal color (arrowhead) on the directional map, suggesting disruption of WM fiber tract organization more severe and complex than that seen with pattern 2 (compare Fig 20). Note that the color change cannot easily be attributed to bulk mass effect as in purely deviated tracts.

Jellison et al., AJNR Am H Neuroradiol 2004; 25: 356-369

Altered states of WM resulting from cerebral neoplasms

Fig 22. DTI pattern 4: near-zero anisotropy, tract unidentifiable.

A–D, T2-weighted MR image (*A*), contrast-enhanced T1-weighted image (*B*), FA map (*C*), and directional map (*D*). This high-grade astrocytoma has destroyed the body of the corpus callosum, rendering the diffusion essentially isotropic and precluding identification on the directional map (arrow).



Jellison et al., AJNR Am H Neuroradiol 2004; 25: 356-369

Thank you for attention

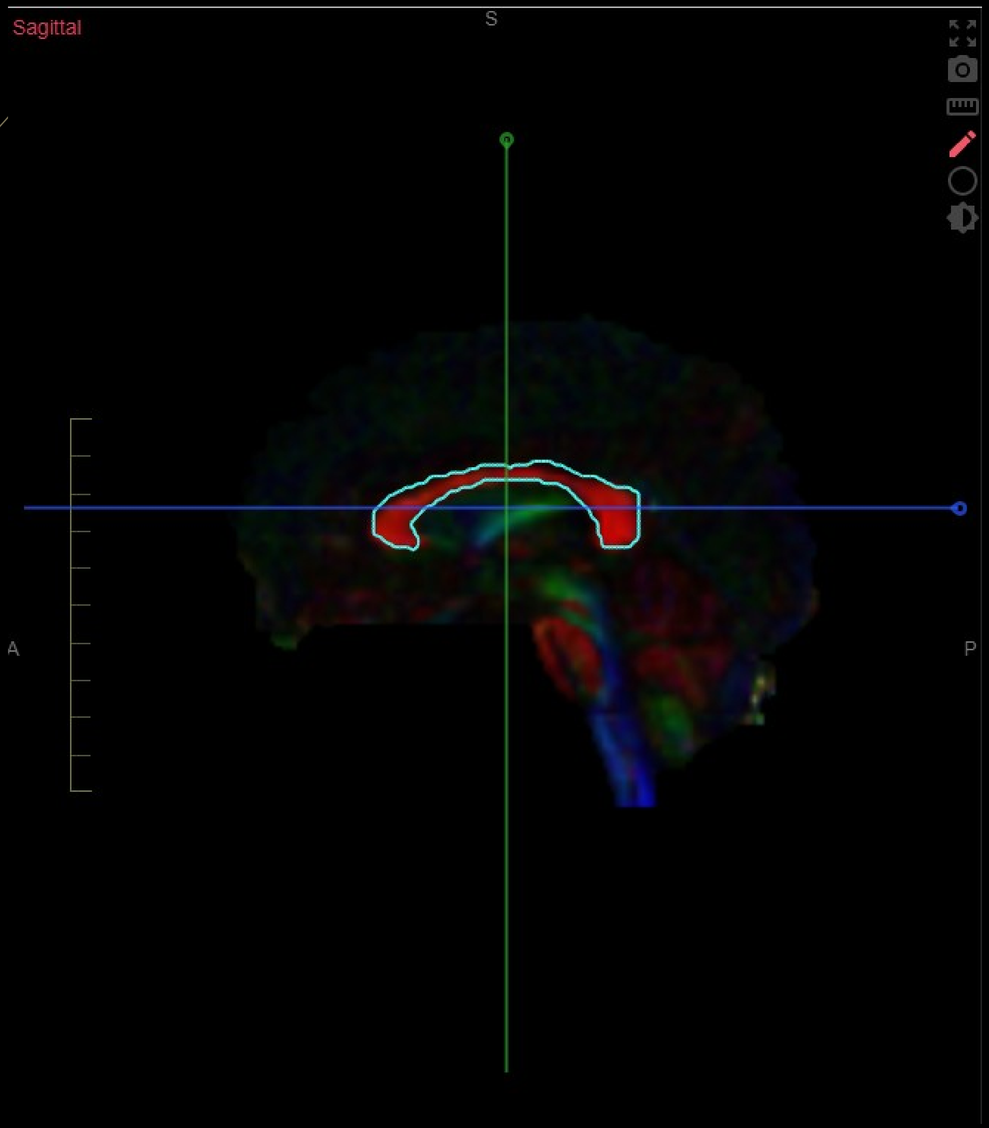
DTI Tractography

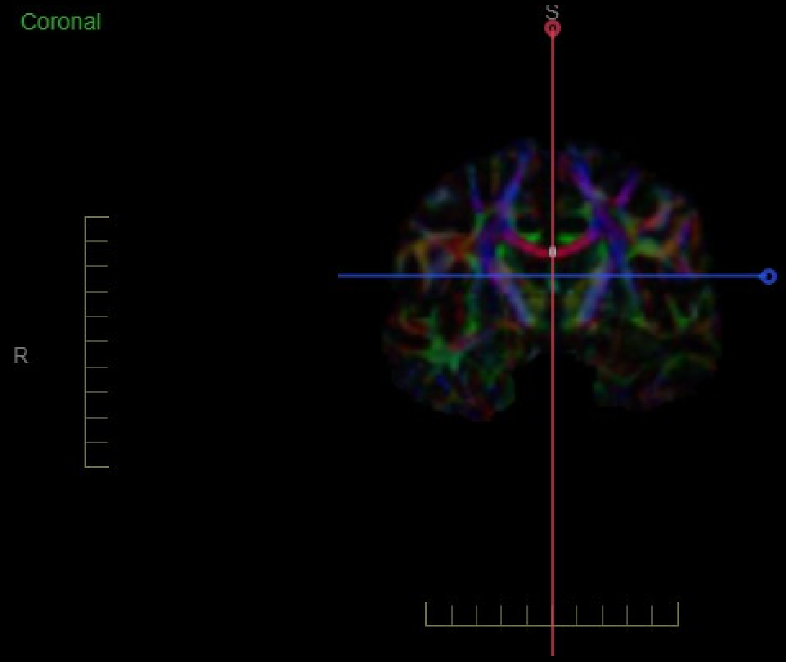
Neuroimage. 2007 July 1; 36(3): 630–644.

Reproducibility of Quantitative Tractography Methods Applied to Cerebral White Matter

Setsu Wakana[1,2], Arvind Caprihan[3], Martina M. Panzenboeck[4], James H. Fallon[4], Michele Perry[5], Randy L. Gollub[6], Kegang Hua[1], Jiangyang Zhang[1], Hangyi Jiang[1,2], Prachi Dubey[1], Ari Blitz[2], Peter van Zijl[1,2], and Susumu Mori[1,2]

