



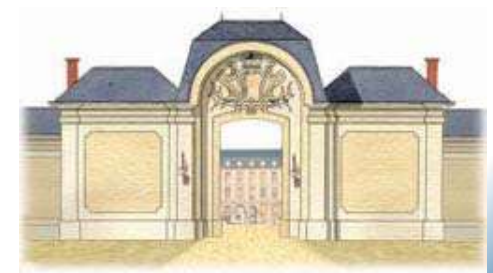
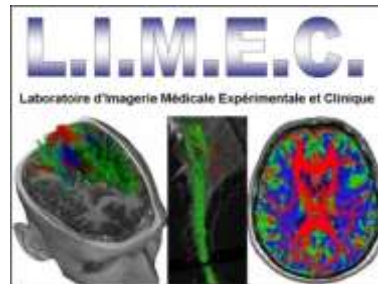
UNIVERSITÉ
PARIS-SUD 11

IRM Fonctionnelle

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1. Rappels Techniques

2. IRM de Diffusion

2.1 Principes

2.2 Applications Cliniques Cérébrales

2.3 IRM de Tenseur de Diffusion

2.3.1 Principes

2.3.2 Anatomie Cérébrale Normale

2.3.3 Applications Cliniques Cérébrales

2.3.4 Anatomie Médullaire Normale

2.3.5 Applications Cliniques Médullaires

3. IRM de Perfusion

3.1 Rappels Physiologiques

3.2 Rappels Méthodologiques - Perfusion en Bolus

3.3 Rappels Méthodologiques - Perfusion ASL

3.4 Applications Cliniques

4. IRM de Perméabilité

4.1 Principes

4.2 Enjeux

5. Spectro IRM

6. IRM d'Activation

6.1 Rappels Physiologiques

6.2 Rappels Méthodologiques

6.3 Applications Cliniques

7. Bilan Fonctionnel

7.1 Status Epilepticus

7.2 Syncinésies du Kallmann de Morsier

7.3 Syringomyélie

7.4 Régénération axonale et Greffe de Moelle

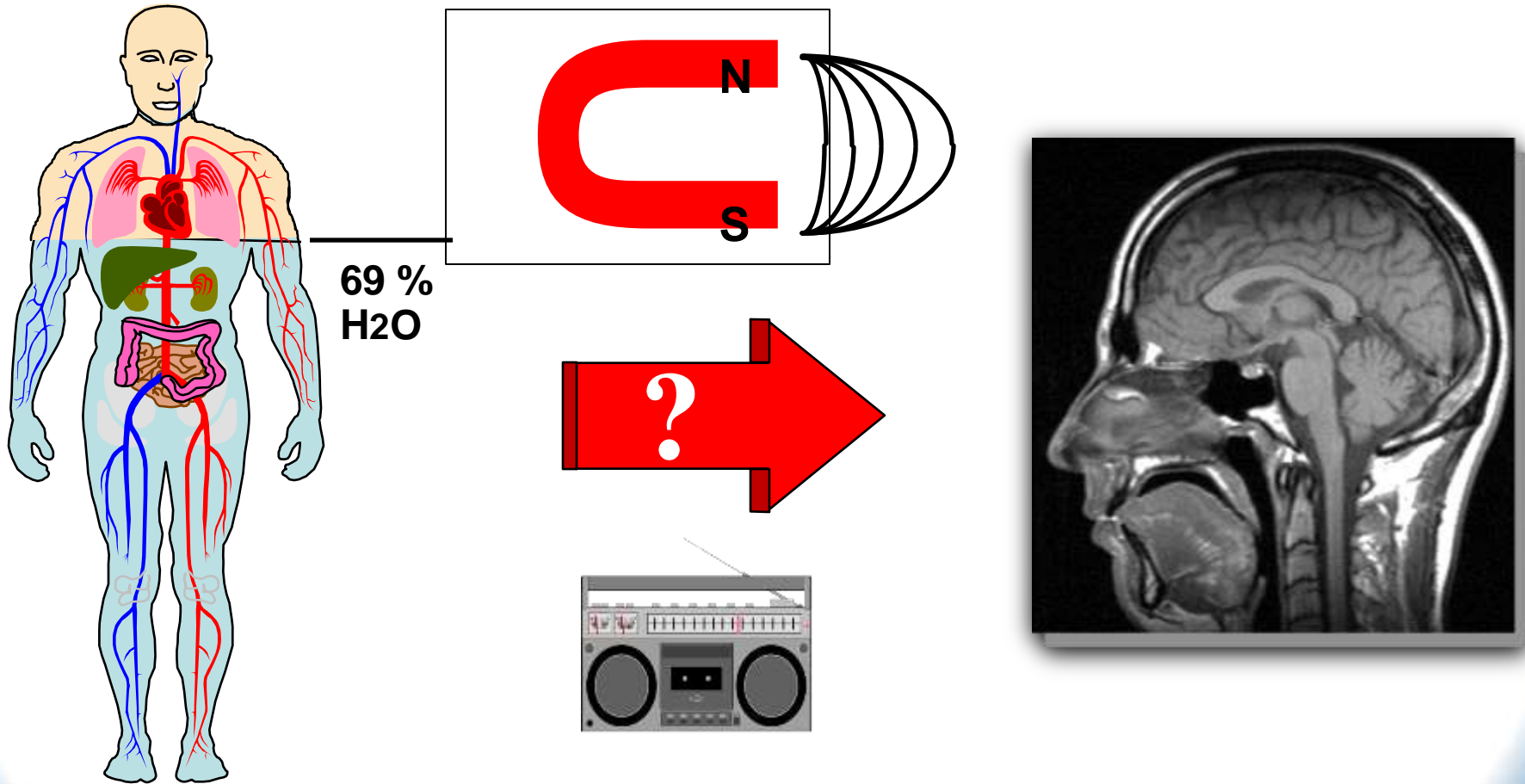
7.5 Bilan Pré-Radiothérapie

7.6 IRM Fonctionnelle Olfactive

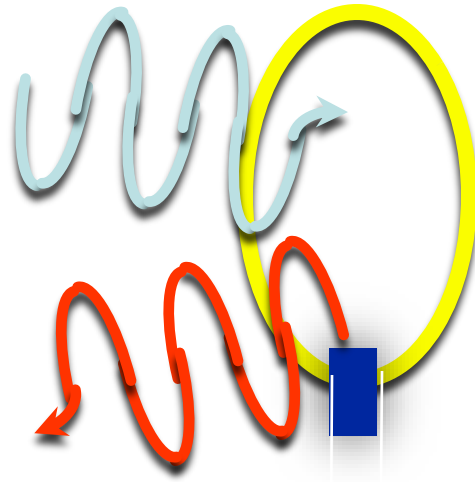
8. Conclusions

1. Rappels Techniques

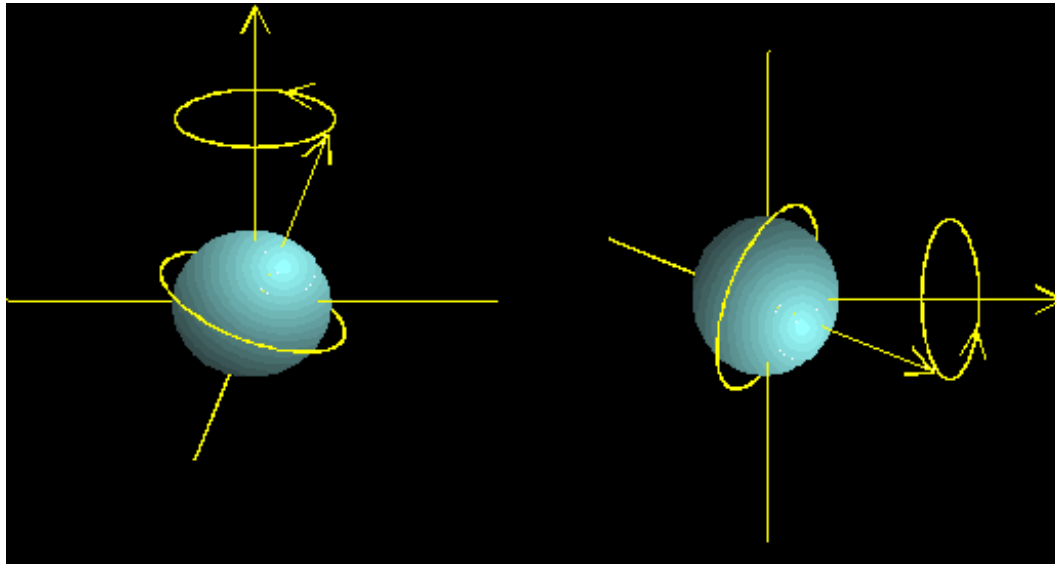
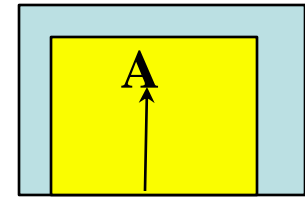
I.R.M.



D'après JM Franconi et F Giboreau. « Bases physiques de l'IRM »



Résonance



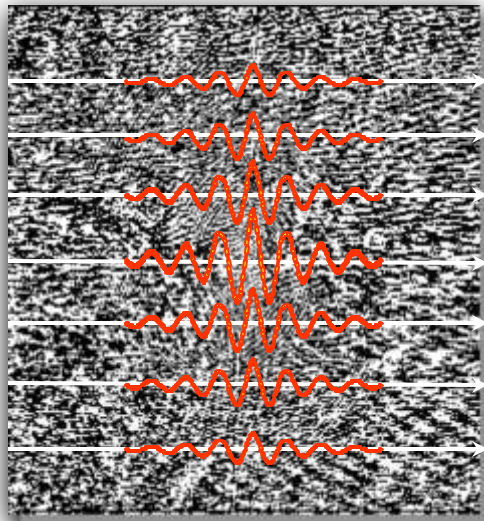
Précession

Forcée

Transformée de Fourier

Phase

Y



?

TF



Temps

X

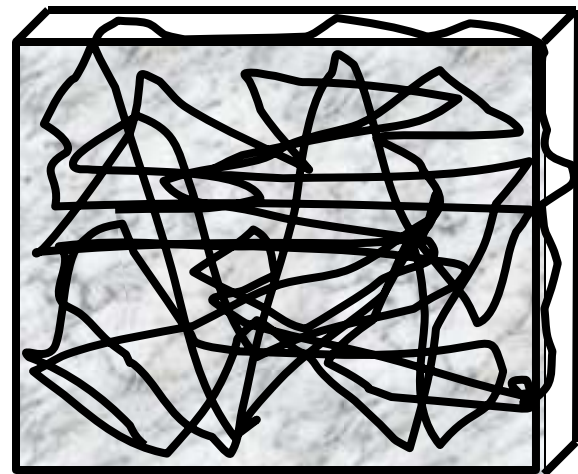
2. IRM de Diffusion

2.1 Principles

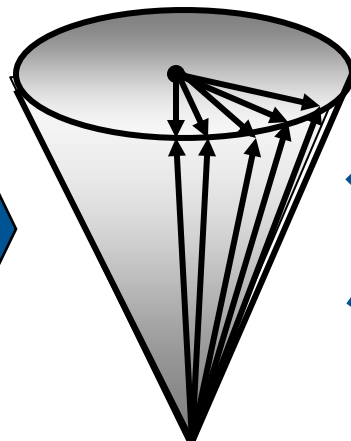
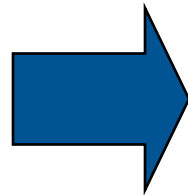
IRM de DIFFUSION

Mesure de la Diffusion en IRM

Marquage spatial des spins tel que tout mouvement d'eau pendant temps $t \Rightarrow$ perte de signal



Mouvements aléatoires



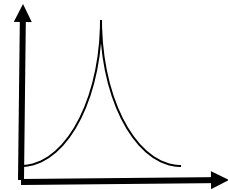
Déphasage

Spins Immobiliers :

Déphasage

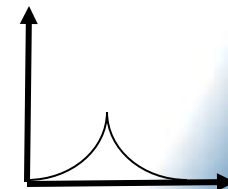


Rephasage



Spins Mobiles :

Atténuation du signal (SA)



$$SA = e^{-b \cdot ADC} = e^{-\gamma^2 G^2 \delta^2 (\Delta - \delta/3) \cdot ADC}$$

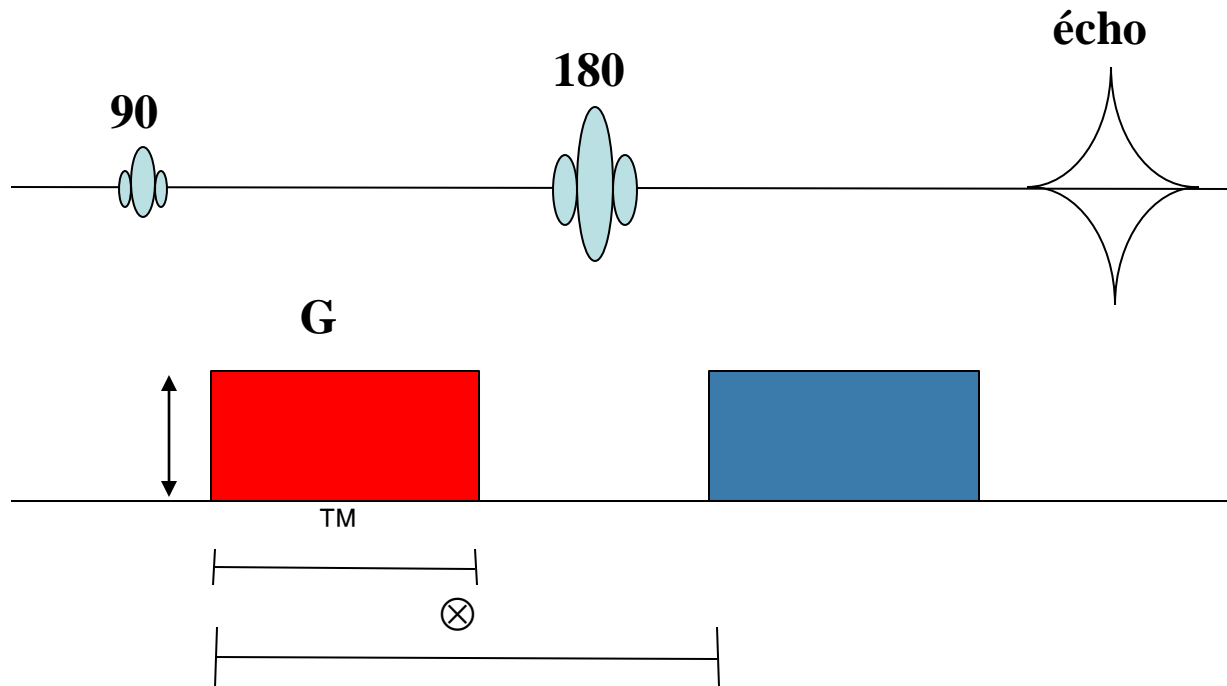
IRM de DIFFUSION

Séquence de Diffusion

- Séquence de diffusion (SE) décrites en 1986 [1] :
(durée H 20') avec mouvements macroscopiques >> microscopiques
- *Echo-planar* (1 image < 100 ms) gèle les mouvements macroscopiques
- Gradients : H 20 mT/m, vitesse de commutation rapide
- Correction des gradients de Foucault
- Artefacts de susceptibilité magnétique
- Distorsion
- Résolution spatiale limitée (128x128)

IRM de DIFFUSION

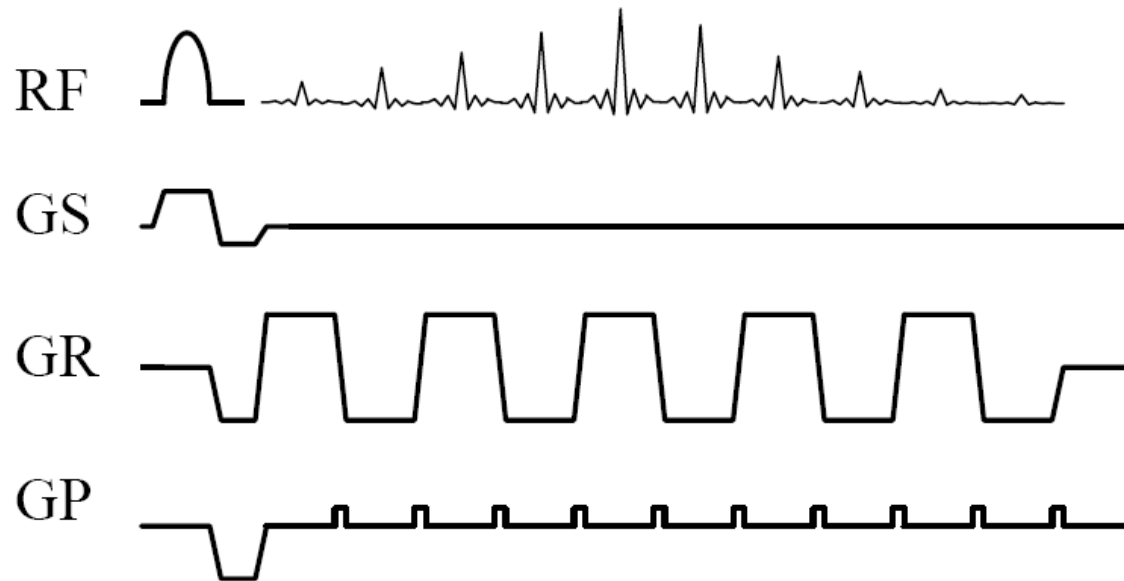
Bases Physiques



$$b = \gamma^2 \delta^2 G^2 (\Delta - \delta/3)$$



IRM de DIFFUSION

Imagerie Echo Planar



IRM de DIFFUSION

Séquence de Diffusion

- Chute du signal est directement liée au mouvement des molécules d'eau.
- Région à diffusion élevée (LCR)  hyposignal
- Région à diffusion basse (ischémie)  hypersignal
- Mesure du coefficient de diffusion (ADC) selon :

$$SA = e^{-b \cdot ADC}$$

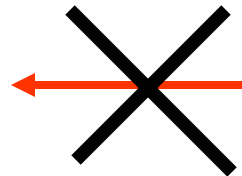
où b dépend de durée et puissance des gradients de diffusion selon :

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$$

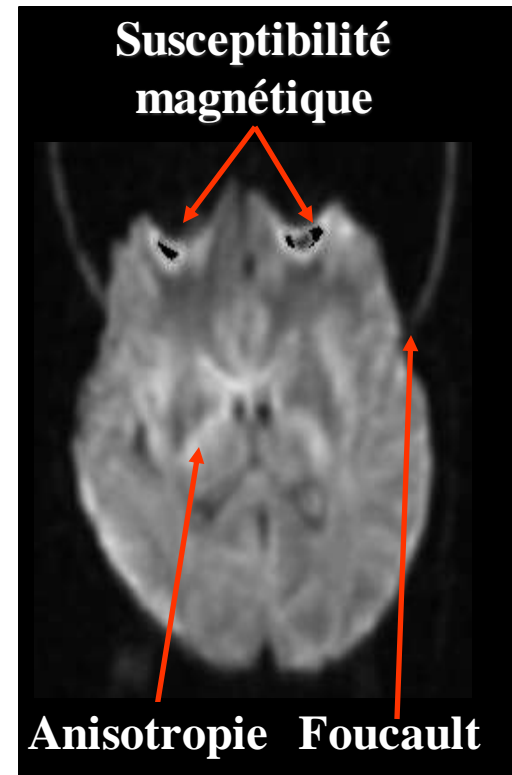
IRM de DIFFUSION

Séquence de Diffusion

- Diffusion diminuée
hypersignal

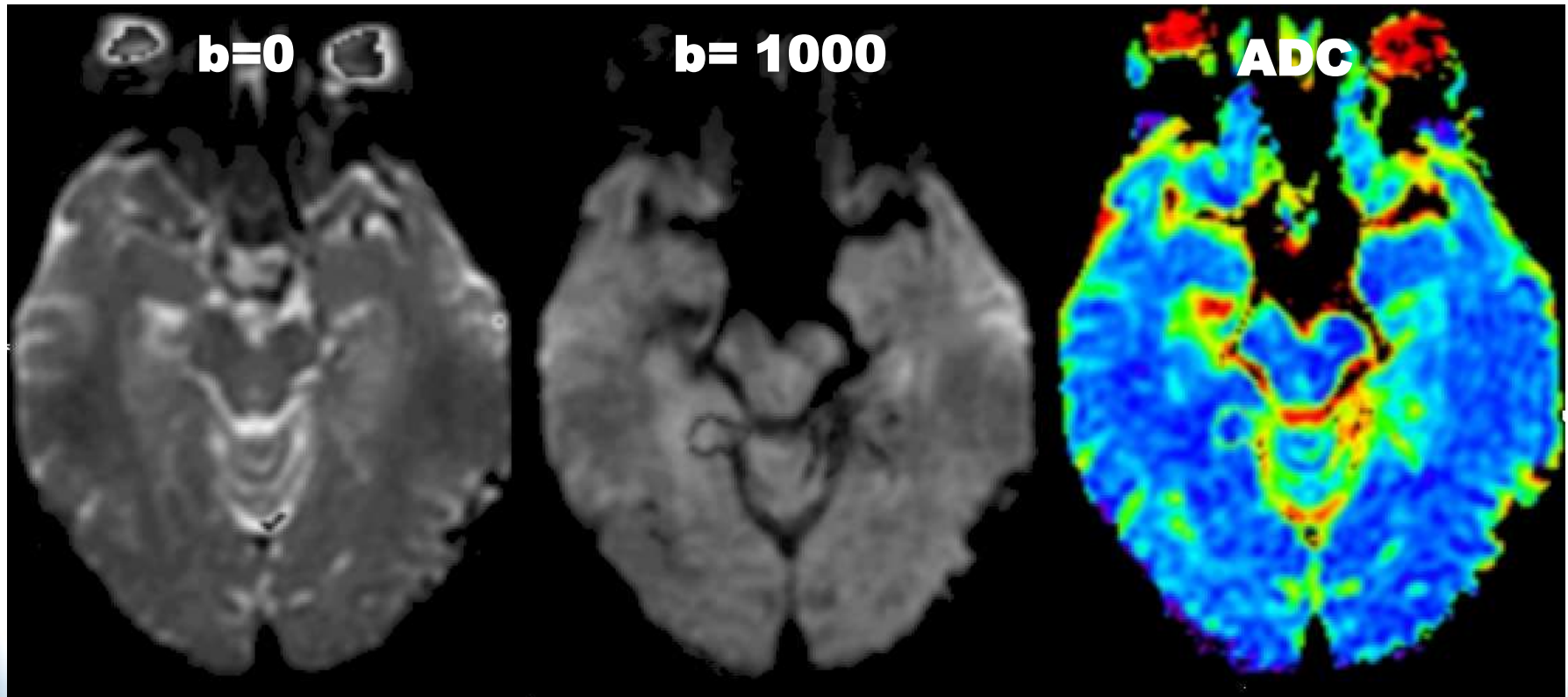


- Susceptibilité magnétique
- Anisotropie
- T2 ↗ (T2 Shine Through)
- Coefficient de diffusion ↘



IRM de DIFFUSION

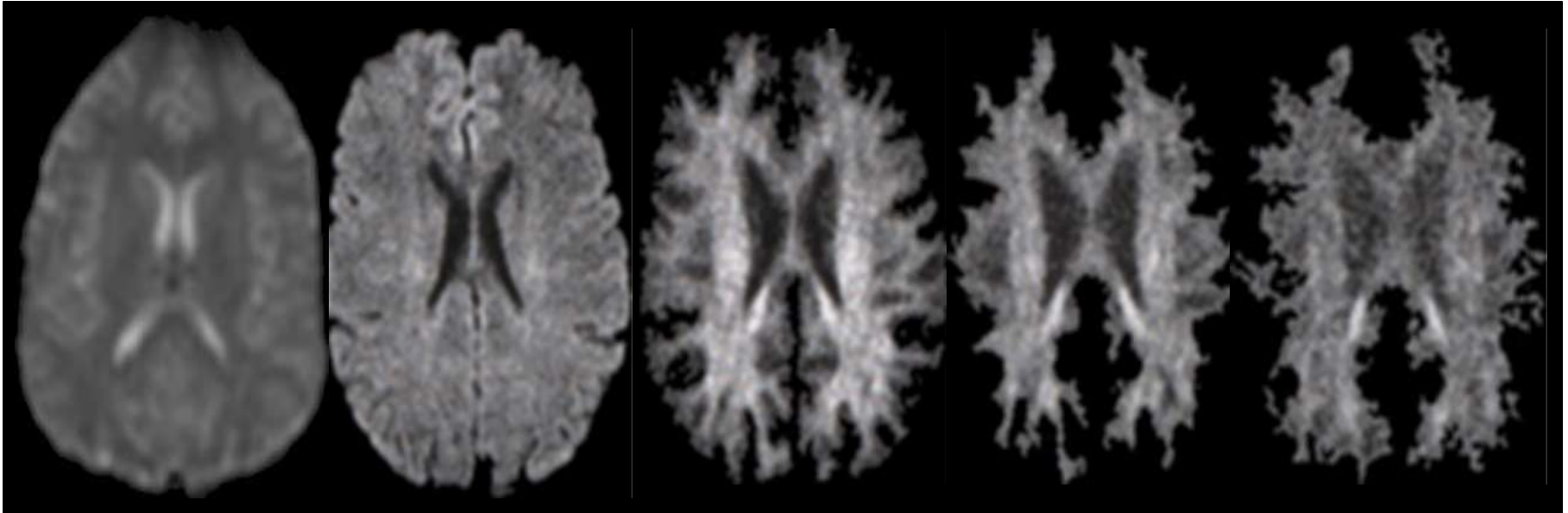
Coefficient Apparent de Diffusion



$$SA \approx e^{-b \cdot ADC} = e^{-\gamma^2 G^2 \delta^2 (\Delta - \delta/3) ADC}$$

IRM de DIFFUSION

Séquence de Diffusion

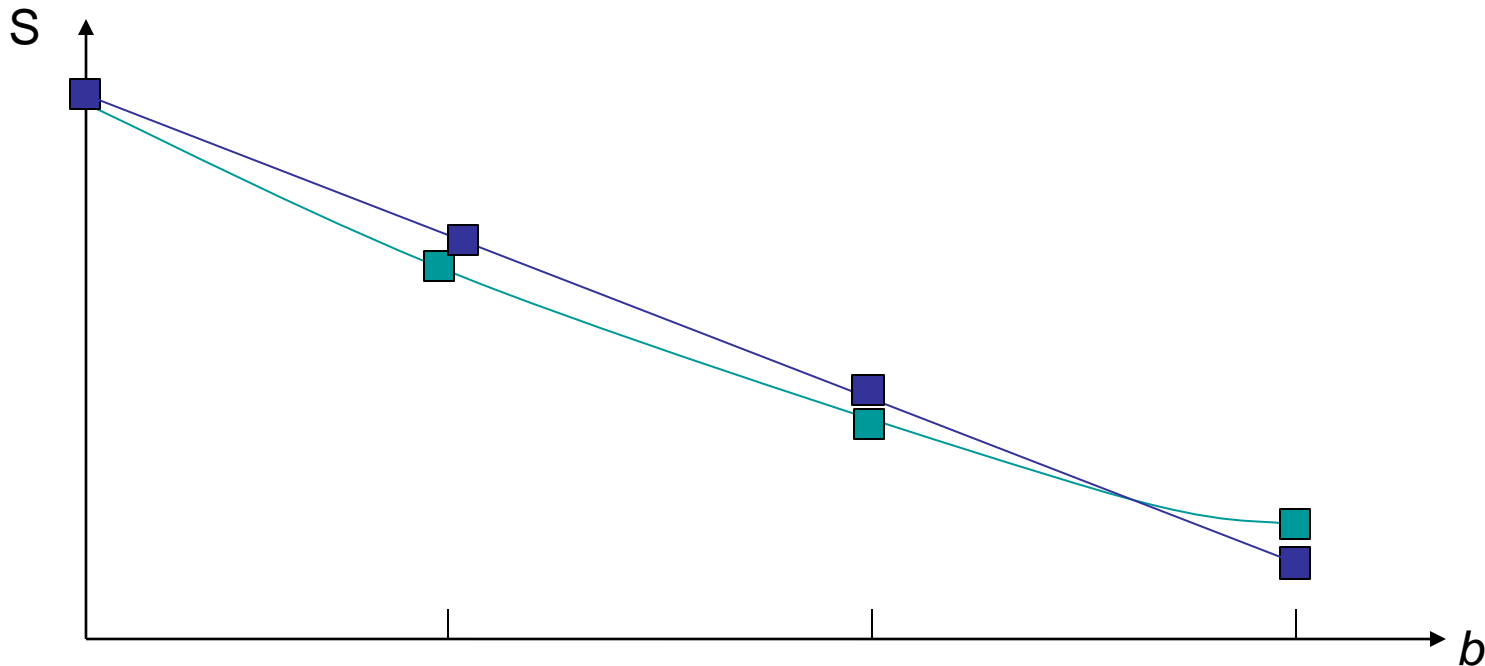


T2 : $b=0$ s/mm² DWI : $b=1000$ s/mm² DWI : $b=2000$ s/mm² DWI : $b=3000$ s/mm² DWI : $b=4000$ s/mm²

IRM de DIFFUSION

Bases Physiques

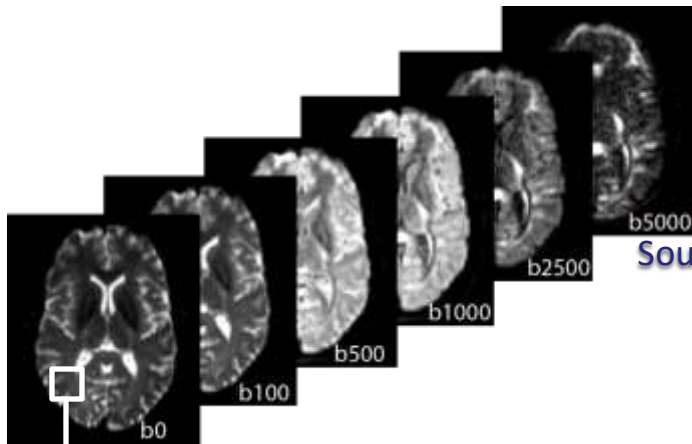
Modèles mono et bi-compartmentaux



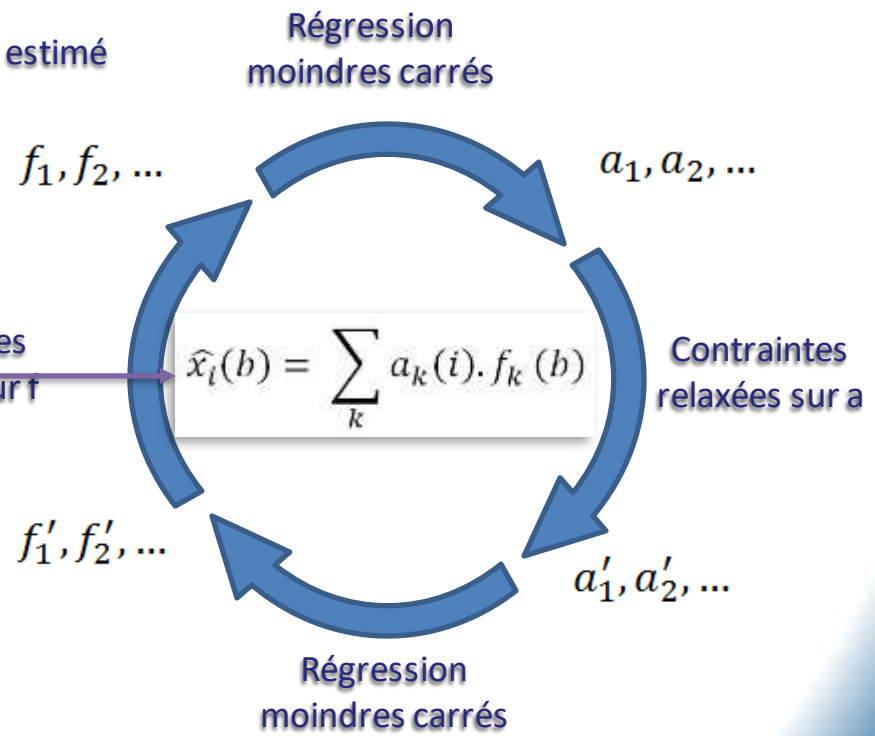
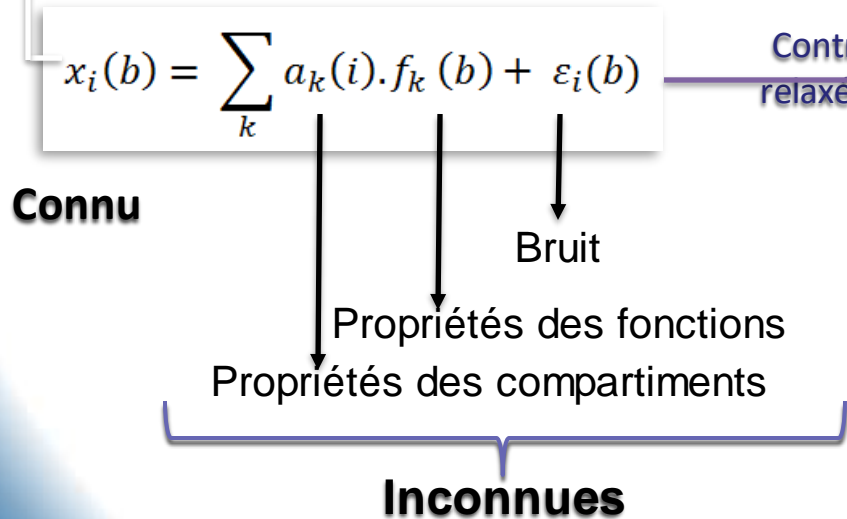
$$S_b = S_0 \cdot e^{-b \cdot D} \text{ versus } S_i(t_e, b) = [S_a \cdot e^{-te/T2a} \cdot e^{-b \cdot Da}] + [S_b \cdot e^{(-te/T2b)} \cdot e^{-b \cdot Db}]$$

IRM de DIFFUSION

Bases Physiques

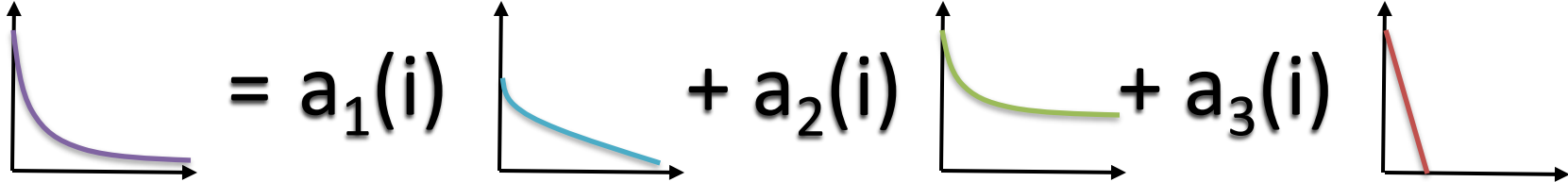


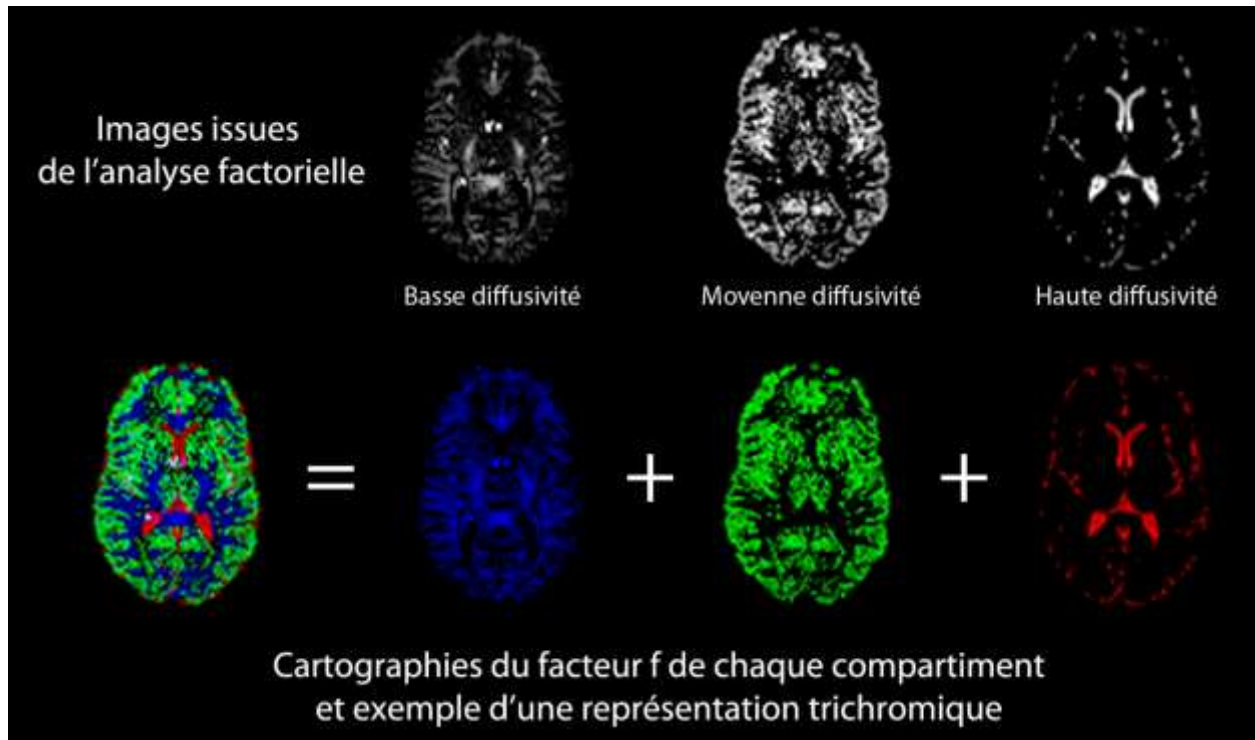
Soustraction du bruit estimé



IRM de DIFFUSION

Bases Physiques

$$x_i(b) = a_1(i) + a_2(i) + a_3(i)$$




2.2 Applications Cliniques

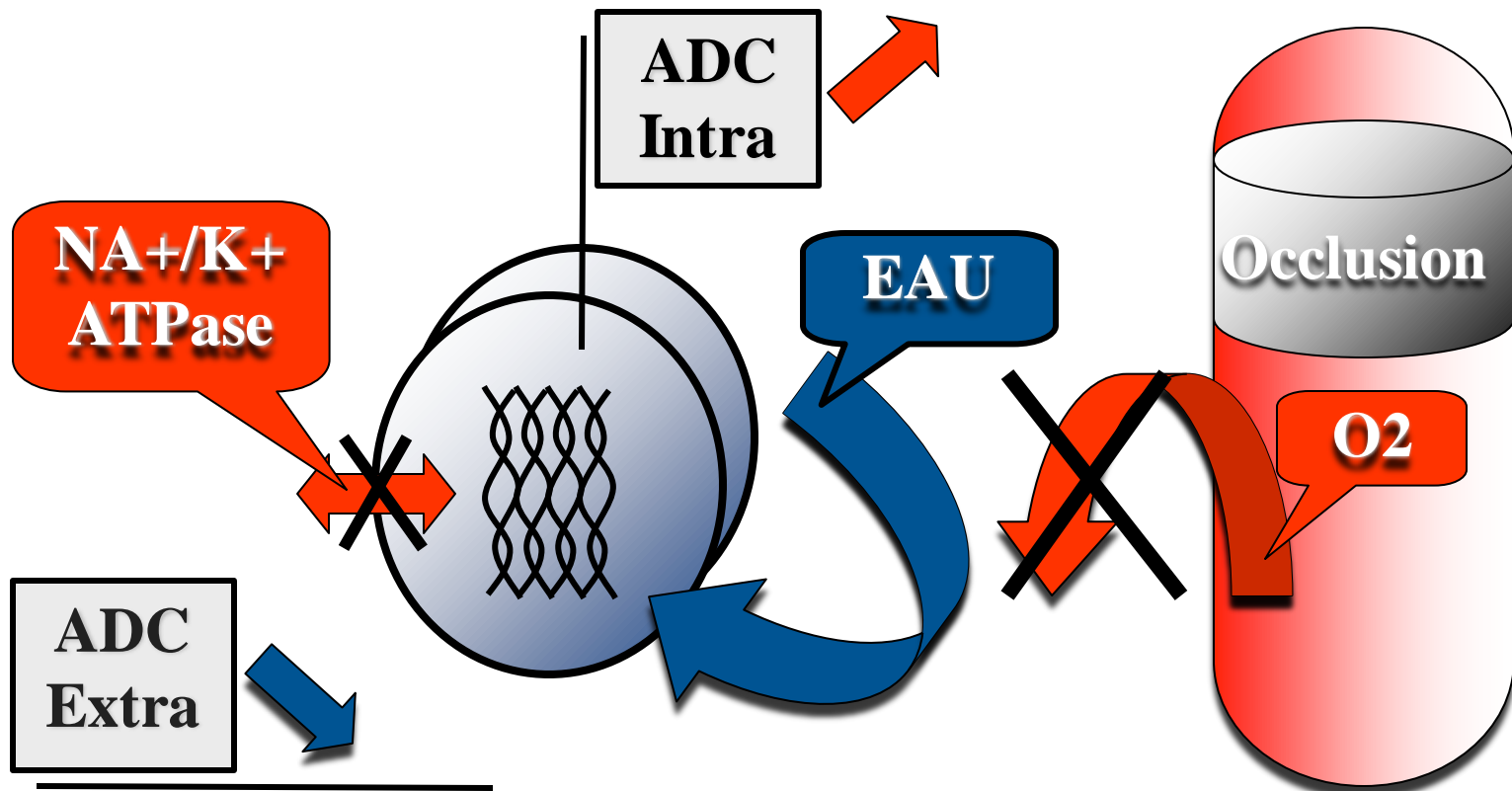
IRM de DIFFUSION

Ischémie Artérielle



IRM de DIFFUSION

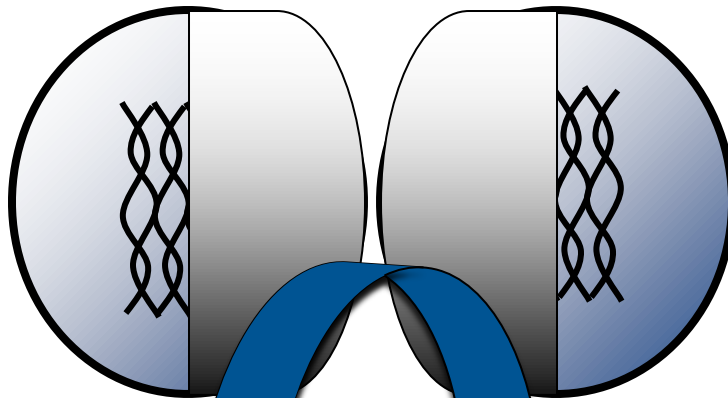
Ischémie Artérielle - Stade Aigu



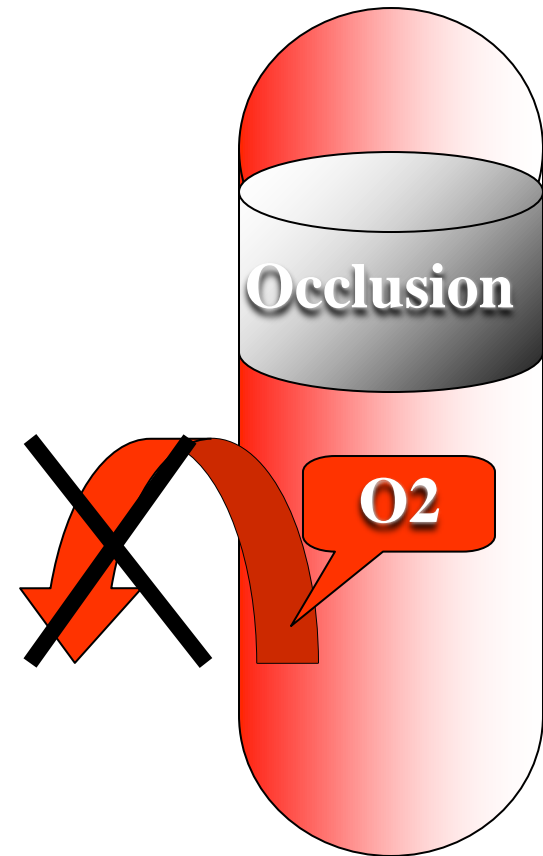
IRM de DIFFUSION

Ischémie Artérielle - Stade Sub-aigu

DSC < 12 ml/min/100 g

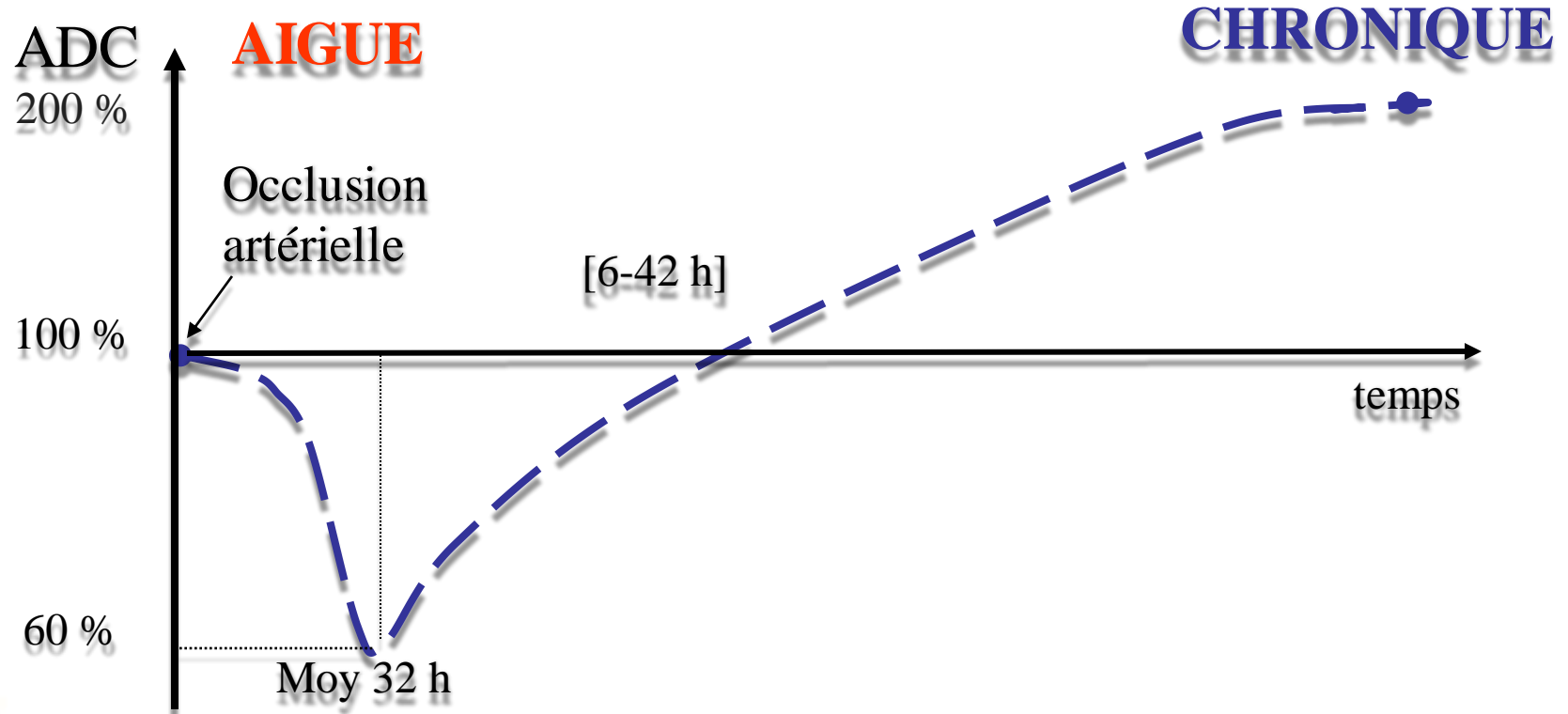


EAU



IRM de DIFFUSION

Variations temporelles de l'ADC

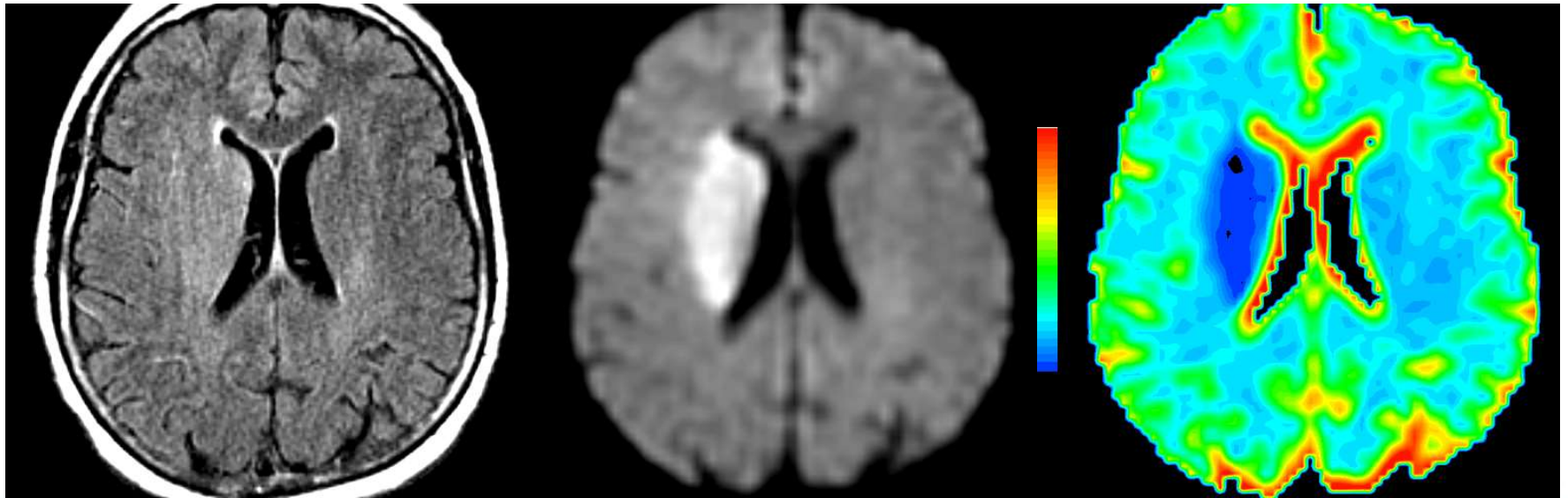


IRM de DIFFUSION

Ischémie Artérielle



Hémiplégie gauche brutale. IRM à 5.5 heures



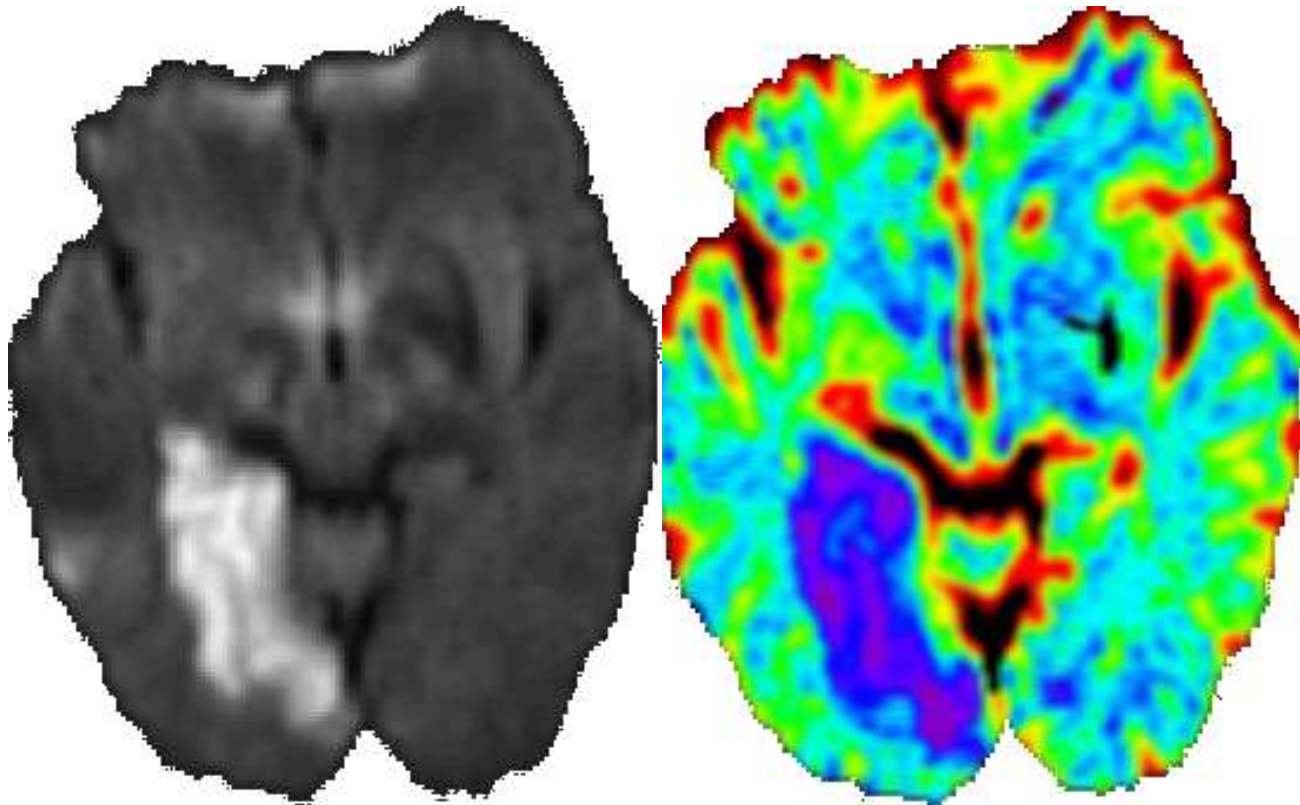
FLAIR

DWI

ADC

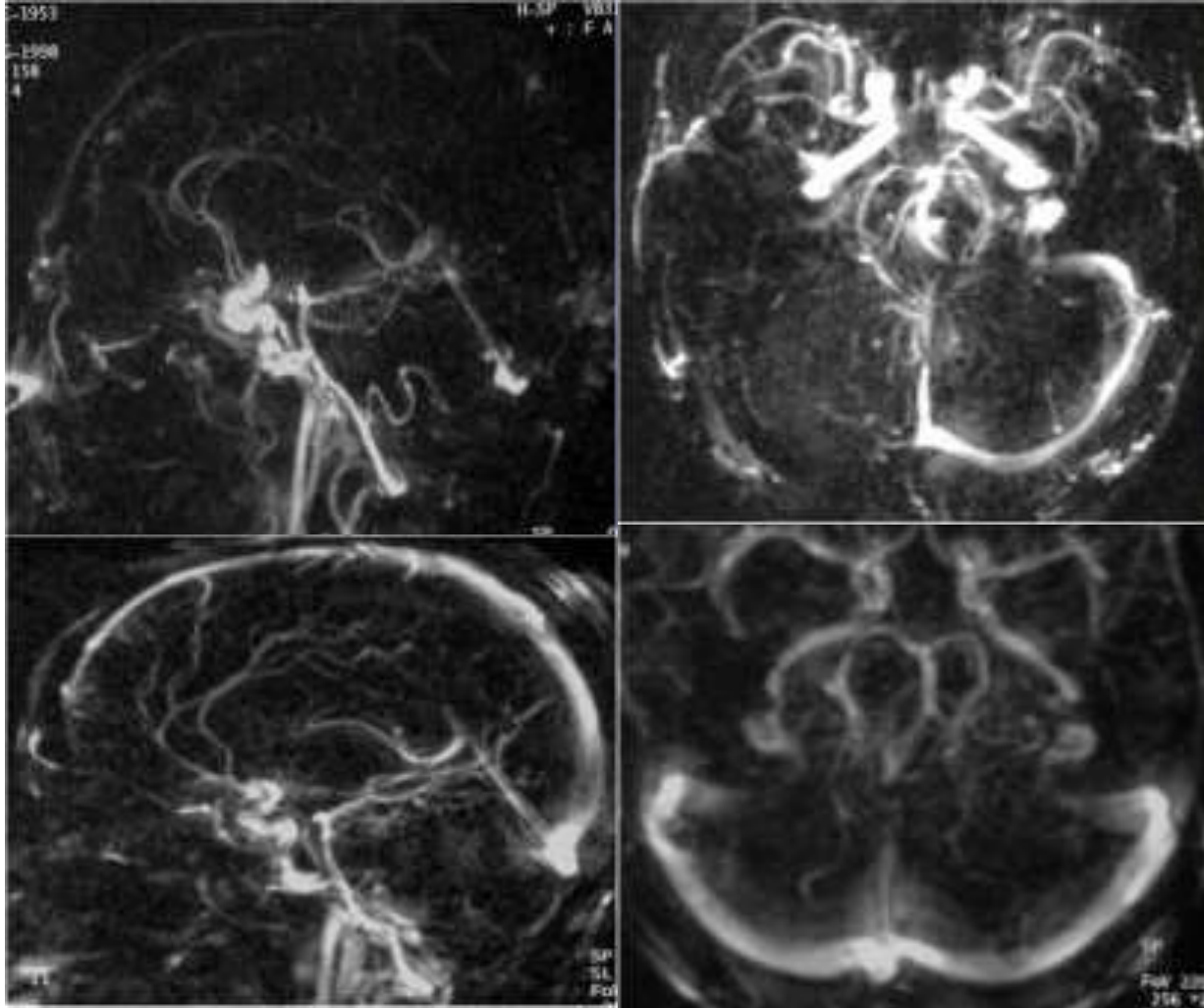
IRM de DIFFUSION

Ischémie Artérielle



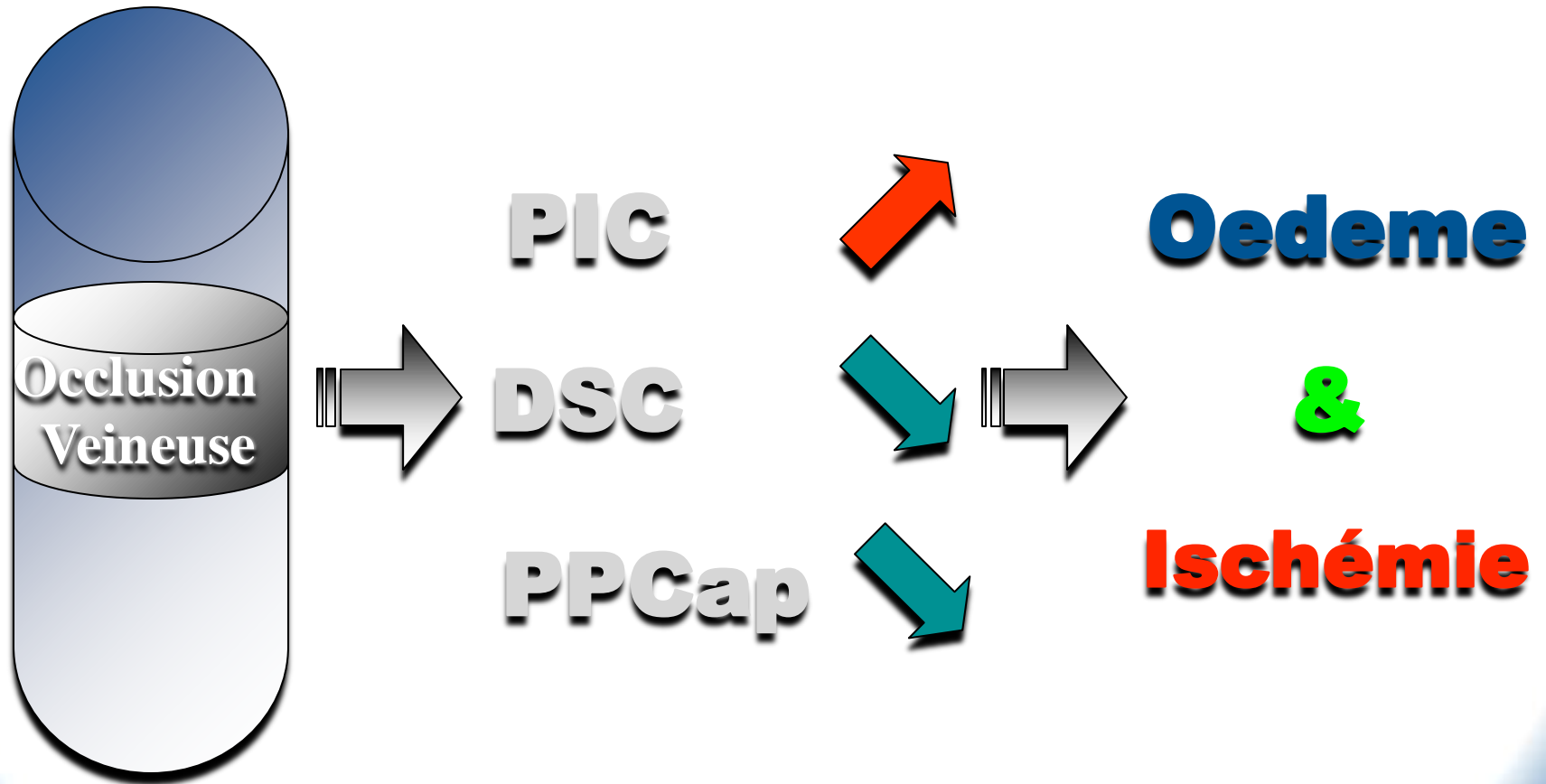
IRM de DIFFUSION

Ischémie Veineuse



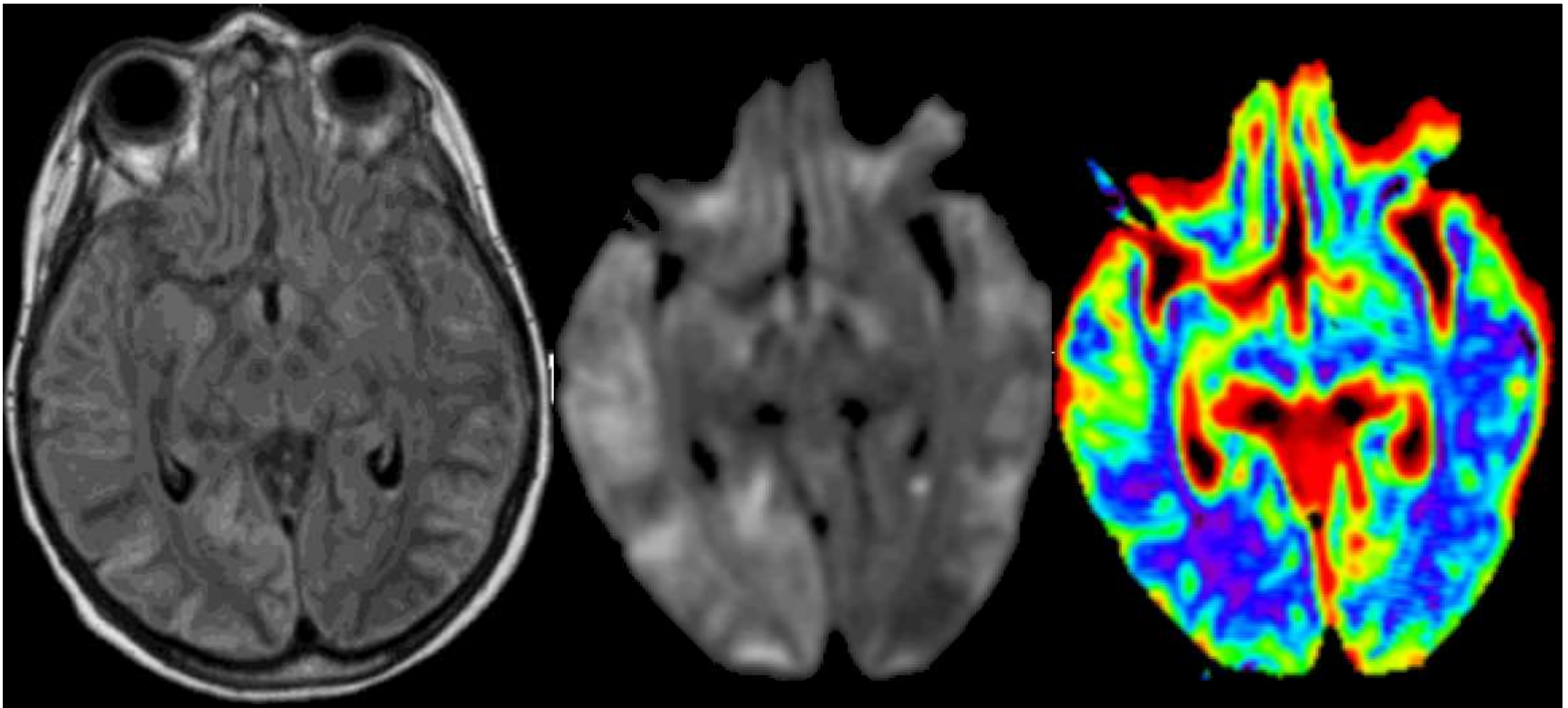
IRM de DIFFUSION

Ischémie Veineuse



IRM de DIFFUSION

Ischémie Veineuse



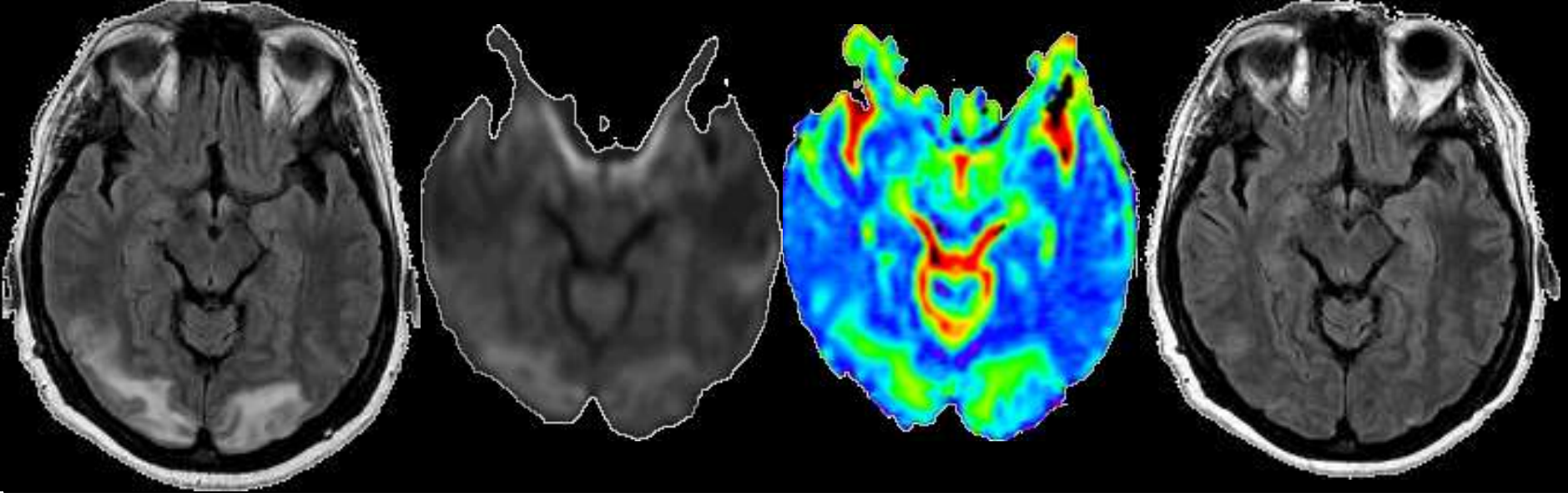
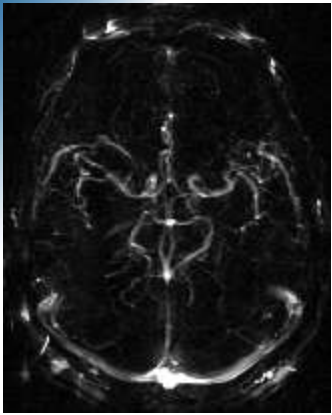
FLAIR

DWI

ADC

IRM de DIFFUSION

Leuco-encéphalopathie PBR



FLAIR

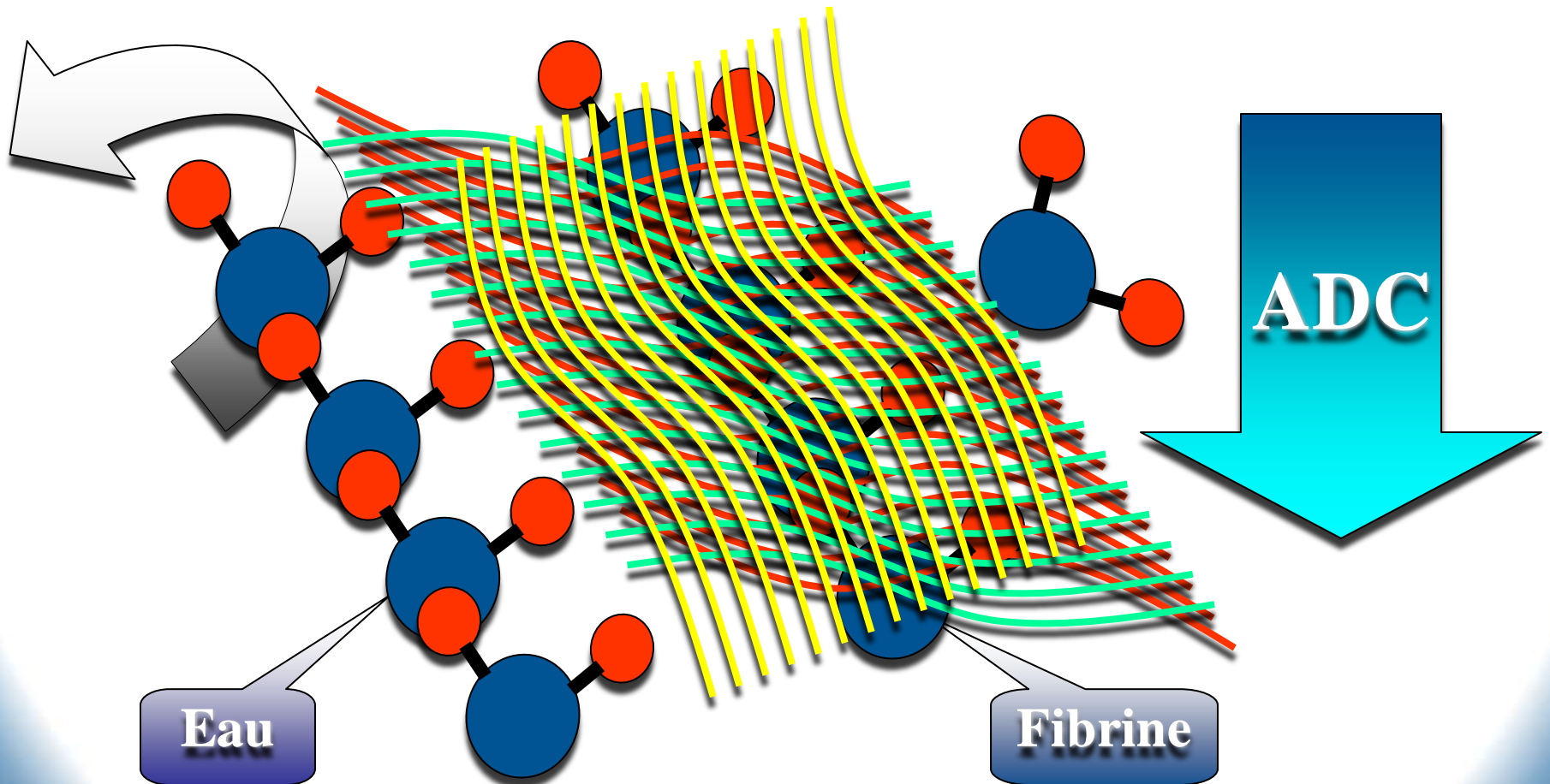
DWI

ADC

FLAIR

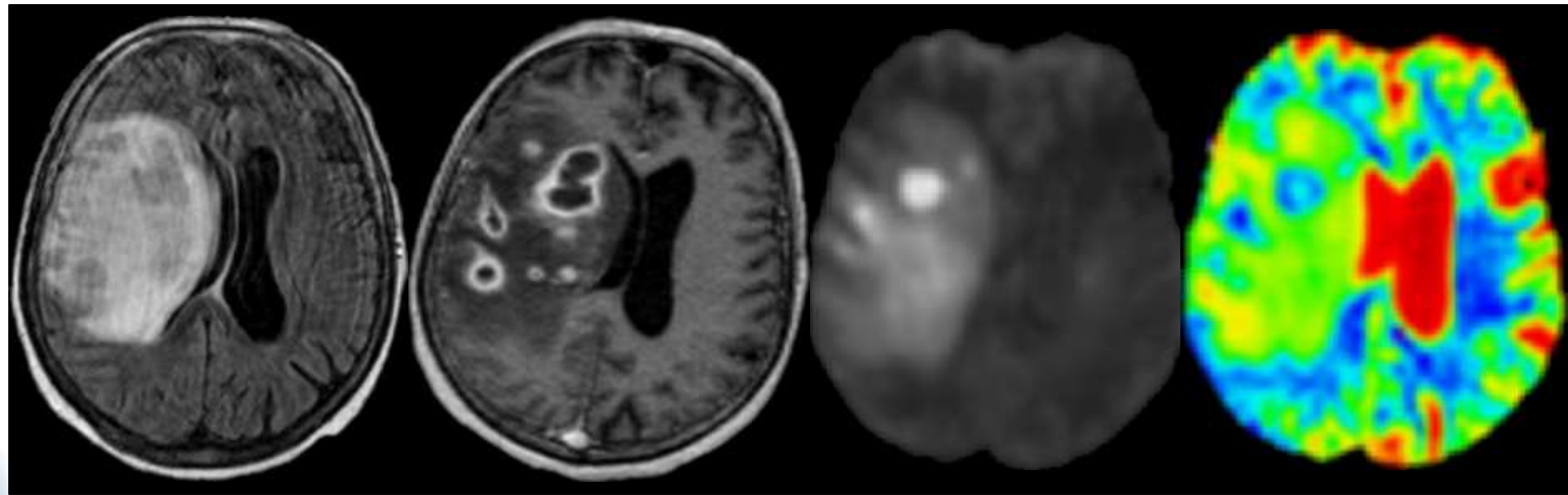
IRM de DIFFUSION

Abcès à Pyogènes



IRM de DIFFUSION

Abcès à Pyogènes



FLAIR

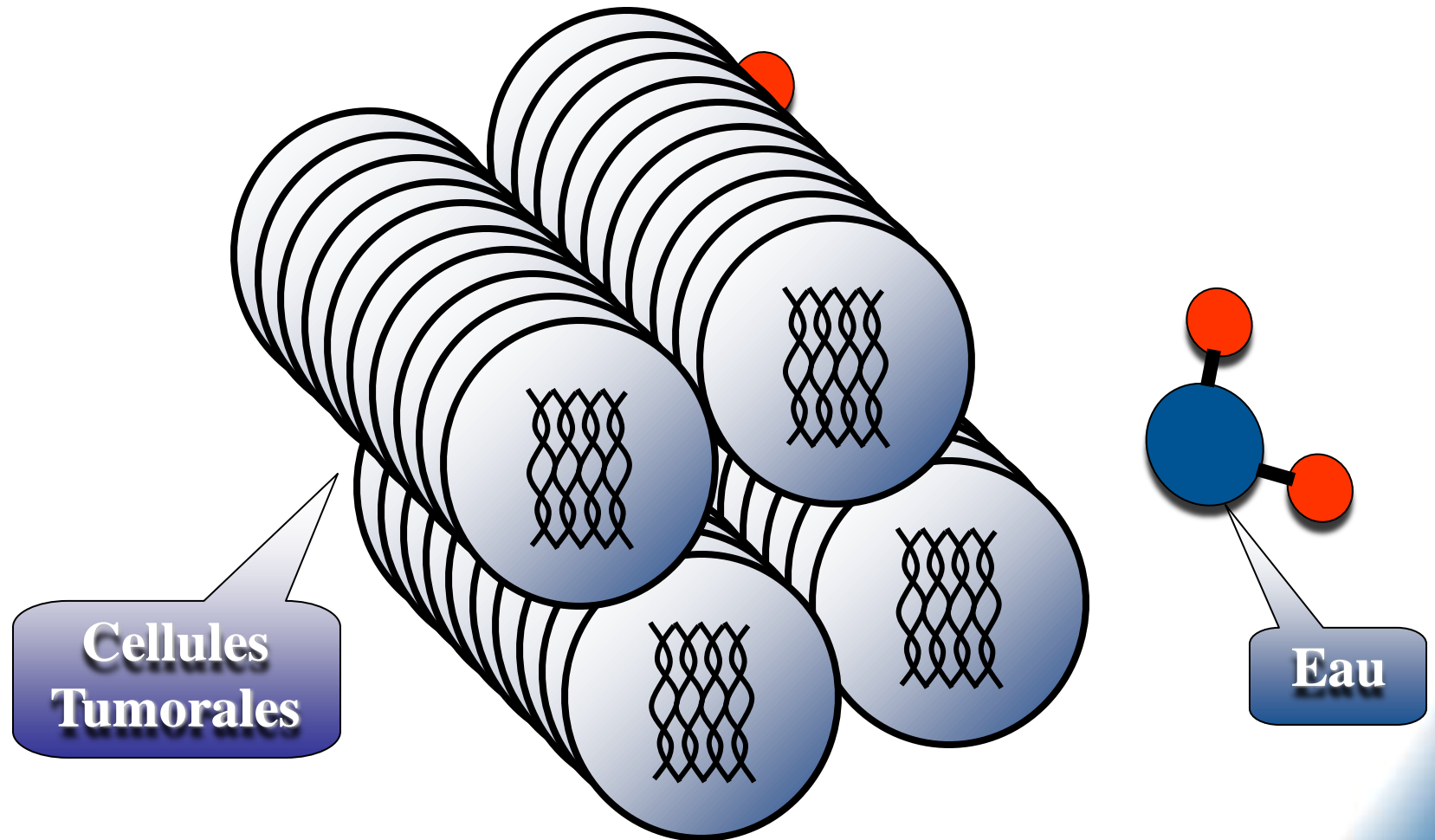
T1 Gado

DWI

ADC

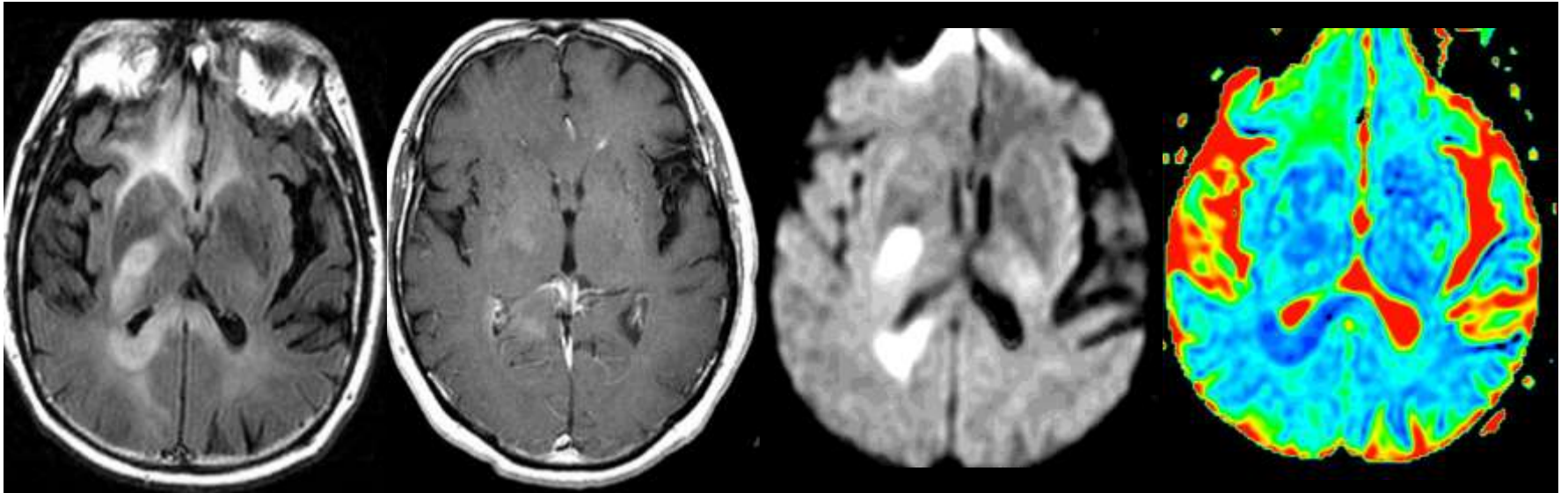
IRM de DIFFUSION

Tumeurs Cellulaires



IRM de DIFFUSION

Lymphome



FLAIR

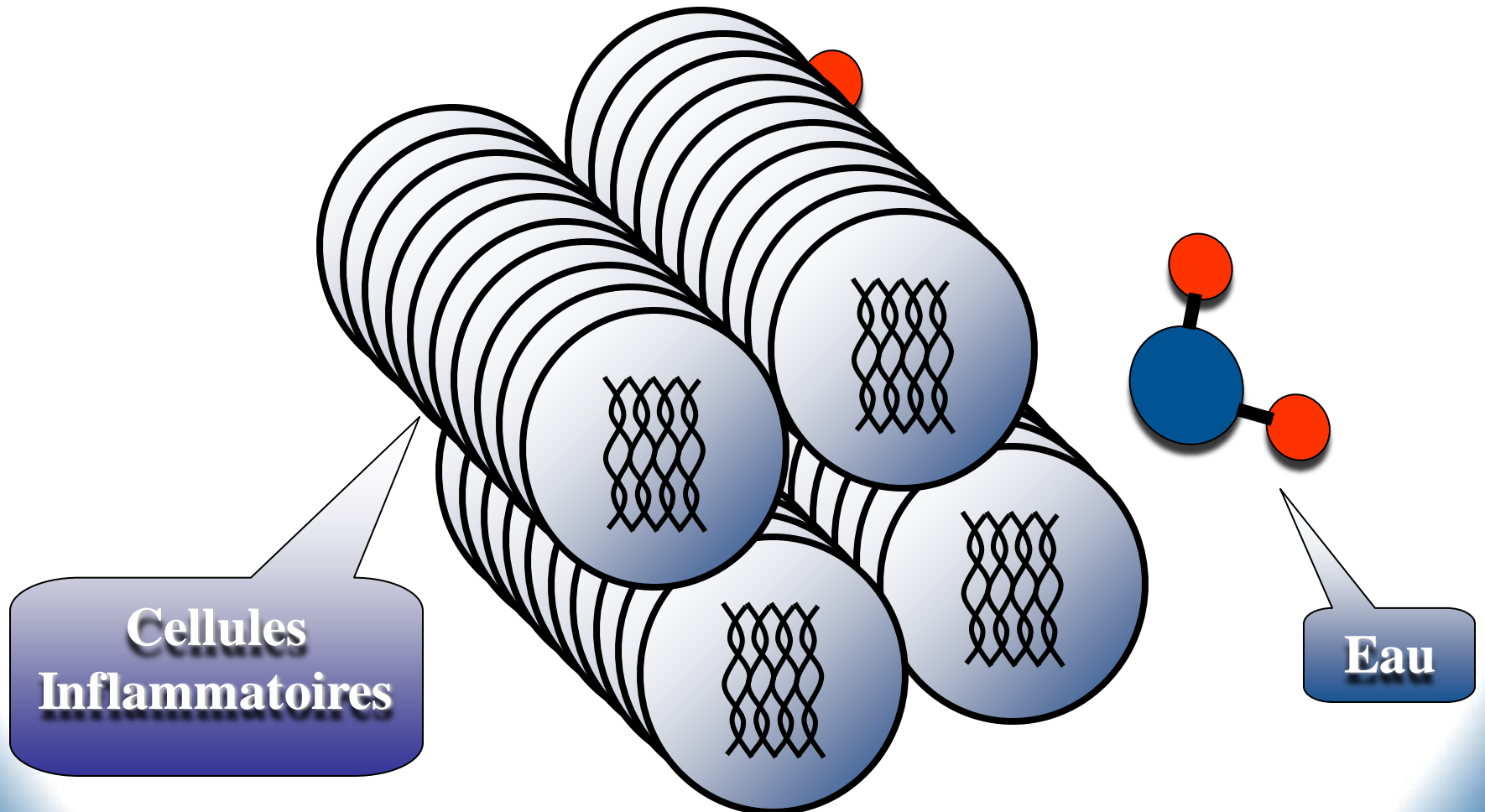
T1 Gado

DWI

ADC

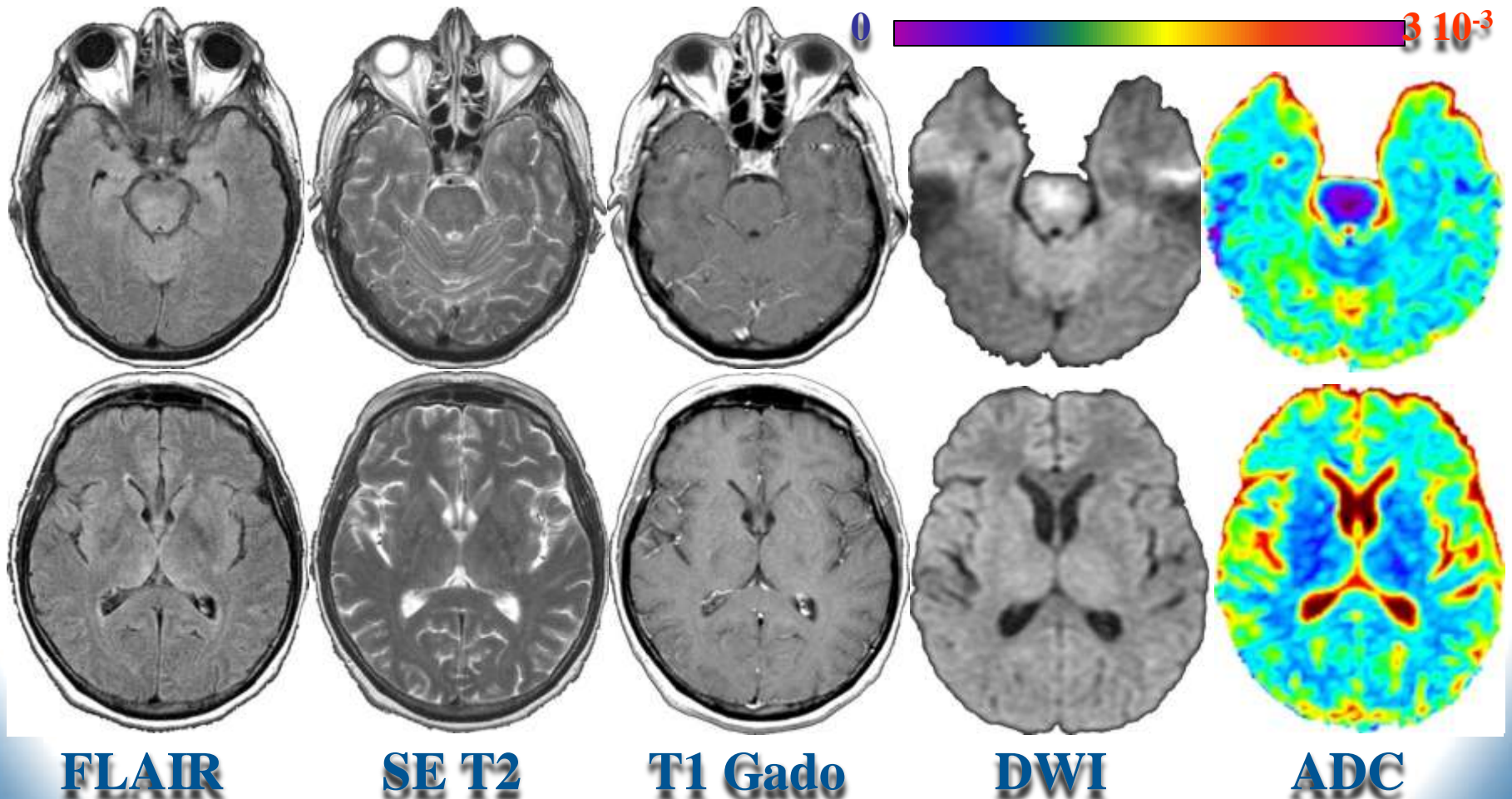
IRM de DIFFUSION

Encéphalites



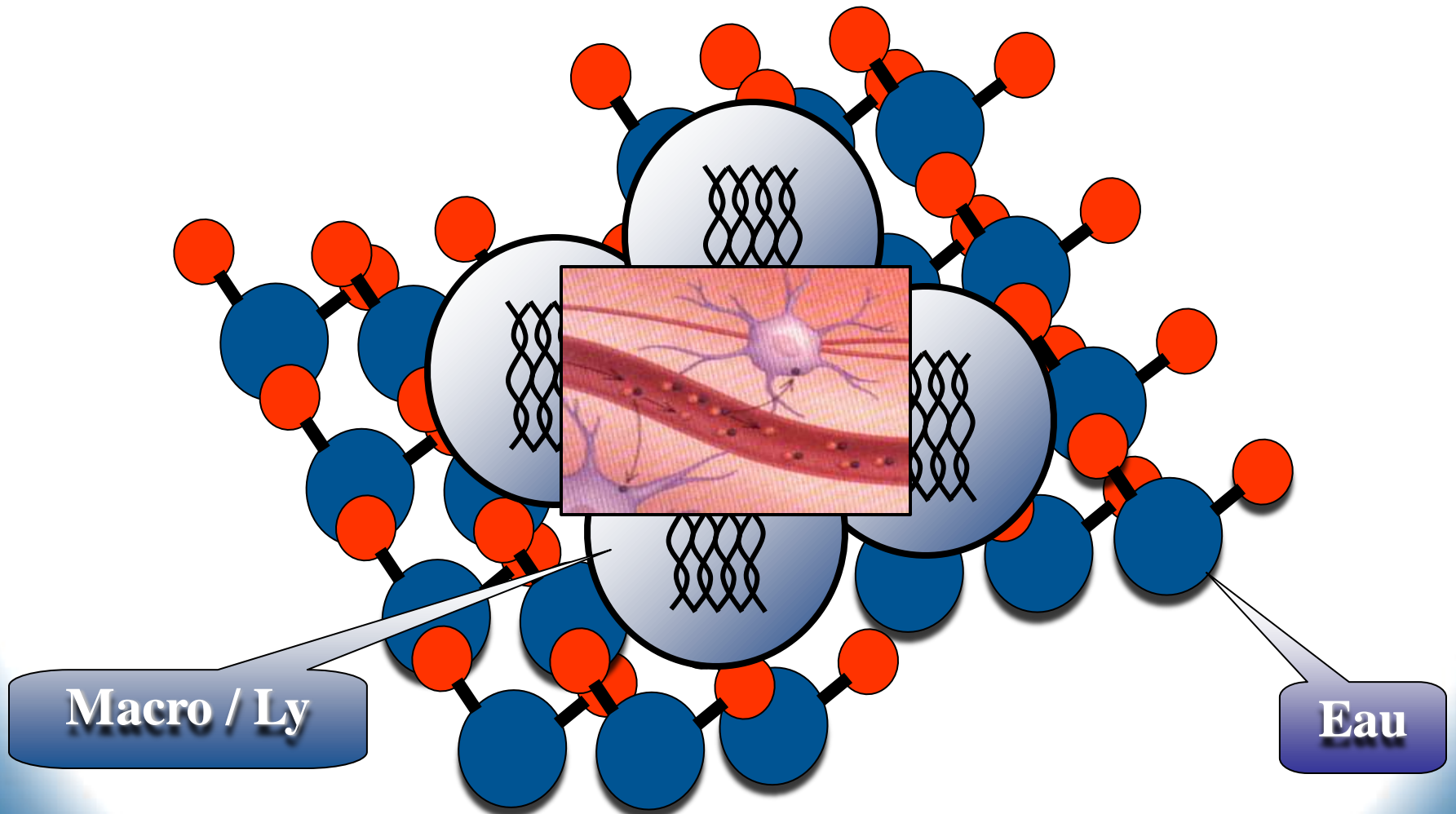
IRM de DIFFUSION

Encéphalite à Virus du Nil



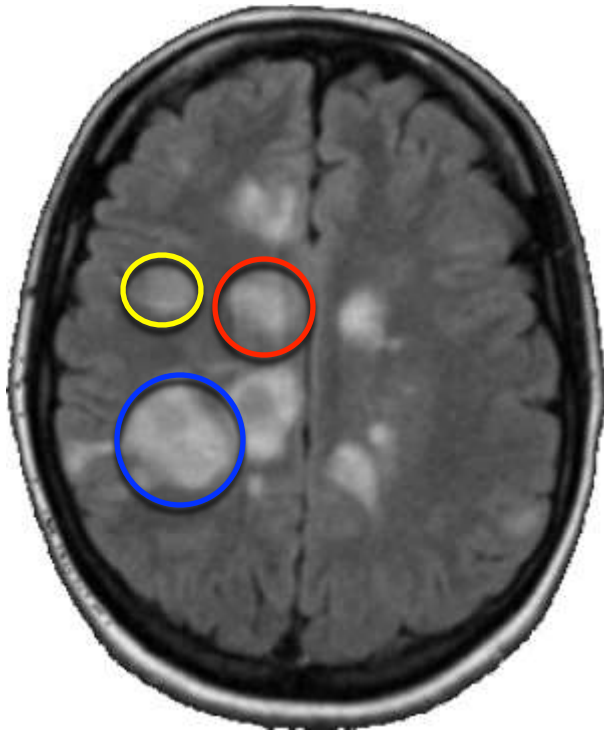
IRM de DIFFUSION

Pathologie Inflammatoire

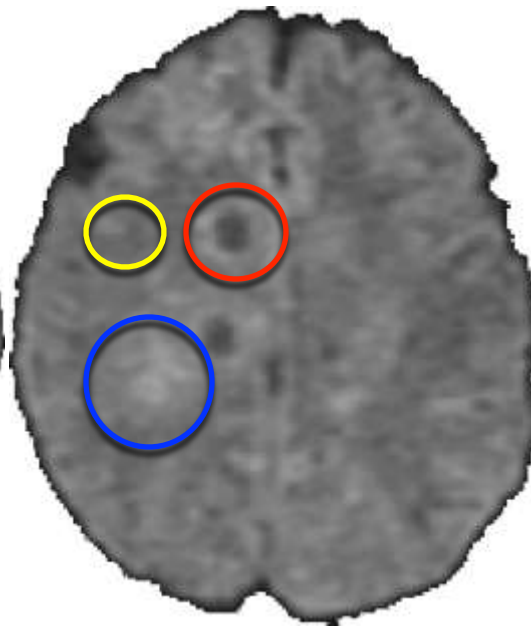


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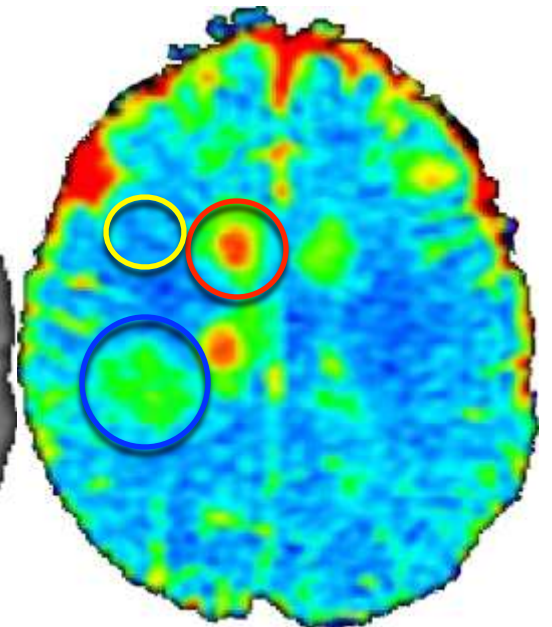
Sclérose en Plaques



FLAIR



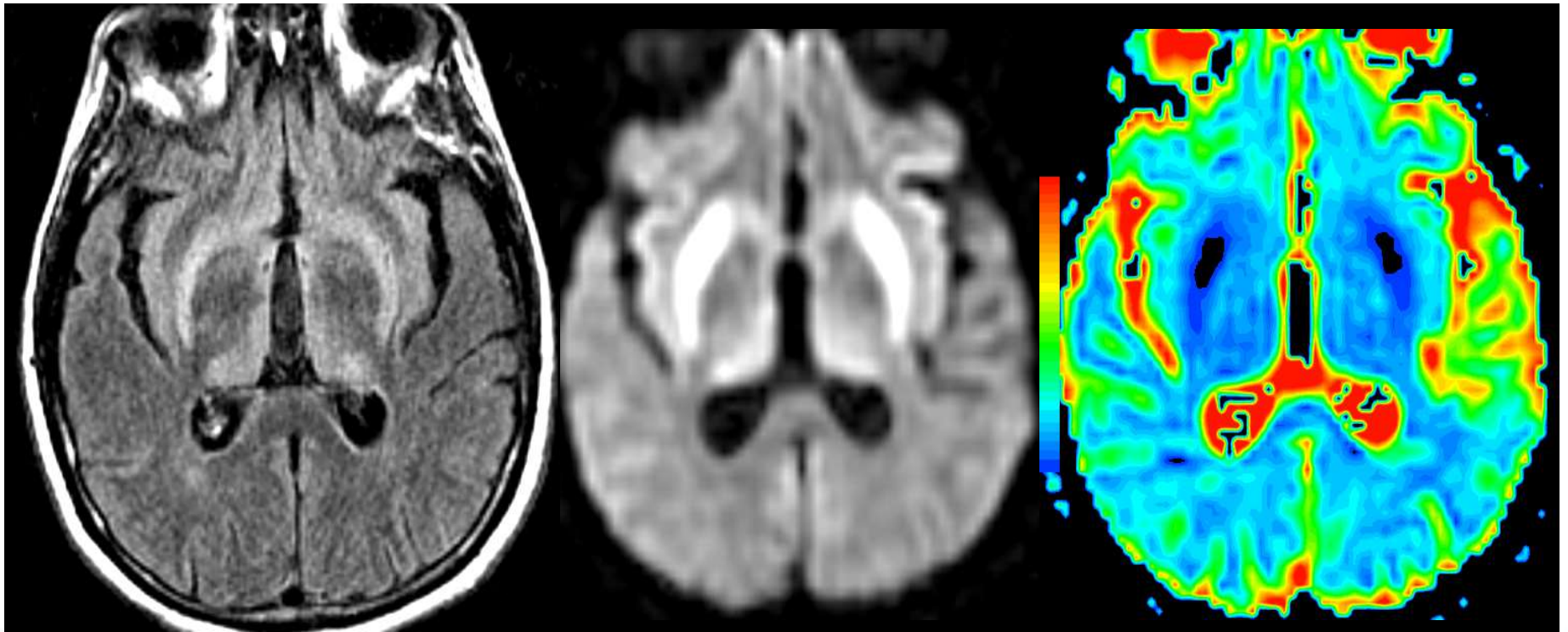
DWI



ADC

IRM de DIFFUSION

Creutzfeldt-Jacob



FLAIR

DWI

ADC

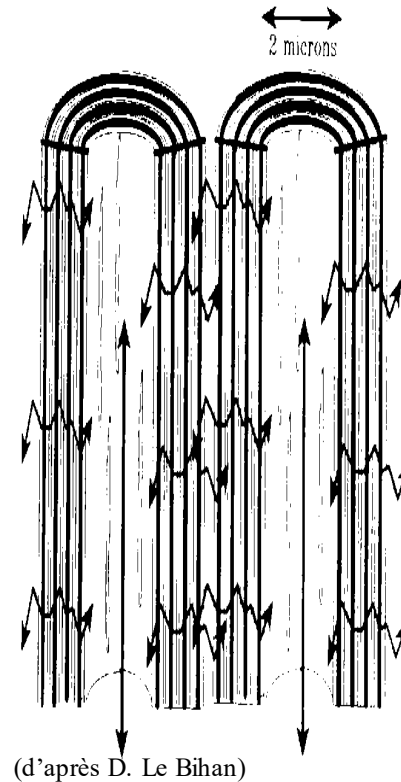
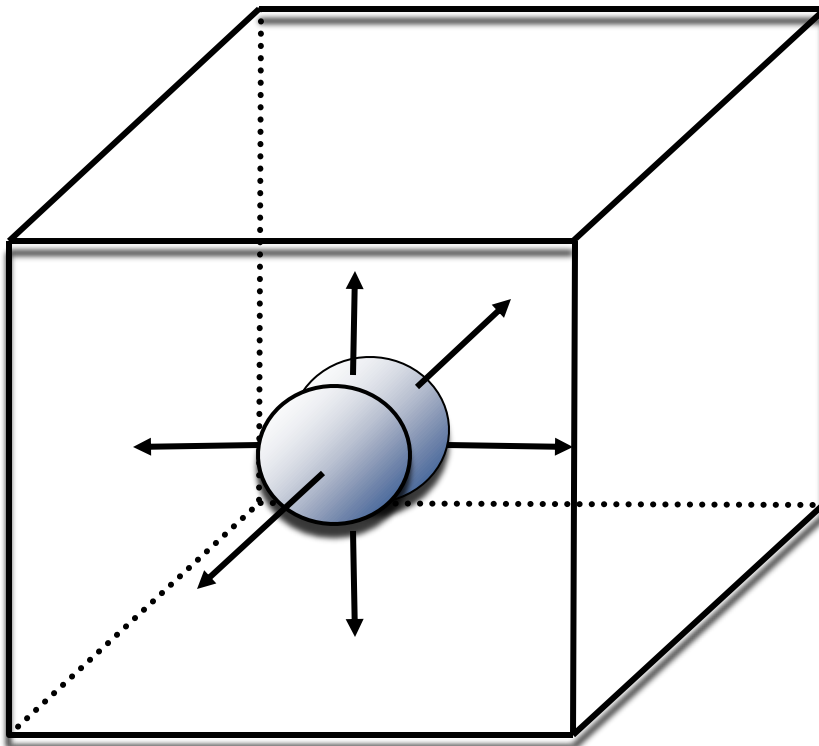
2.3 IRM de Tenseur de Diffusion

2.3.1 Principes

IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre

- Description complète des propriétés de diffusion d'un voxel
- Tenseur de diffusion (gradients dans ≥ 6 dir. de l'espace)

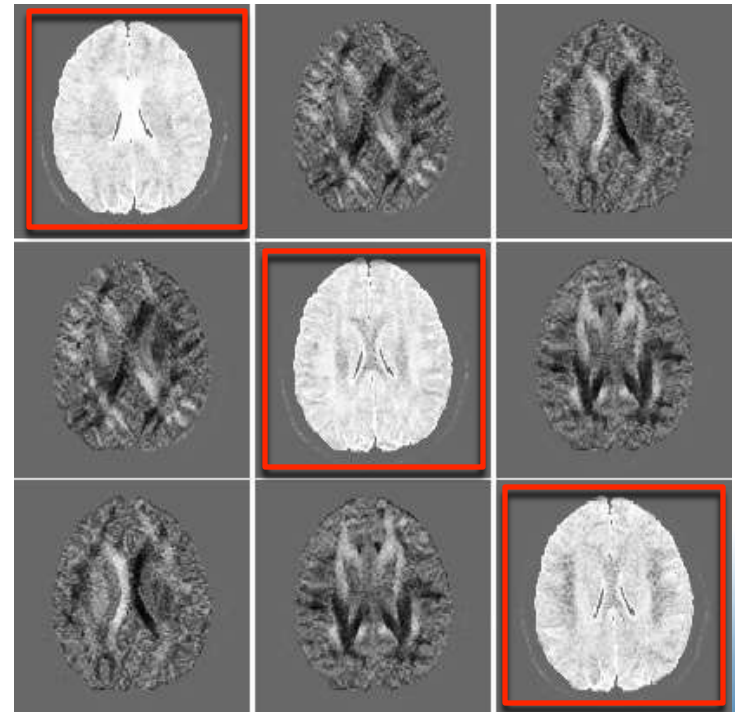


IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre

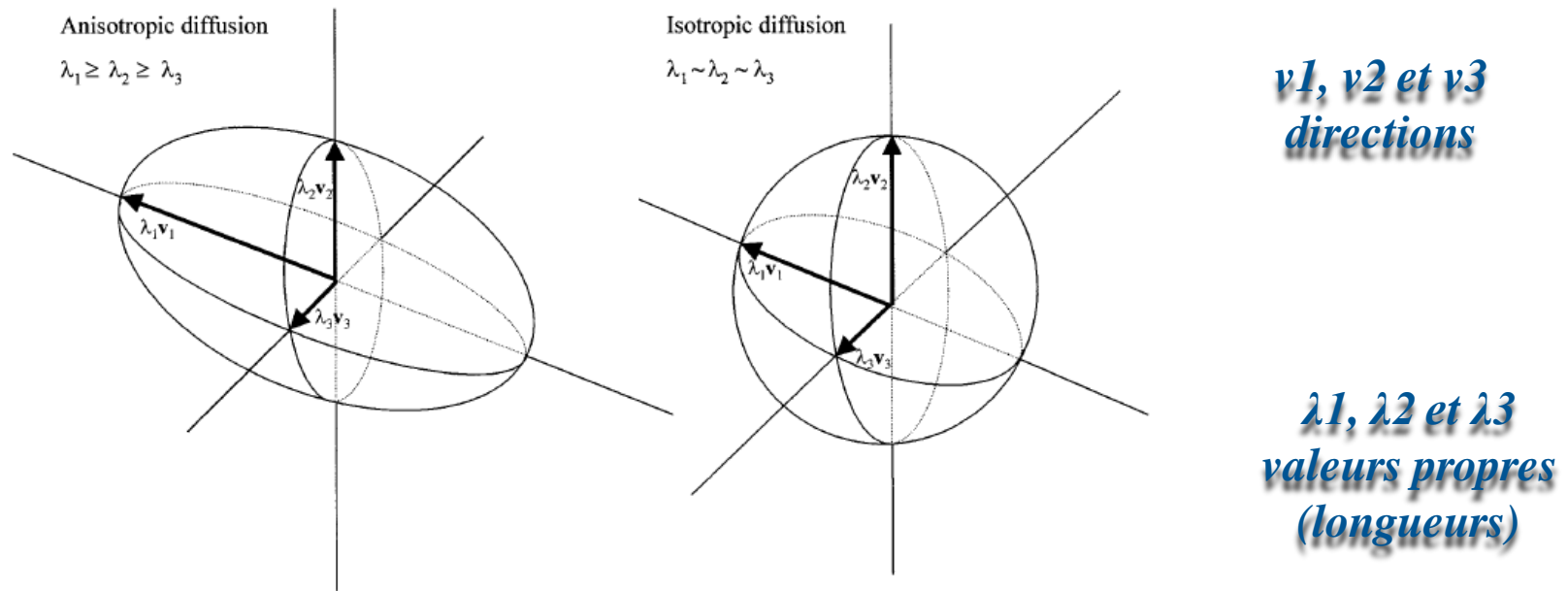
- DTI mesure l'ADC dans 6 directions de l'espace;
- le modèle: tenseur de diffusion D = matrice symétrique 3x3;
- le tenseur est calculé pour chaque voxel

$$D = \begin{pmatrix} D_{xx} & D_{xy} & D_{xz} \\ D_{yx} & D_{yy} & D_{yz} \\ D_{zx} & D_{zy} & D_{zz} \end{pmatrix}$$



IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre



- Tenseurs utilisés pour décrire la diffusion peuvent être conceptualisés et visualisés comme des ellipsoïdes
- Si les trois valeurs propres sont égales, la diffusion est isotrope et le tenseur de diffusion peut être visualisé comme une sphère

IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre

Paramètres de la diffusion anisotrope :

$$FA = \sqrt{\frac{3}{2}} \cdot \frac{\sqrt{(\lambda_1 - \lambda)^2 + (\lambda_2 - \lambda)^2 + (\lambda_3 - \lambda)^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

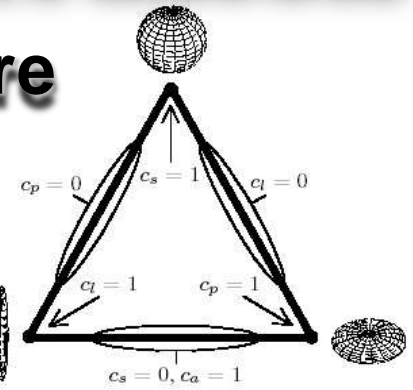
$$RA = \frac{1}{\sqrt{3}} \frac{\sqrt{(\lambda_1 - \lambda)^2 + (\lambda_2 - \lambda)^2 + (\lambda_3 - \lambda)^2}}{(\lambda_1 + \lambda_2 + \lambda_3)} \quad AI = \frac{ADC_{\max} - ADC_{\min}}{ADC_{\text{mean}}}$$

$$VR = \frac{V_{\text{ellipsoïde}}}{V_{\text{sphère}}} = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda)^3} = \frac{\lambda_1 \lambda_2 \lambda_3}{\left(\frac{\lambda_1 + \lambda_2 + \lambda_3}{3}\right)^3} = 27 \frac{\text{Det}(D)}{\text{Trace}(D)^3}$$