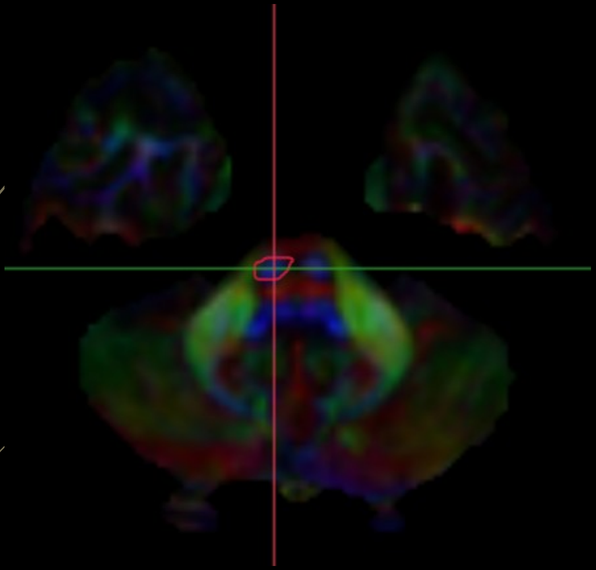
DTI Tractography: Corpus Callosum



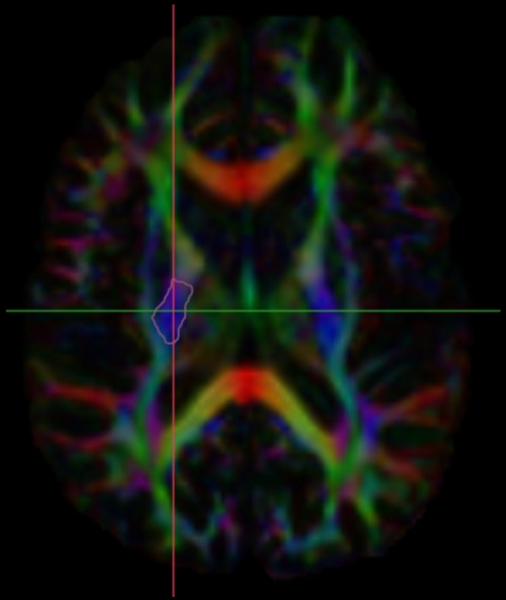


Single ROI

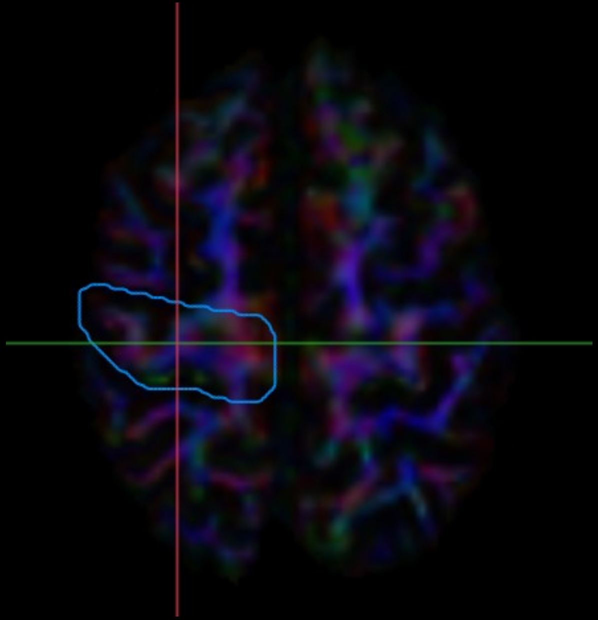
DTI Tractography: Corticospinal Tract



ROI 1



ROI 2



ROI 3

DTI Tractography: Uncinate Fasciculus

Tract #9: Uncinate fasciculus (UNC) (Fig.9)—The most posterior coronal slice in which the temporal lobe is separated from the frontal lobe is selected (Figs. 9a and 9c). The first ROI includes the entire temporal lobe and the second ROI includes the entire projections toward the frontal lobe.

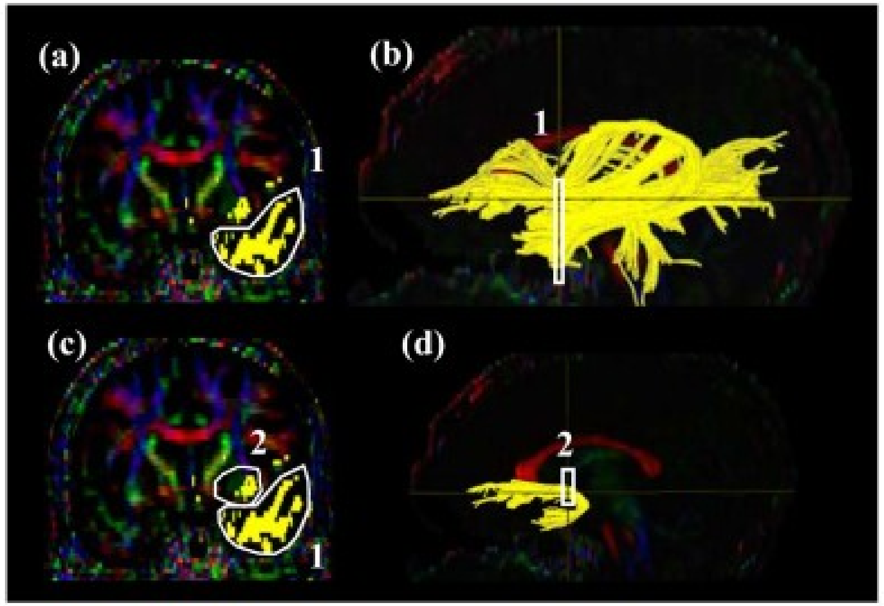


Figure 9.
Locations of the ROIs for the uncinate fasciculus (UNC) on a coronal slice (a and c) and their locations in the mid-sagittal slice (b and d). The coronal slice (a and c) is the most posterior slice where the frontal and temporal lobe is separated. The least-diffusion-weighted image could be used for better anatomical guidance.

DTI Tractography: SLF & AF