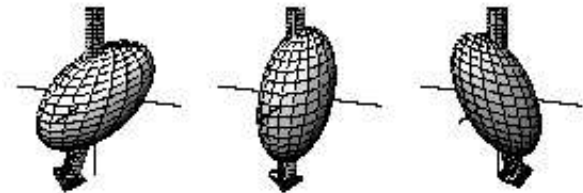
IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre

$$SA = e^{-\sum b_{ij} D_{ij}}$$



linear



planar

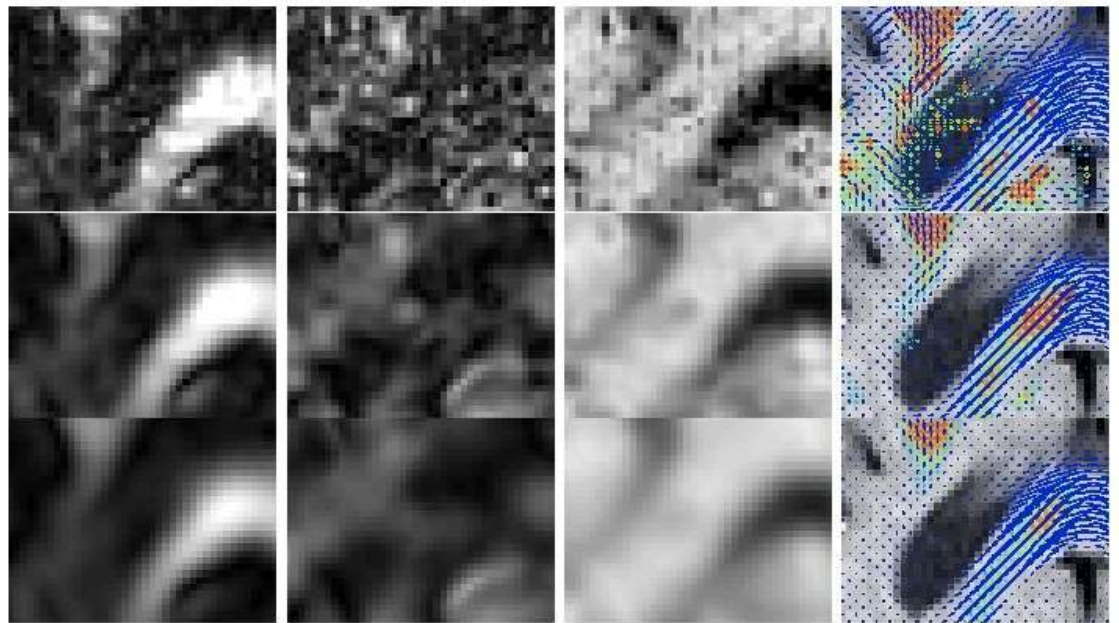
spherical

tensor map

$$c_l = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2 + \lambda_3}$$

$$c_p = \frac{2(\lambda_2 - \lambda_3)}{\lambda_1 + \lambda_2 + \lambda_3}$$

$$c_s = \frac{3\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3}$$

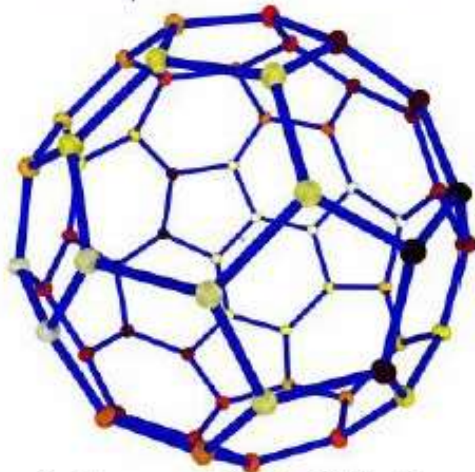


IRM de Tenseur de Diffusion

Méthodologie et Mise en Oeuvre



Vector representation for 30 directions



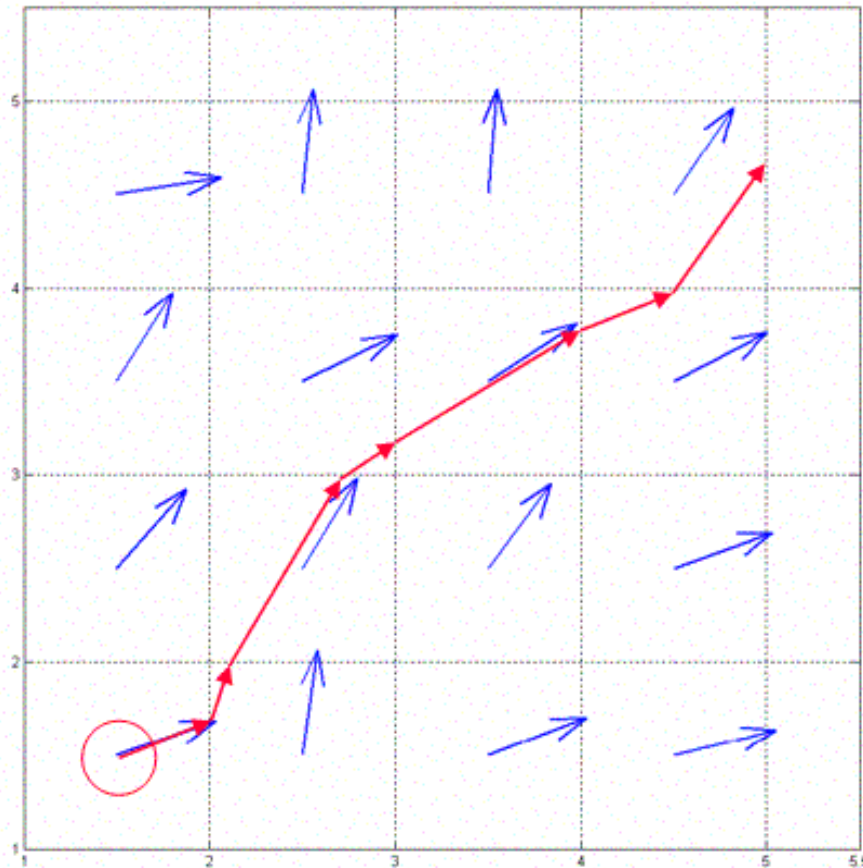
Point representation for 30 directions

Choix du nombre de directions :

- Compromis entre qualité (SNR) et durée de l'acquisition
- Utilisation du modèle mono-compartmental (1 valeur de b) et du tenseur de diffusion (pas de DSI : nb directions < 30)
- Corrections des macro-mouvements liée au nb de directions

IRM de Tenseur de Diffusion

Tractographie - Modèle FACT



A partir du point $S(0)$, on a l'équation en 3D suivante :

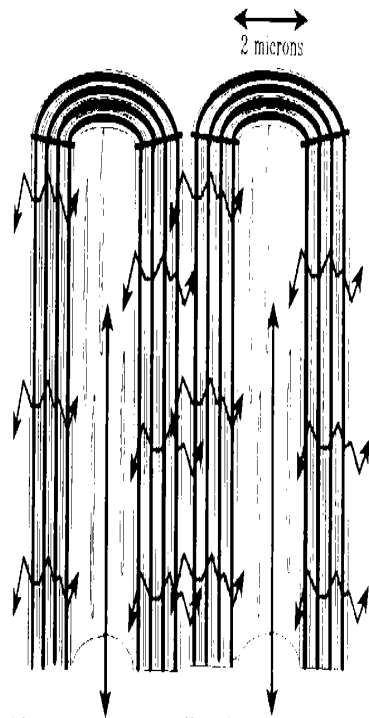
$$\delta S(t)/\delta t = R(t)$$

Avec :

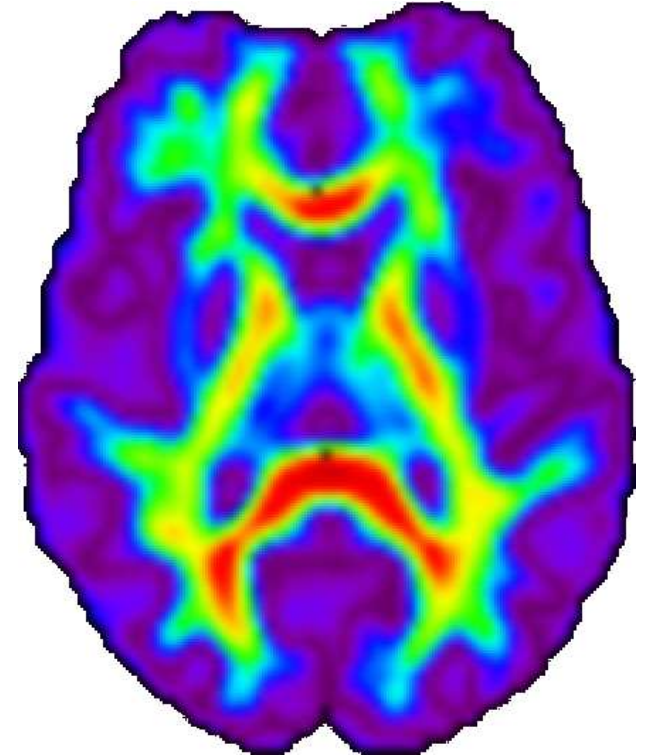
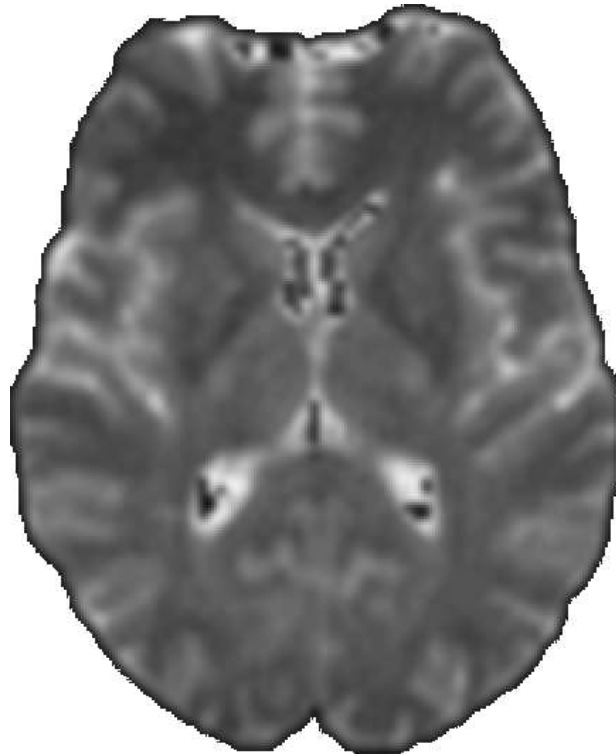
- $S(t)$: position de la fibre curviligne au temps t
- $R(t)$: tangente à la direction du faisceau

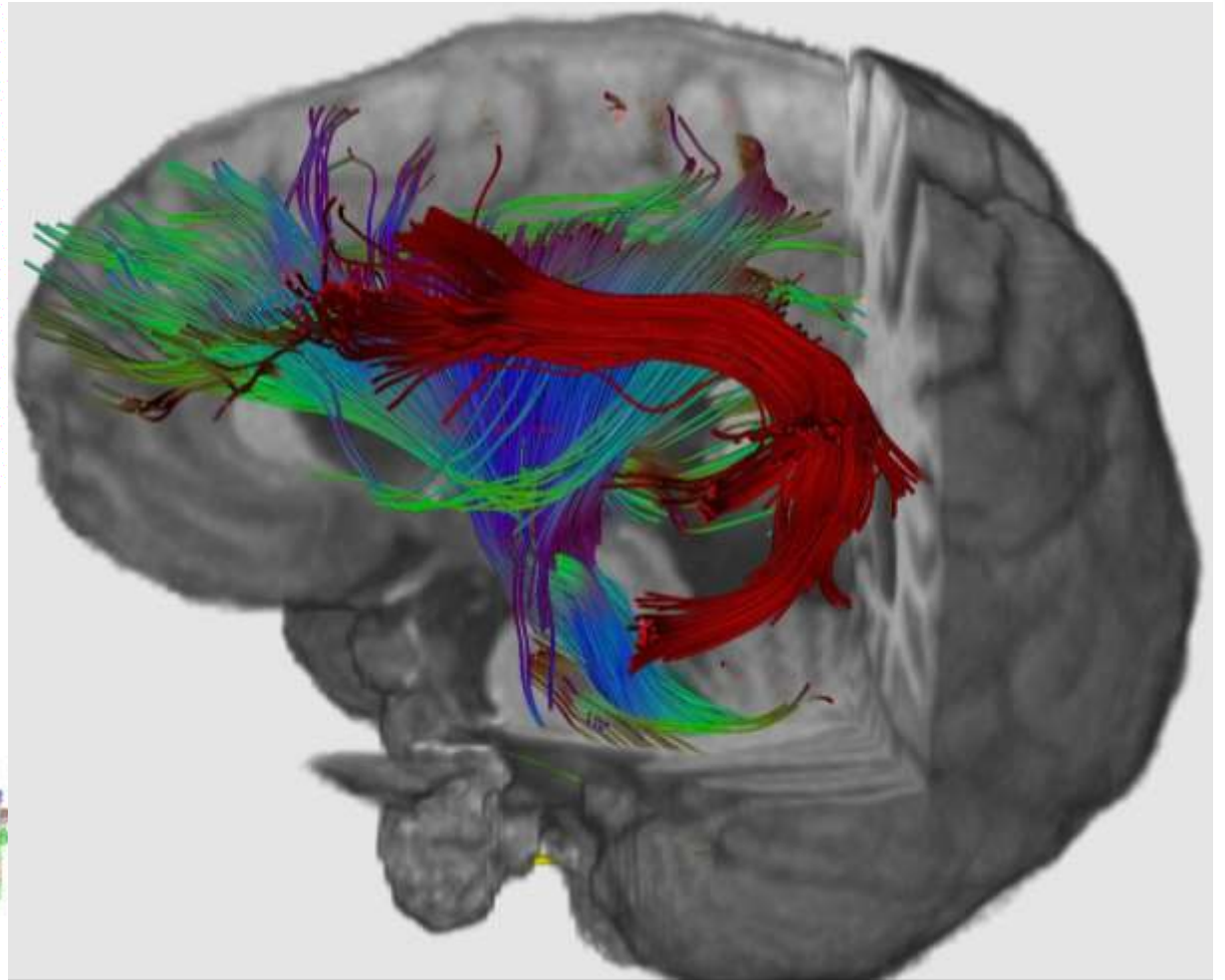
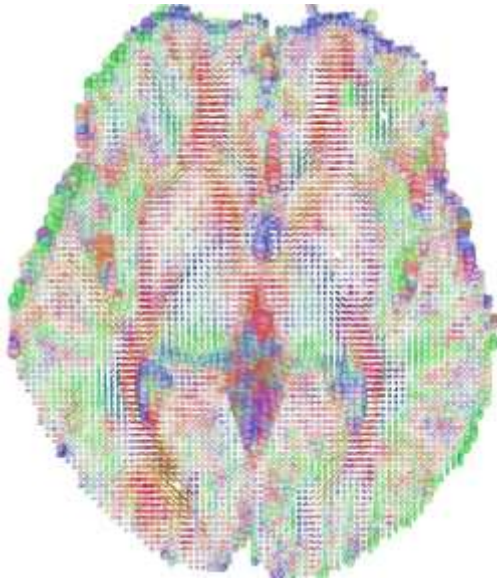
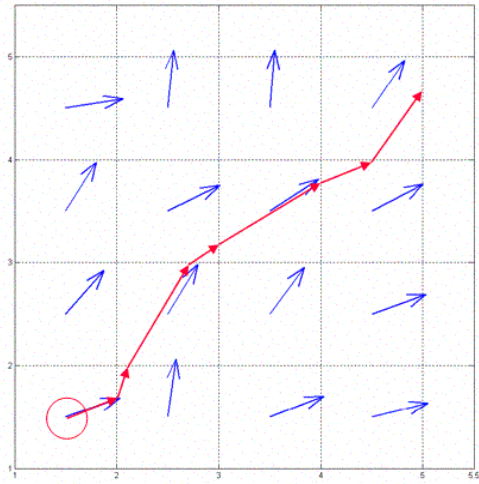
IRM de Tenseur de Diffusion

Tractographie



(d'après D. Le Bihan)





IRM de Tenseur de Diffusion

Tractographie - Modèle Advection - Diffusion

- Mélange d'un terme de diffusion et d'advection.
- Diffusion : suit la direction principale du tenseur v_1 .
- Advection : combinaison linéaire entre la direction précédente v_{in} et $v_{out} = Dv_{in}$.

$$v_{out} = \underbrace{c_l v_1}_{\text{diffusion}} + \underbrace{(1 - c_l) \left((1 - \omega) v_{in} + \omega v_{out} \right)}_{\text{advection}}$$

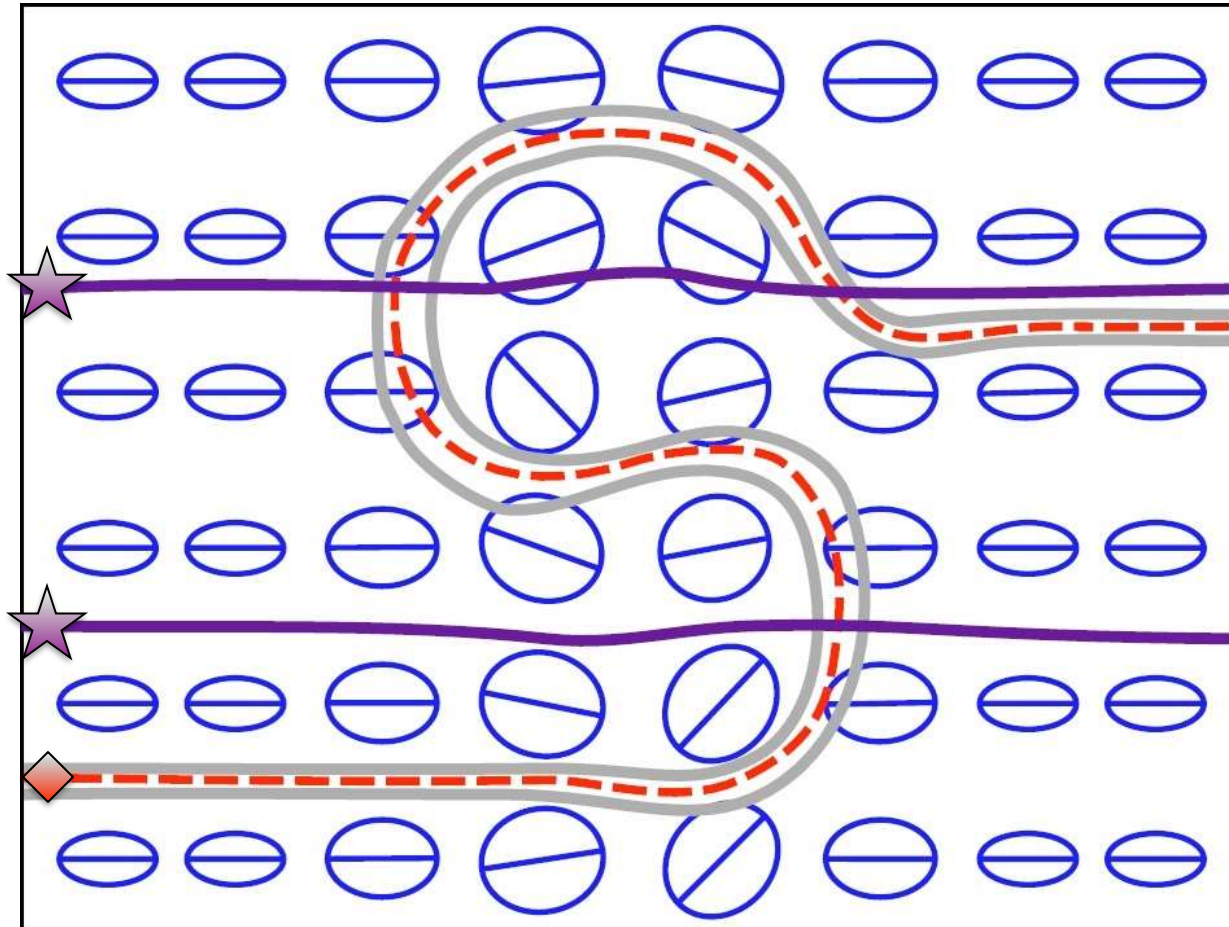
- Amélioration: interpolation tri-linéaire du champ de tenseurs avec les métriques Log-Euclidiennes ⁽²⁾.

(1) : Weinstein et al., IEEE Viz'99

(2) : Fillard et Al, IEEE 2007

IRM de Tenseur de Diffusion

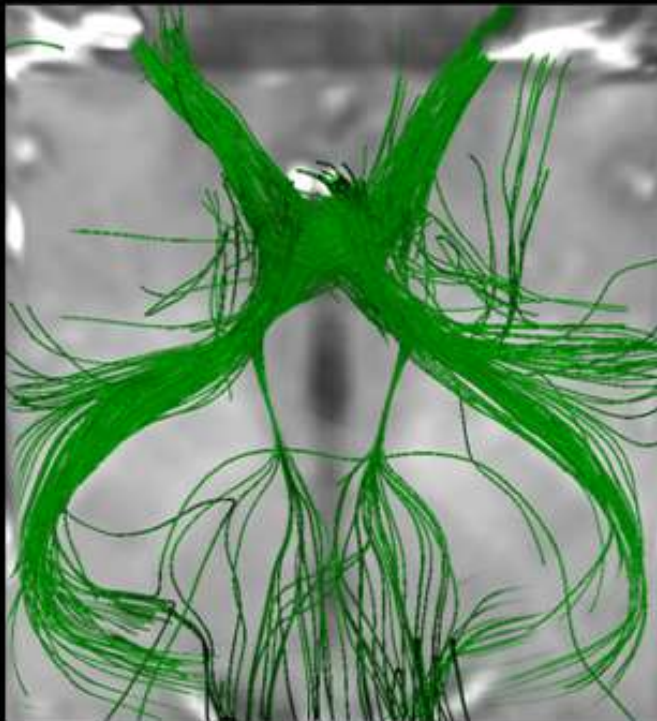
Tractographie - Comparaison FACT / AD



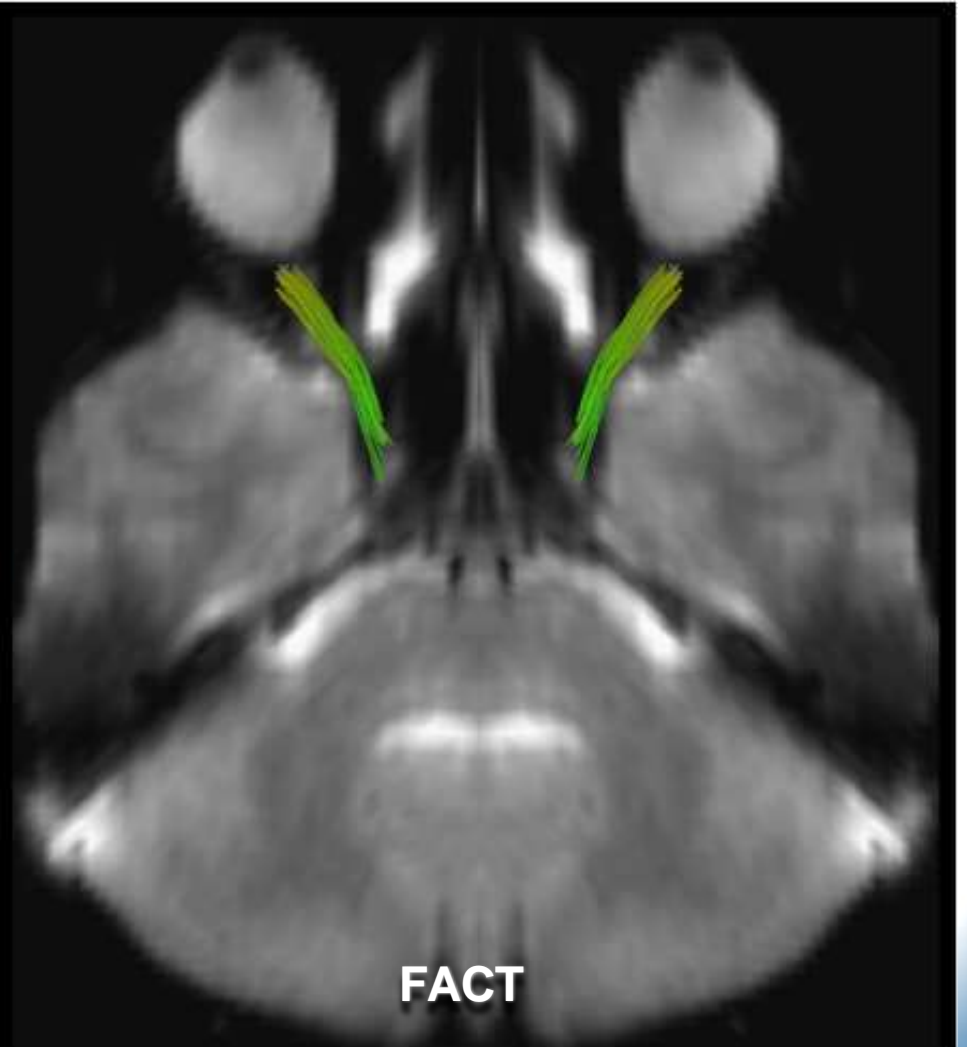
Streamline vs Advection - Diffusion

IRM de Tenseur de Diffusion

Tractographie - Comparaison FACT / AD

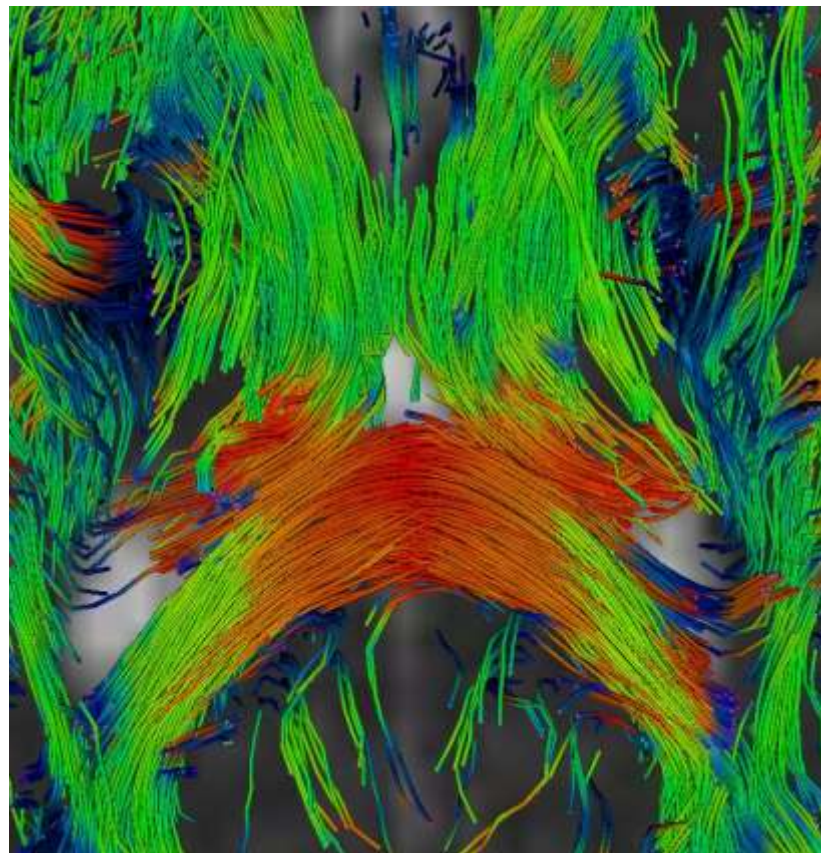
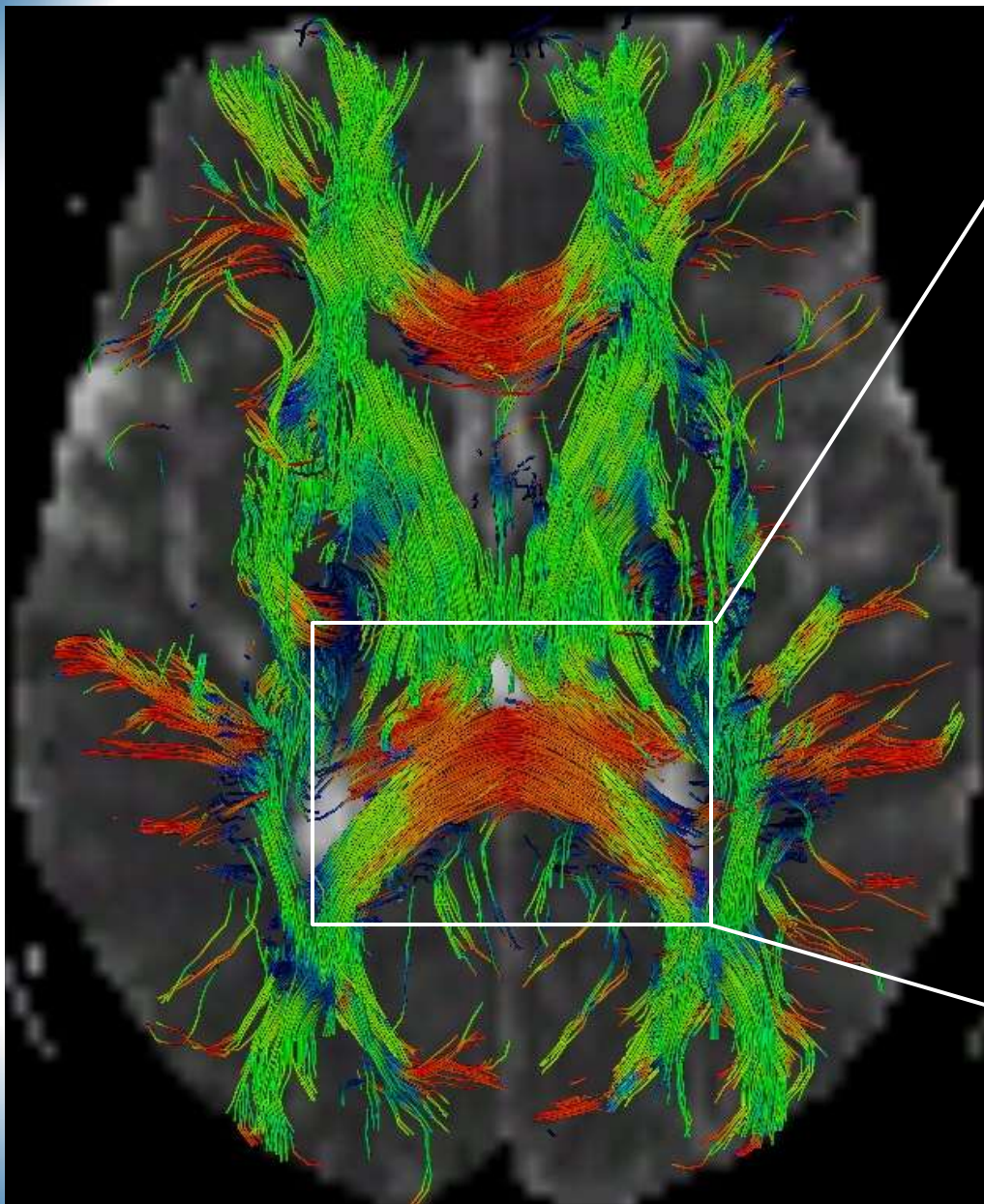


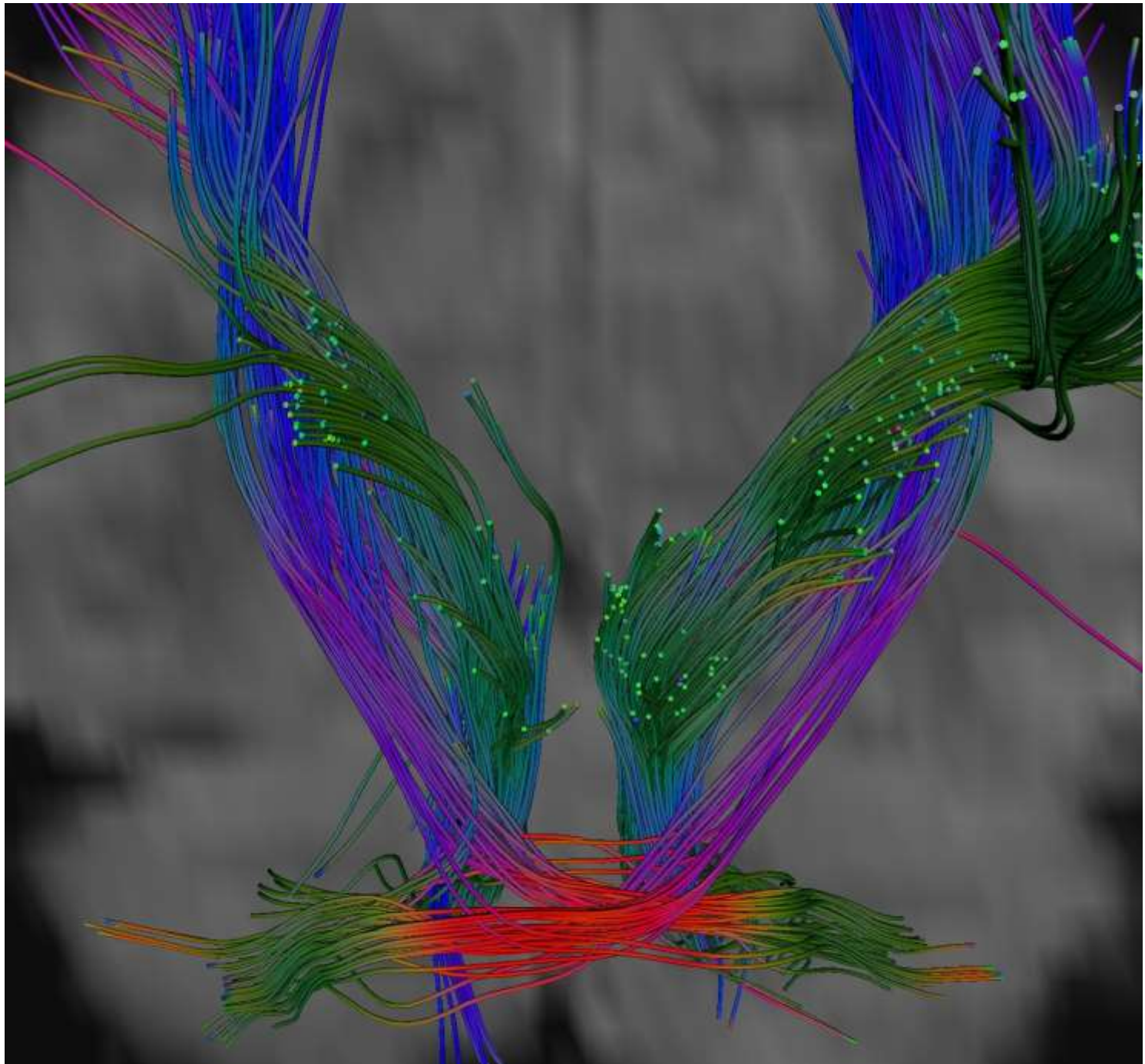
AD + Log-Euclidiens

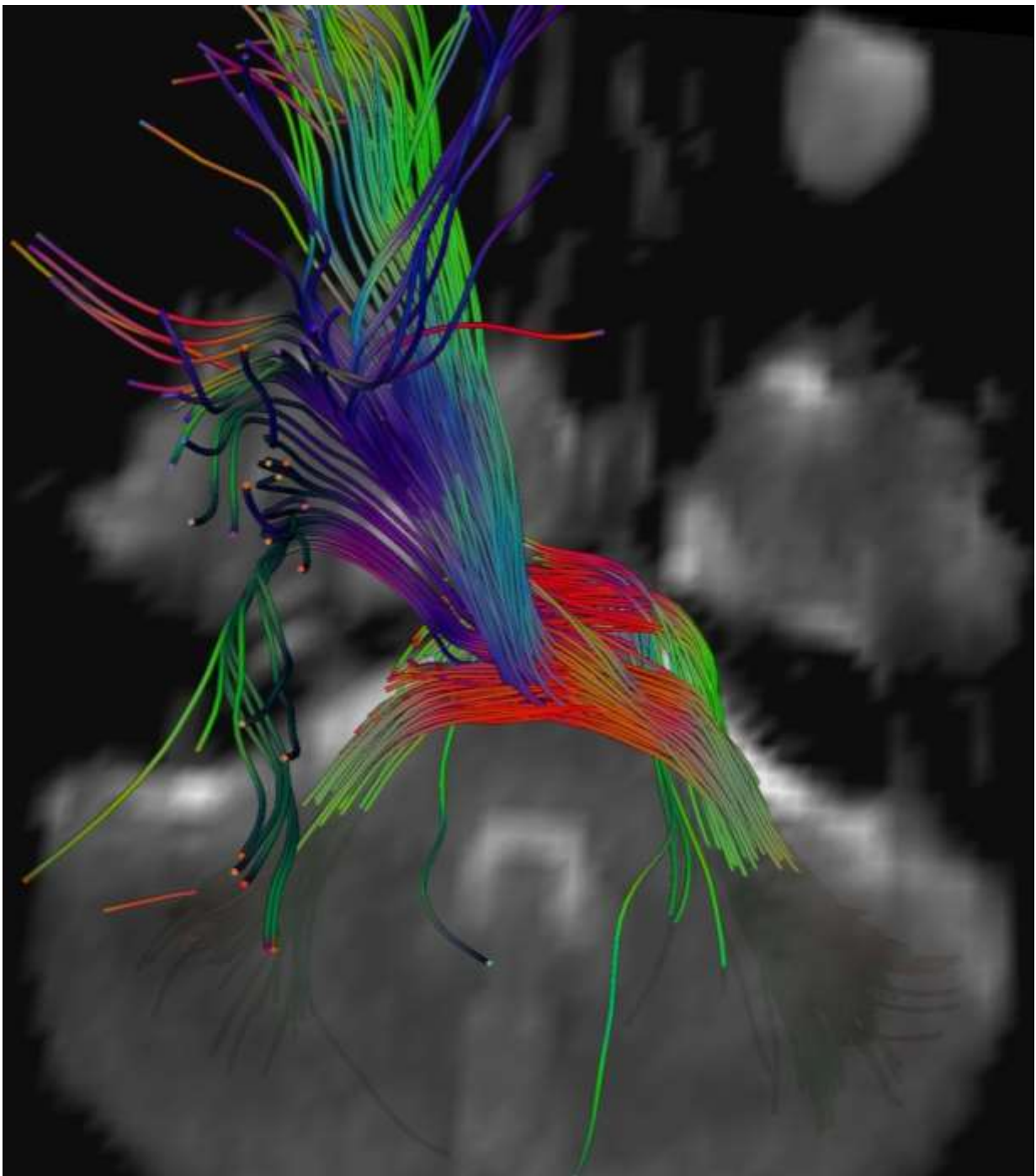


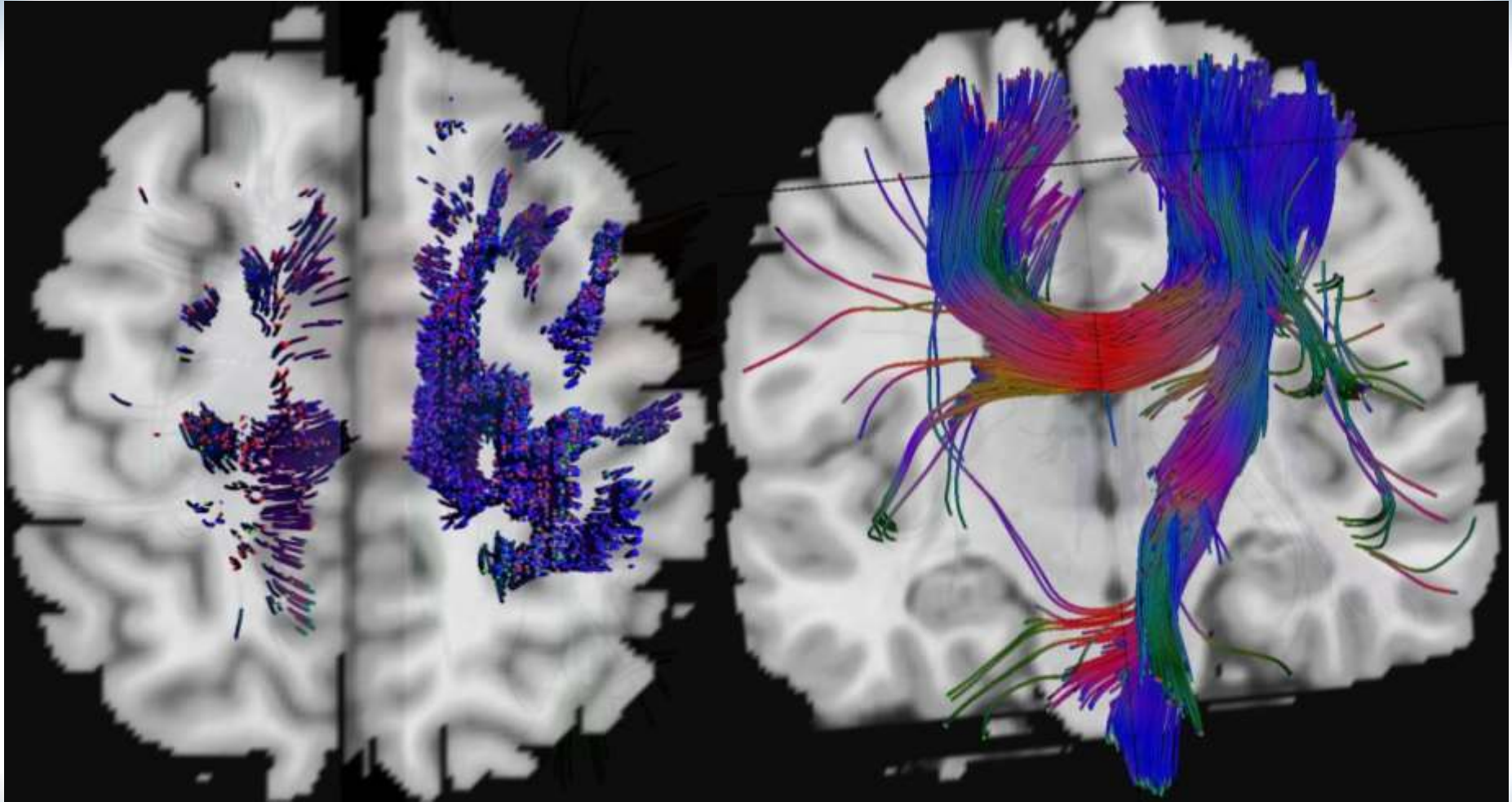
FACT

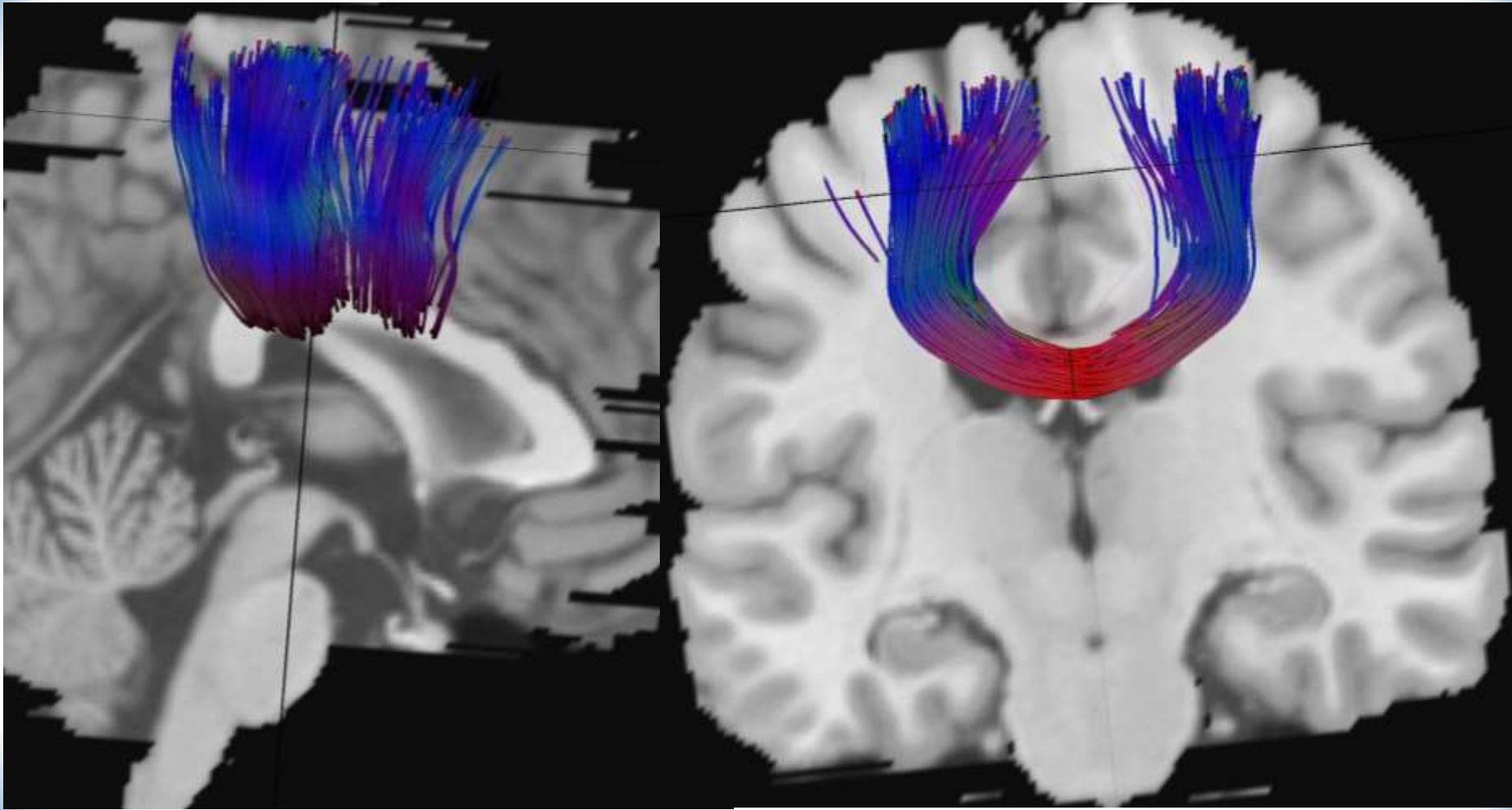
2.3.2 Anatomie Cérébrale Normale

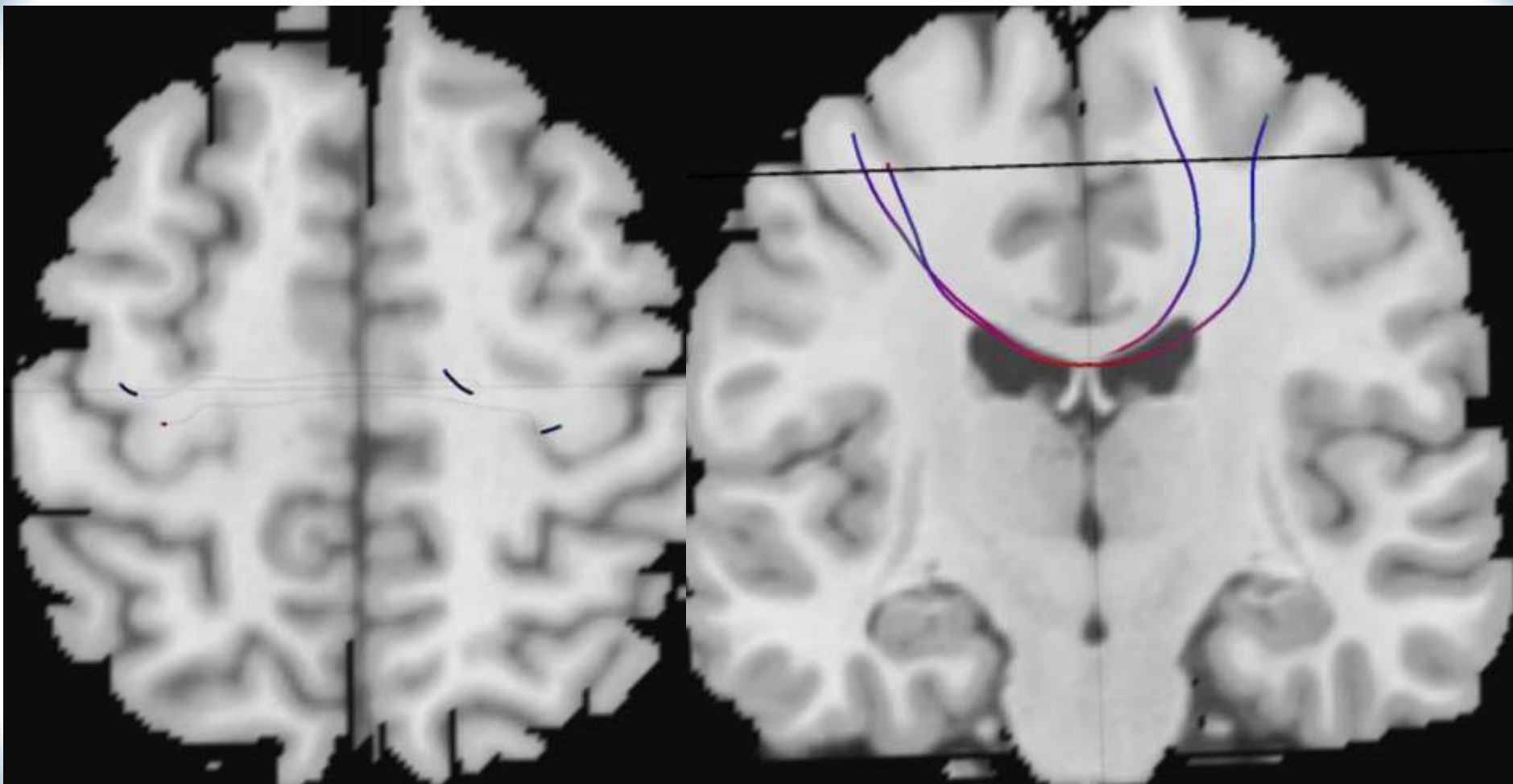


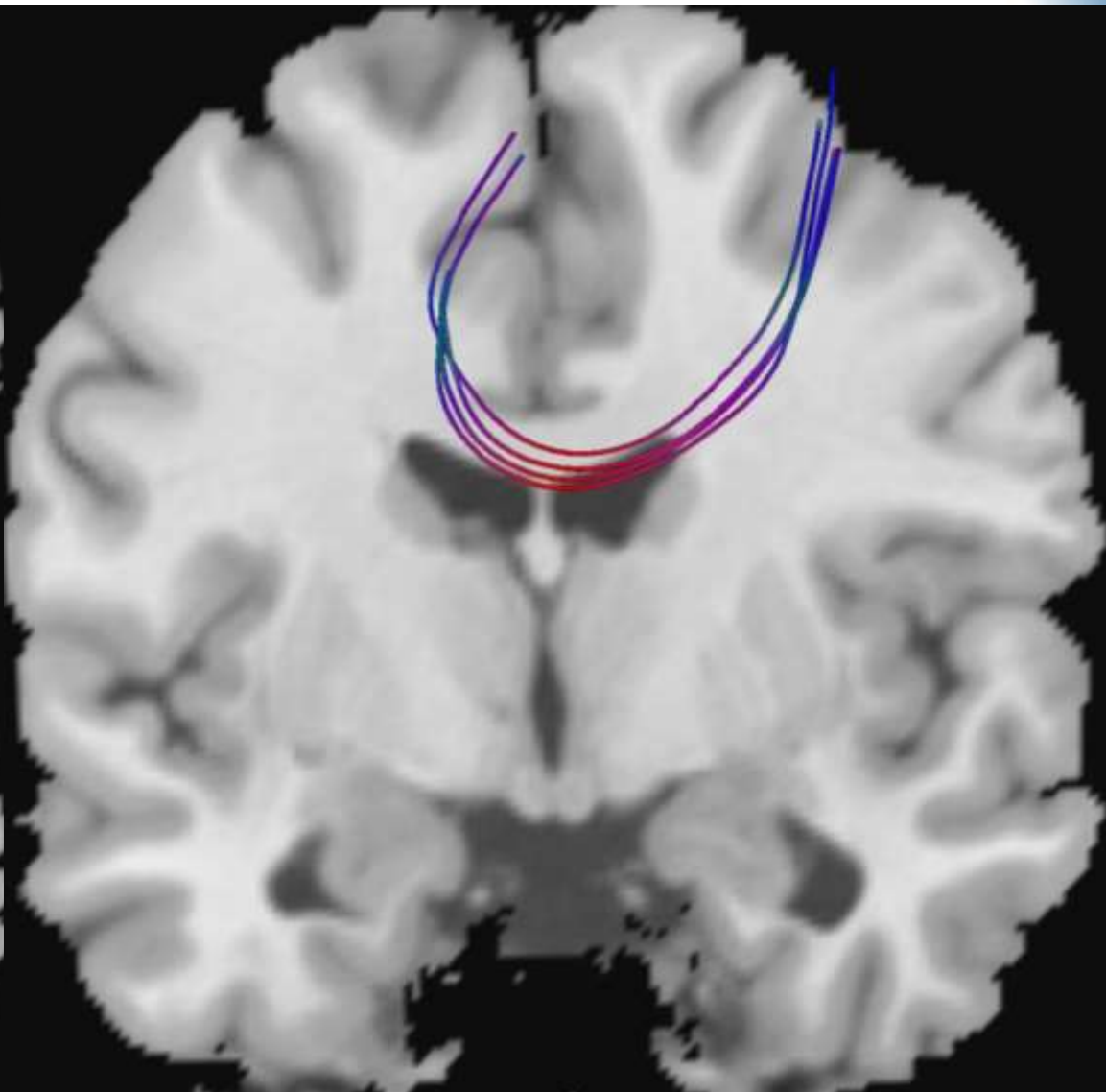
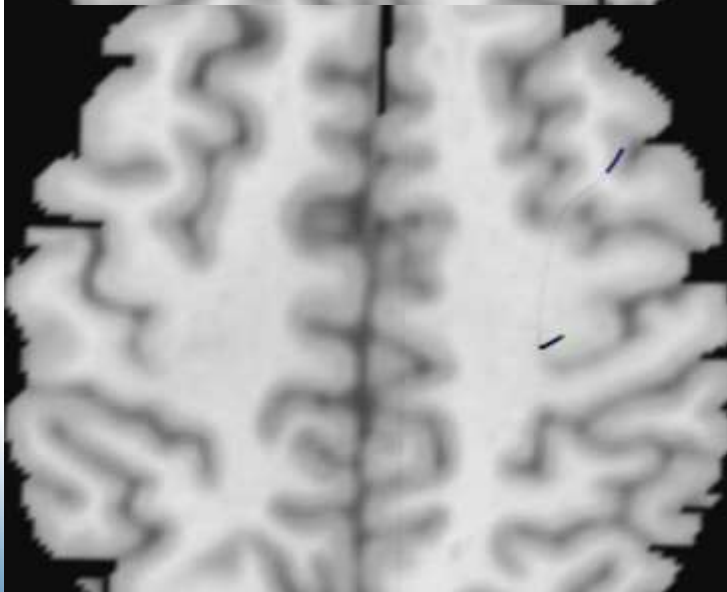
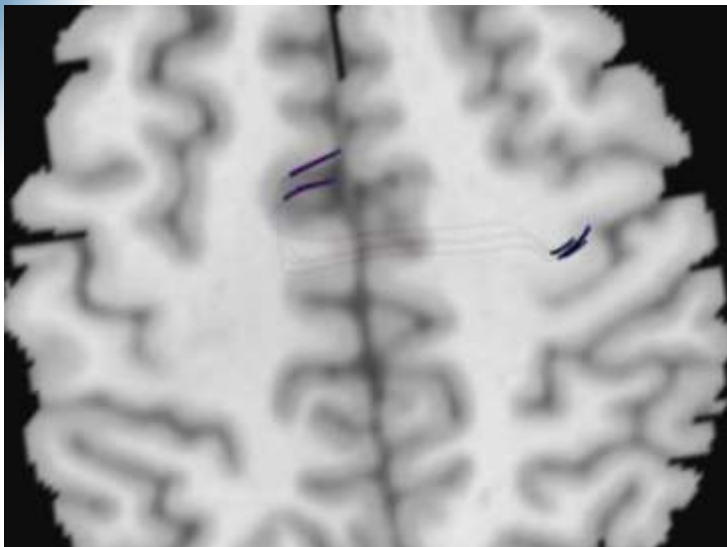






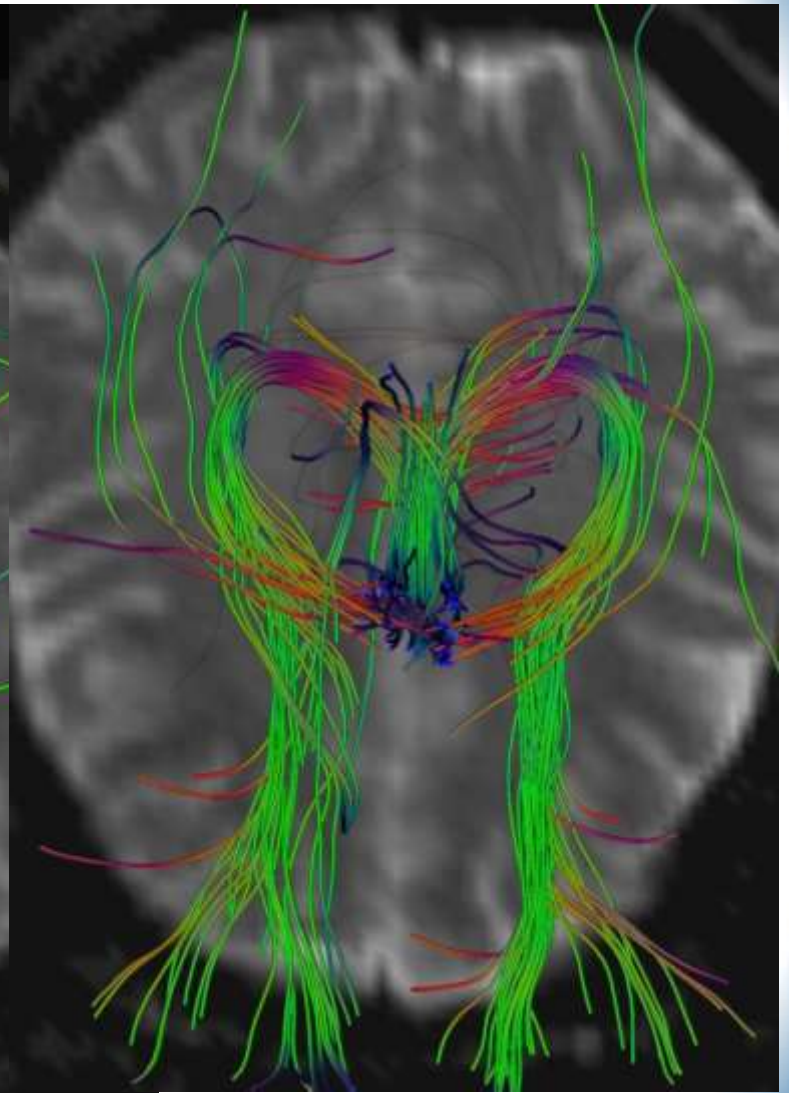
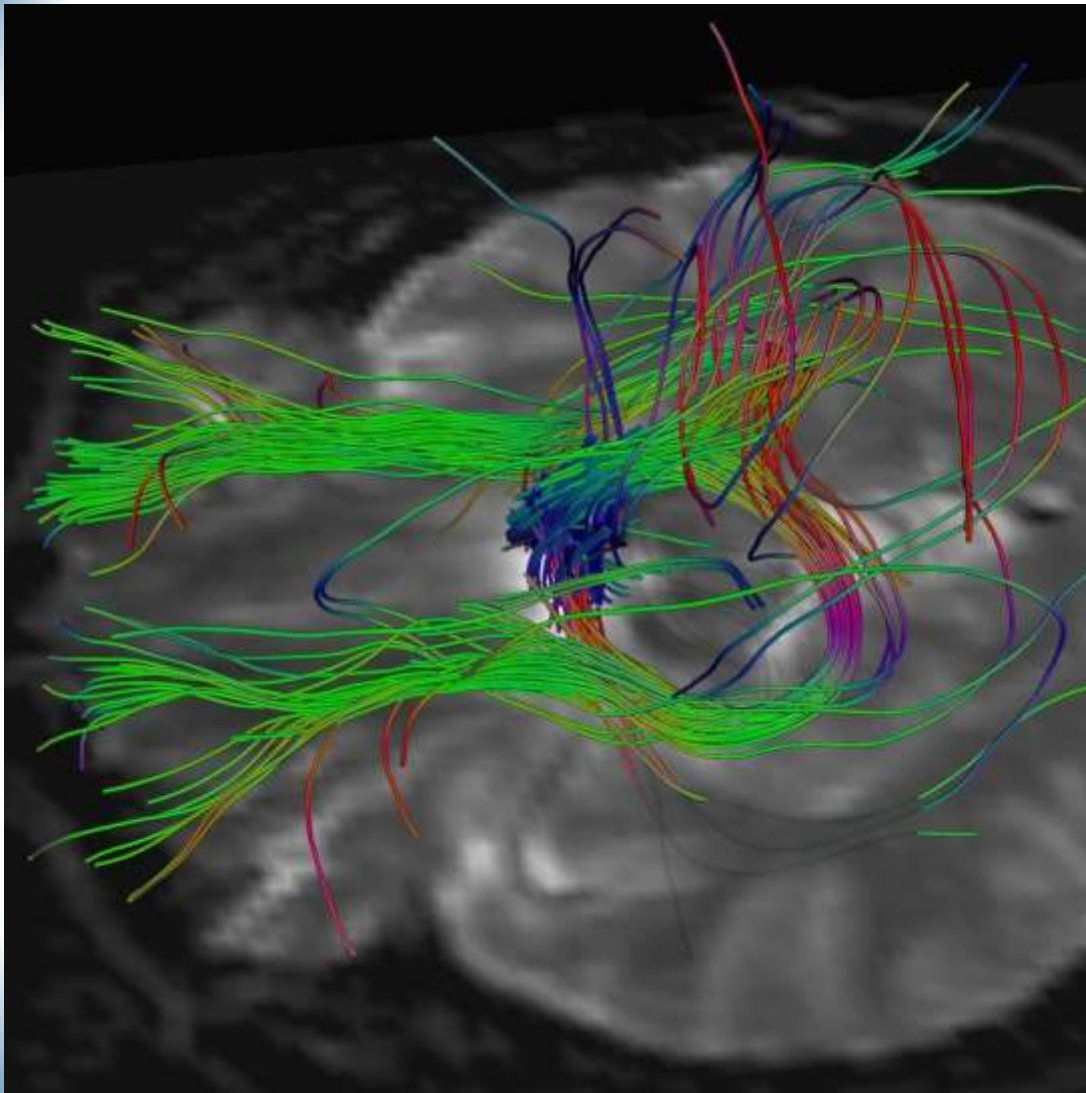


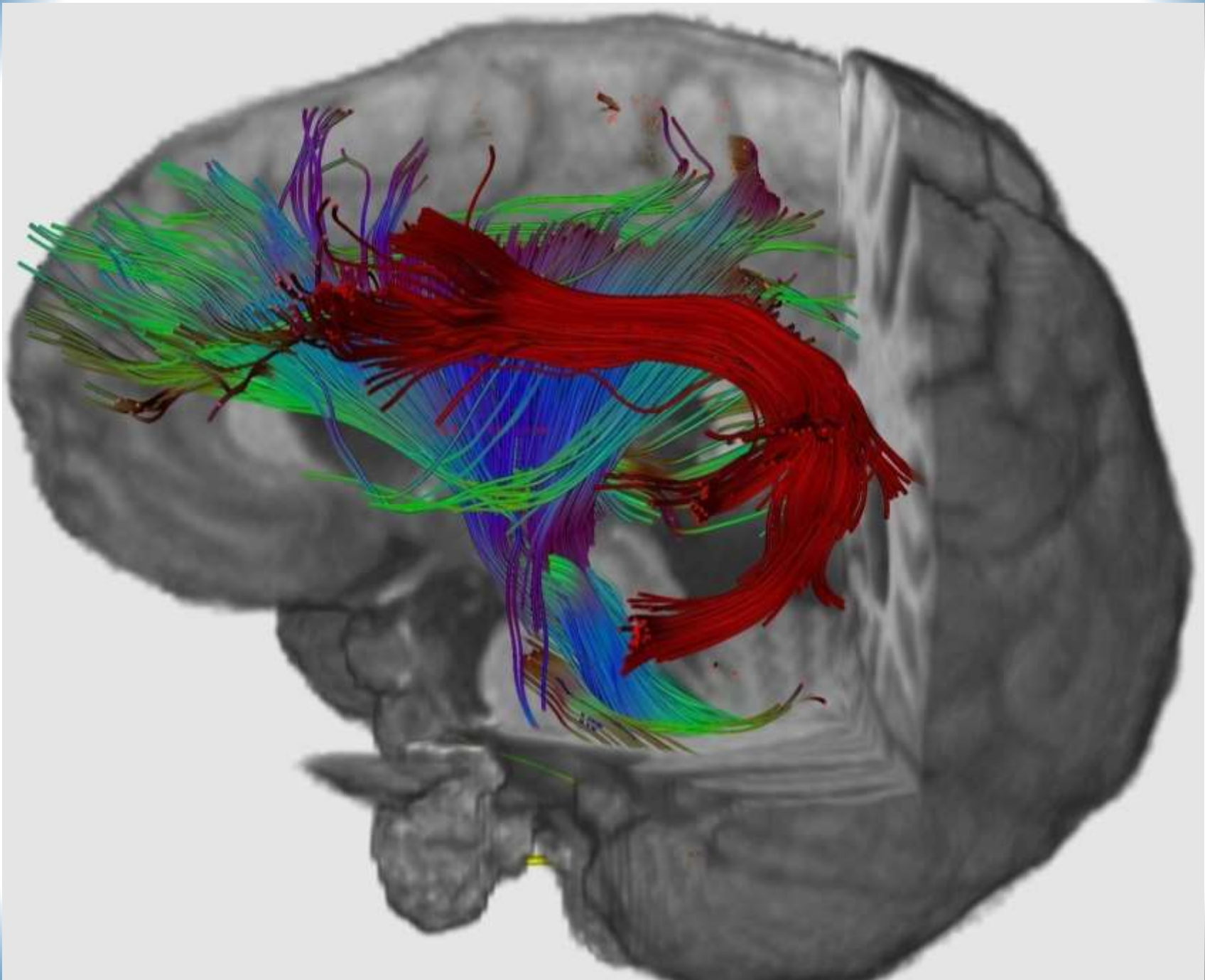


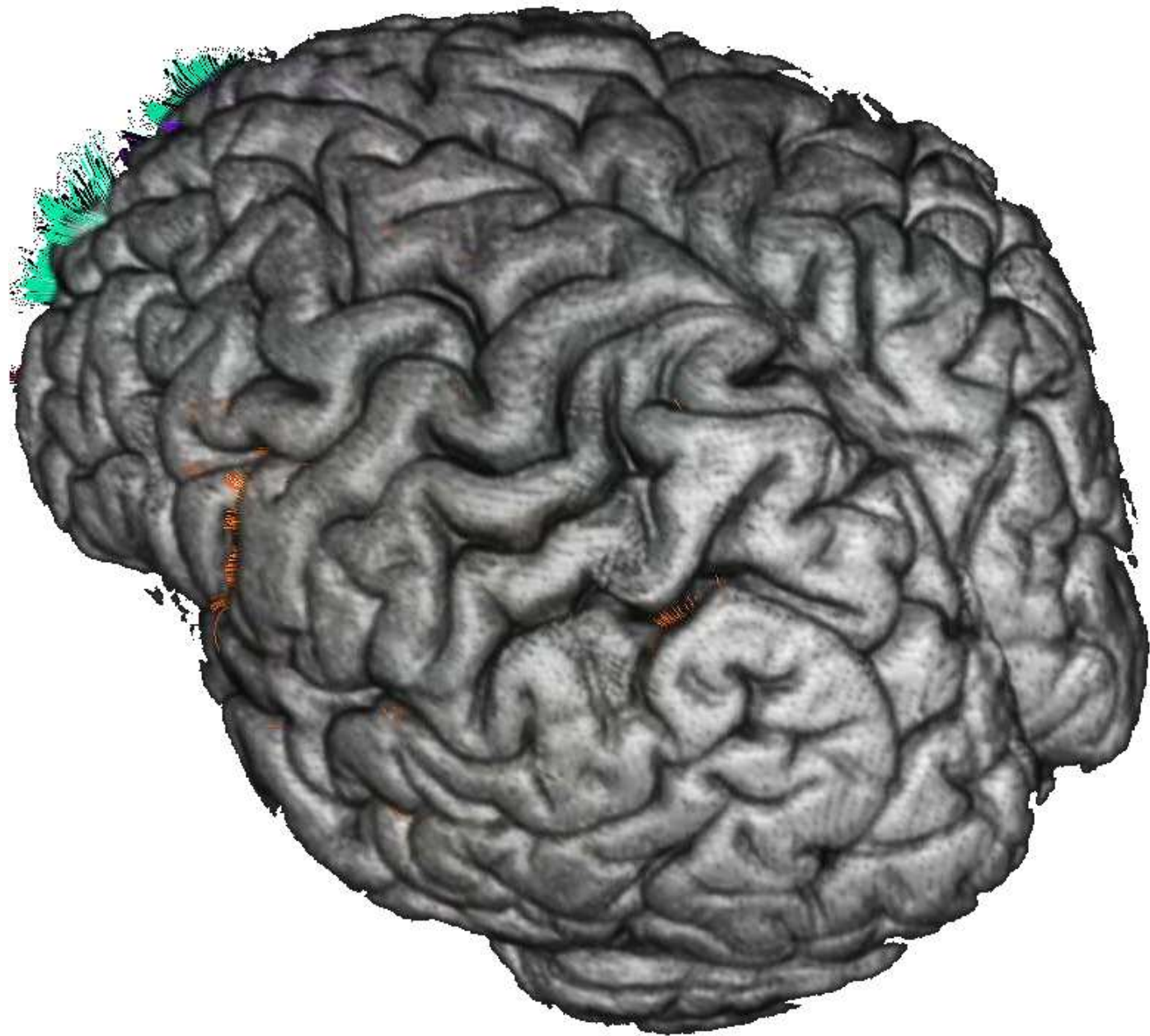


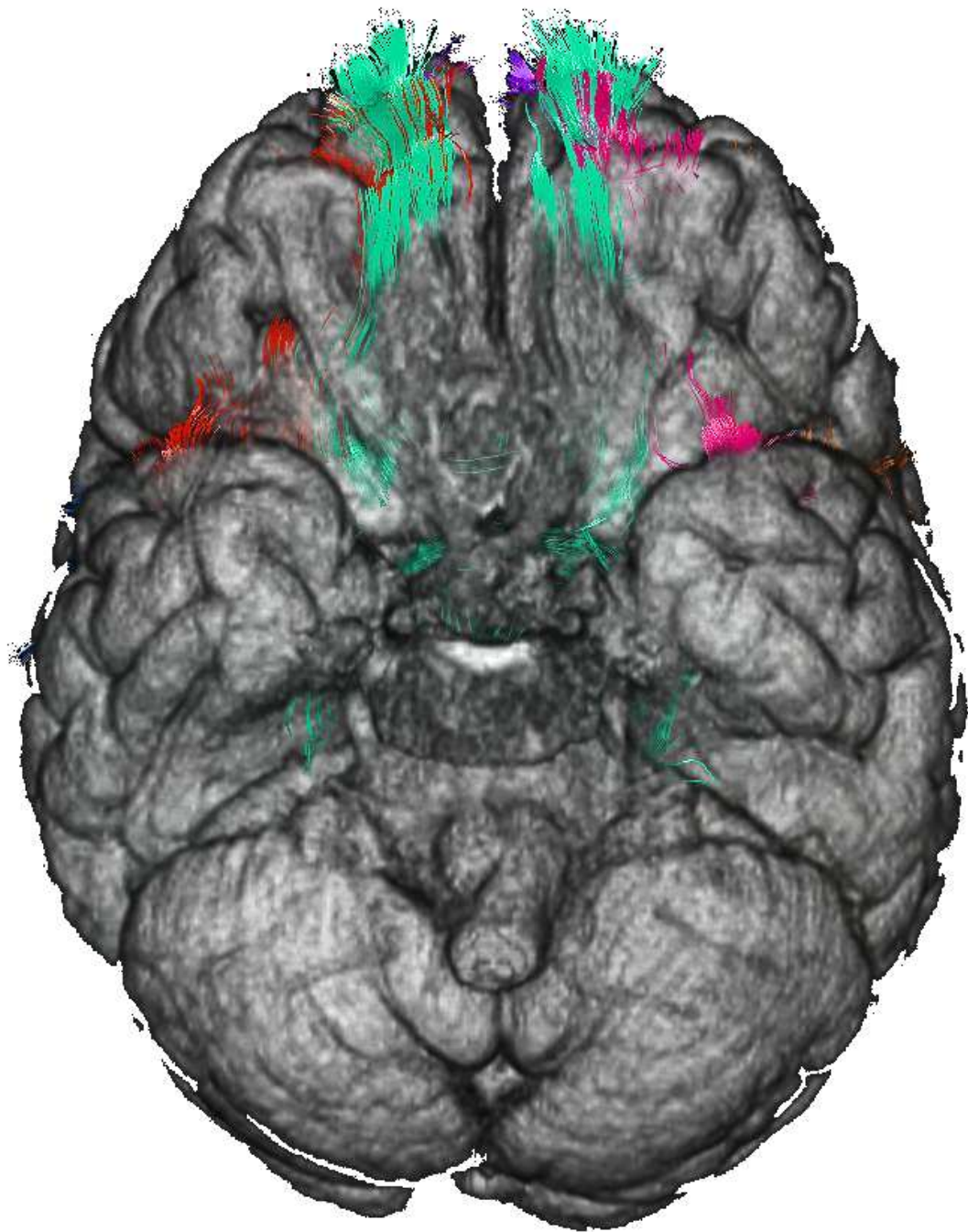


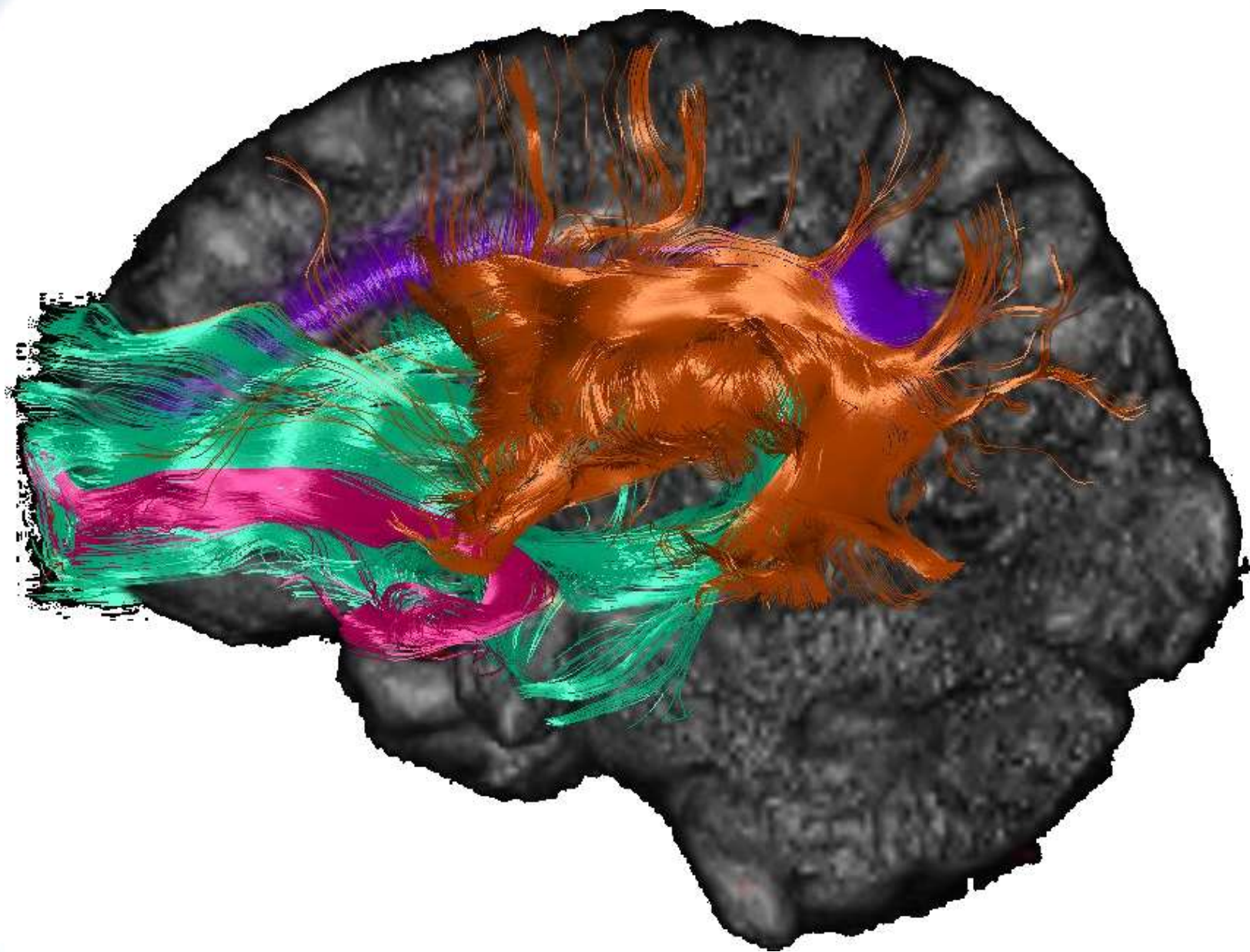
CST Sym



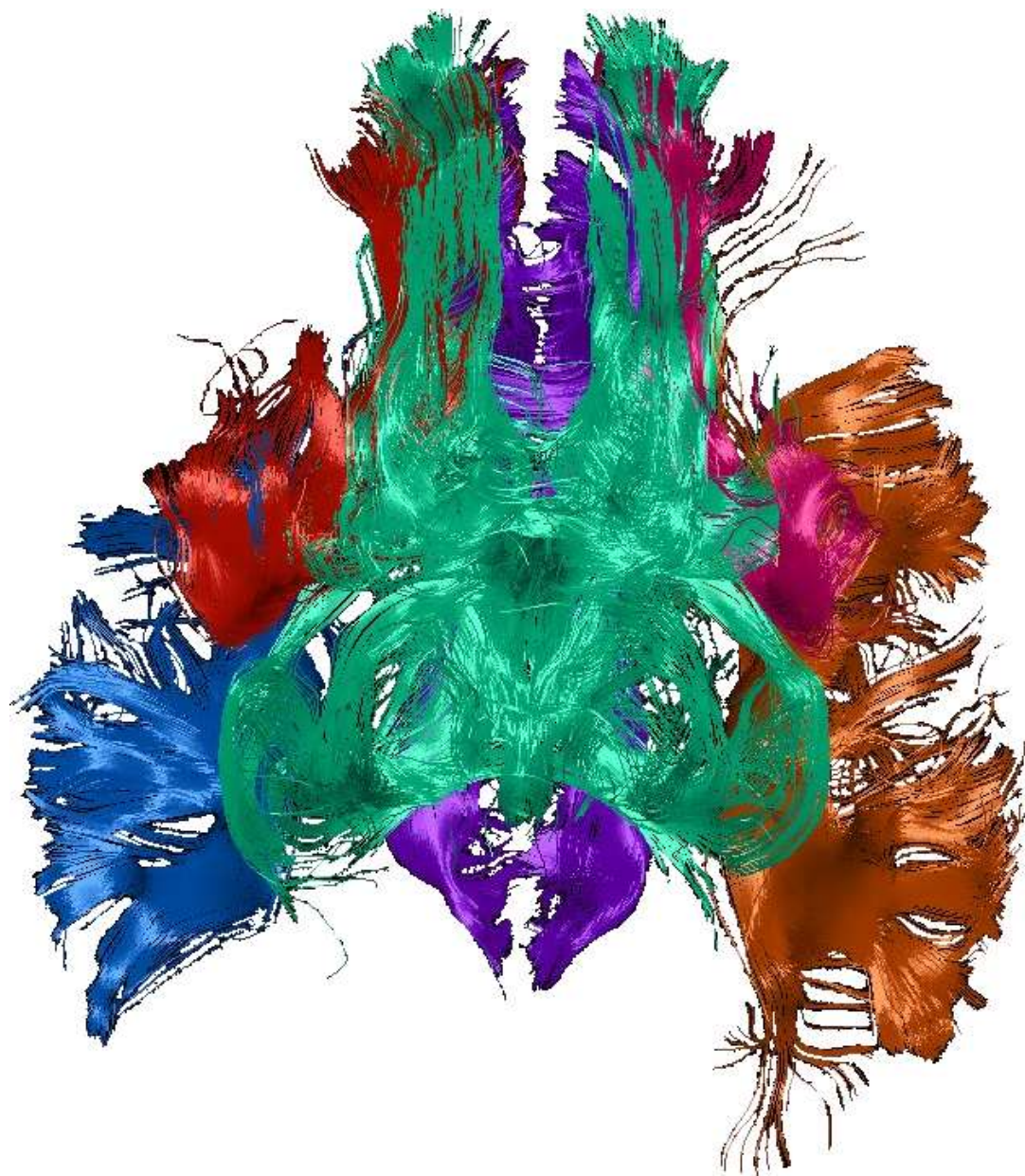


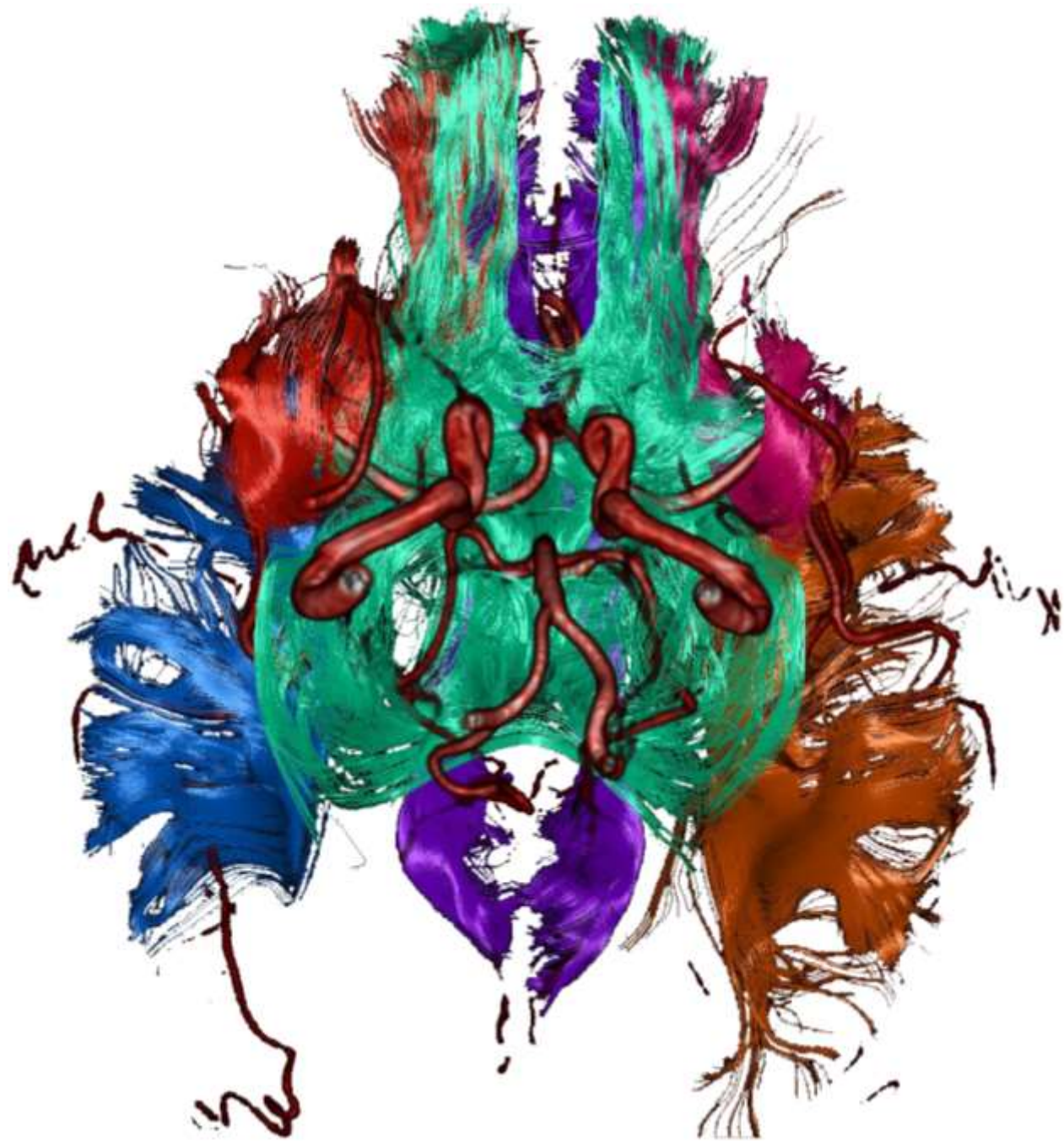


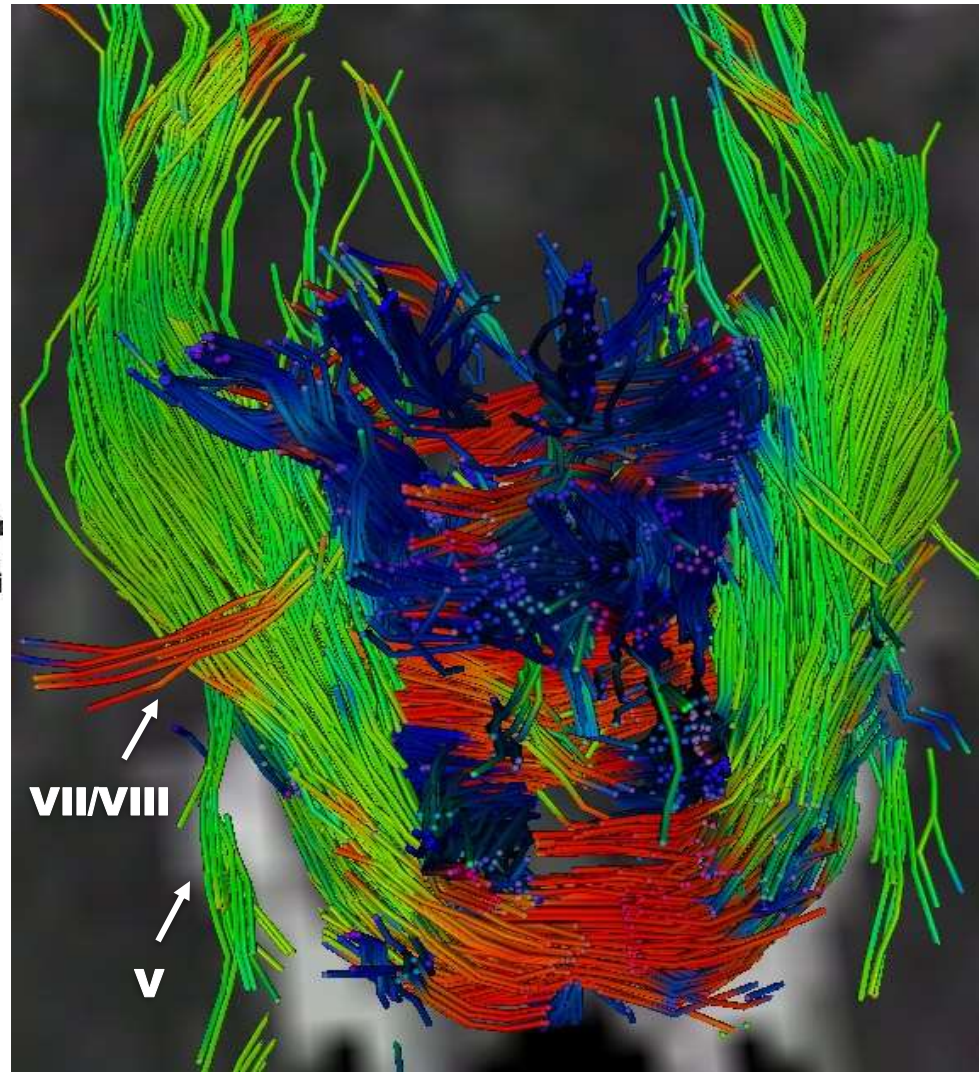
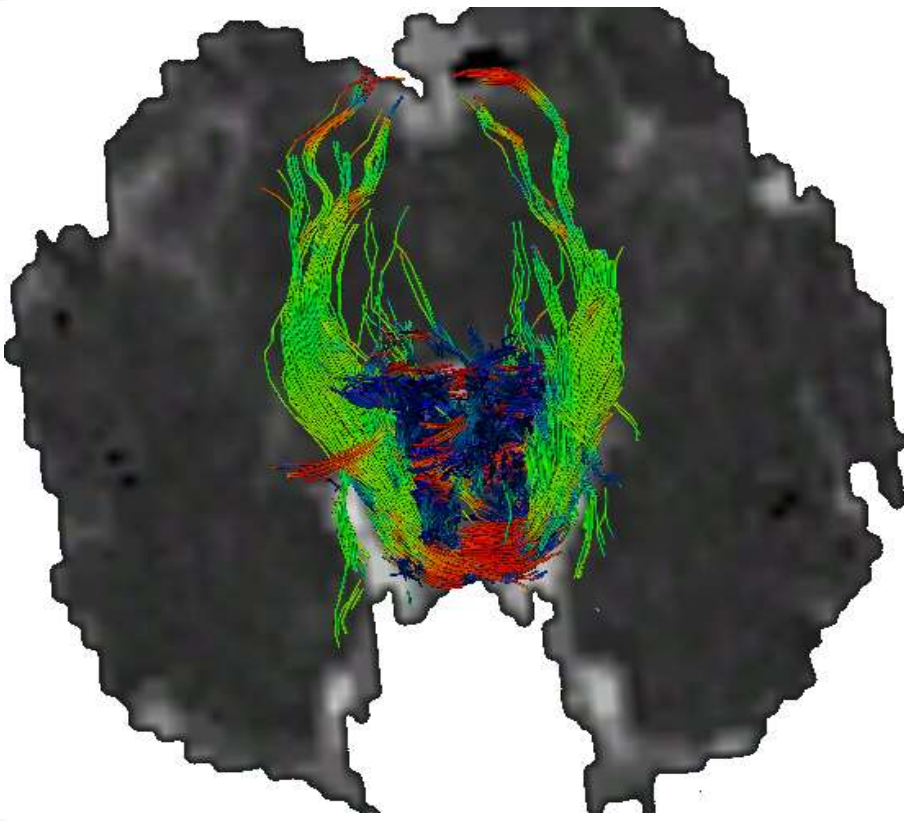


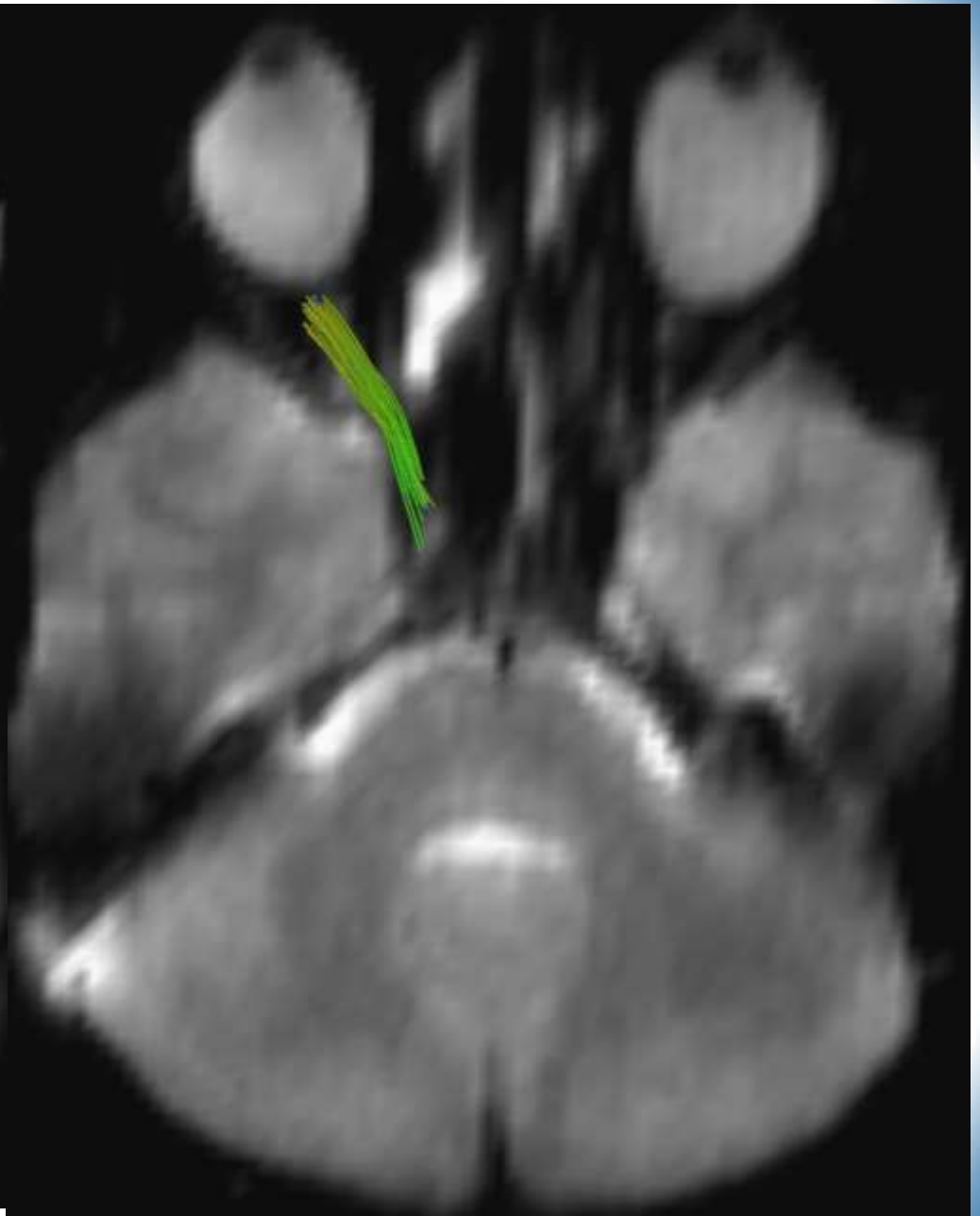
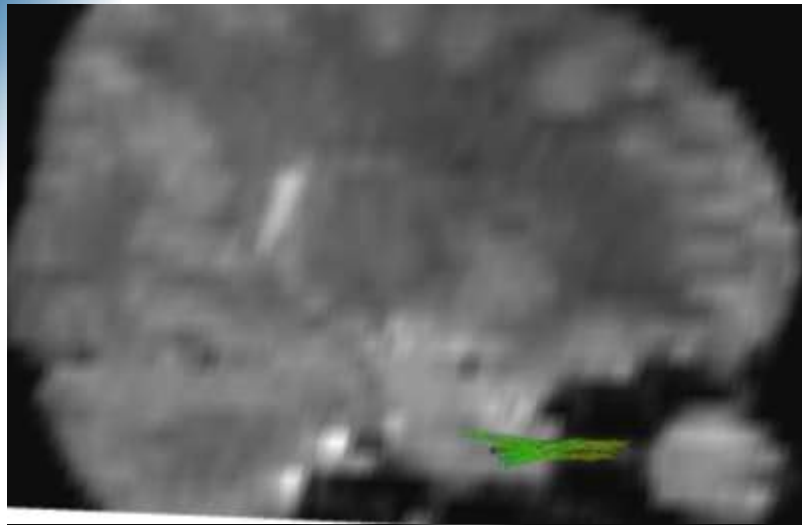






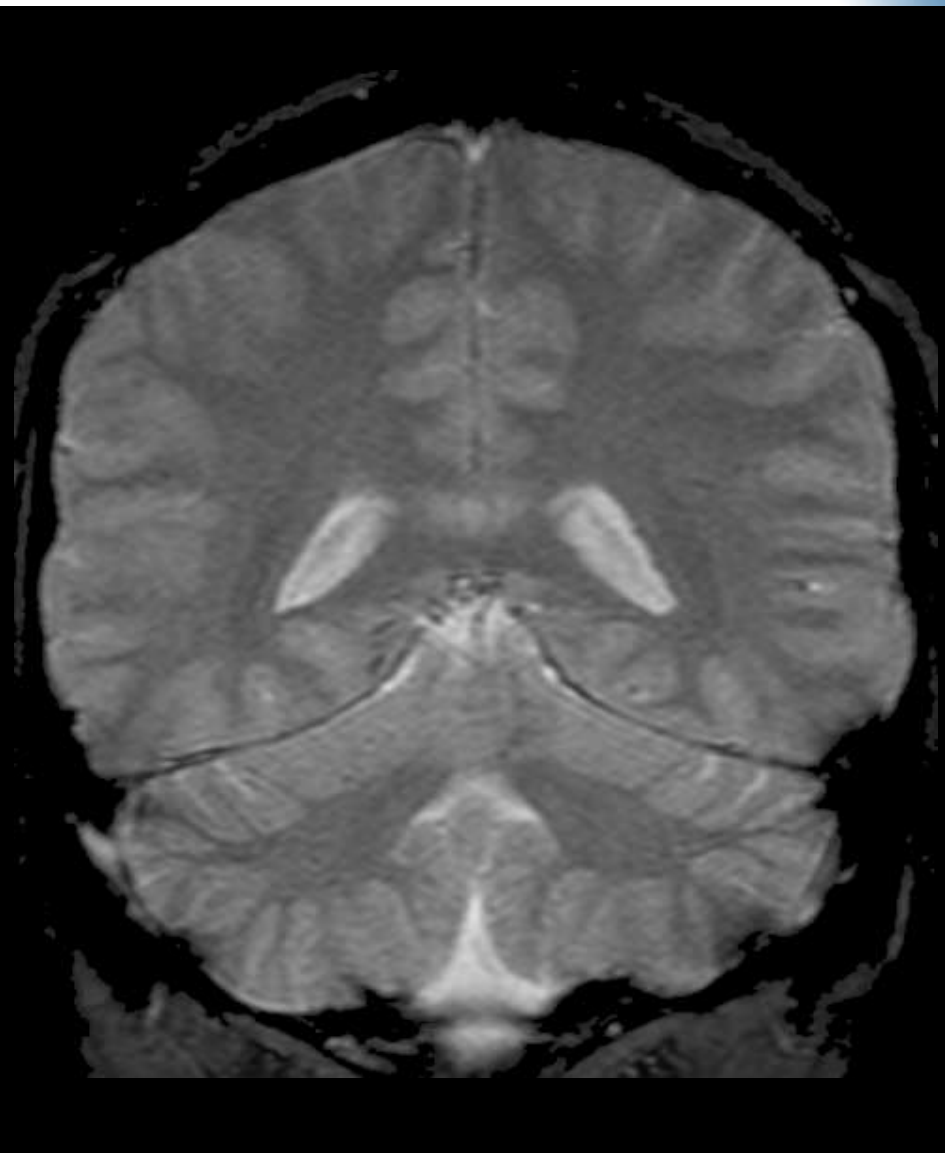
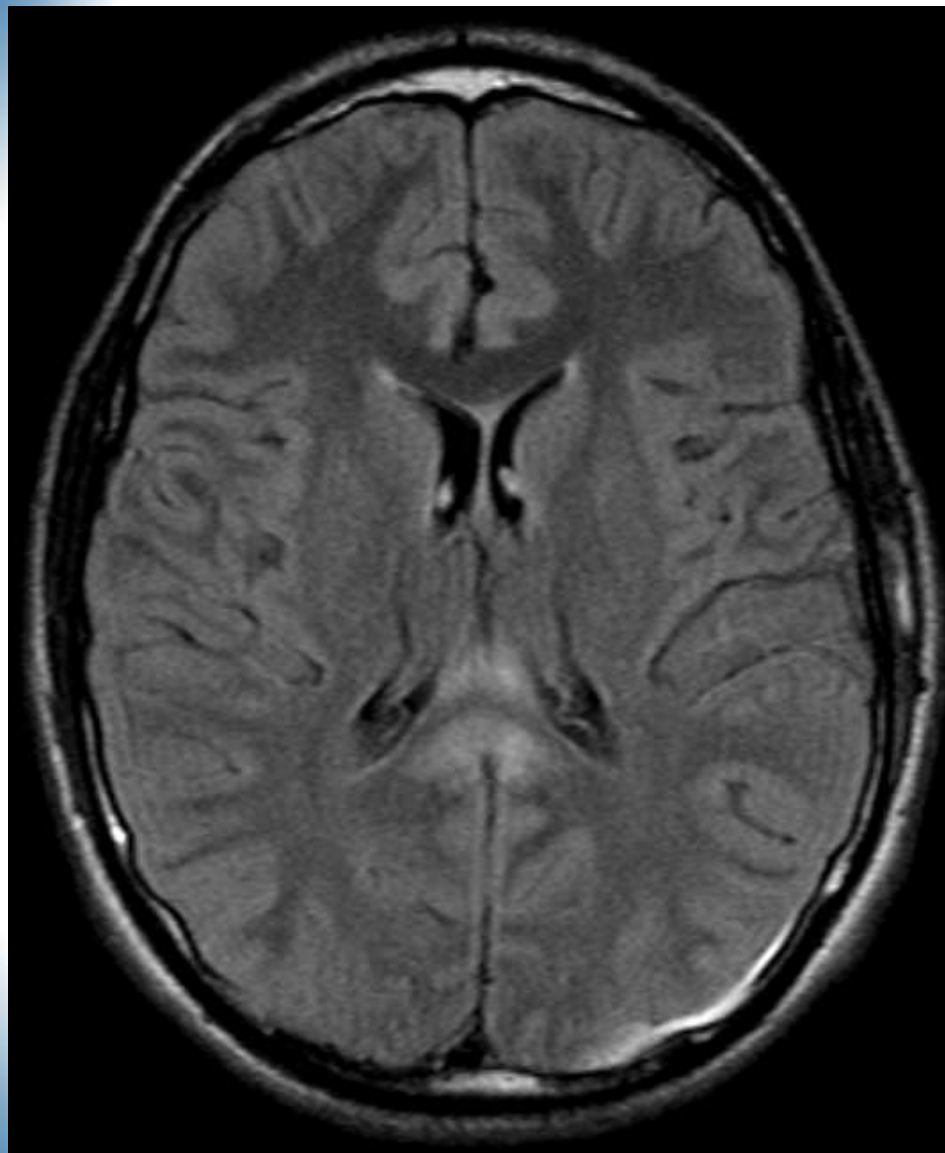


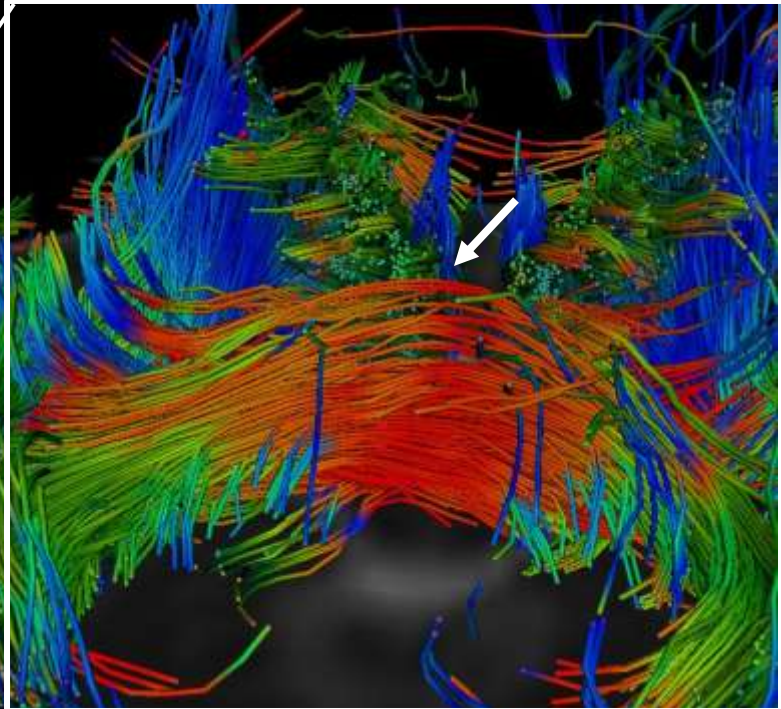
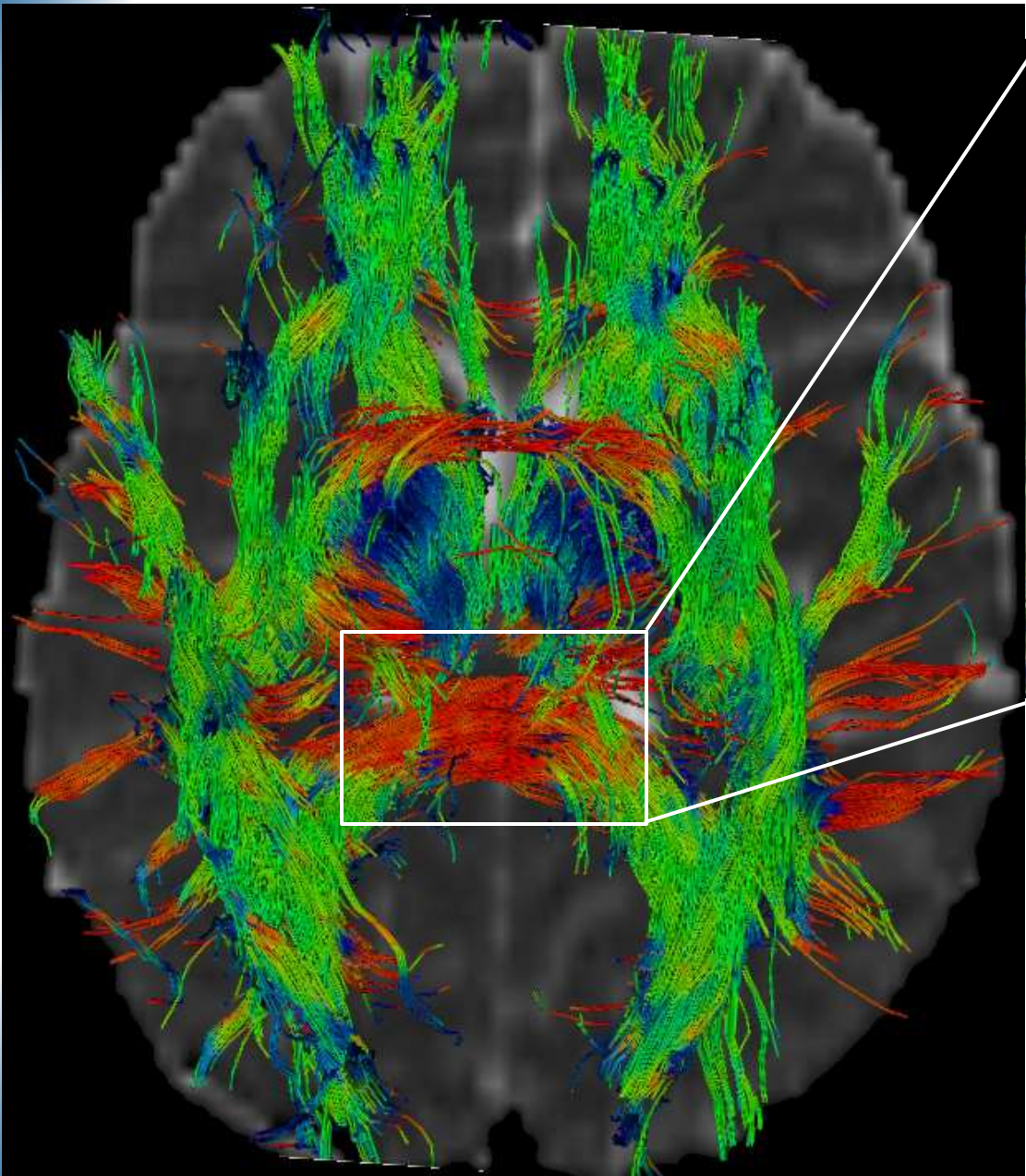


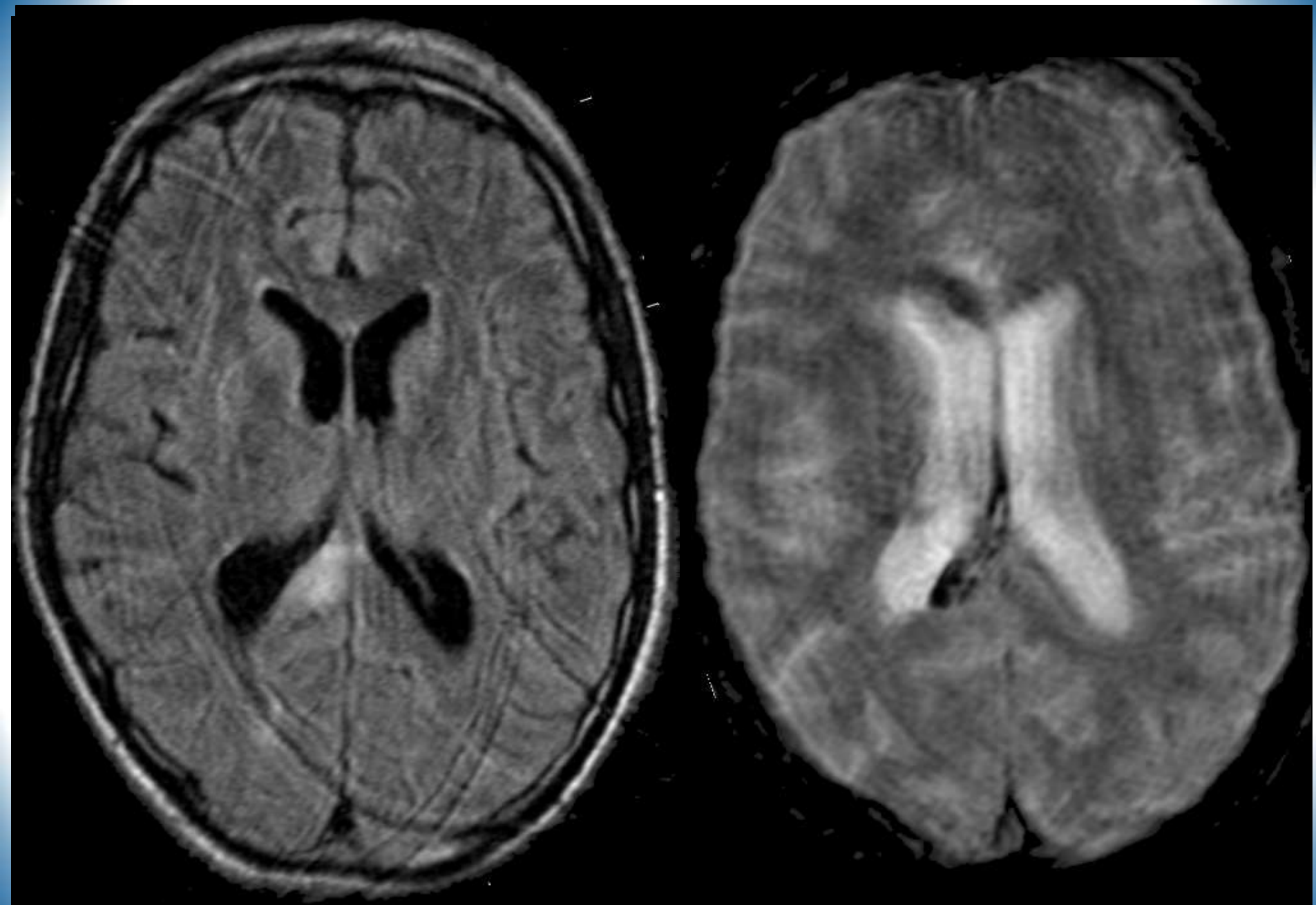


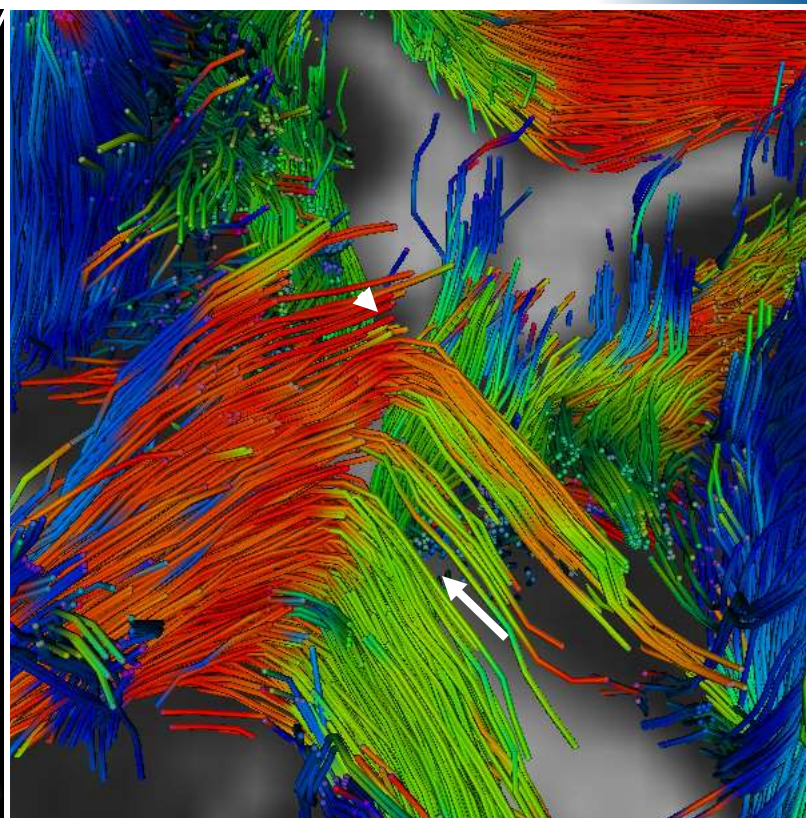
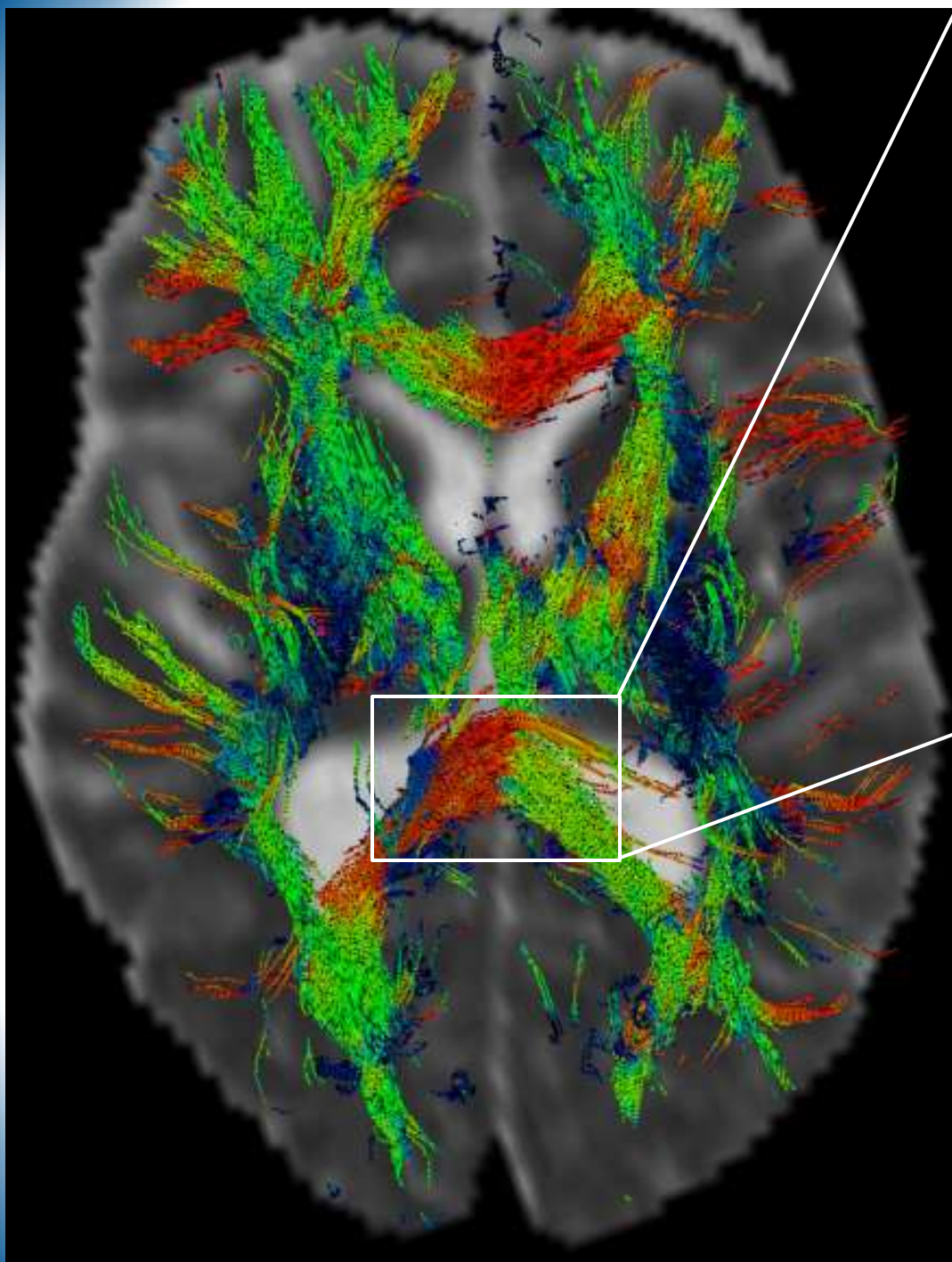
2.3.3 Applications Cliniques Cérébrales

Lésions de Cisaillement axonal

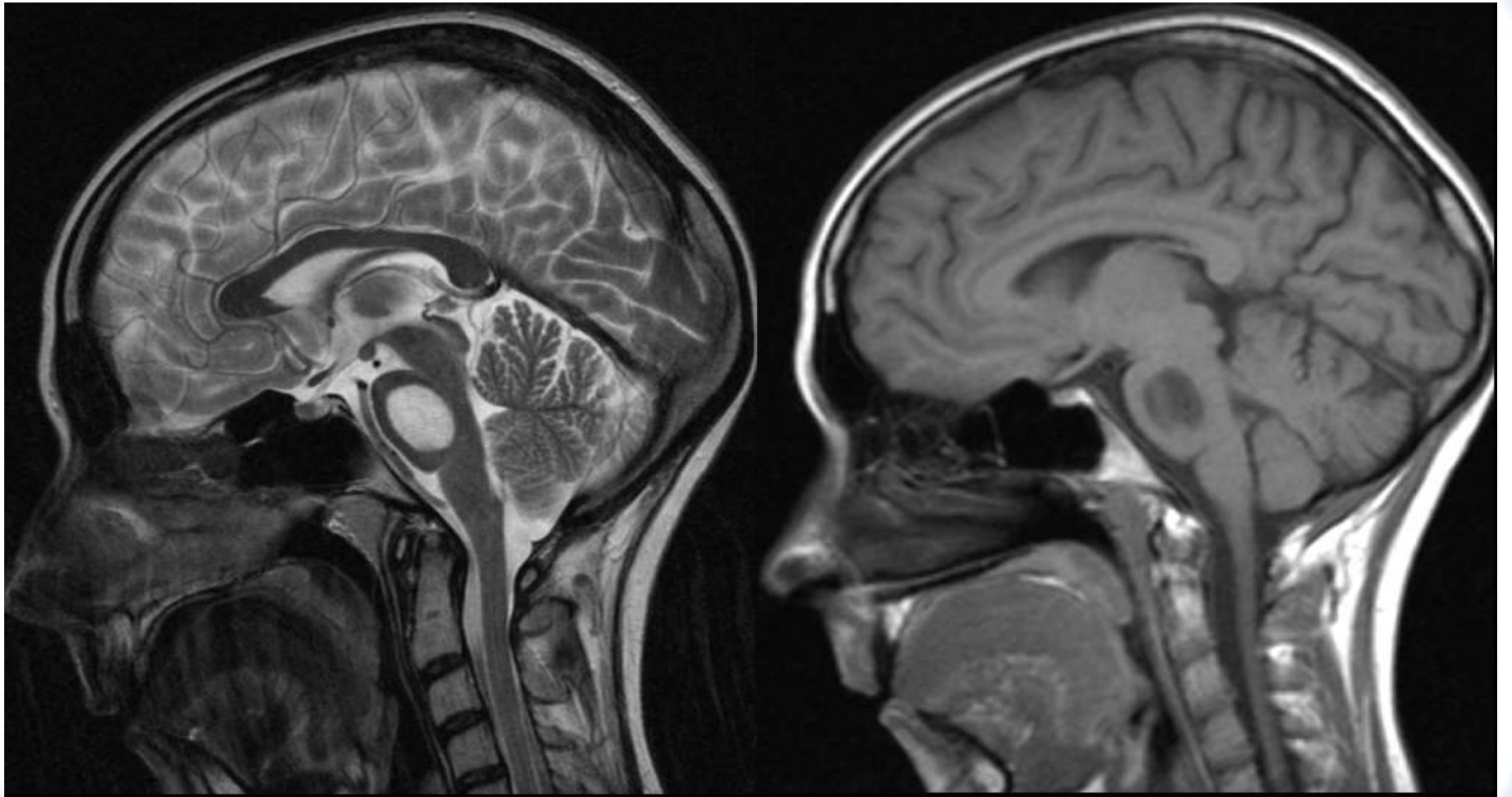


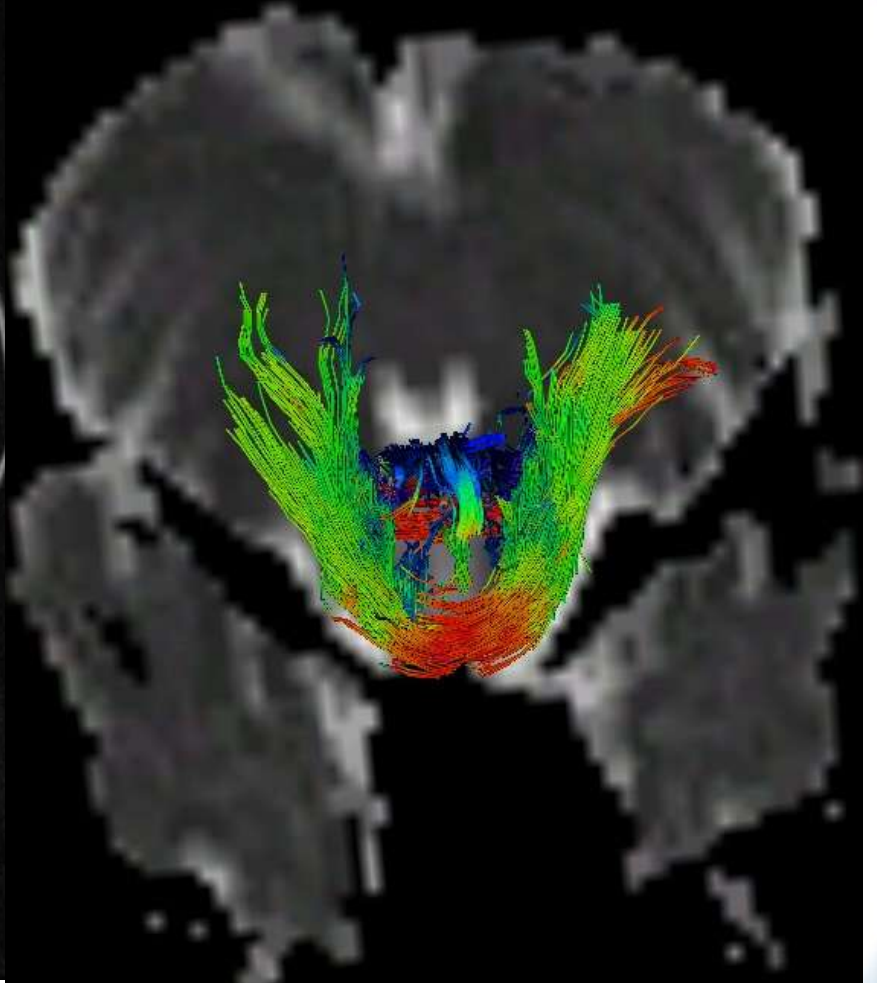


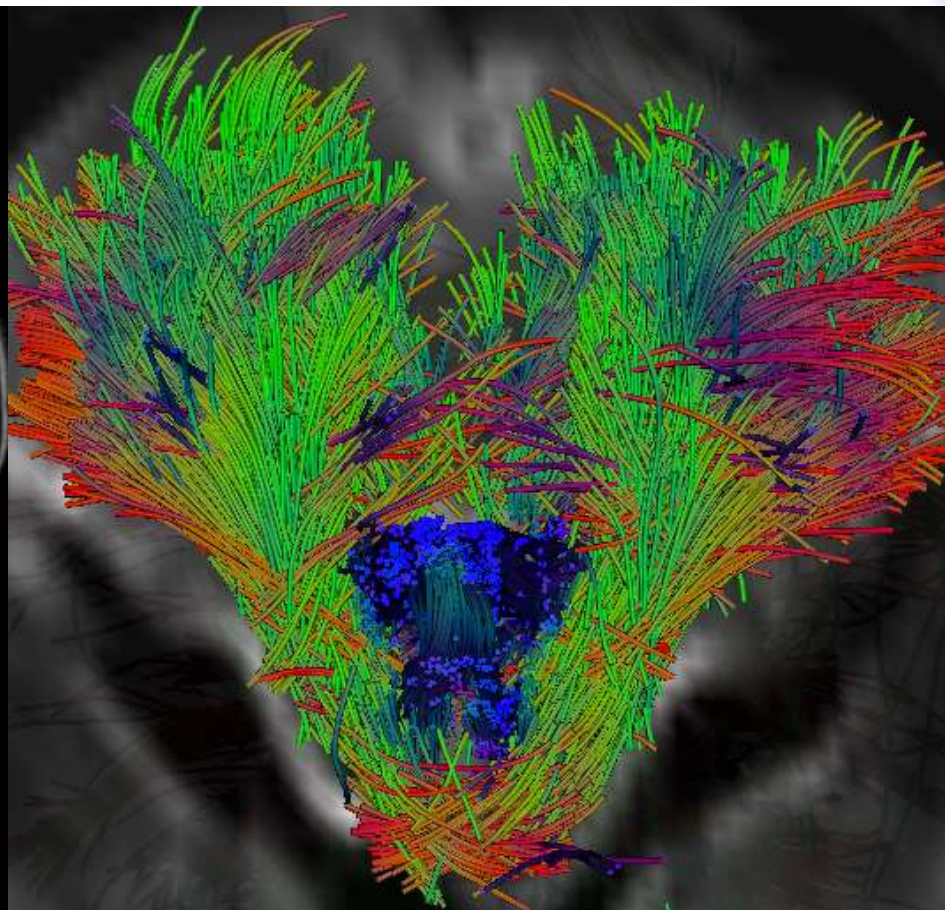




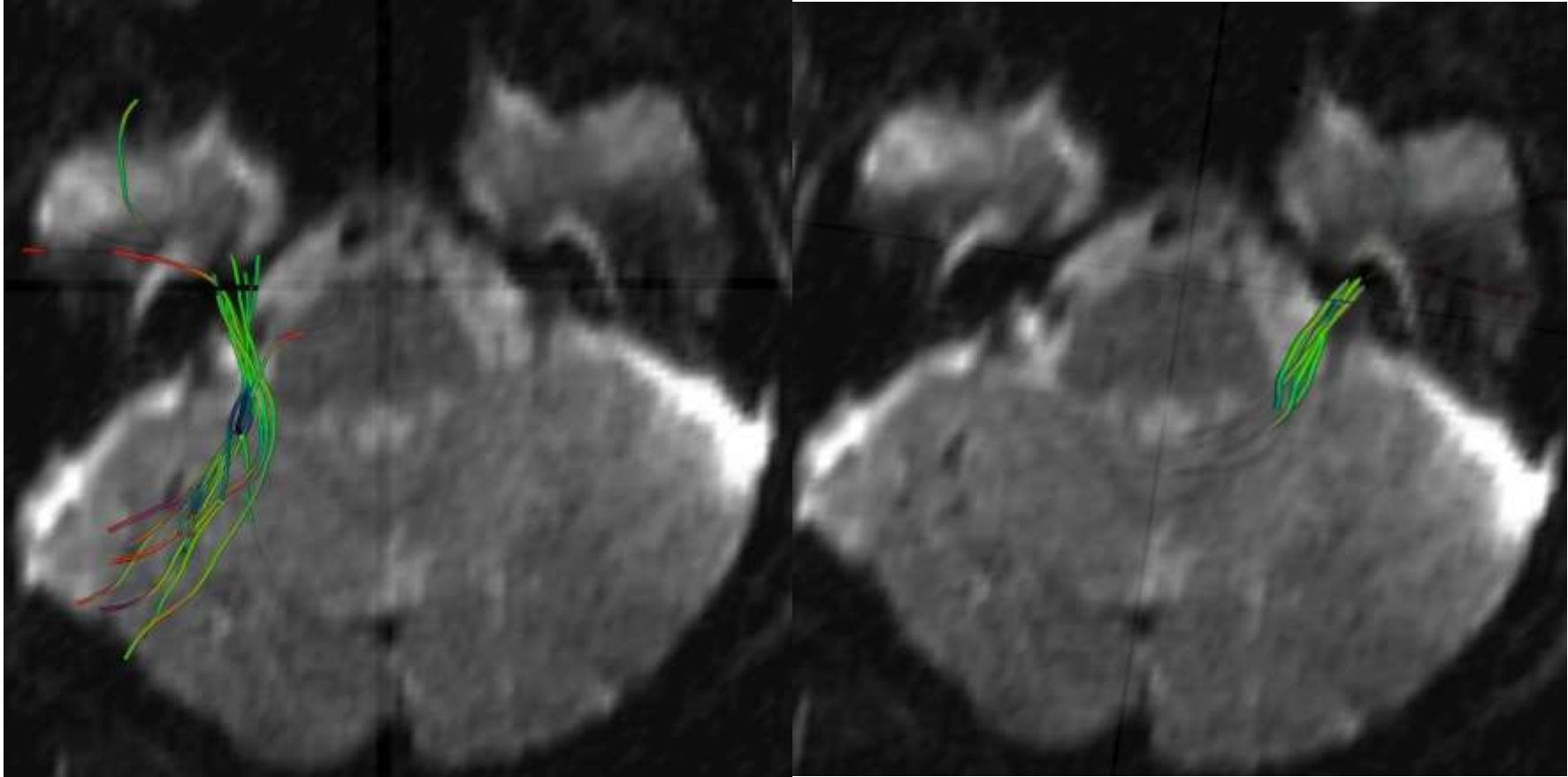
Myélinolyse Centro-pontique

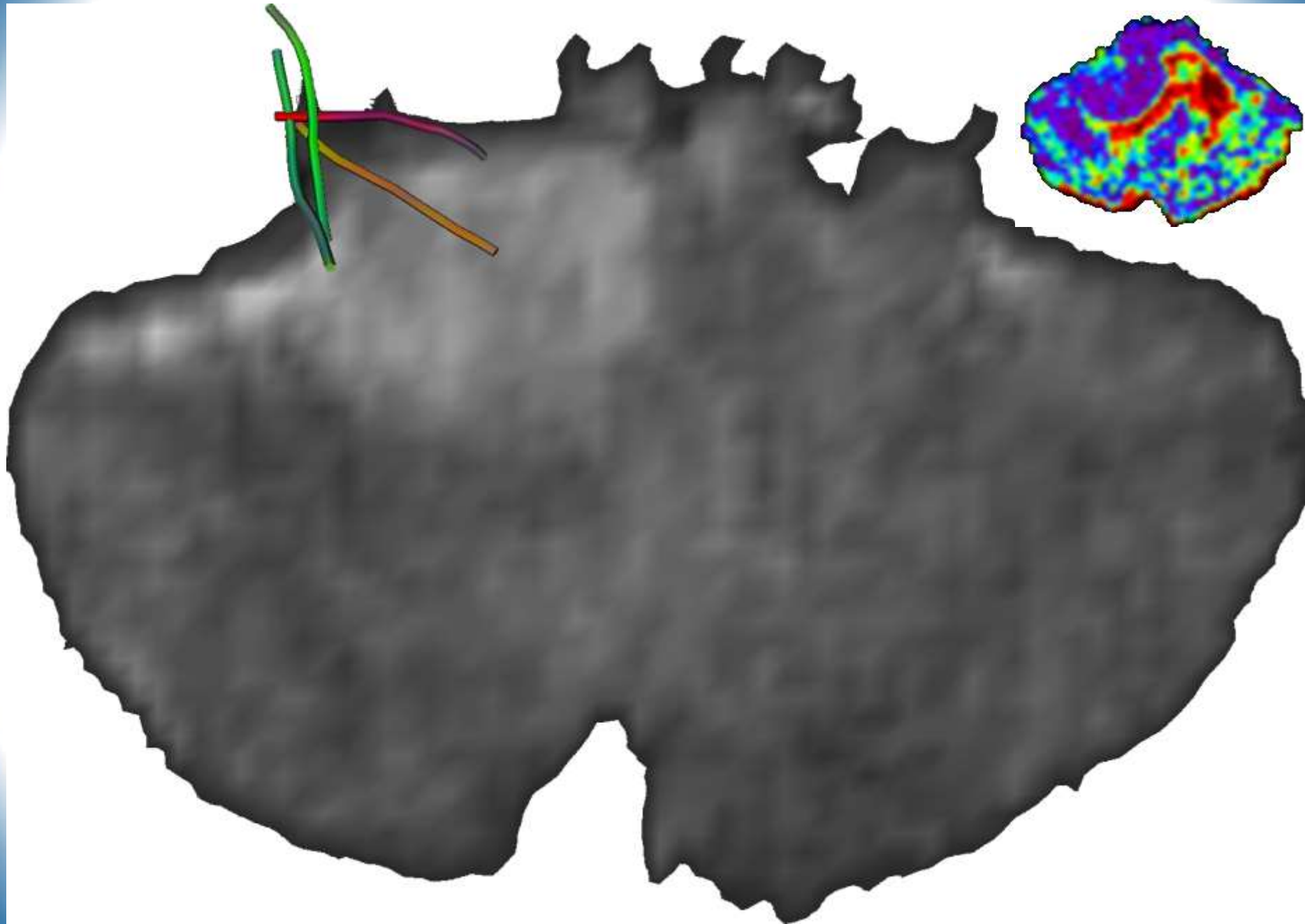






Tumeurs de l'Angle Ponto-Cérébelleux



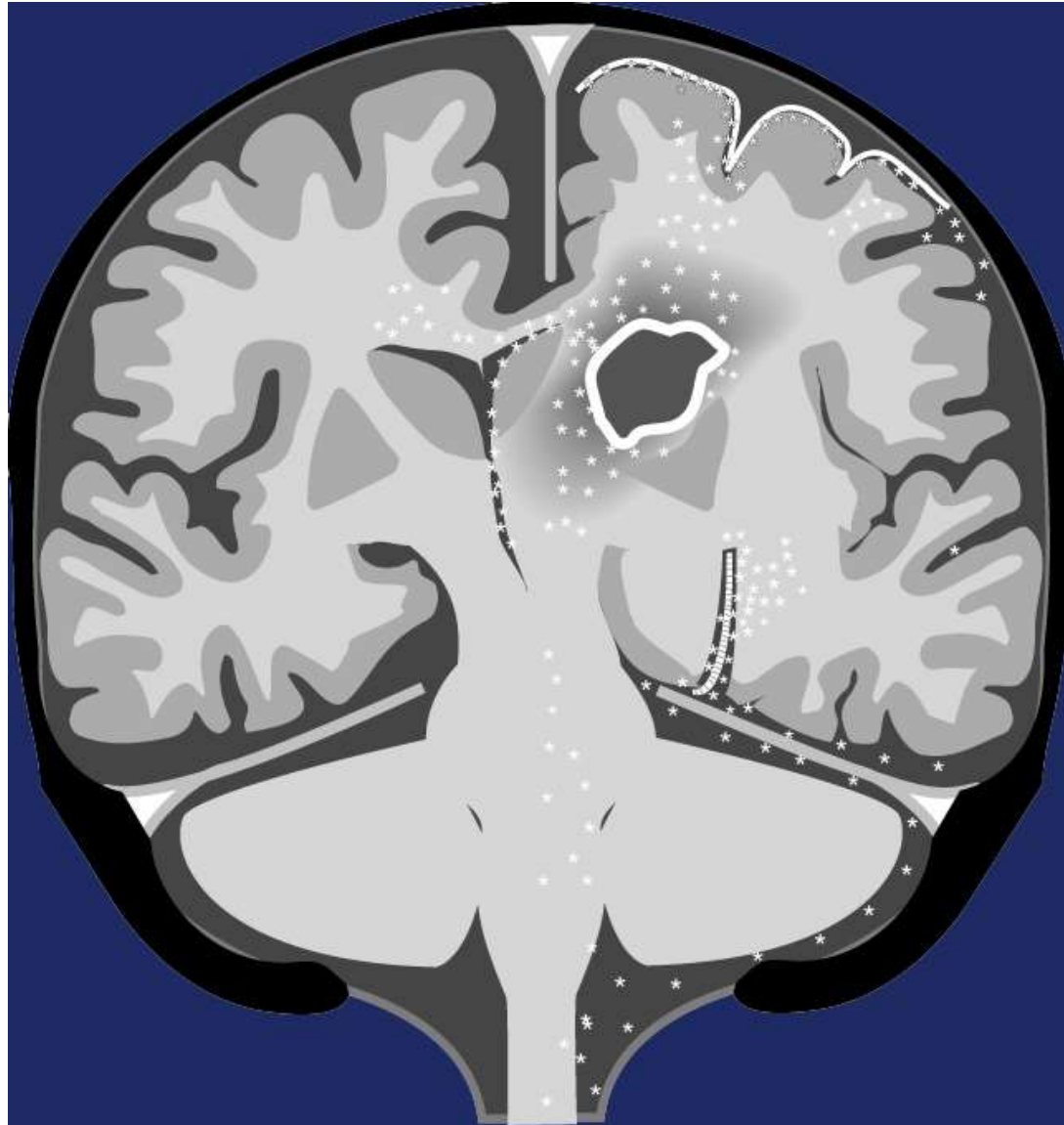


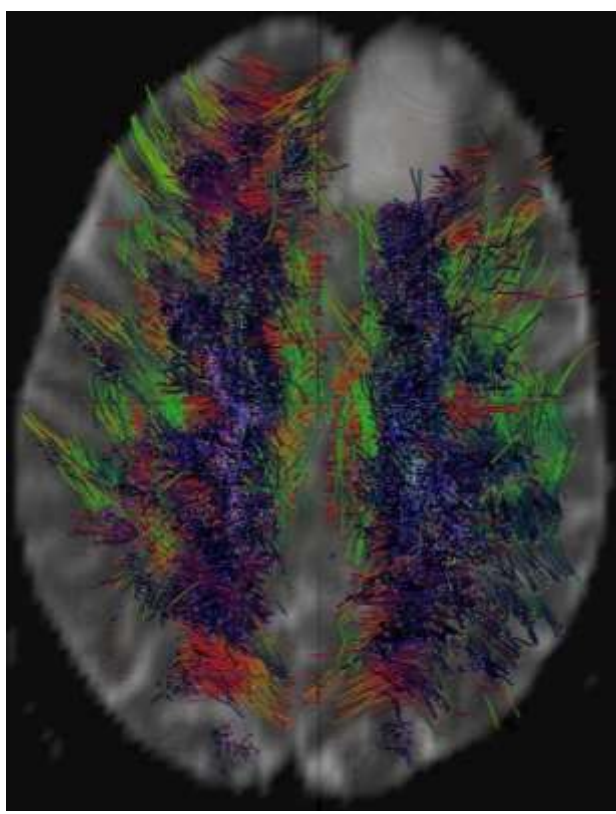
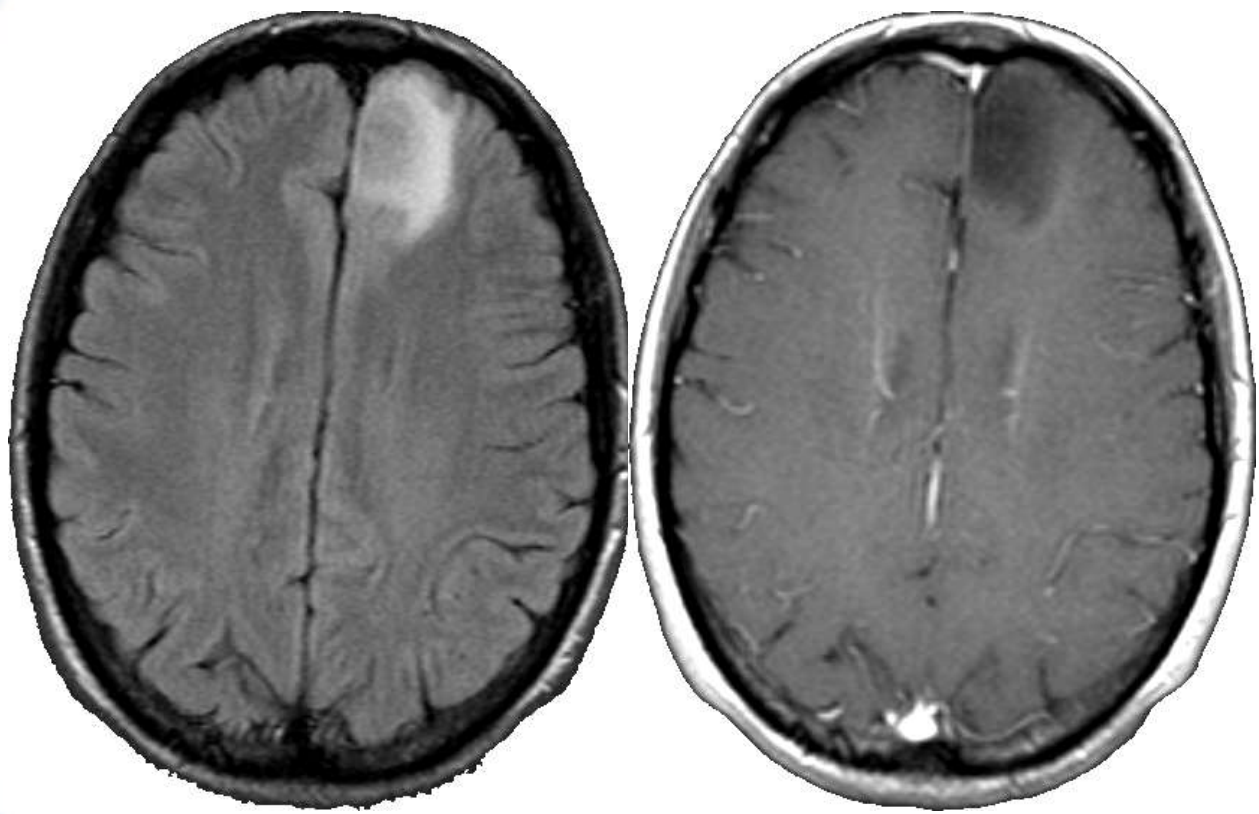
Névrites Optiques Rétro-Bulbaires

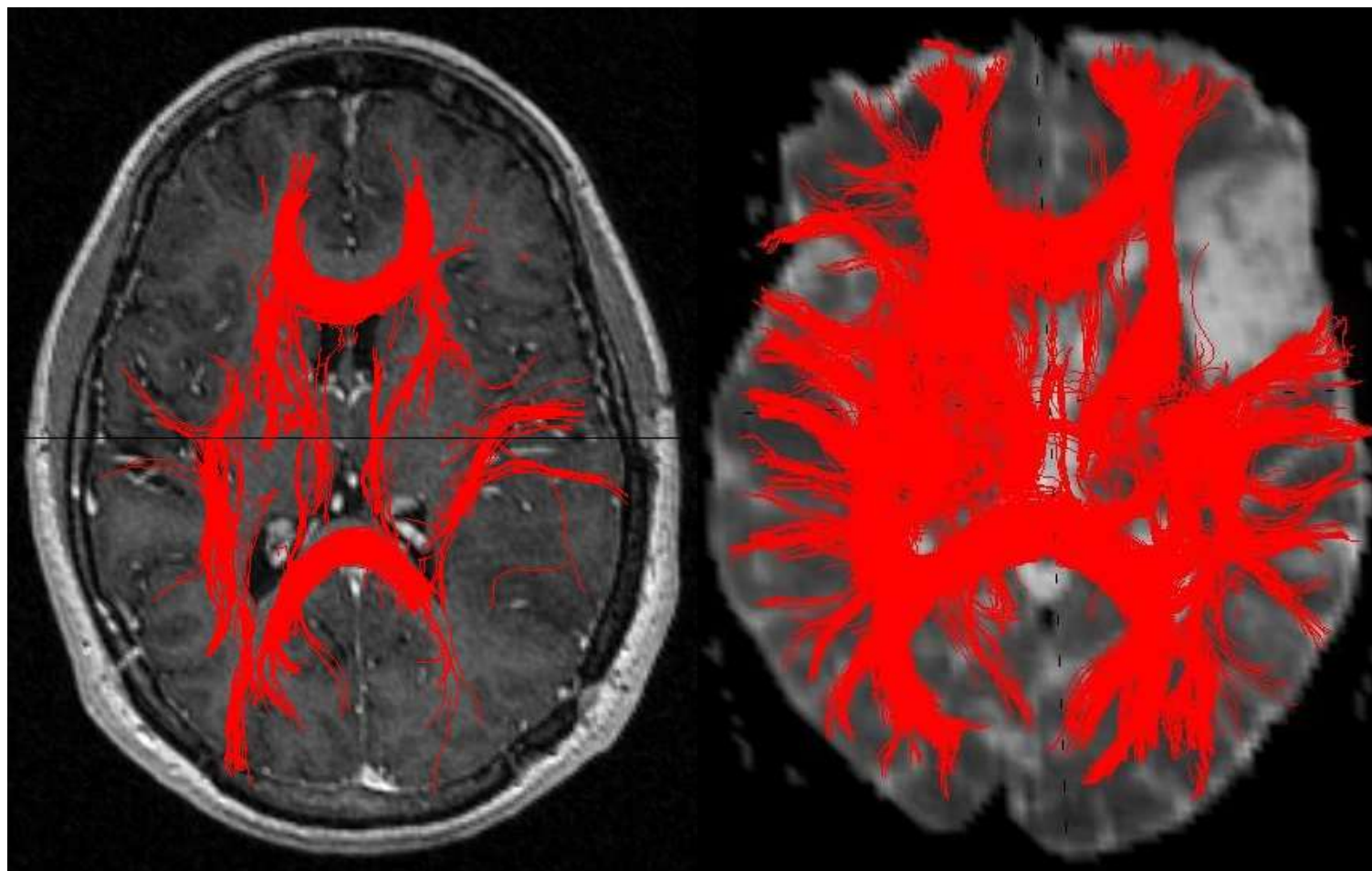


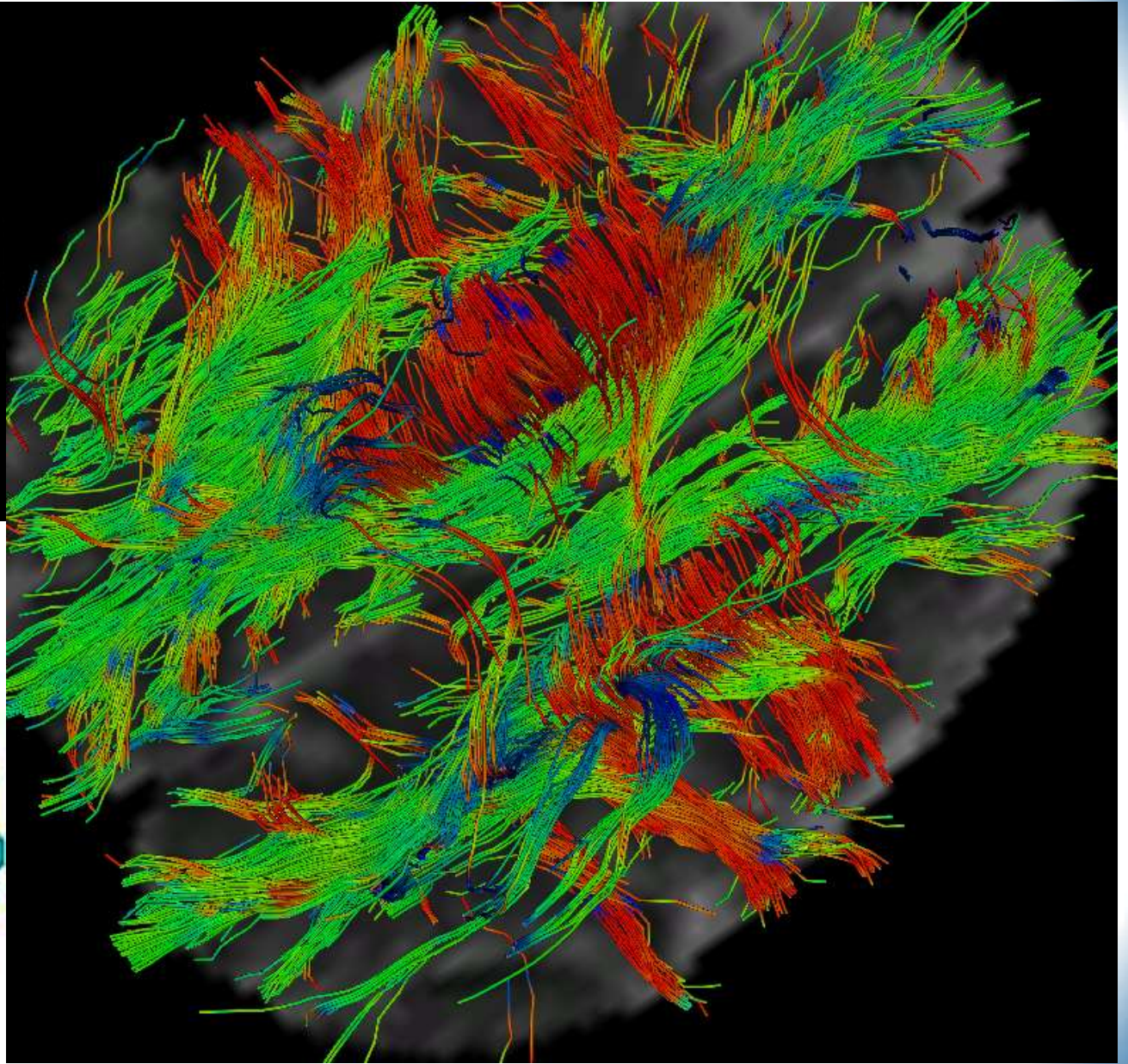
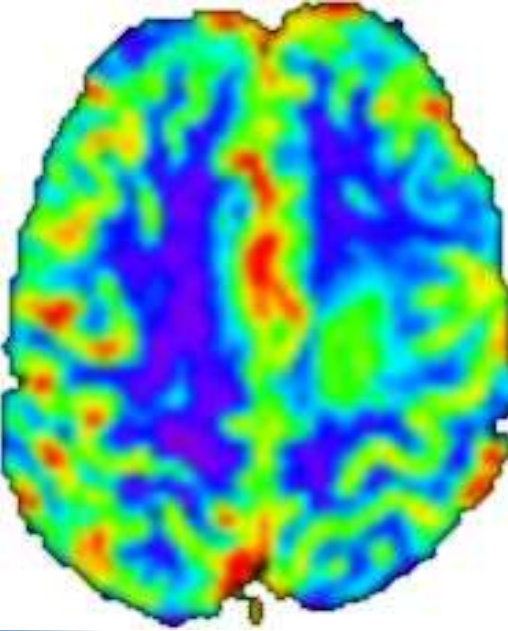
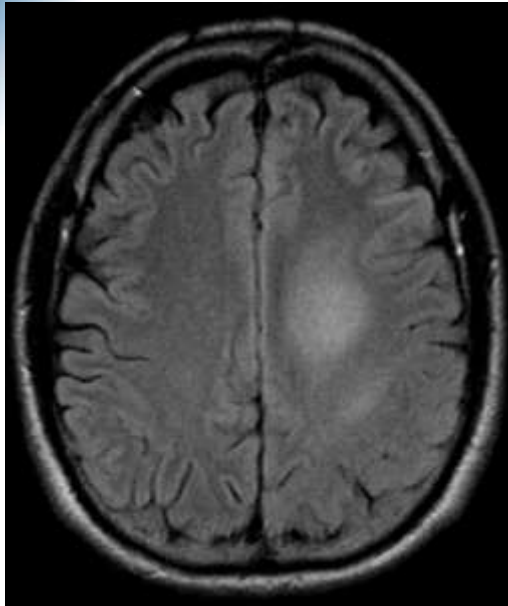
Tumeurs Cérébrales et Syndromes Inflammatoires

Dissémination des tumeurs gliales



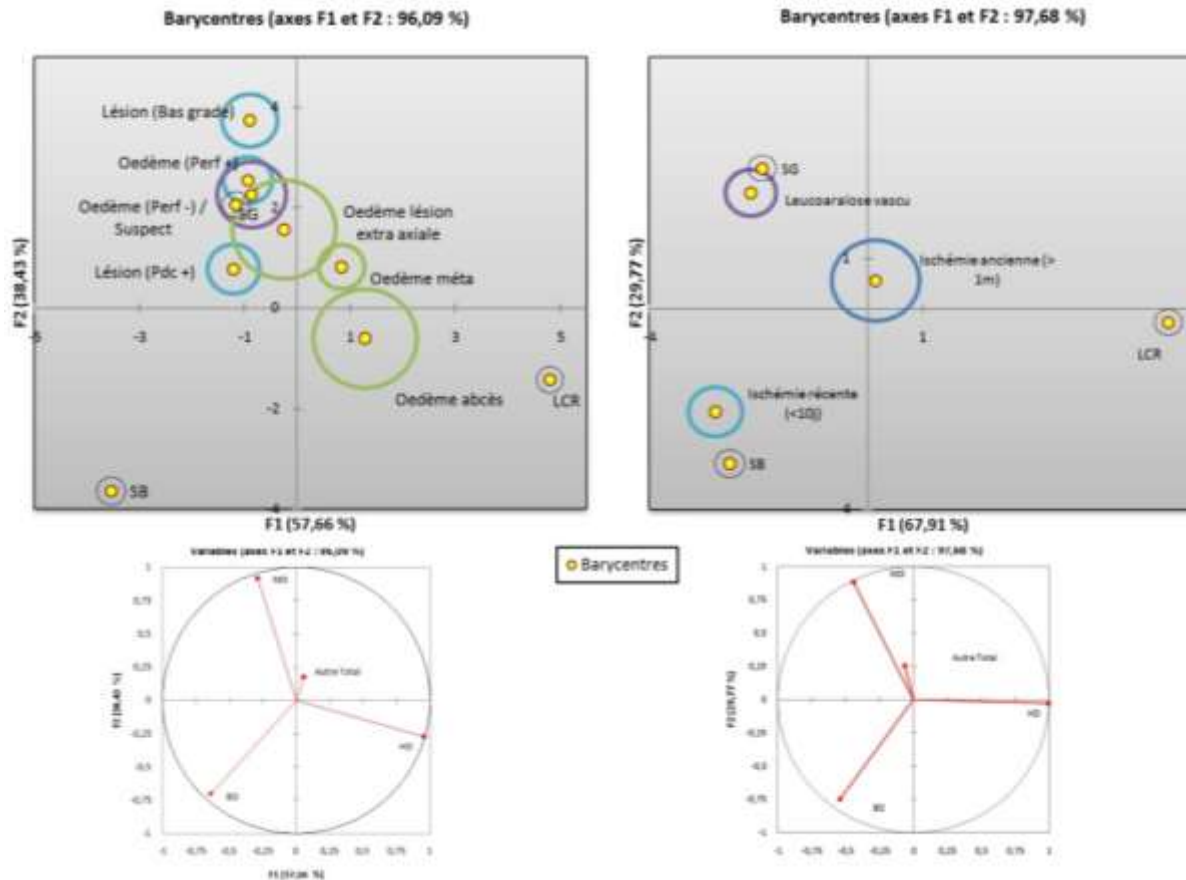




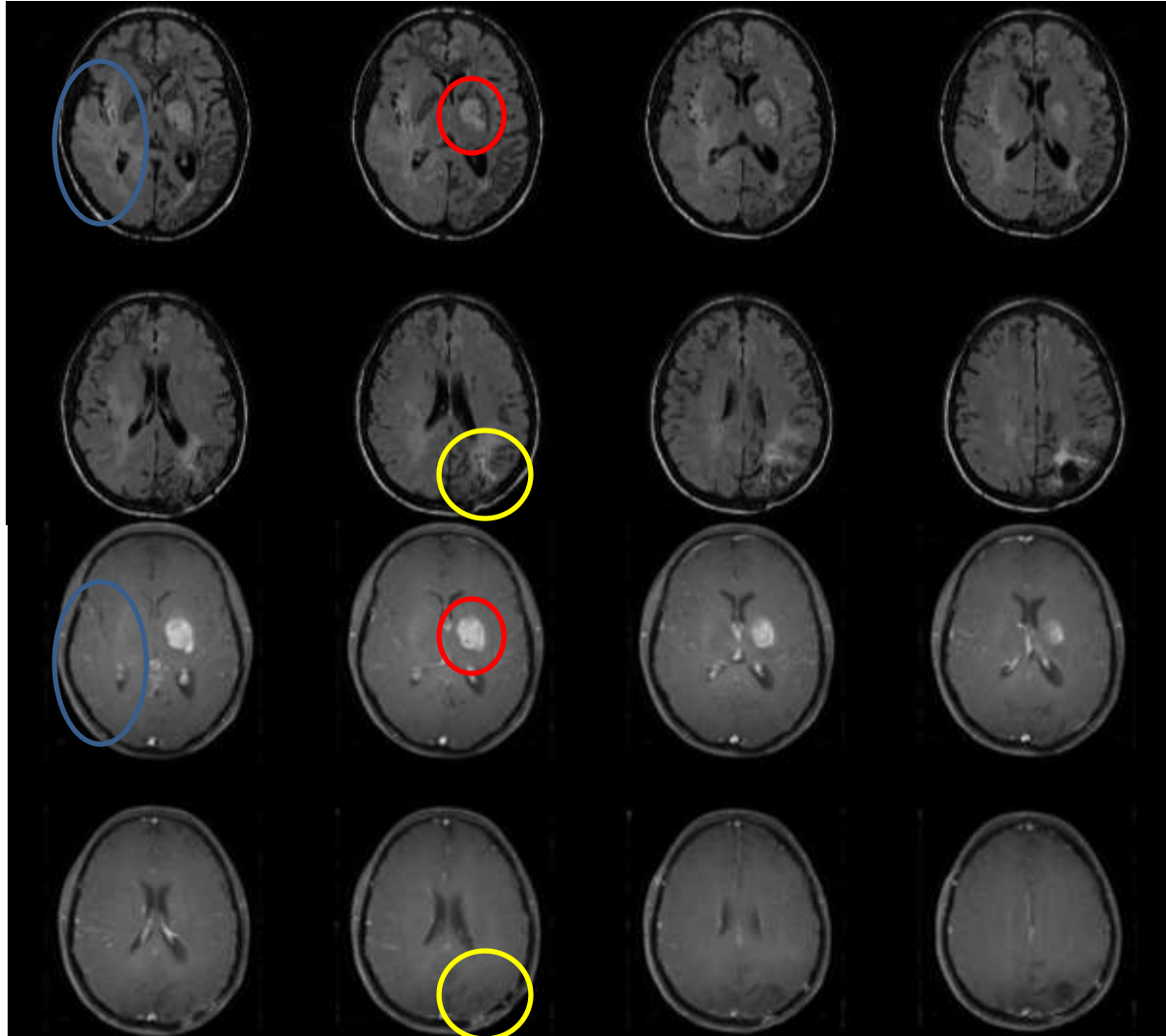


Tumeurs Cérébrales

Analyse en Composantes Principales



Types cellulaires : **bas** **intermediaire** **haut** grade



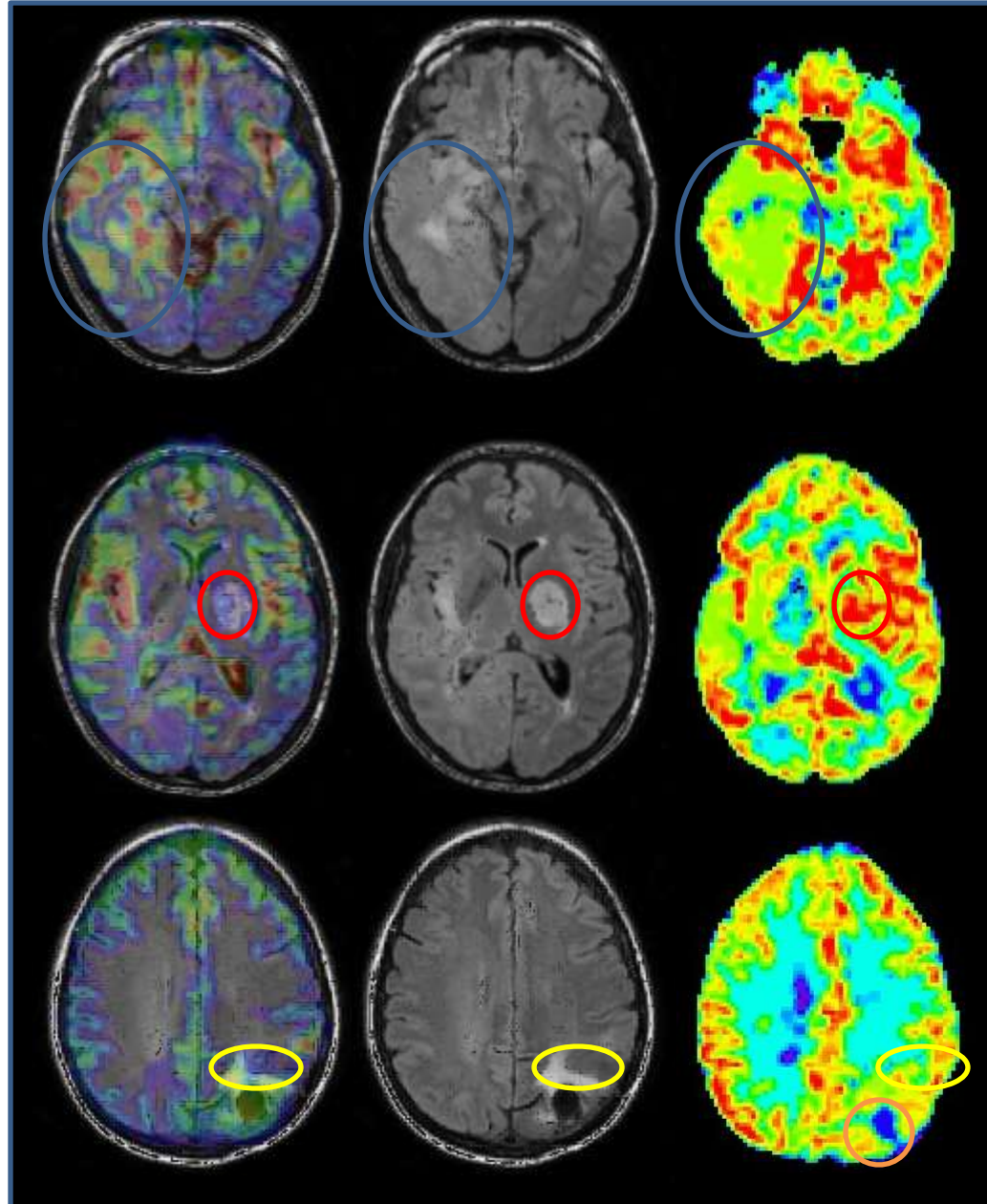
Trois types de densité cellulaire



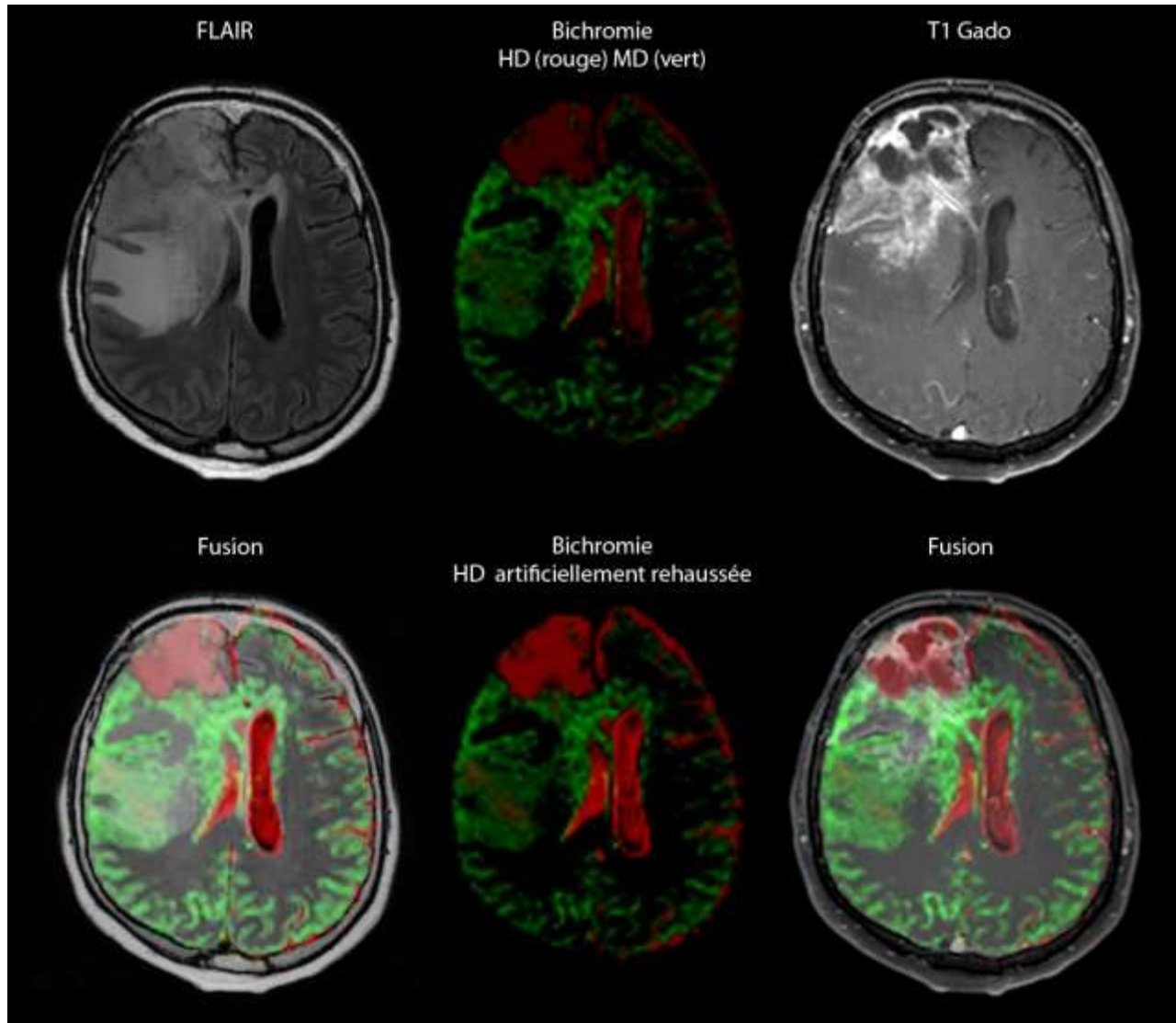
bas intermediaire haut grade



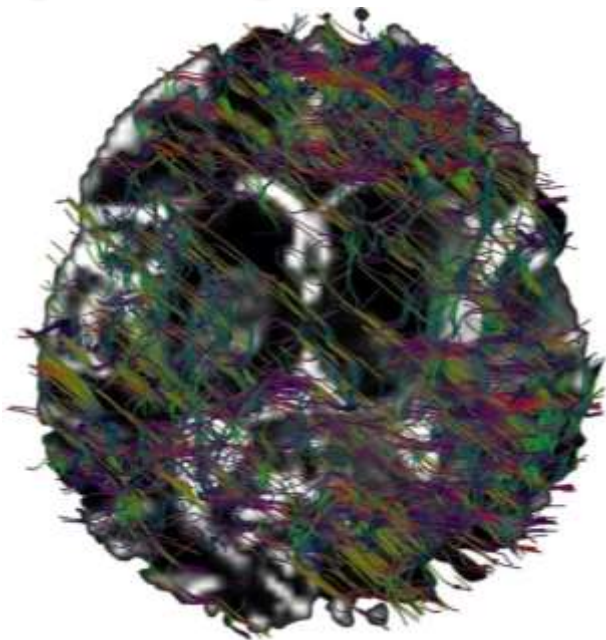
Types cellulaires : **bas** **intermediaire** **haut** grade **Eau**



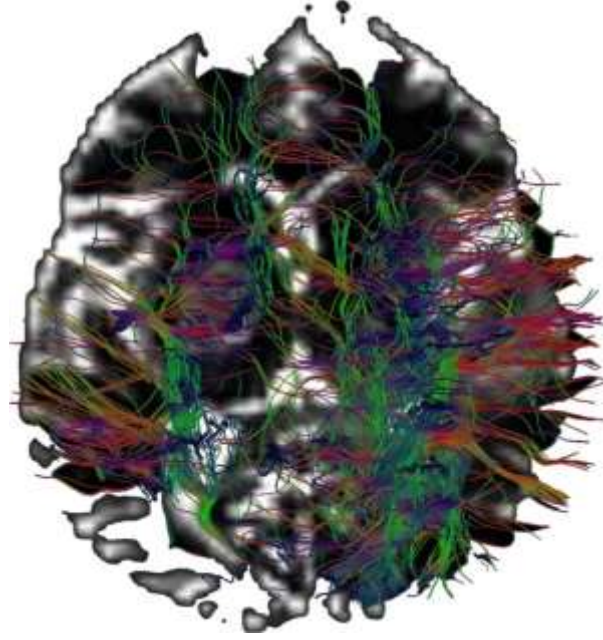
Oligodendrogliome frontal droit opéré récidivant



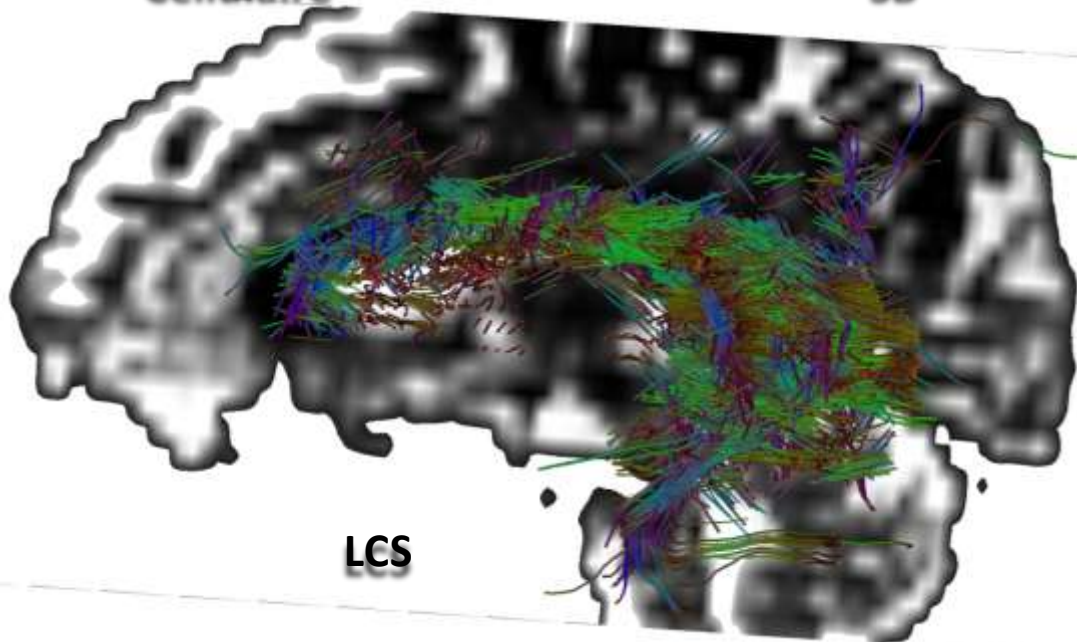
Tractographie compartimentale : Cellulaire, Substance Blanche et LCS



Cellulaire

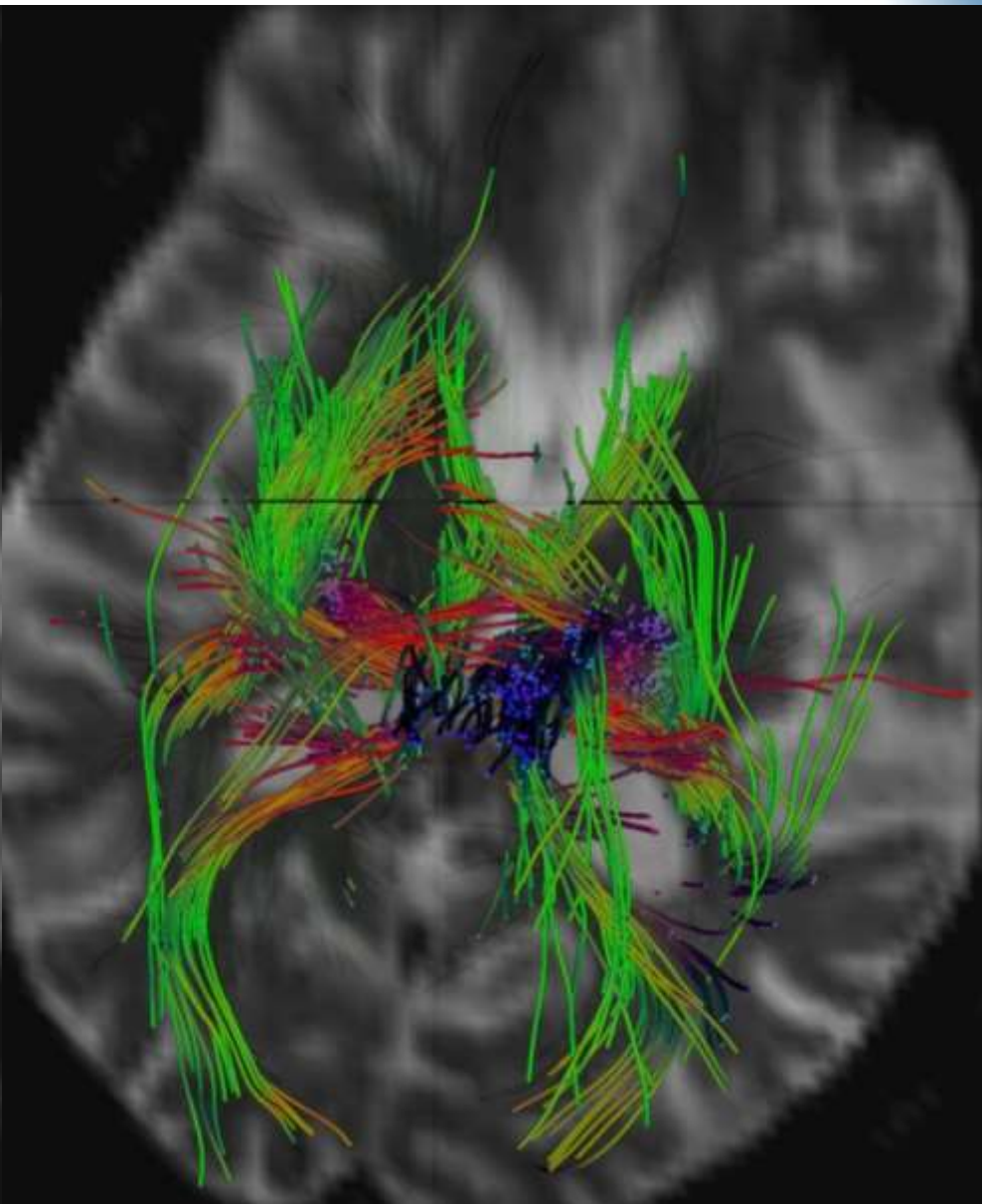
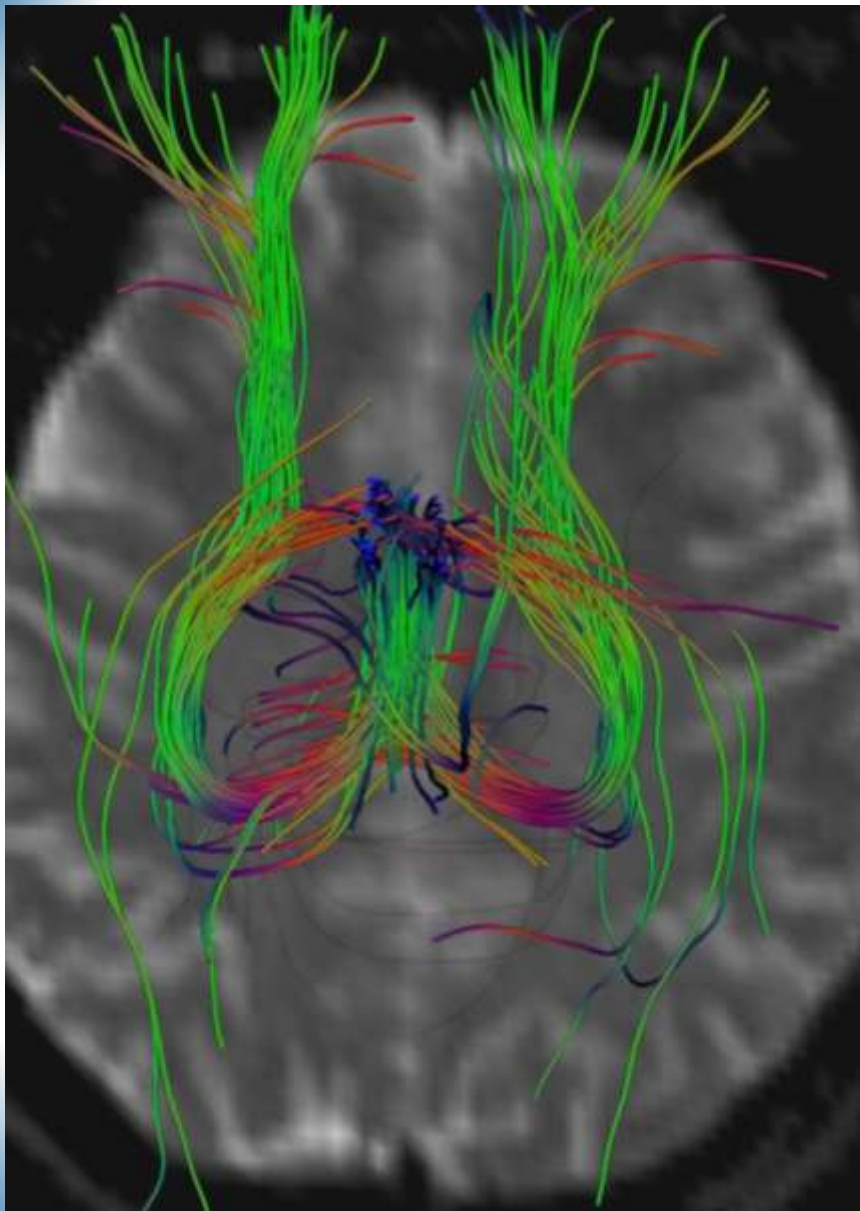


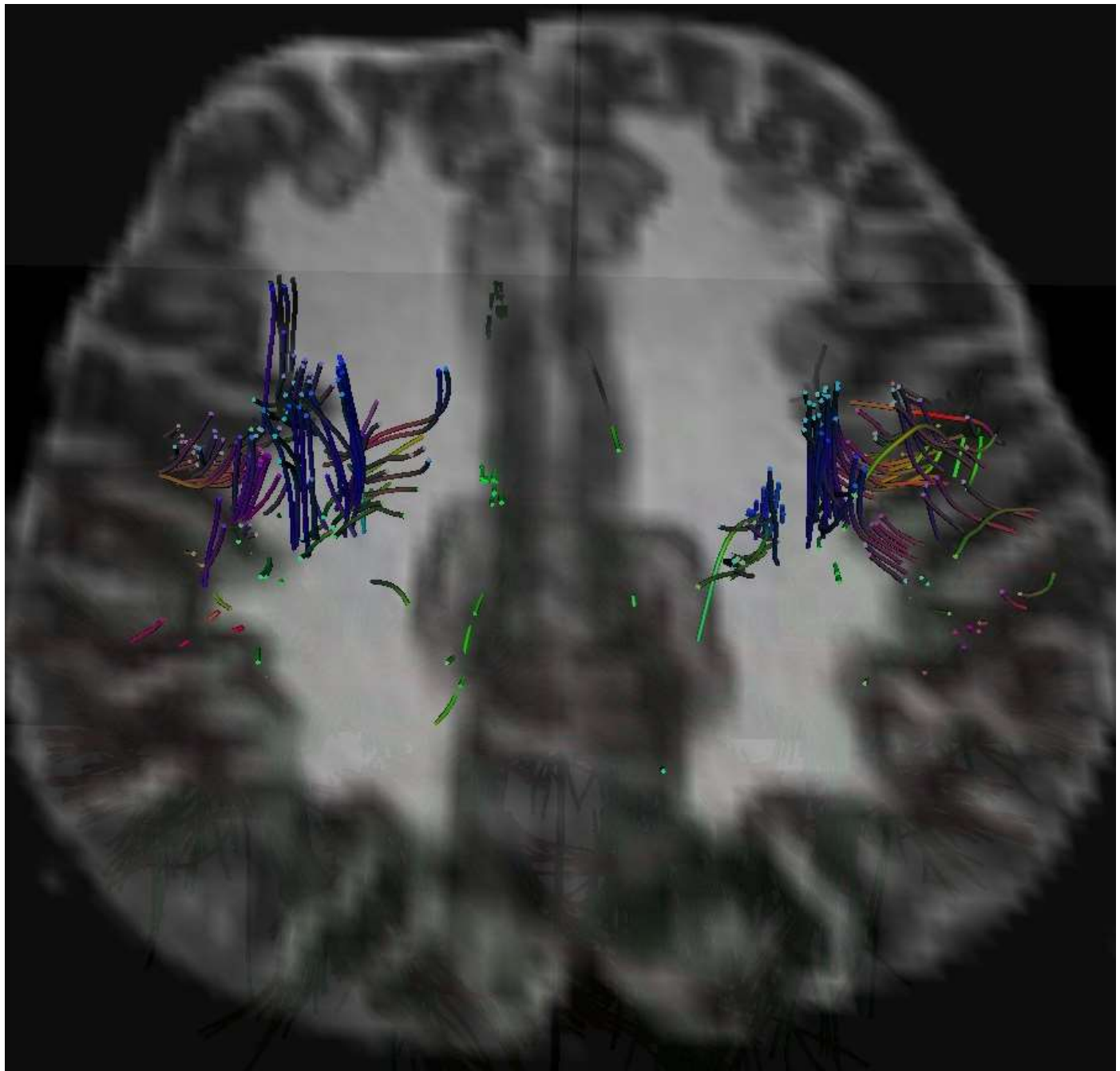
SB



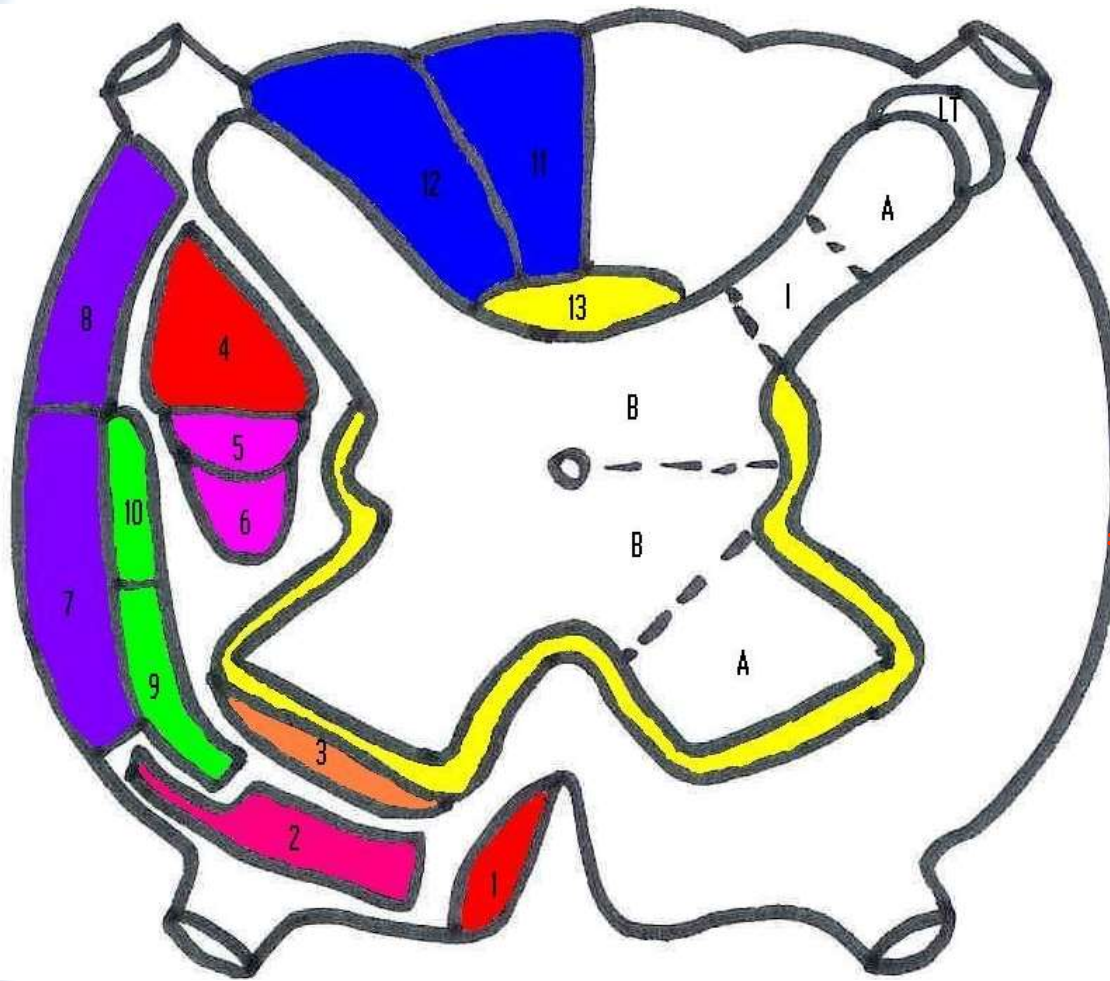
LCS

Syndromes Schizoïdes





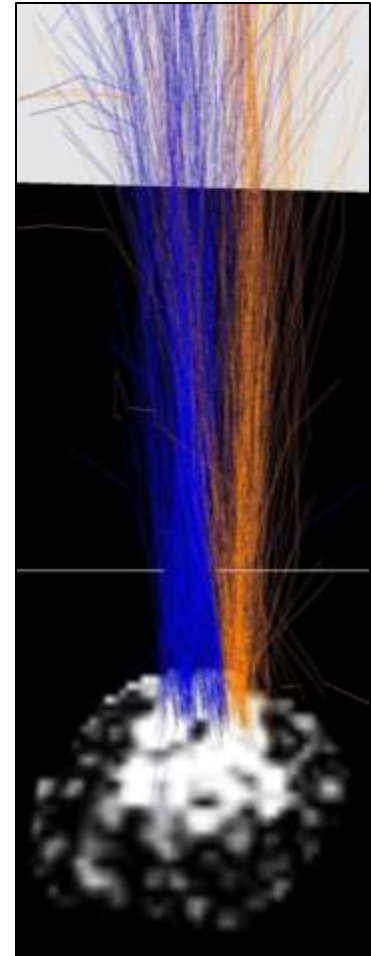
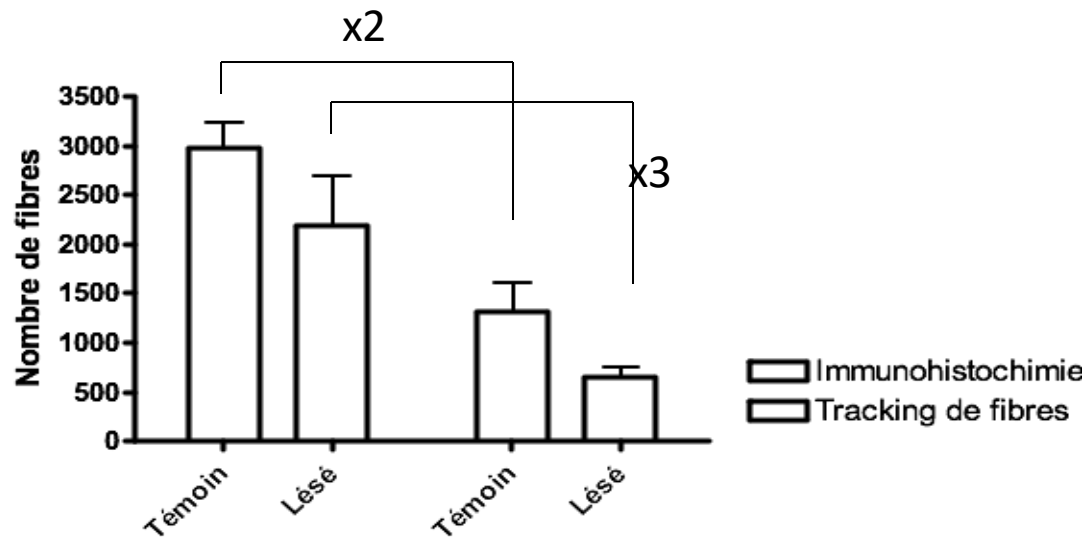
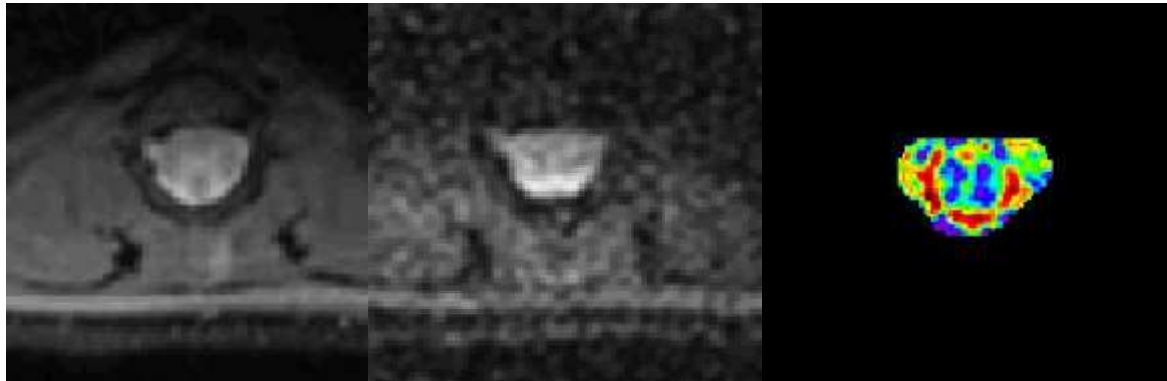
2.3.4 Anatomie Médullaire Normale

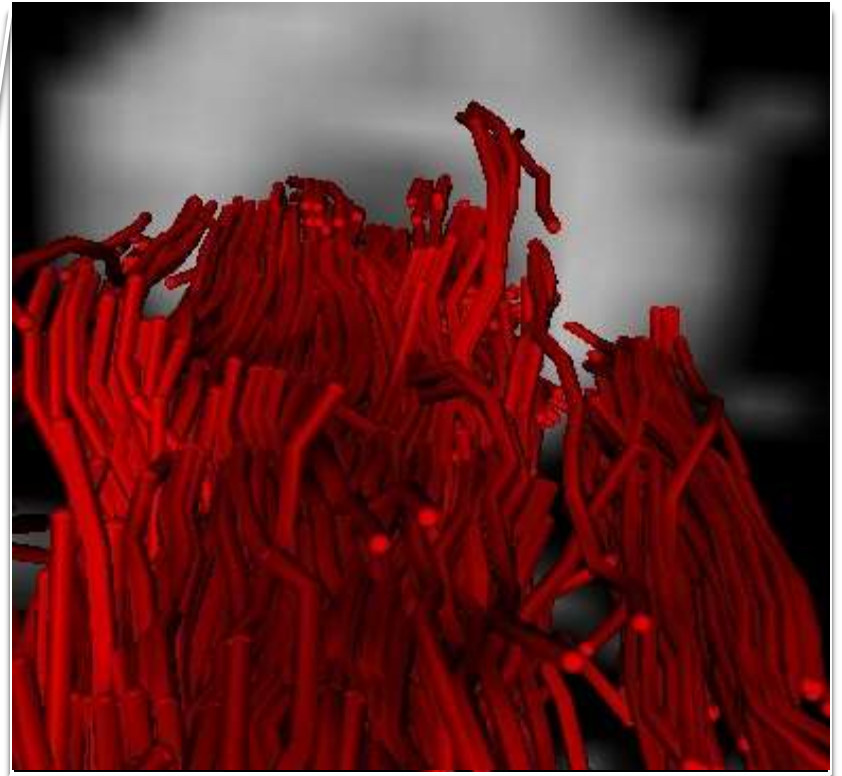
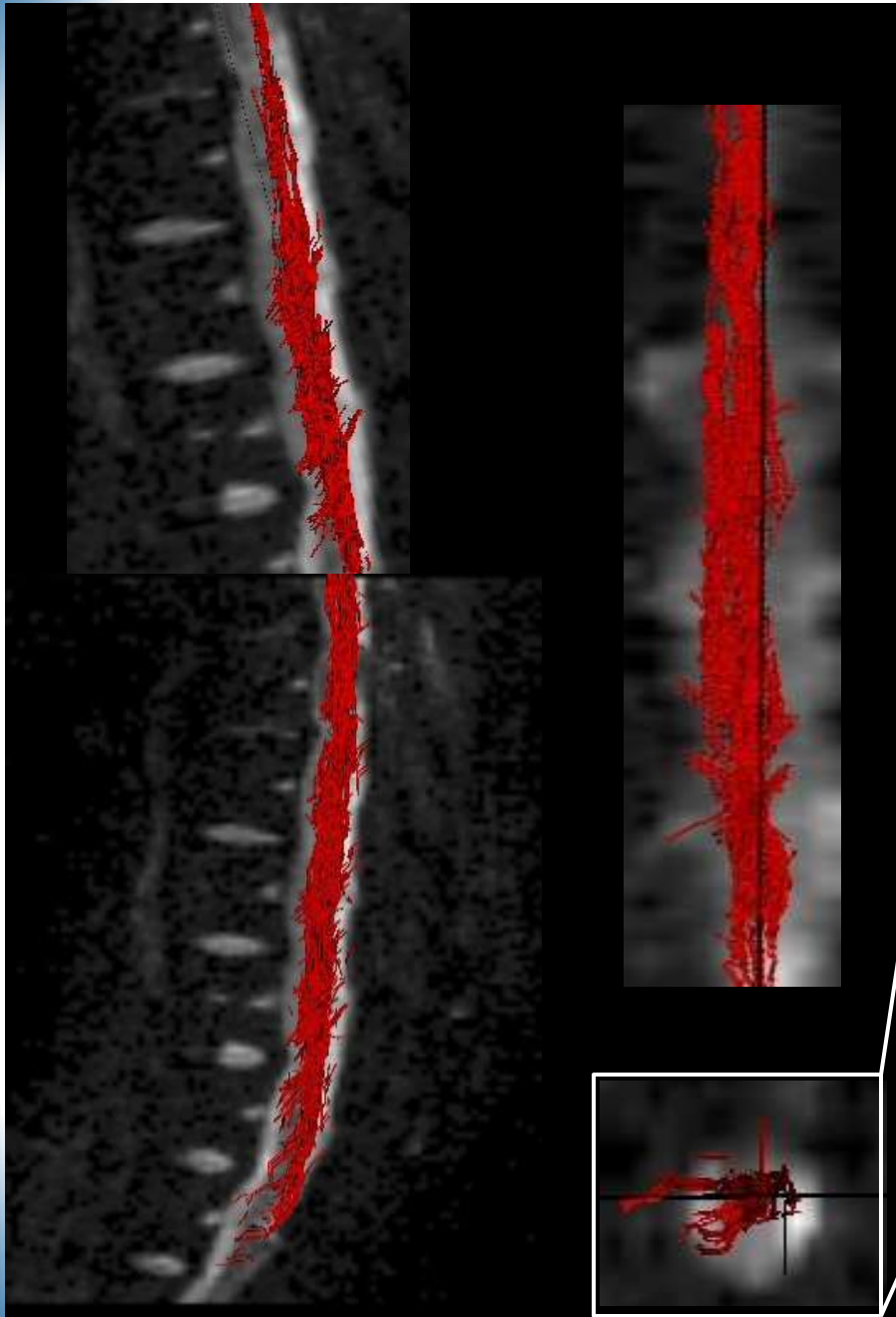


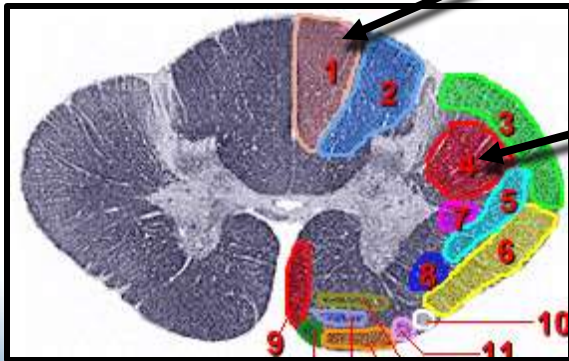
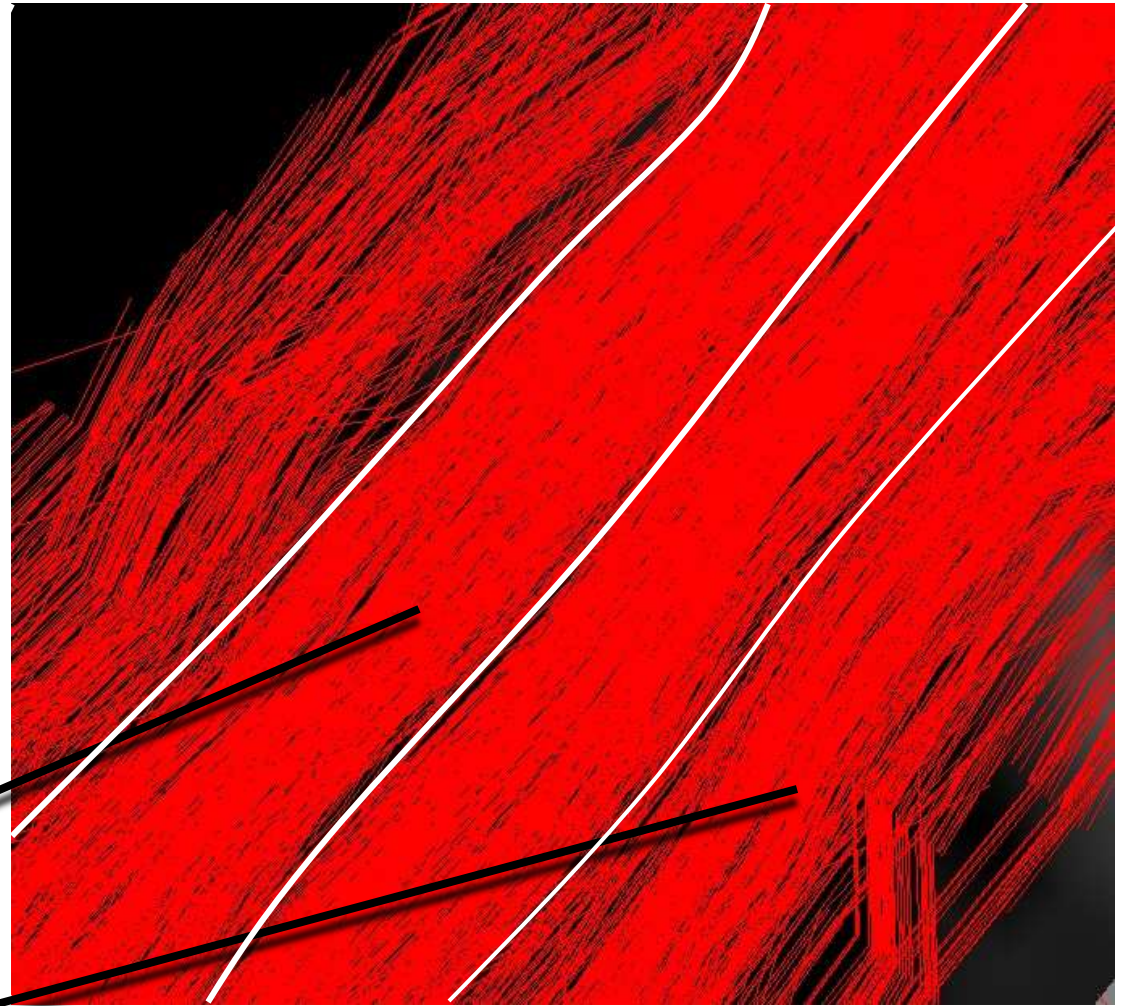
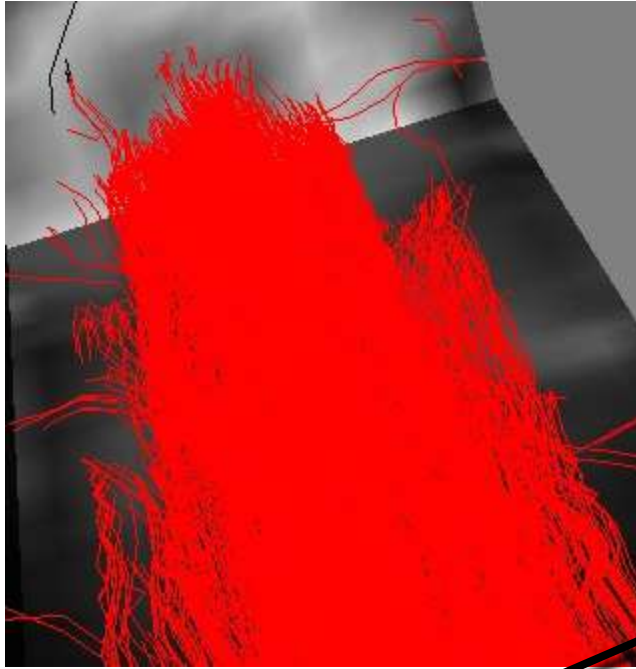
- 1-Faisceau cortico-spinal ventral
 - 2-Champ de faisceaux extrapyramidaux
 - 3-Faisceau tecto-spinal
 - 4-Faisceau cortico-spinal dorsal
 - 5-Faisceau rubro-spinal
 - 6-Faisceau réticulo spinal latéral
 - 7-Faisceau spino-cérébelleux ventral
 - 8-Faisceau spino-cérébelleux dorsal
 - 9-Faisceau spino-thalamique ventral
 - 10-Faisceau spino-thalamique dorsal
 - 11-Faisceau gracile
 - 12-Faisceau cunéiforme
 - 13-Faisceaux propres
- A- Apex
 B- Base
 I- Isthme
 LT- Lame Terminale

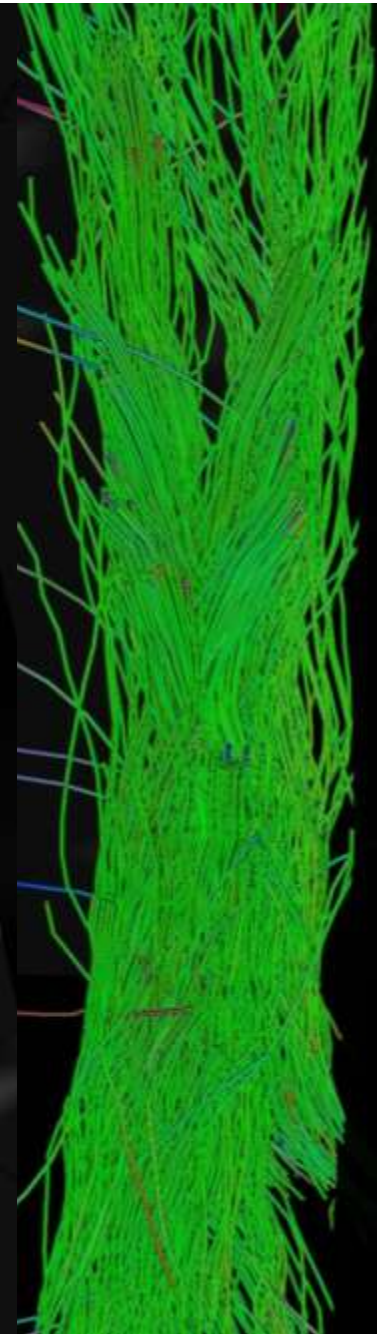
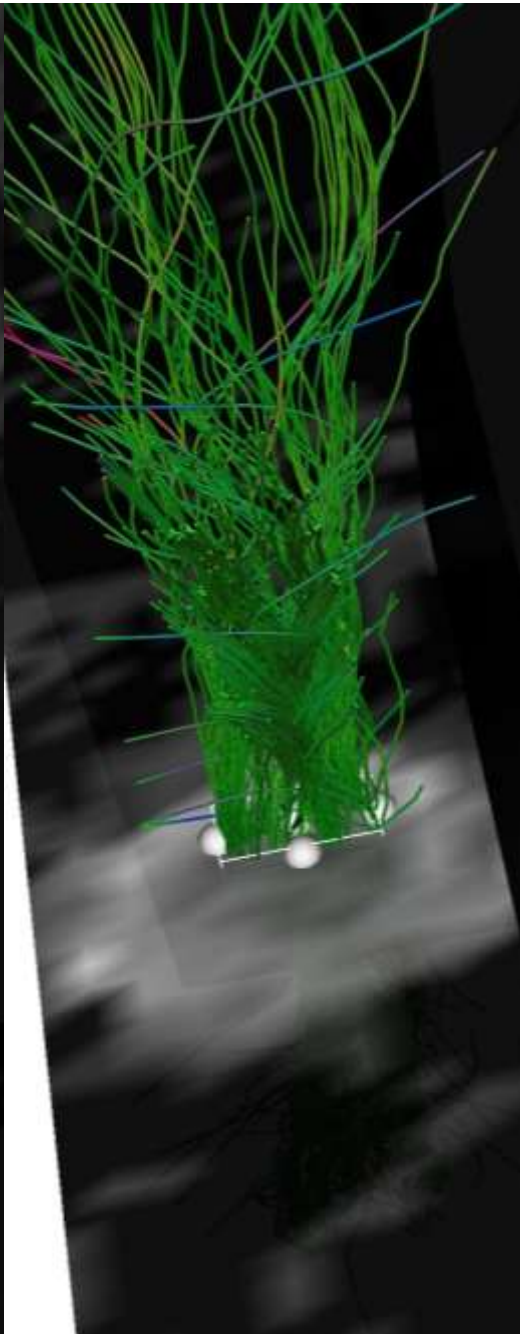
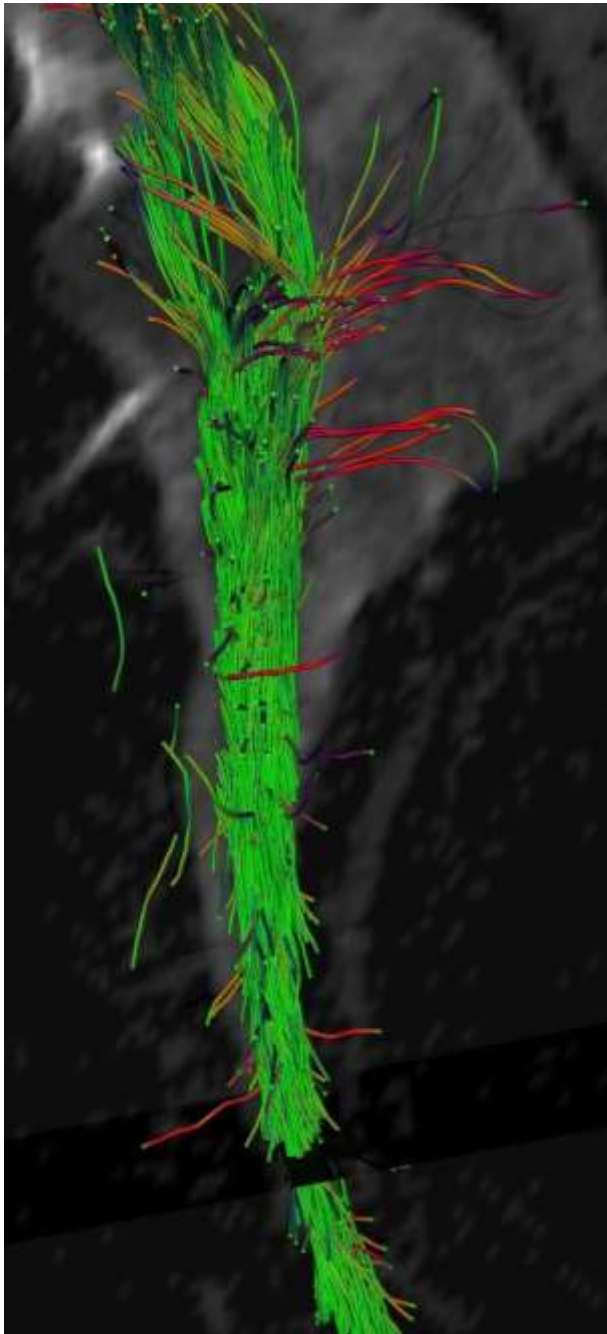
Tractographie Médullaire

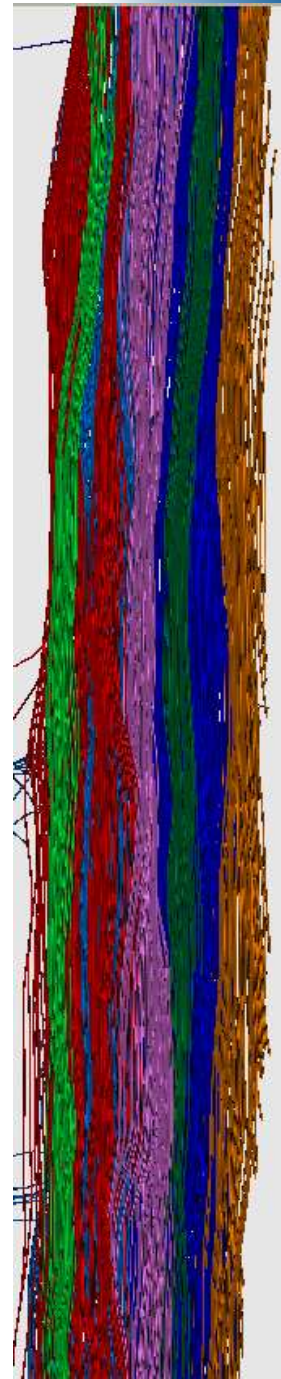
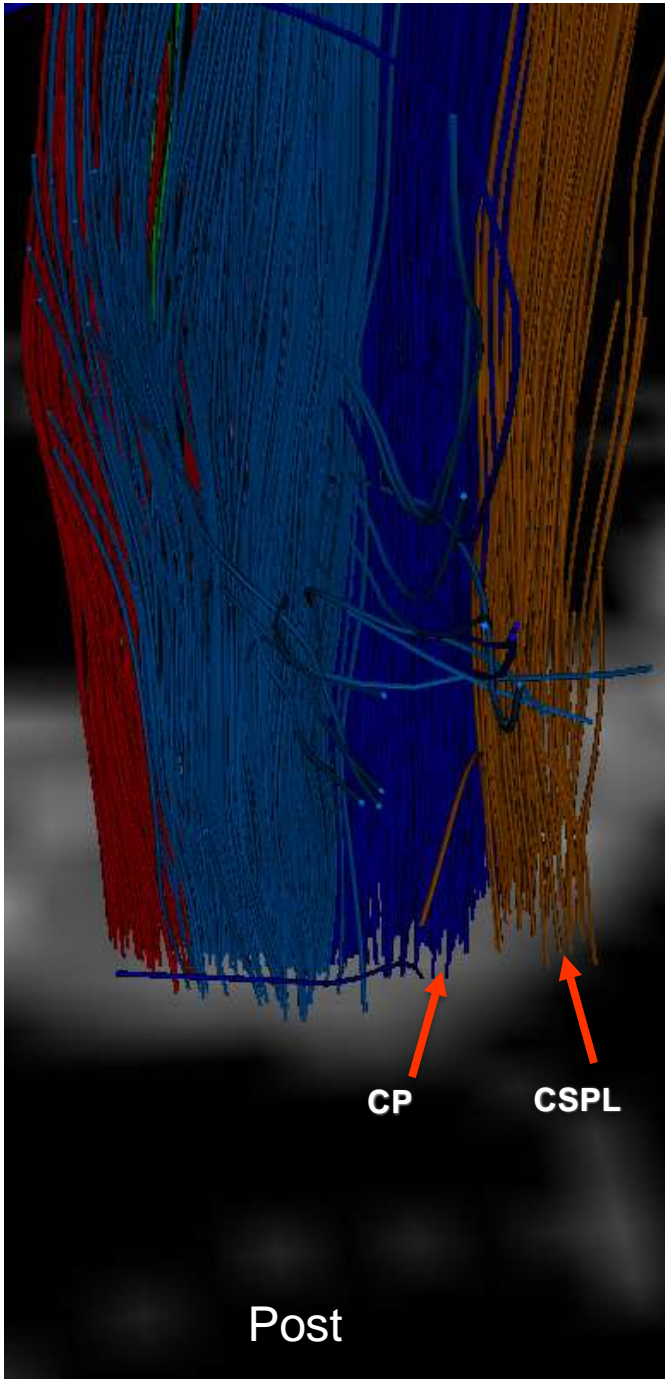
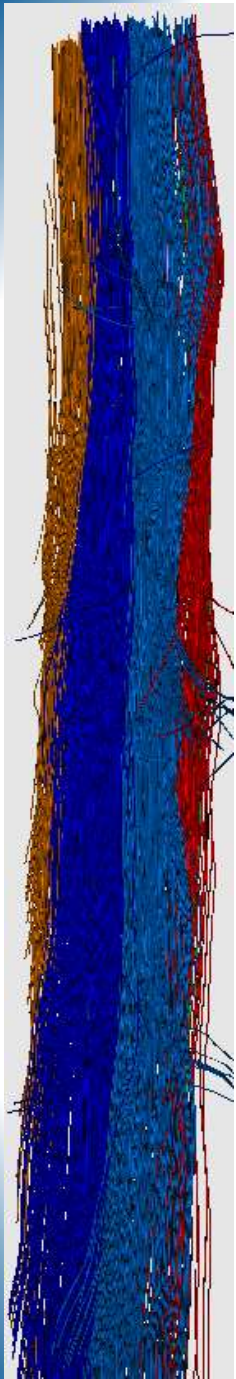
Vérifications Expérimentales

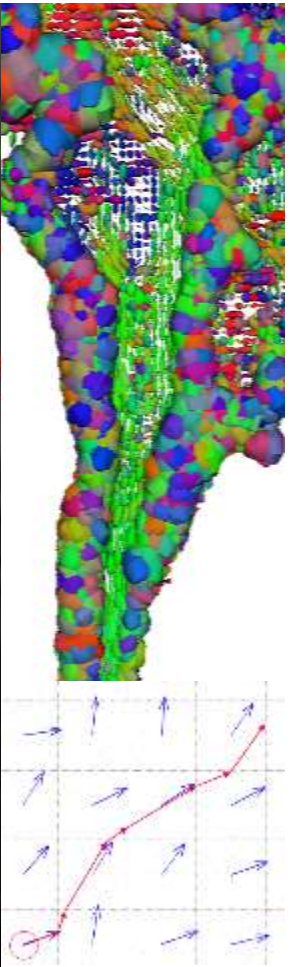
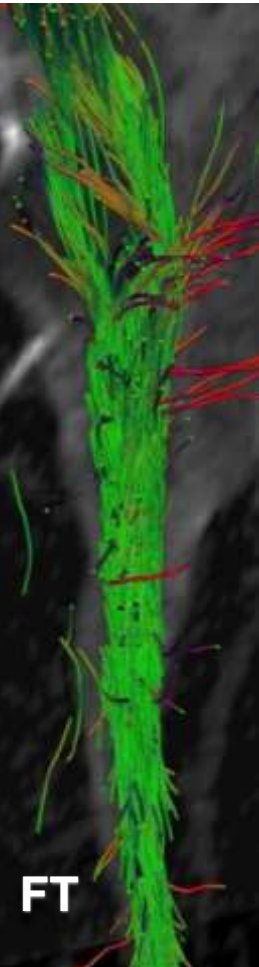
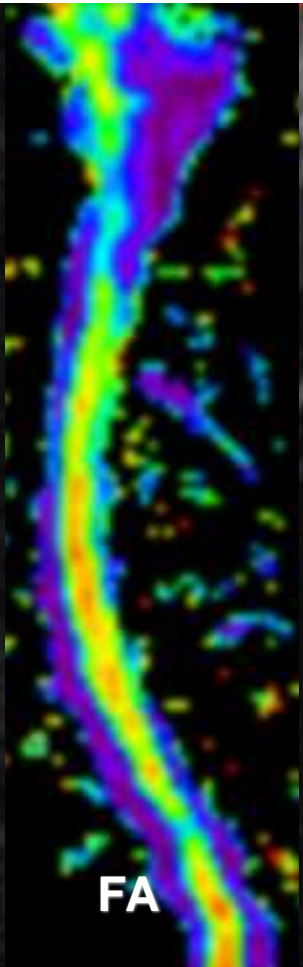
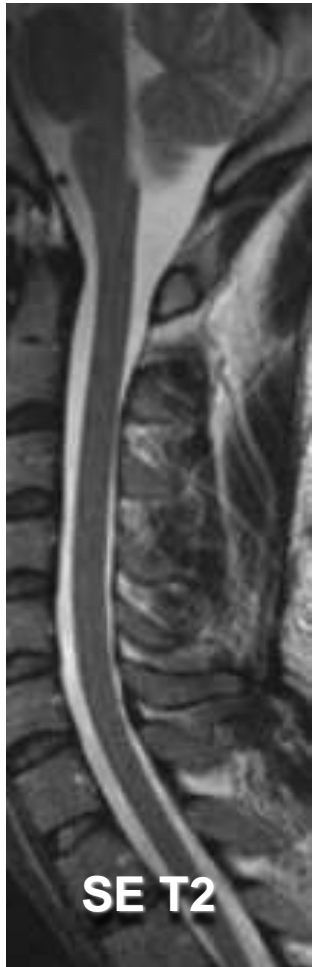












IRM de Tenseur de Diffusion

Tractographie médullaire - Sujet Sain

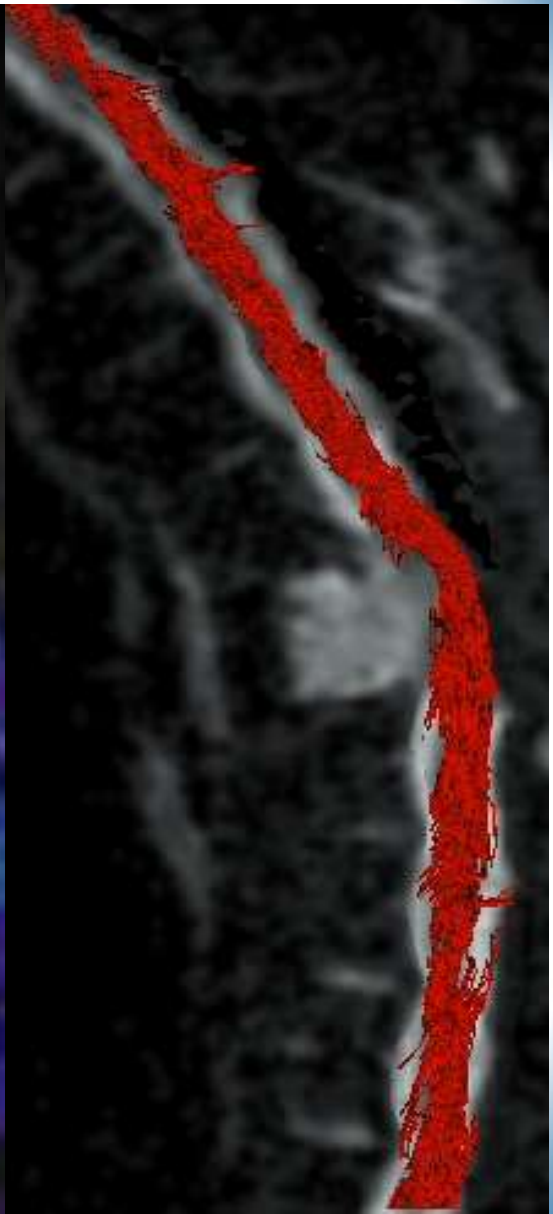
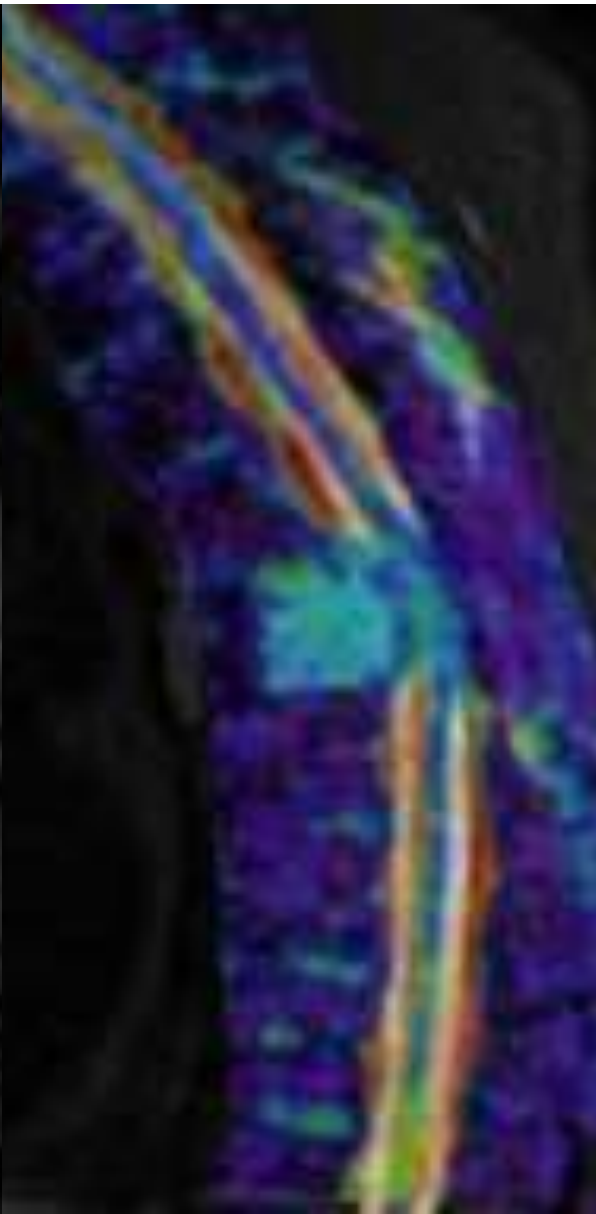
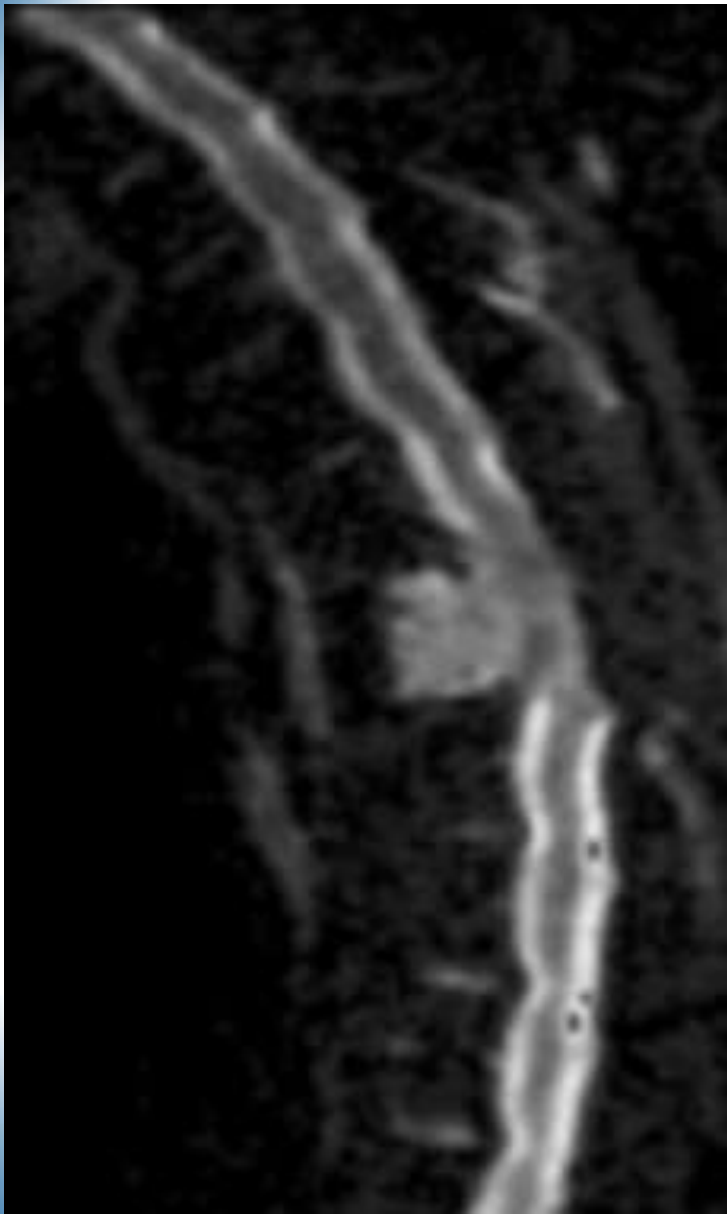
Faisceaux	ADC moyen	FA moyen	Nb « fibres »
CSLD	1.05	0,71 ± 0.02	22 (soit ~3 M)
CPD	0.96	0,79 ± 0.02	65 (soit ~9 M)
CPG	0.96	0,80 ± 0.02	63 (soit ~9 M)
CSLG	1.03	0,73 ± 0.02	19 (soit ~3 M)

NB : Résultats obtenus en région cervicale moyenne (C4) avec un voxel de 6 mm³.

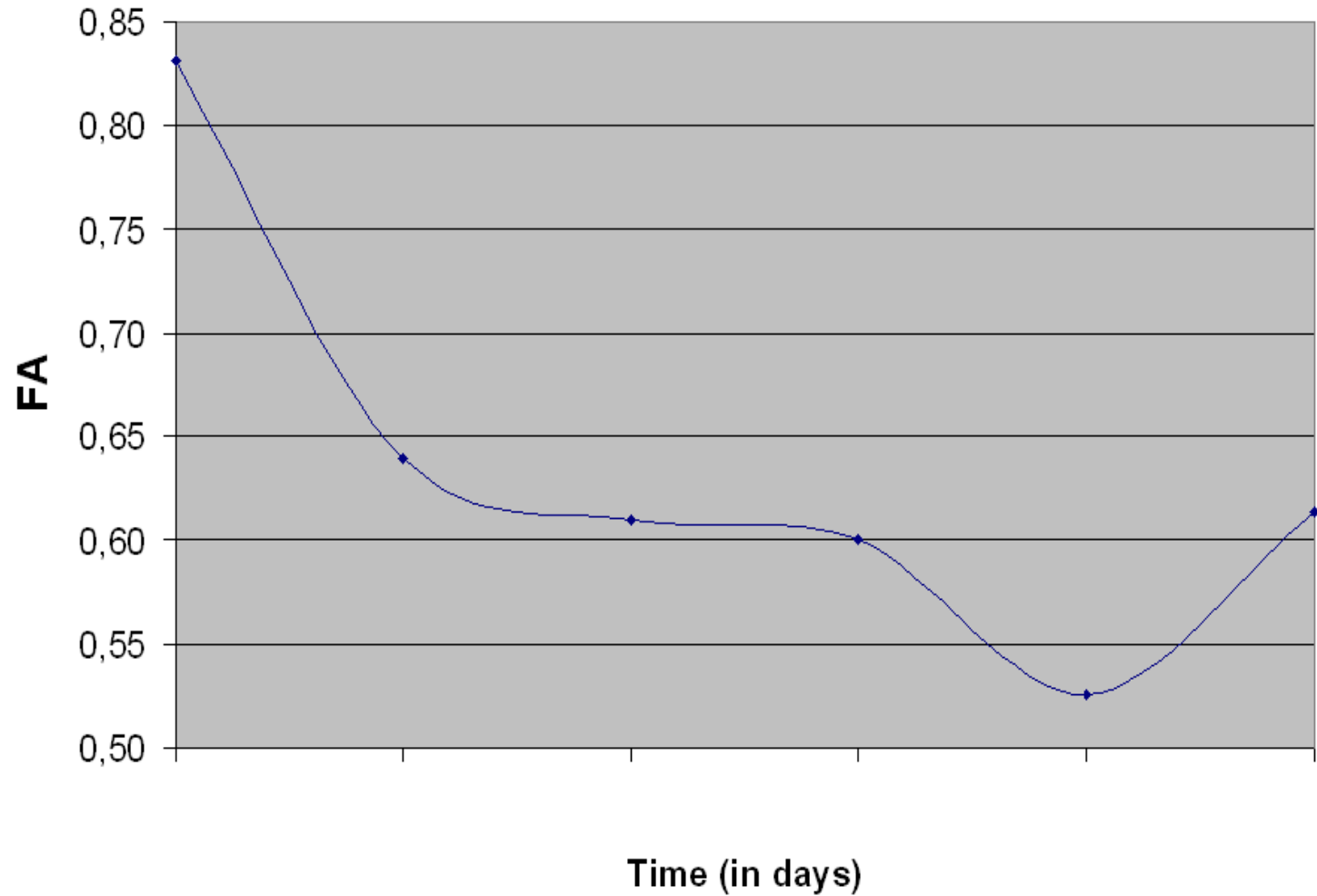
Dix fibres sont arbitrairement affichées dans un voxel, avec une moyenne histologique connue de 20000 fibres / mm³, soit environ 12000 fibres réelles par « fibre » représentée.

2.3.5 Applications Cliniques

Compressions Médullaires



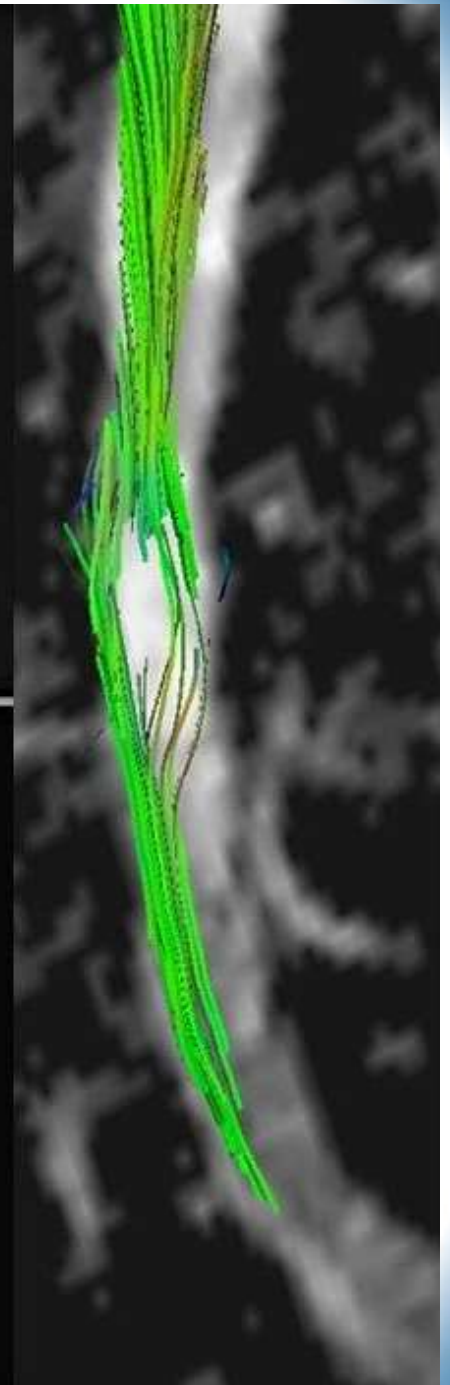
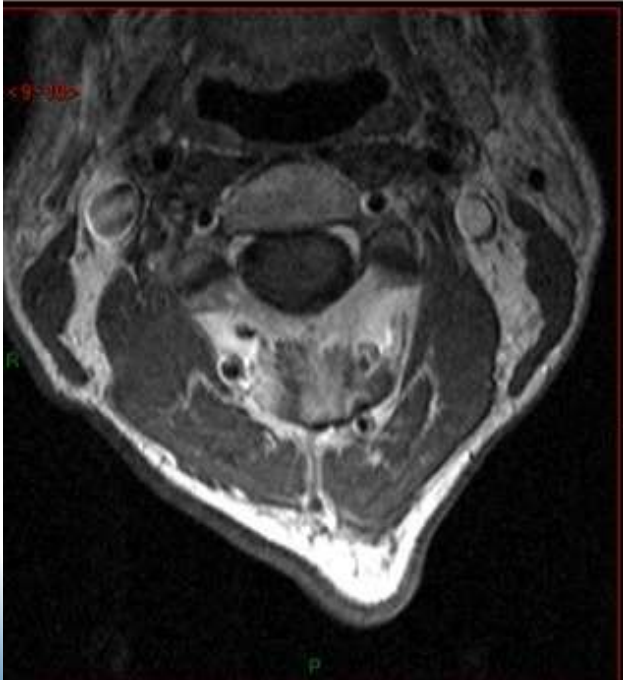
FA versus Time



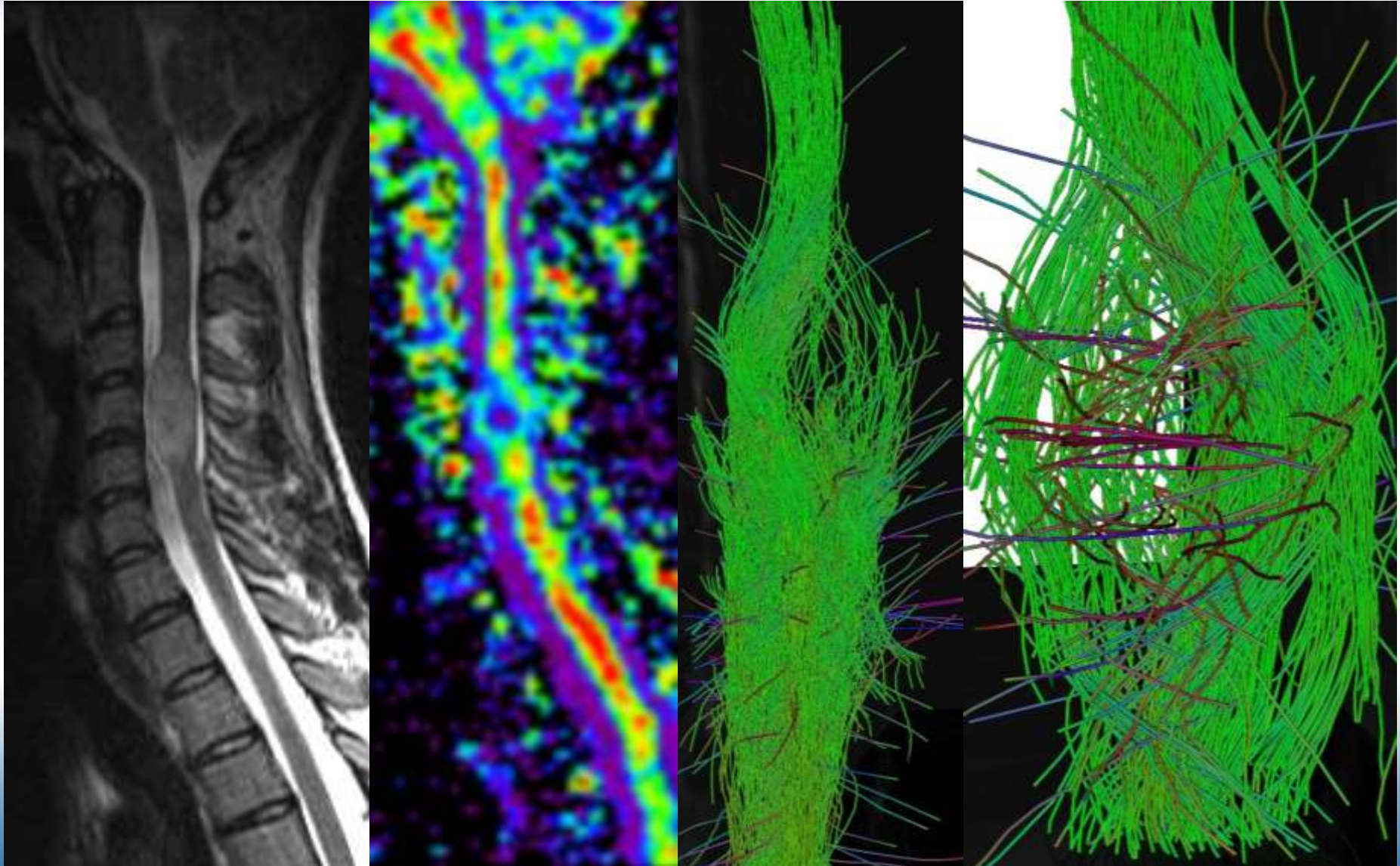
Tumeurs Médullaires

Ependymome

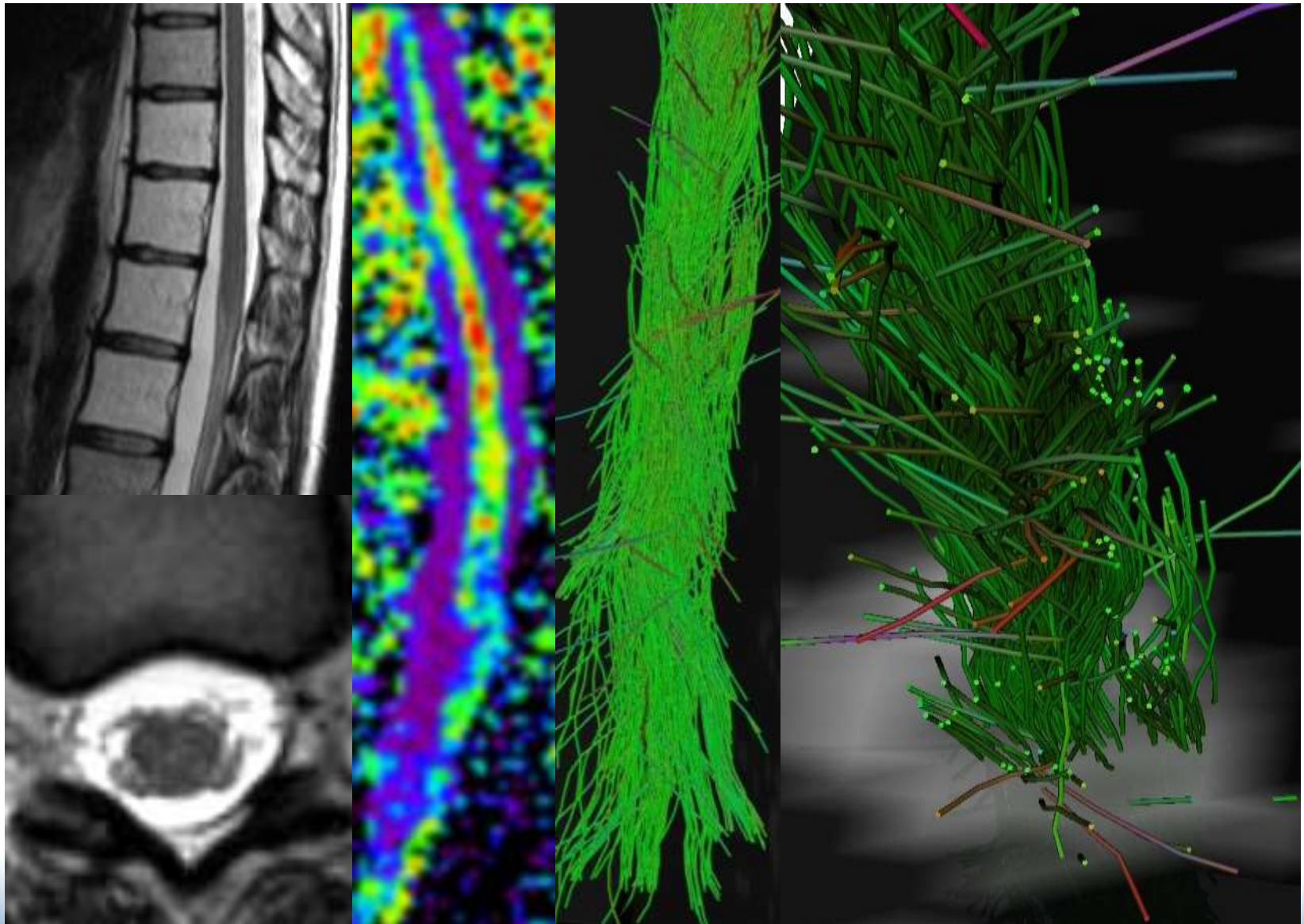




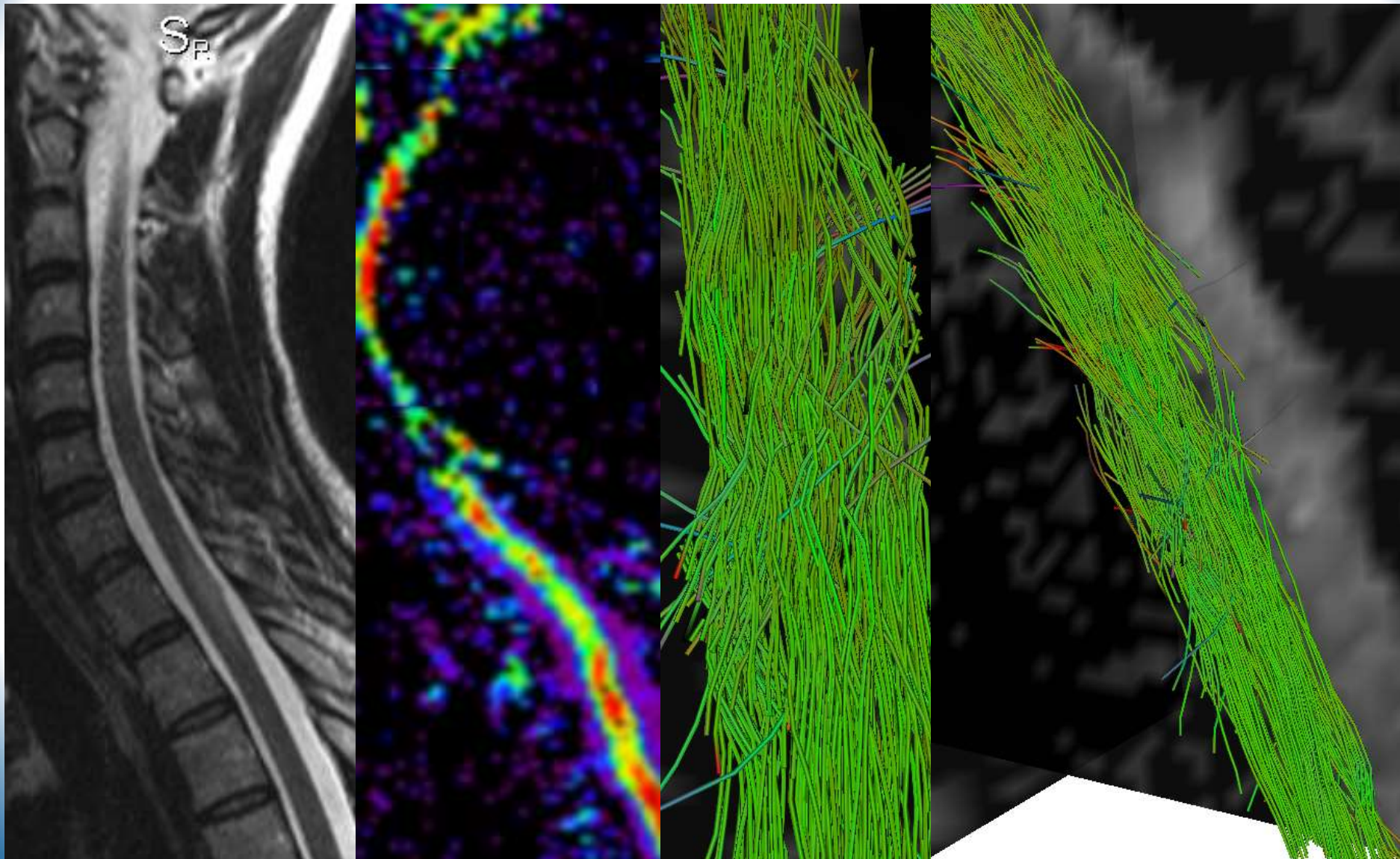
Astrocytome



Métastases

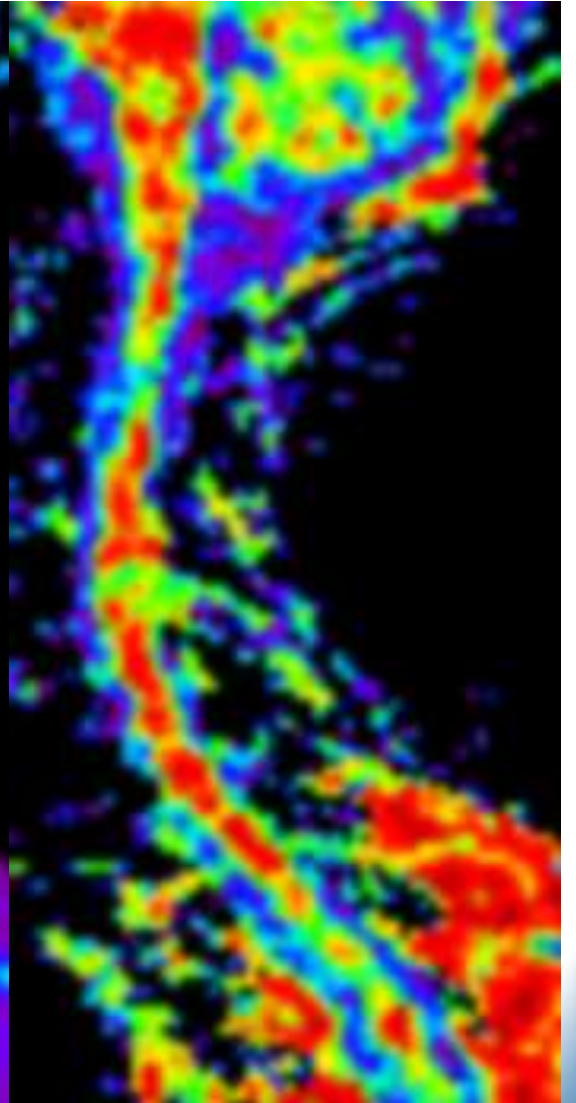
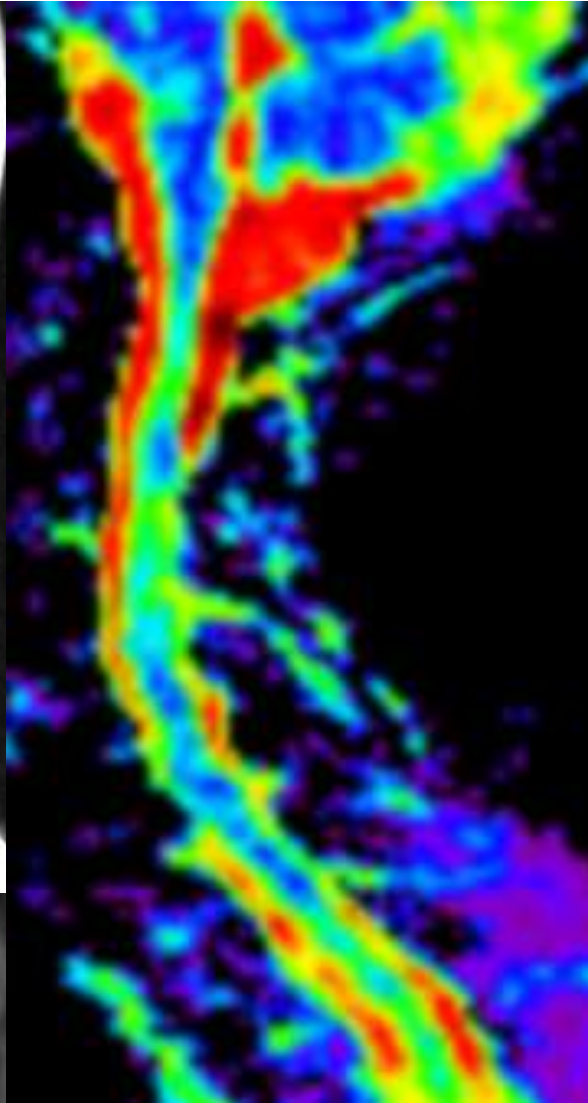


Hémangioblastome

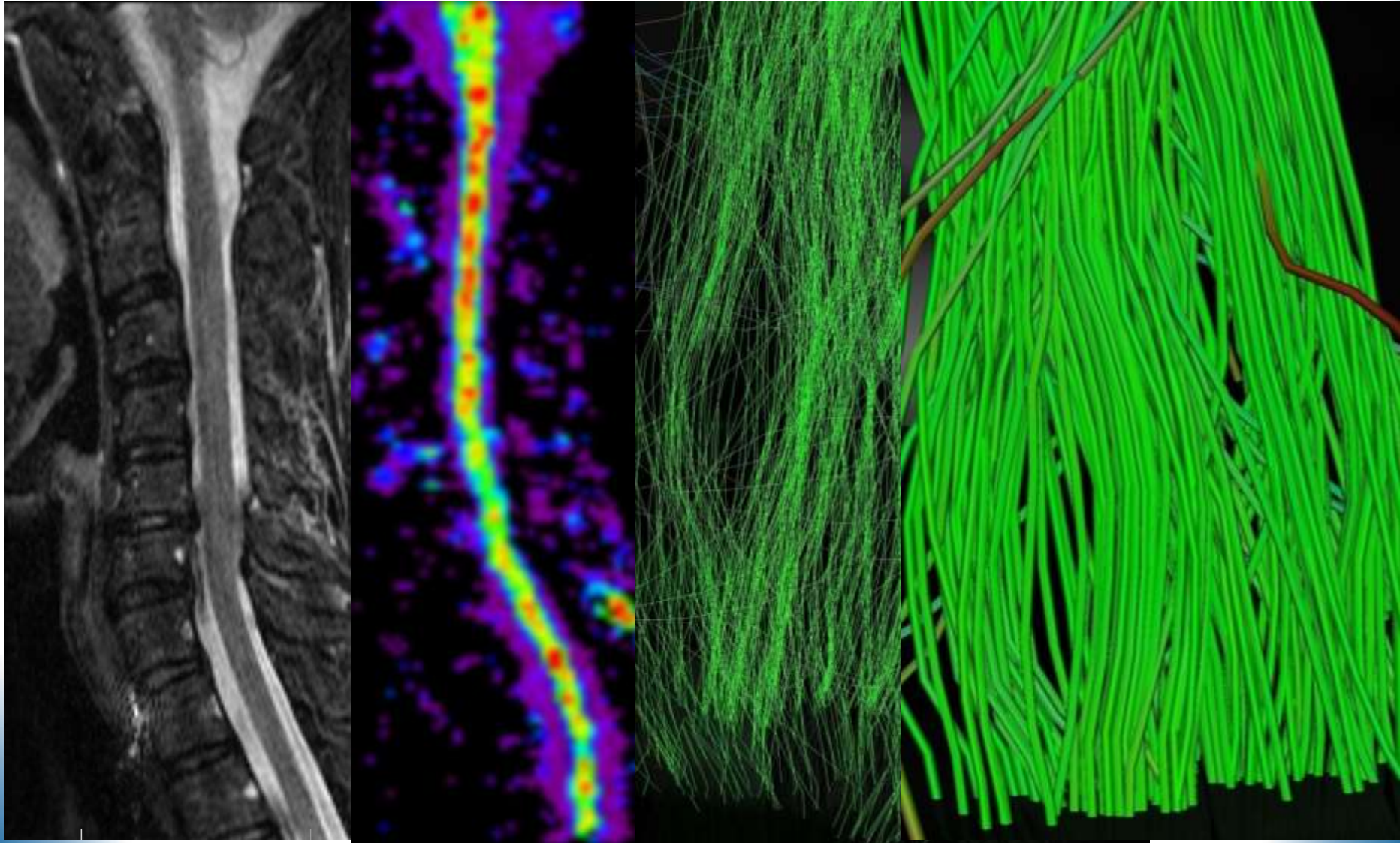


Processus Inflammatoires Médullaires et Régénération Axonale

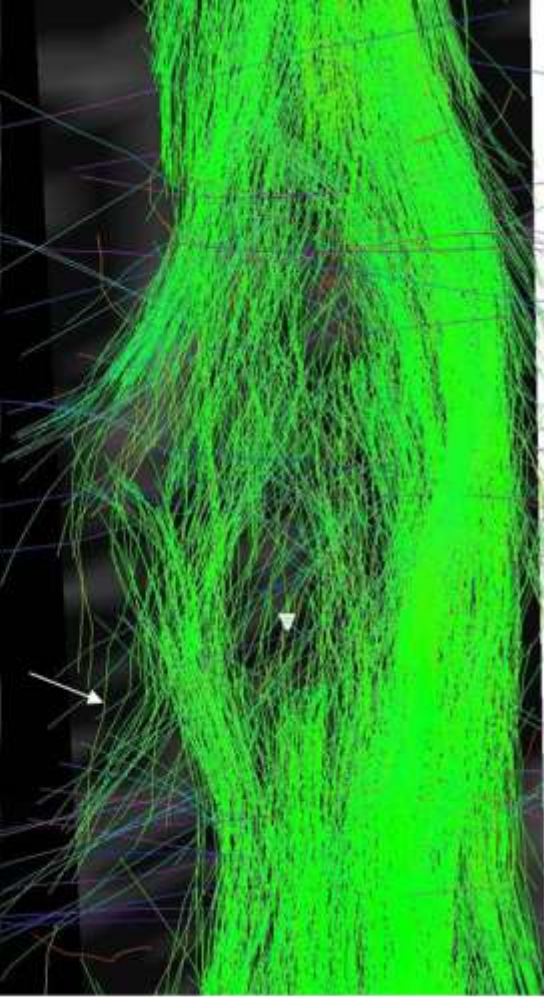
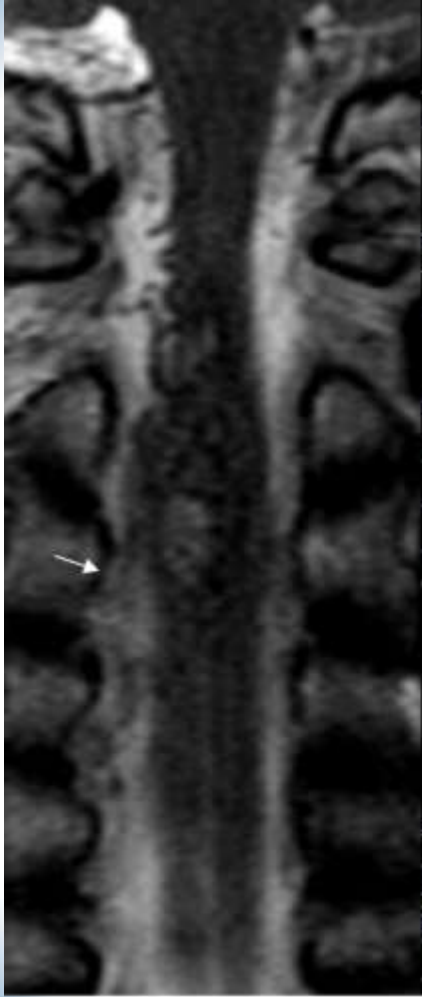
Myélites



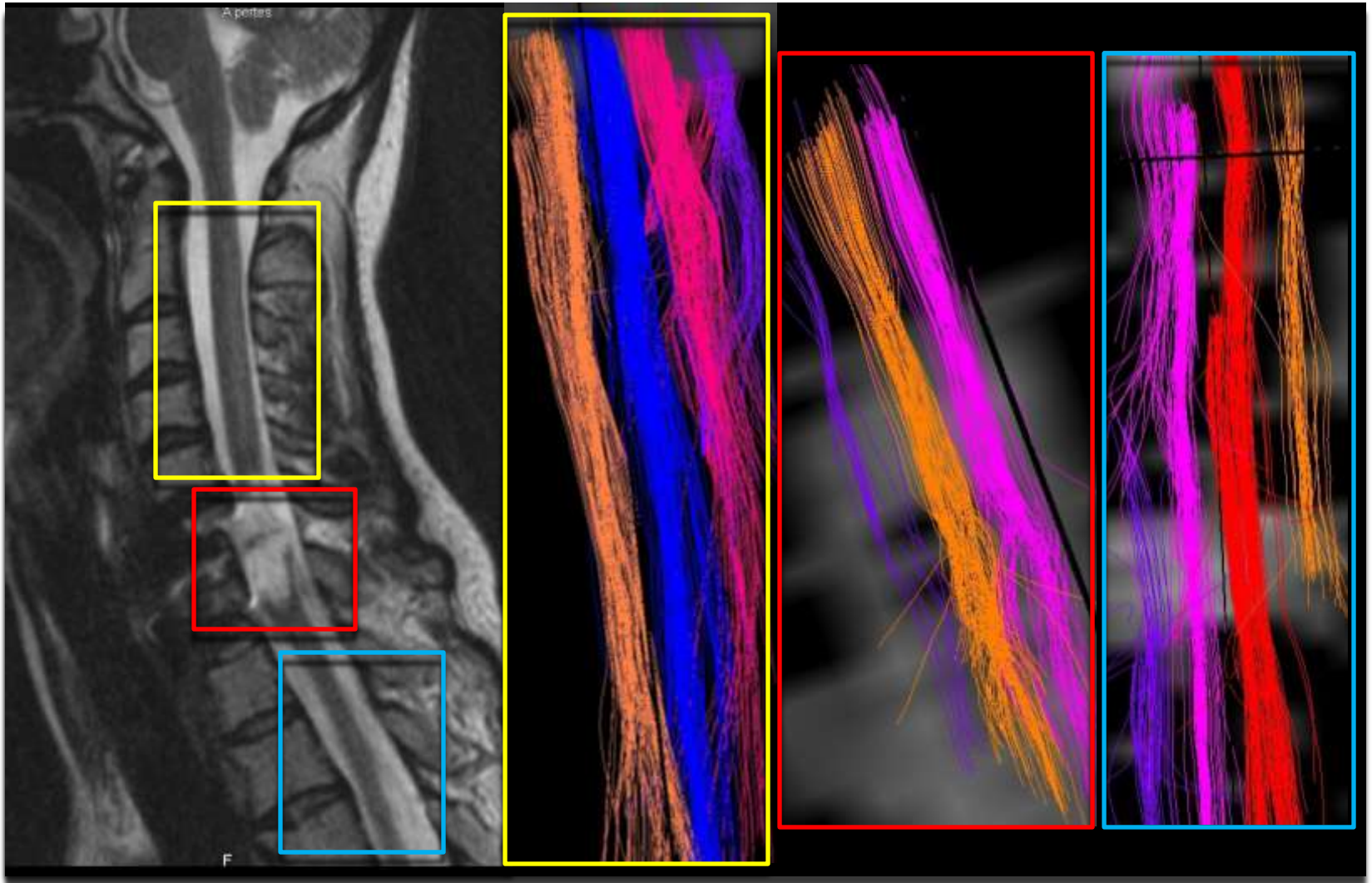
Sclérose en Plaques



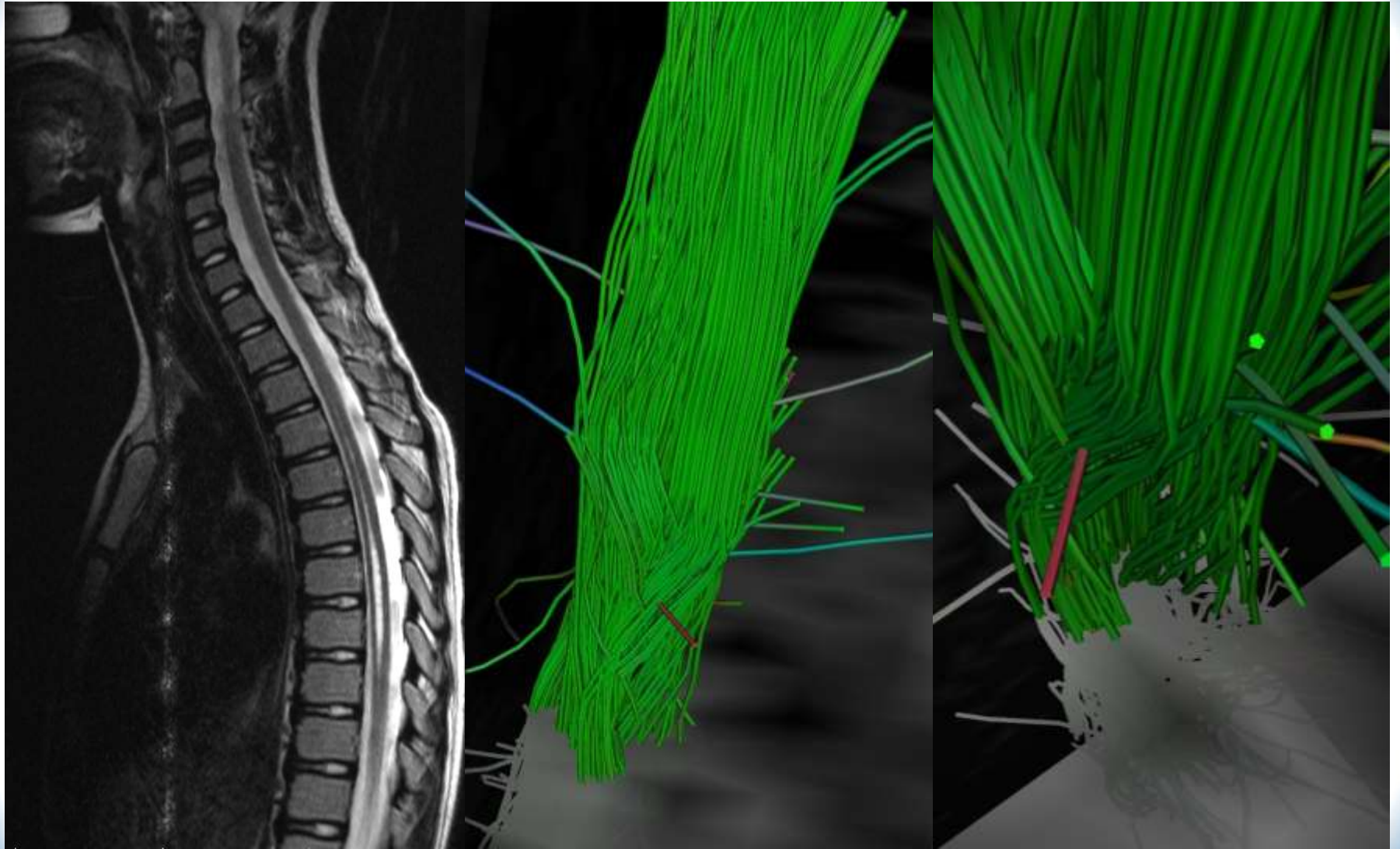
Processus Vasculaires Malformatifs

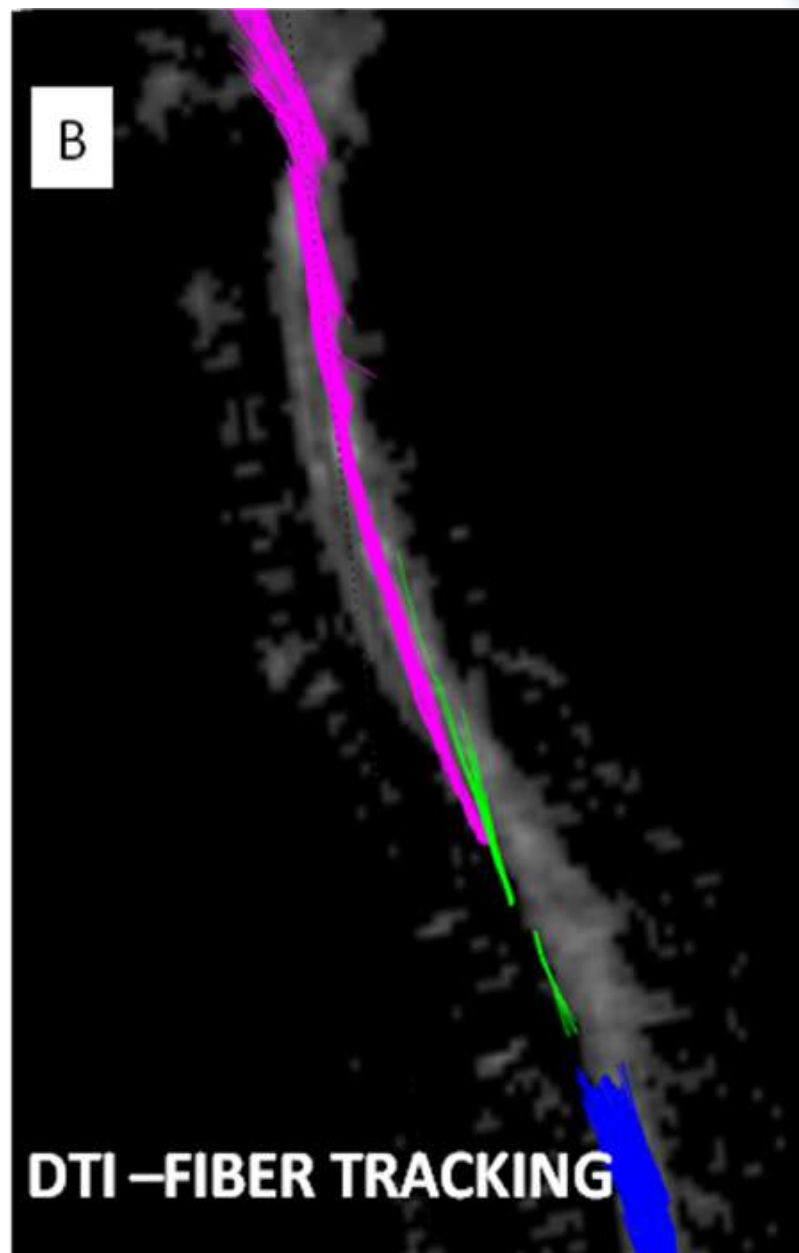


Sections Médullaires



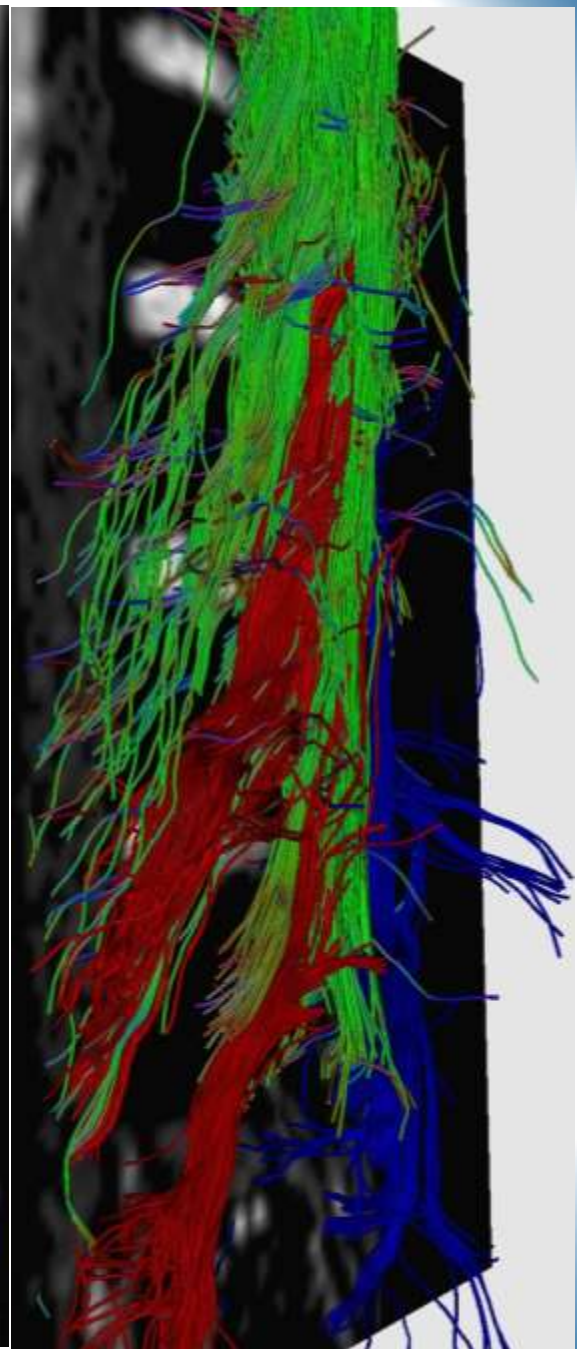
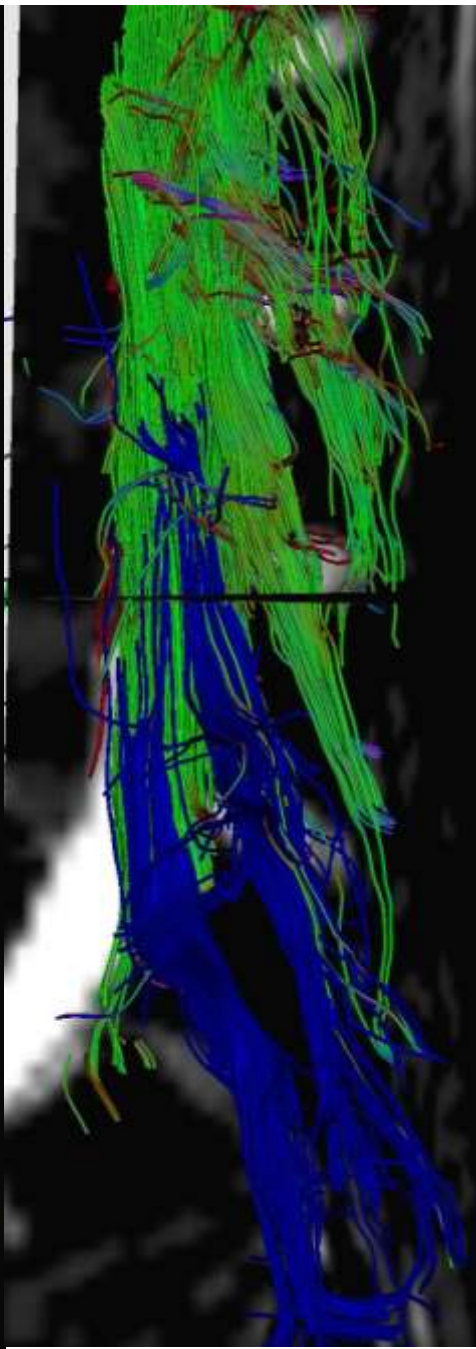
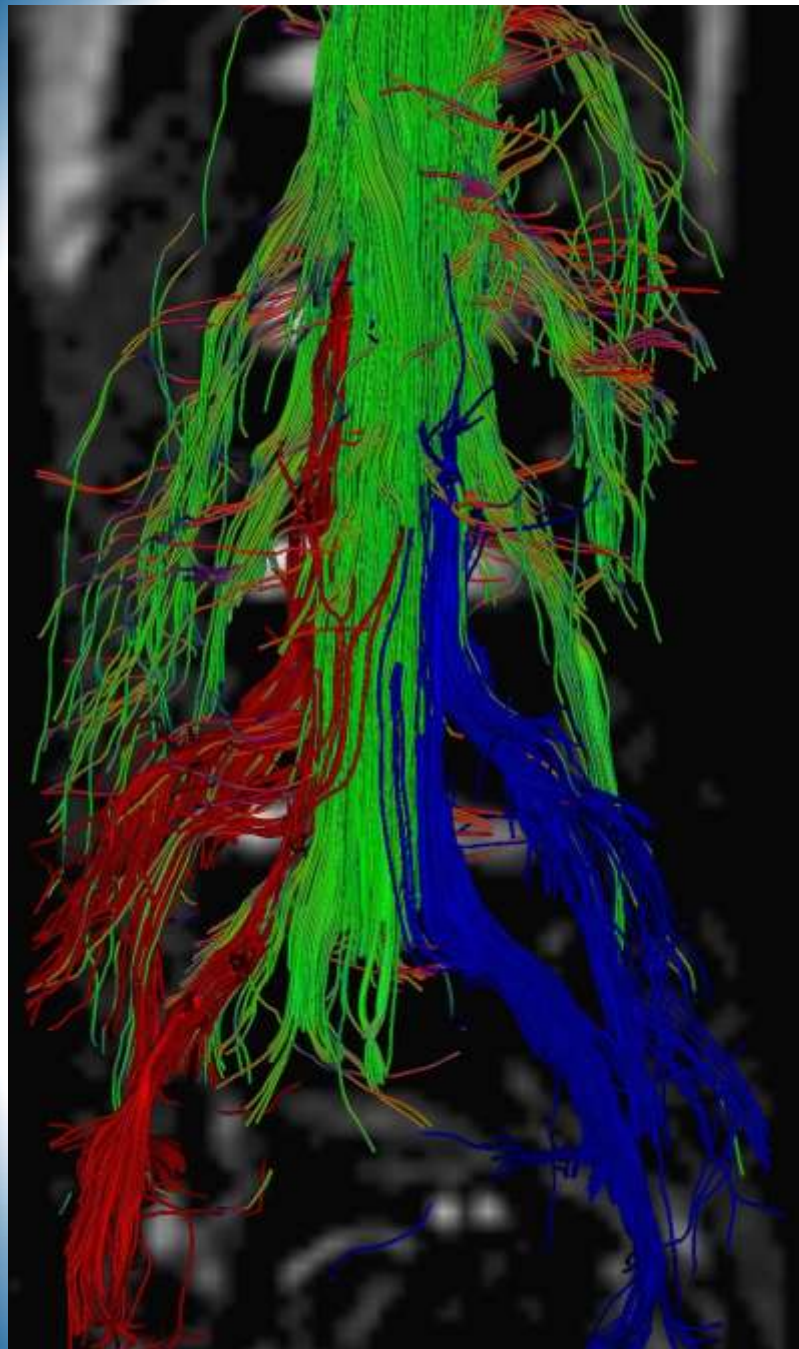
Syringomyélie



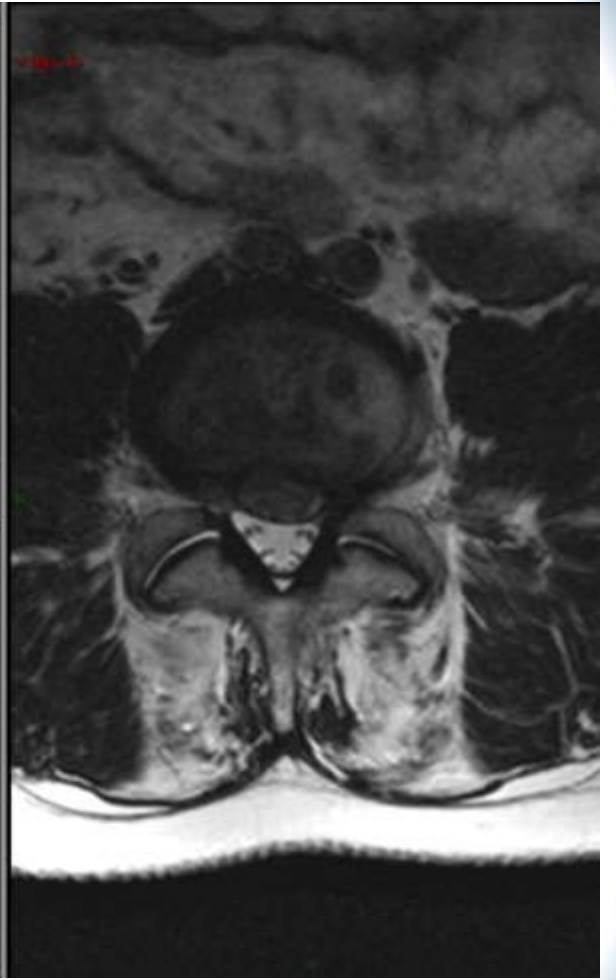


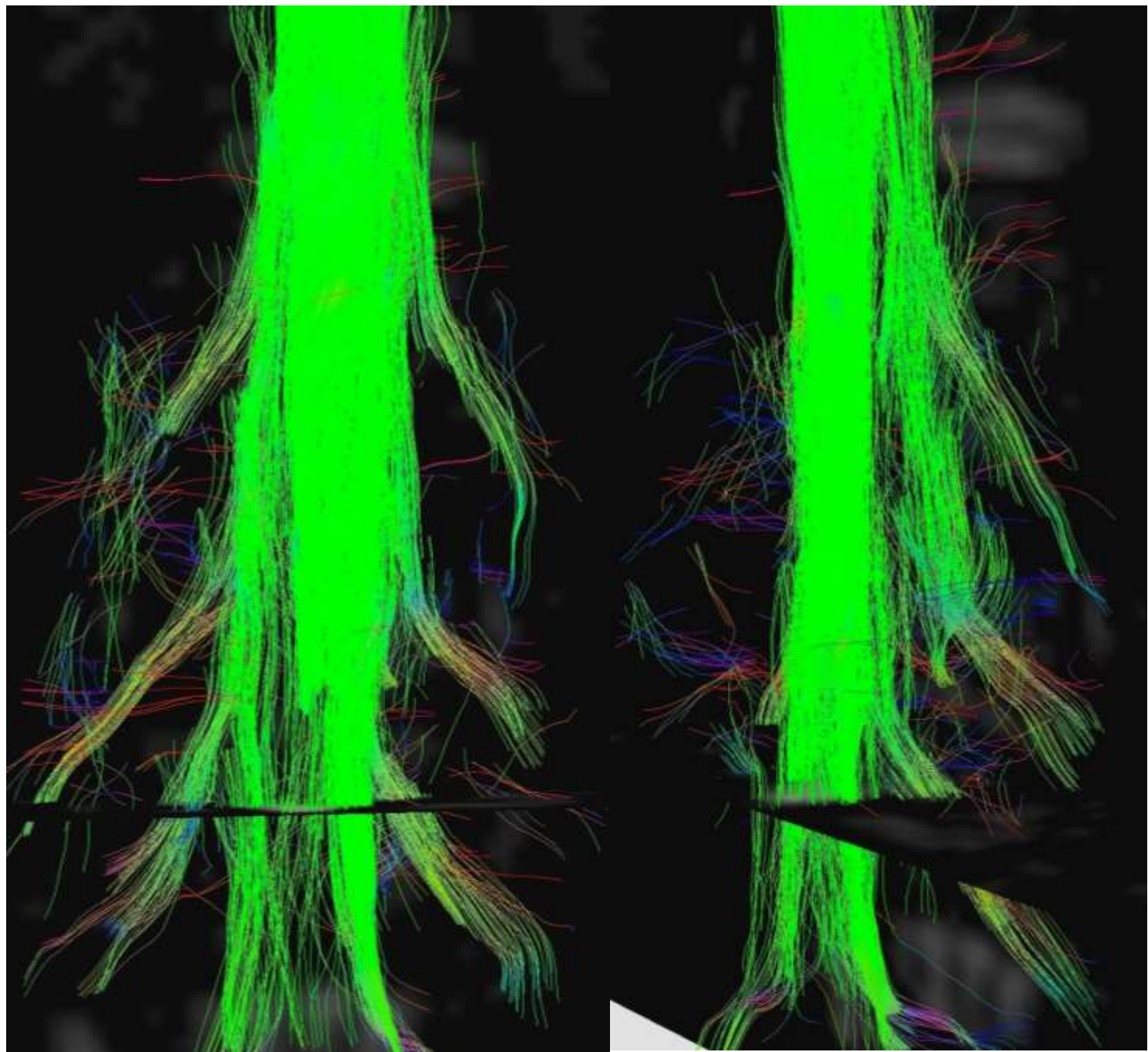
Radiculopathies





Hernies Discales



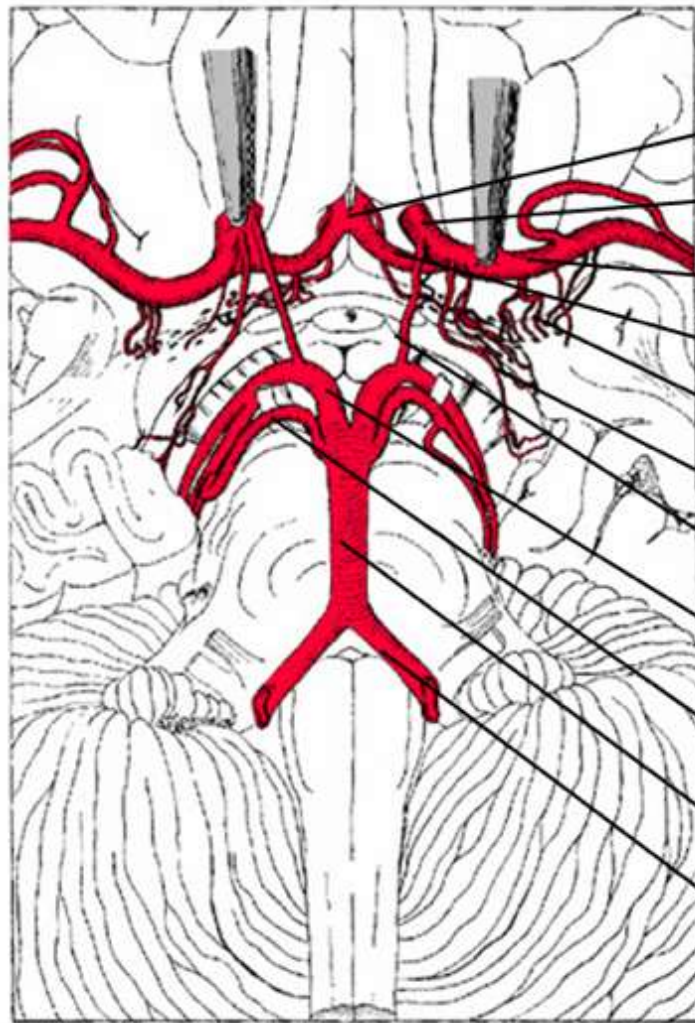


3. IRM de Perfusion

3.1 Rappels Physiologiques

IRM de Perfusion

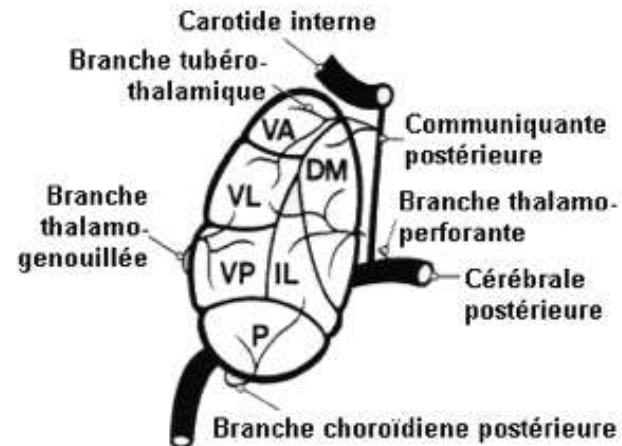
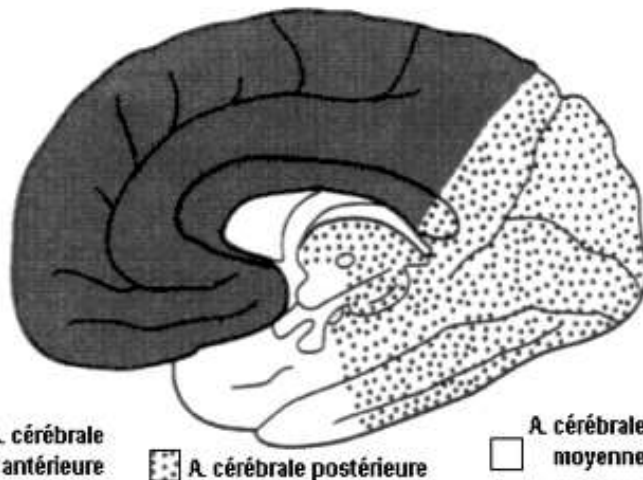
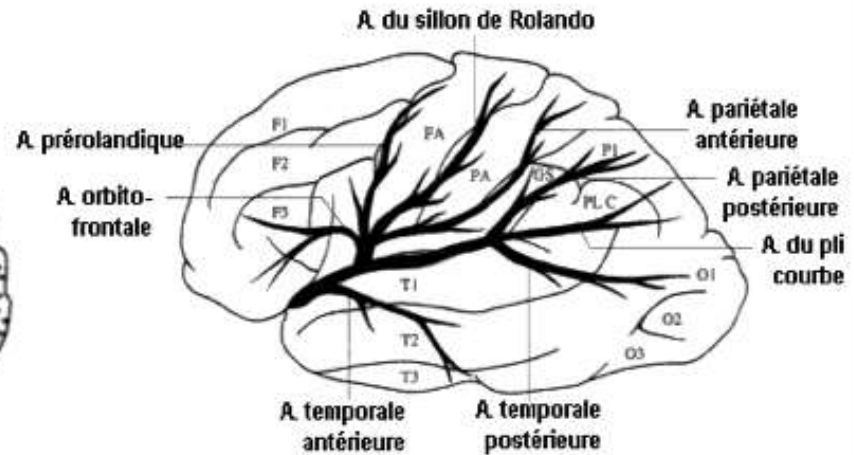
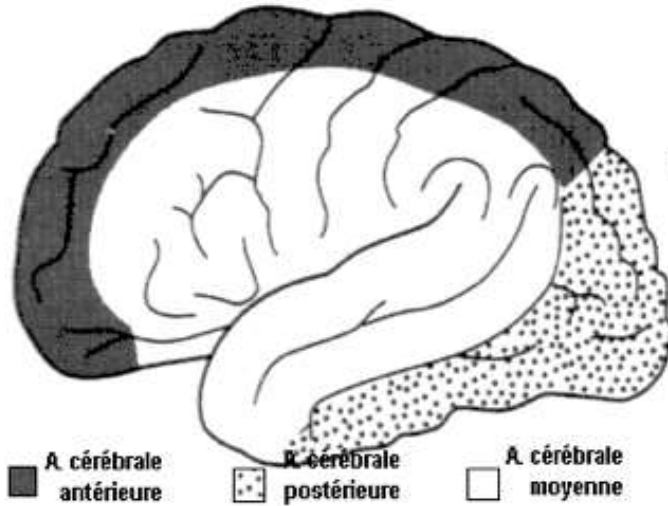
Circulation Artérielle



- Art. Comunicante Ant.
- Art. Carotide Int.
- Art. Cérébrale Moyenne
- Art. Cérébrale Ant.
- Art. Lenticulostrée
- Art. Choroïdienne Ant.
- Art. Comunicante Post.
- Art. Cérébrale Post.
- Art. Cerebelleuse Sup
- Art. Basilaire
- Art. Vertébrale (V4)

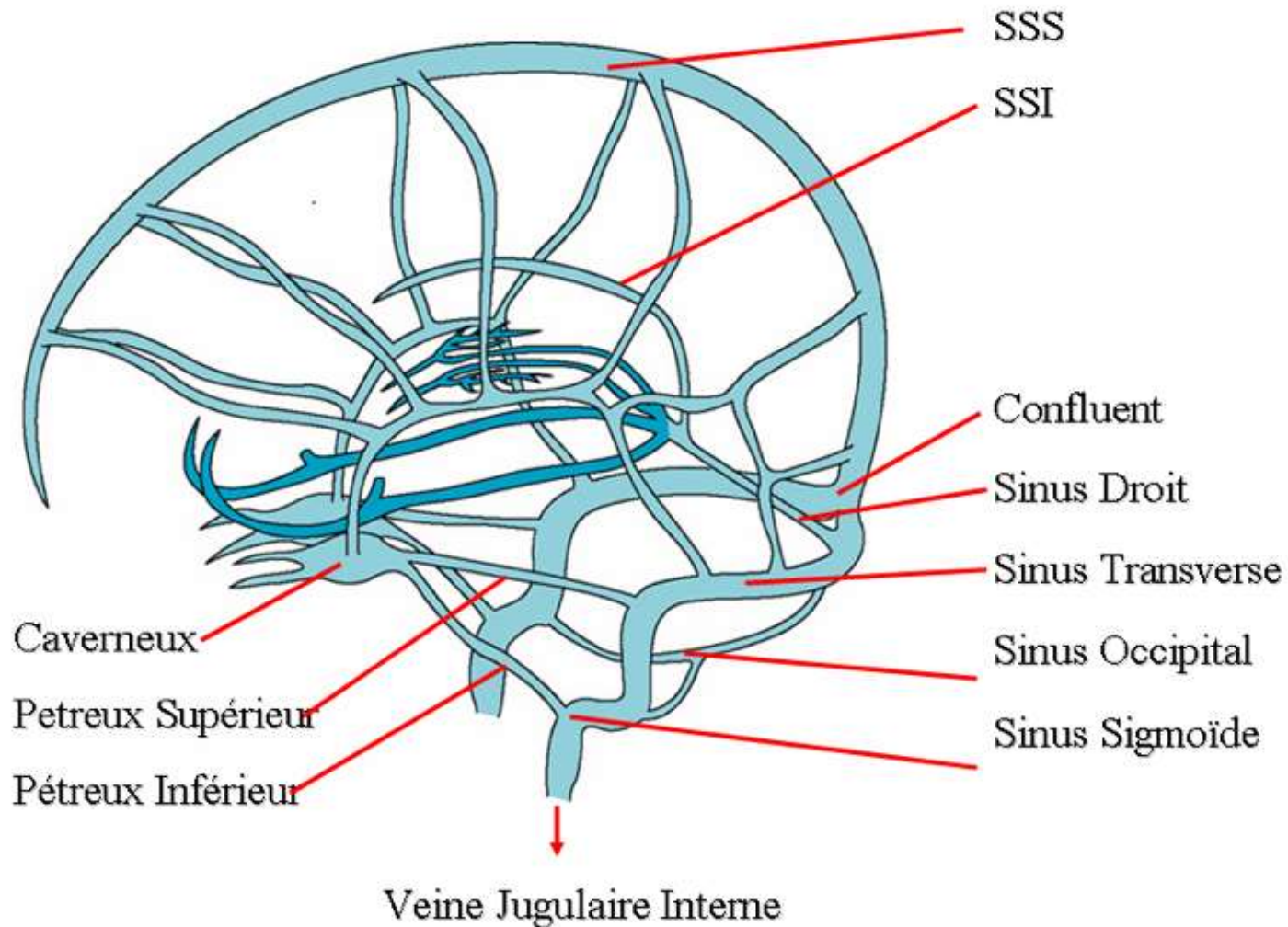
IRM de Perfusion

Circulation Artérielle



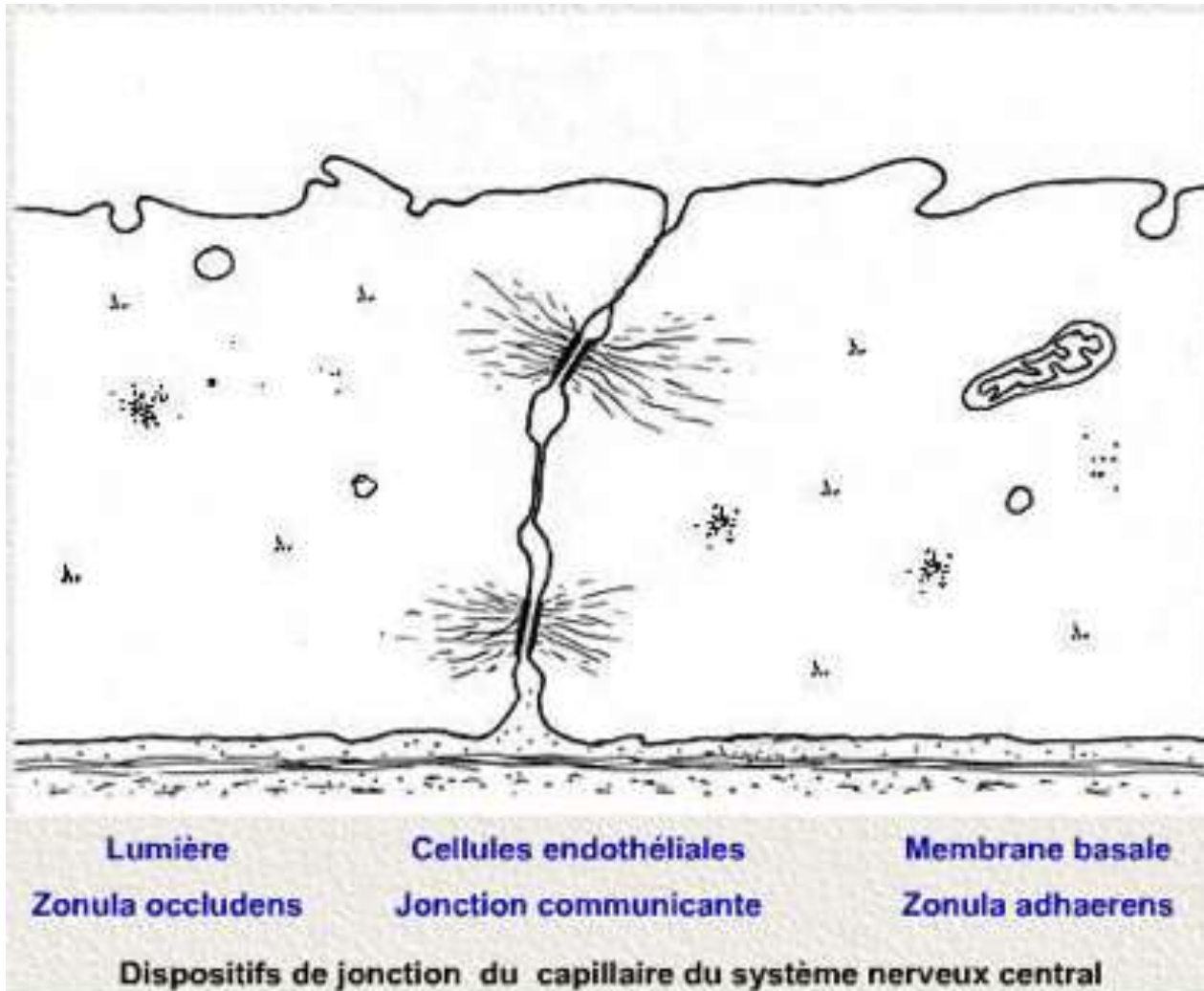
IRM de Perfusion

Circulation Veineuse



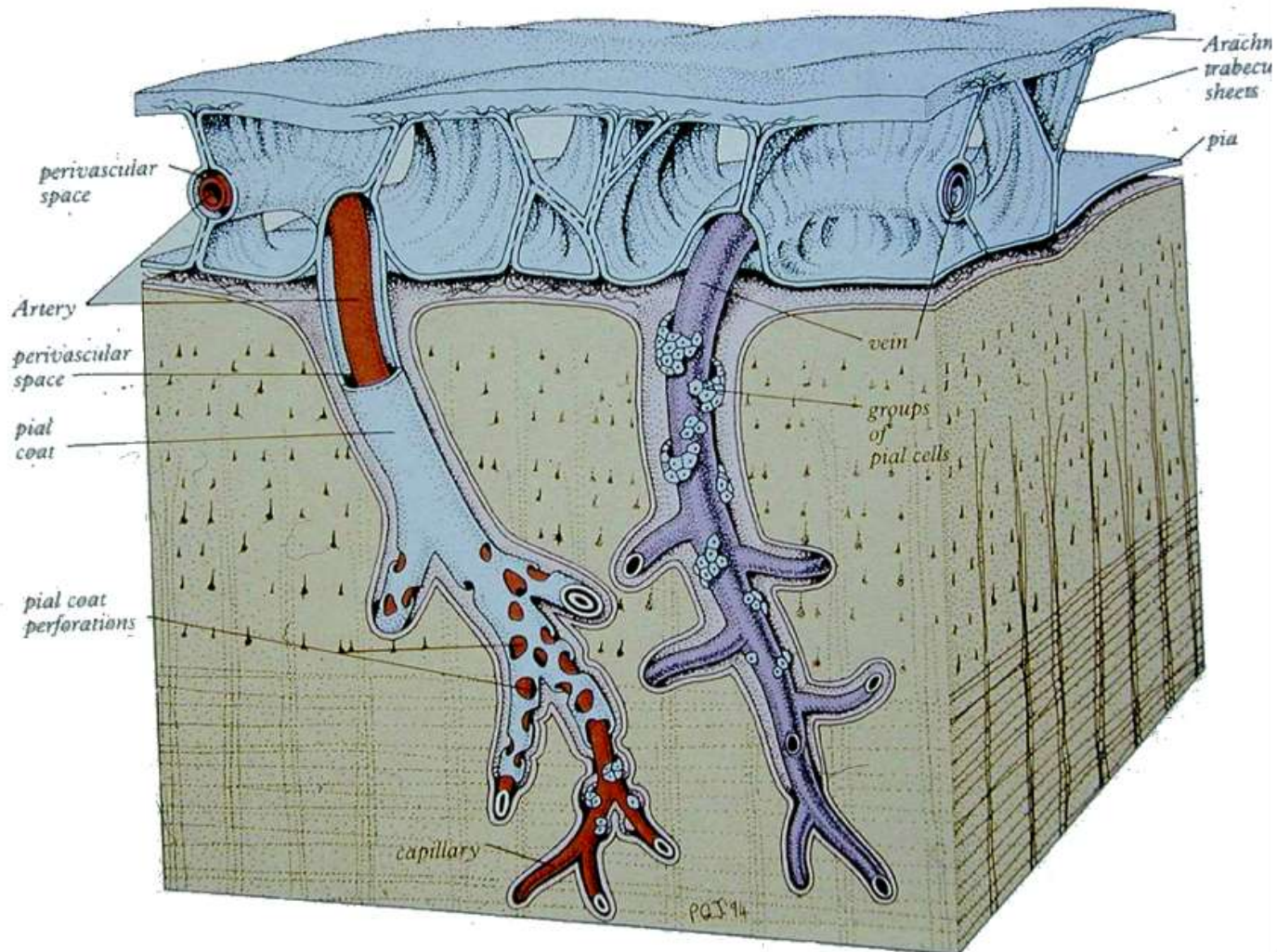
IRM de Perfusion

Micro-circulation et BHE



IRM de Perfusion

Circulation Péri-vasculaire



IRM de Perfusion

Rappels Physiologiques

Perfusion Cérébrale : Capacité d'autorégulation.

Décrite par le Volume Sanguin Cérébral (**CBV**), le Débit Sanguin Cérébral (**CBF**) et le Temps de Transit Moyen (**MTT**)

Valeurs normales :

	Substance Grise	Substance Blanche
CBV	4 ml/100g	2 ml/100g
CBF	60 ml/min/100g	20 ml/min/100g
MTT	4 s	6 s



IRM de Perfusion

Rappels Physiologiques

Perfusion Cérébrale pathologiques (perte autorégulation) :

-Ischémie : CBV  et CBF 

-Olighémie : CBV  et/ou  et CBF 

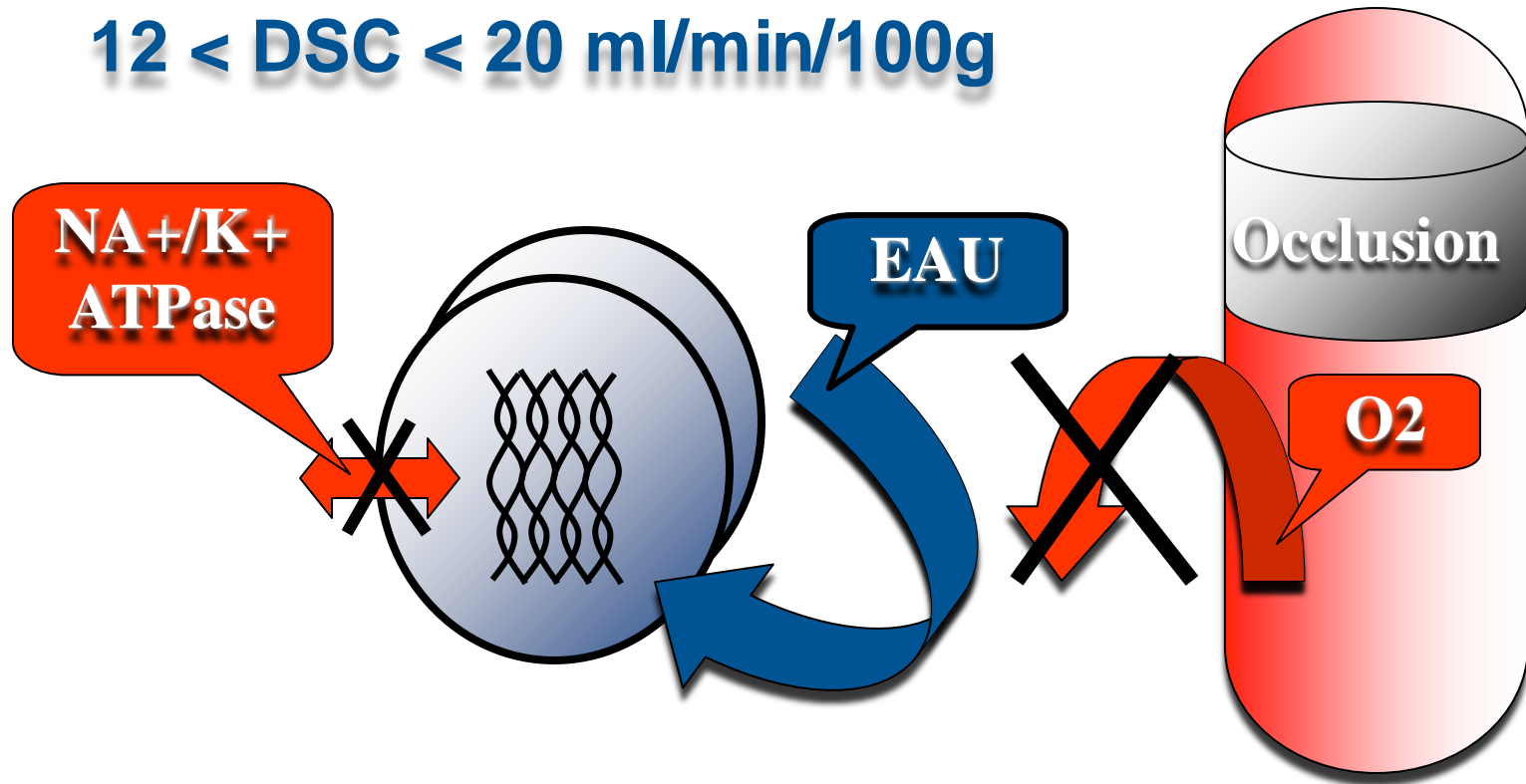
-Hyperperfusion : CBV  et CBF 

SG	Ischémie	Olighémie	Hyperperfusion
CBV	<2 ml/100g	≥ 4 ml/100g	> 4 ml/100g
CBF	<20 ml/min/100g	≤ 60 ml/min/100g	>80 ml/min/100g
MTT	>7 s	4-6 s	<2 s

IRM de Perfusion

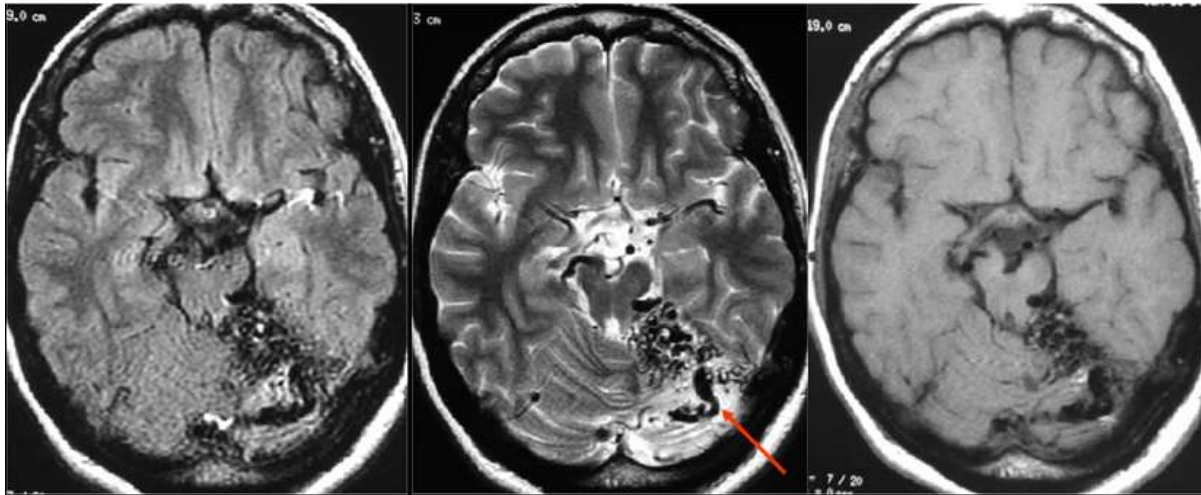
Rappels Physiologiques

$12 < \text{DSC} < 20 \text{ ml/min/100g}$



IRM de Perfusion

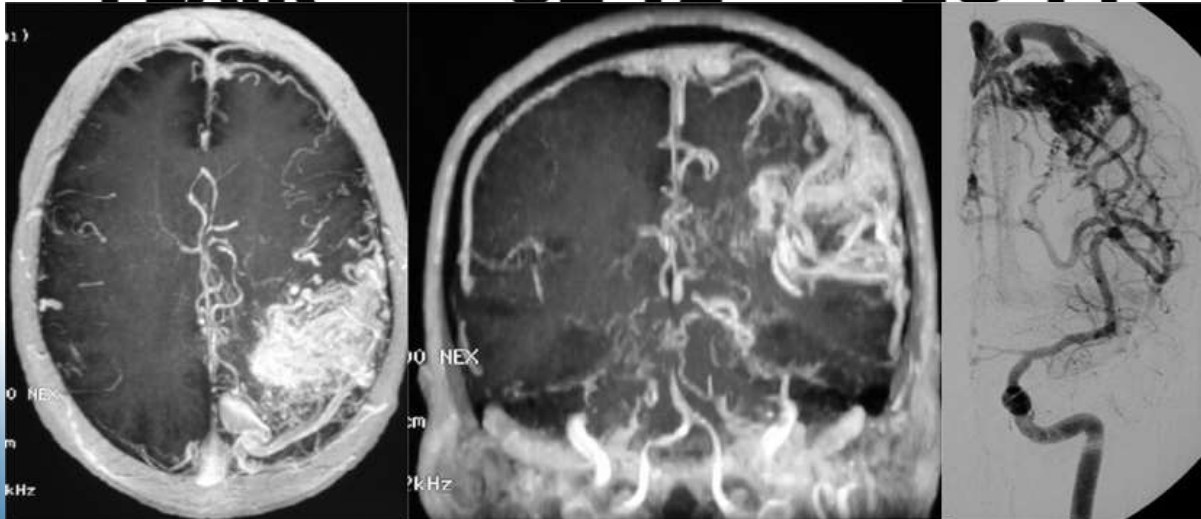
Shunts Artérioveineux « simples » = MAV ou FAV



FLAIR

SE T2

EG T1



MPVR GADO

ARTERIO

- Communication directe artère-veine (=nidus, fistule)

- Manifestations cliniques :

- Rupture (50%)
- Epilepsie (35%)
- Céphalées (10%)
- Déficit (5%)

- Anomalies de Perfusion à l'artériographie :

- Hypervascularisation
- Stase veineuse (+++)
- » Vol « artériel

- BHE intacte si pas rupture

- Manifestations à distance du nidus possibles

3.2 Rappels Méthodologiques

IRM de Perfusion en Bolus

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM

- *Injection en bolus de contraste (Gadolinium)*
- Marquage intrinsèque du flux :
 - Mouvement intra-voxel cohérent (Le Bihan, 1986) :
densité de capillaires fonctionnels
 - Déoxyhémoglobine (BOLD)
 - Arterial Spin Labeling
- Marquage continu (CASL)
- Marquage pulsé (EPSTAR : double FLAIR)
- Traceurs Exogènes :
 - Fluor
 - Deutérium
 - Oxygène
 - Xenon

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

GADOLINIUM bolus IV substance paramagnétique non diffusible



circule dans le secteur intravasculaire si intégrité de BHE



augmente la différence de susceptibilité magnétique entre le lit capillaire et le parenchyme adjacent



Gradients de champ magnétiques internes



↗ déphasage des spins



↘ signal lors du passage du Gadolinium

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Méthode au Premier Passage (= Stewart-Hamilton)

- *Traceur non-diffusible (pas de rupture de la BHE)*
- *Traceur et sang parfaitement mélangés*
- *Quantité de traceur faible (pas de perturbation du système)*
- *Traceur circule à la vitesse du sang*
- *Pas d'accumulation ou de stagnation de traceur*
- *Processus linéaire et stationnaire*
- *Recirculation du traceur doit pouvoir être négligée*



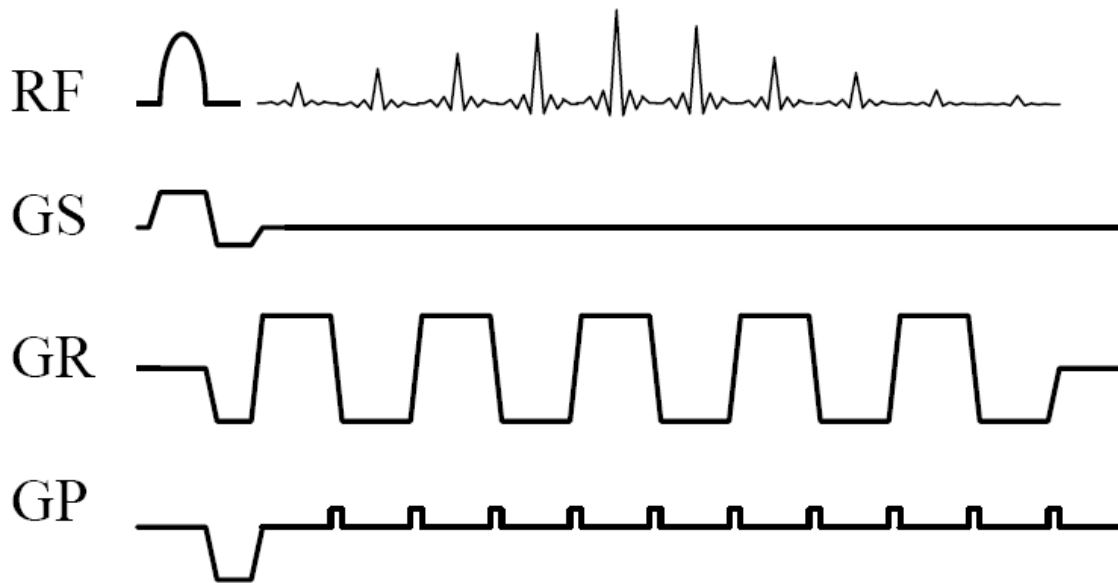
0.1 mm

(Duvernoy, 1981)

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Séquence de Perfusion EPI (*Echo Planar Imaging*)



- IRM 1.5 Tesla
- Echo de gradient T2 ($>$ SE T2)
- TR 2000 ms, TE 30ms

•Importants artéfacts de susceptibilité magnétique

•Utilisable en SE ou GE pour mesure de perfusion

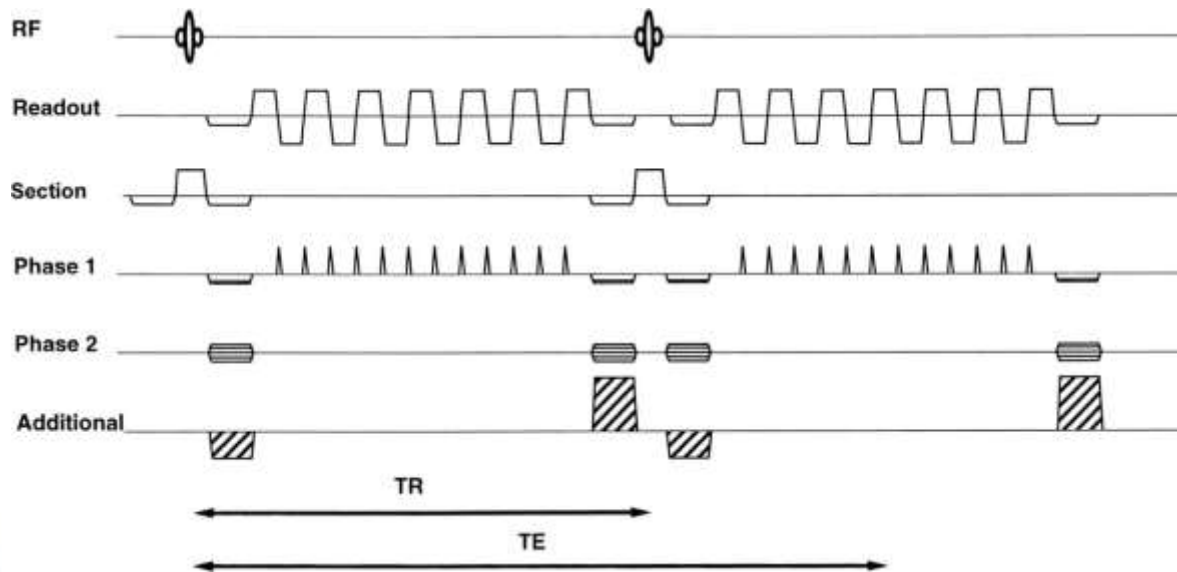
•SE : microcirculation mais faible SNR

•GE : fort SNR mais Artériel + capillaire + veines

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Séquence de Perfusion PRESTO (*Principle of Echo Shifting with a Train of Observations*)



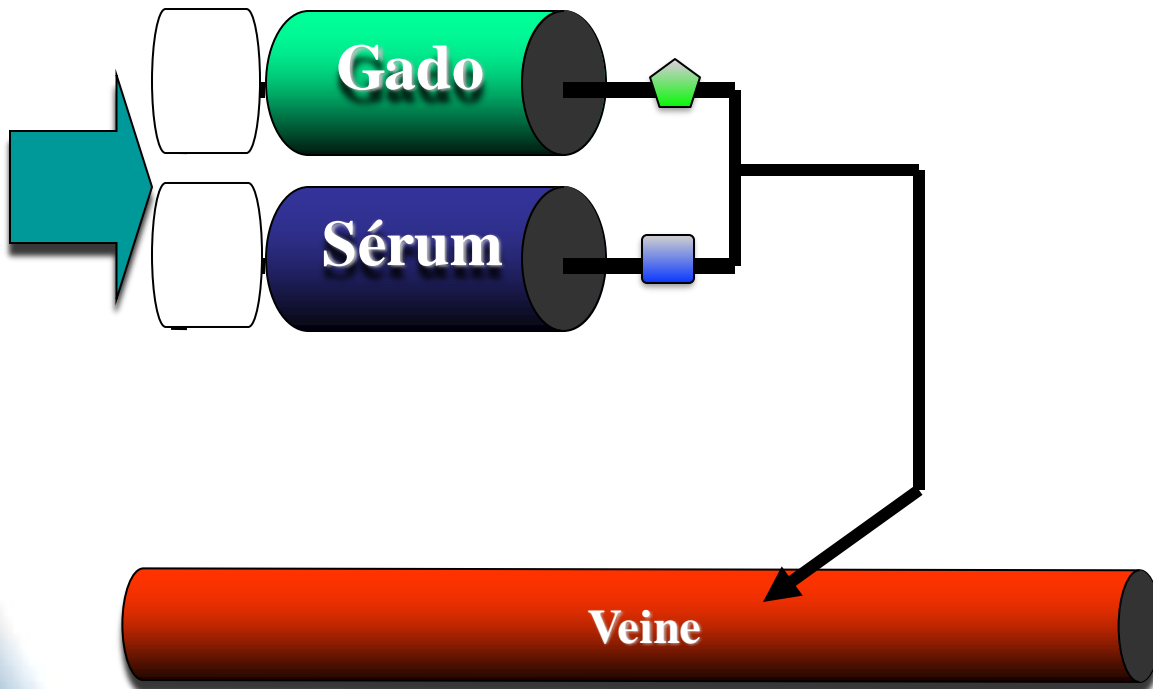
- Acquisition 3D
- Réduction artéfacts de susceptibilité
- Bonne résolution temporelle
- Résolution spatiale médiocre
- Segmentation EPI avec train d'écho plus court que valeur T2*
- TE plus long que TR
- Mesures de perfusion similaires à EPI

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Mesure de la Perfusion cérébrale en IRM par Injection en Bolus

Injection de Bolus de Chélate de Gd

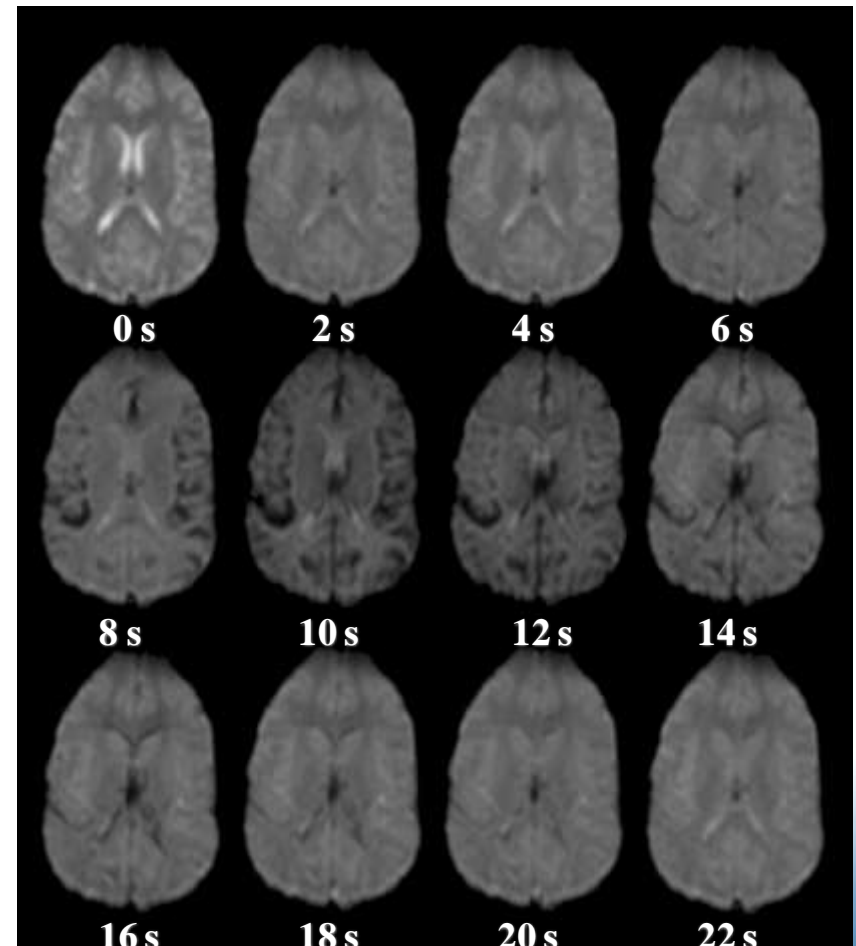
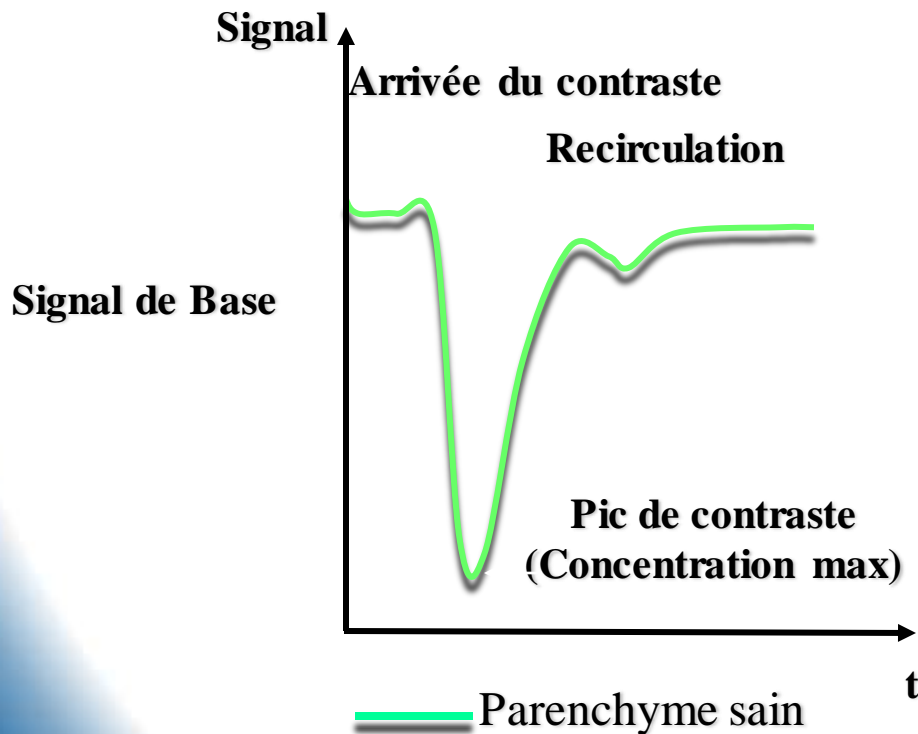


- Perfusion avec KT 18 G pli du coude G
- Injection 15 cc Gado en bolus, suivi de 15 cc de sérum physiologique
- Délai injection : 3 s après le début de l'acquisition
- Débit injection : 7 cc/s
- Durée injection : de 2 s

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

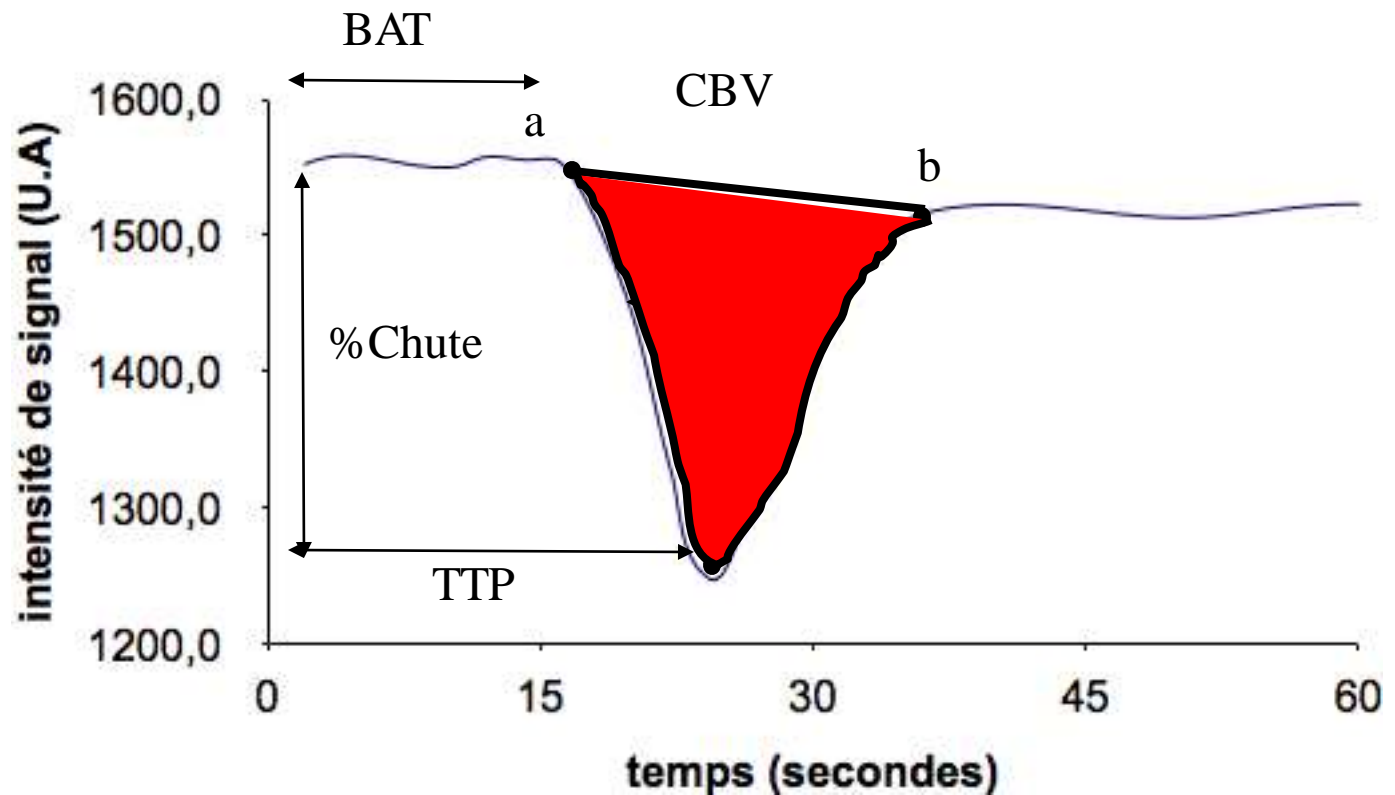
Etude de la cinétique du 1^{ier} passage de contraste dans le lit capillaire cérébral.



IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

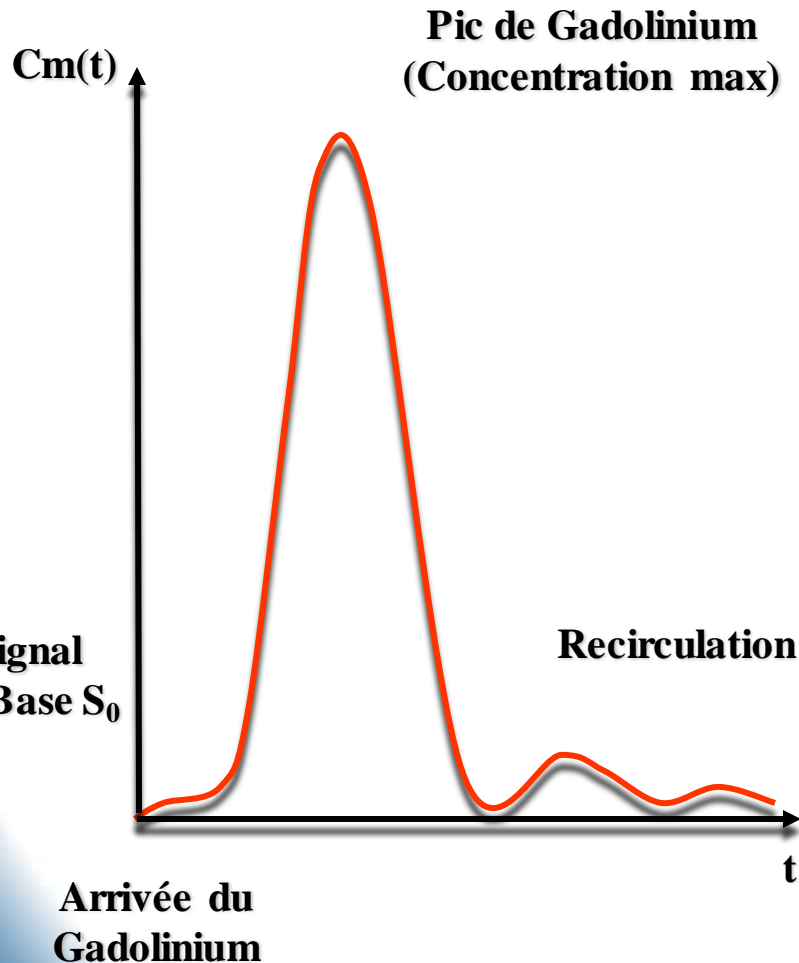
Méthodes de mesures de la Perfusion



IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Méthodes de mesures de la Perfusion



Selon théorie de la dilution des indicateurs, la concentration de Gadolinium est proportionnelle au différentiel du signal $\otimes S(t)$, fonction de la variation de l'effet de susceptibilité $\otimes R^2$

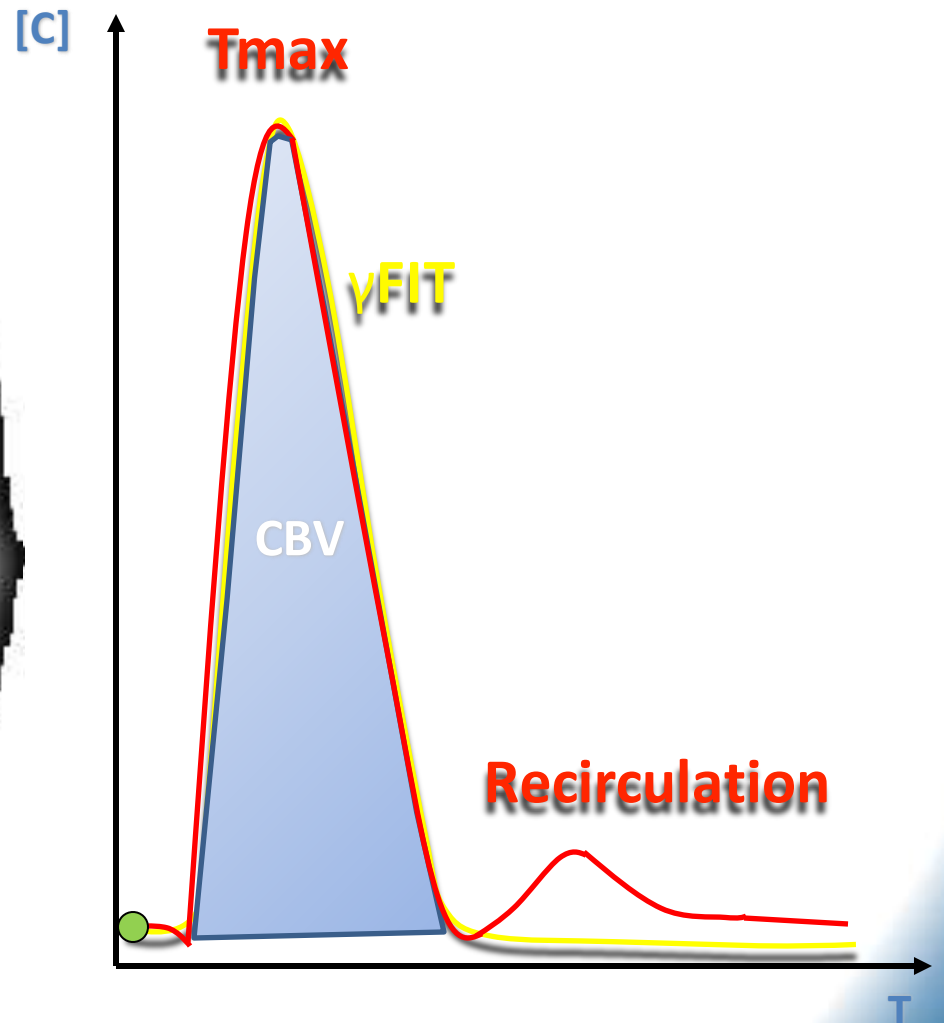
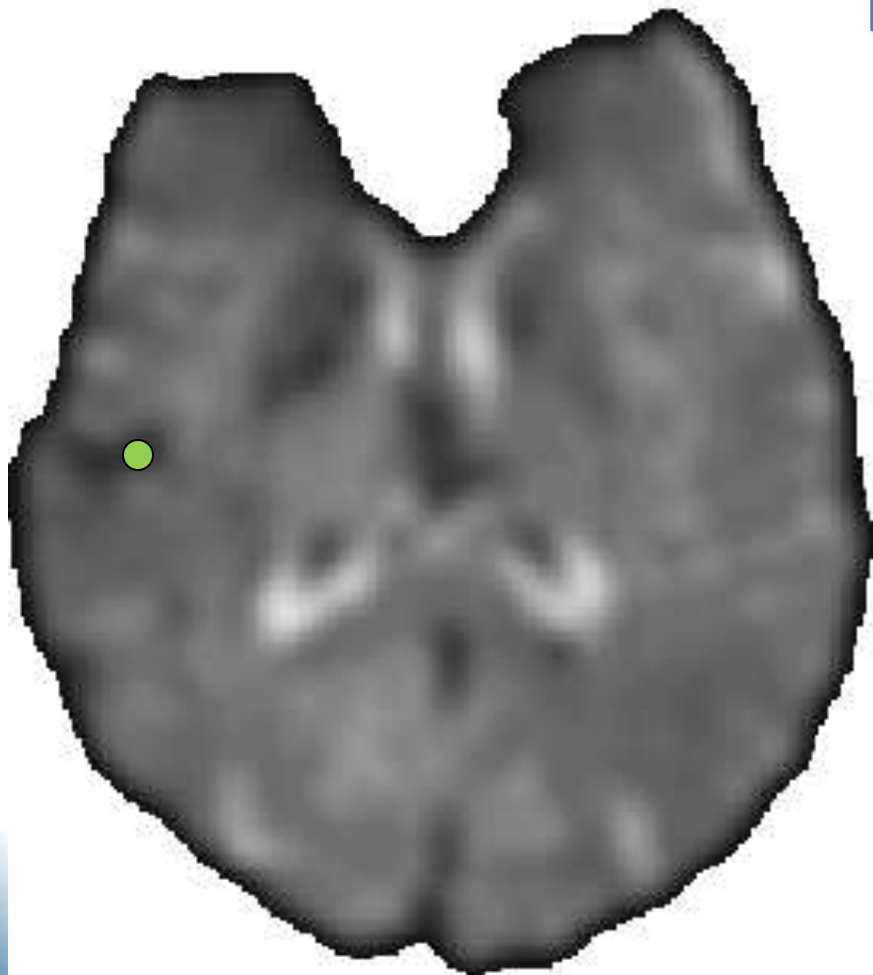
$$C_m(t) = -\frac{K}{TE} \ln \left(\frac{S_i(t)}{S_{i0}} \right)$$

Avec

$C_m(t)$: Concentration de Gado
K : Constante séquence dépendante
S(t) : Valeur du signal au temps t
TE : Temps d'écho
 S_0 : Signal de base (au temps 0)
 $\otimes S(t)$: $S(t)/S_0$

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*



IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Description de la Courbe Tissulaire

- embol de produit de contraste non idéal
- Quantification nécessite la détermination de la fonction d'entrée artérielle (**déconvolution**)

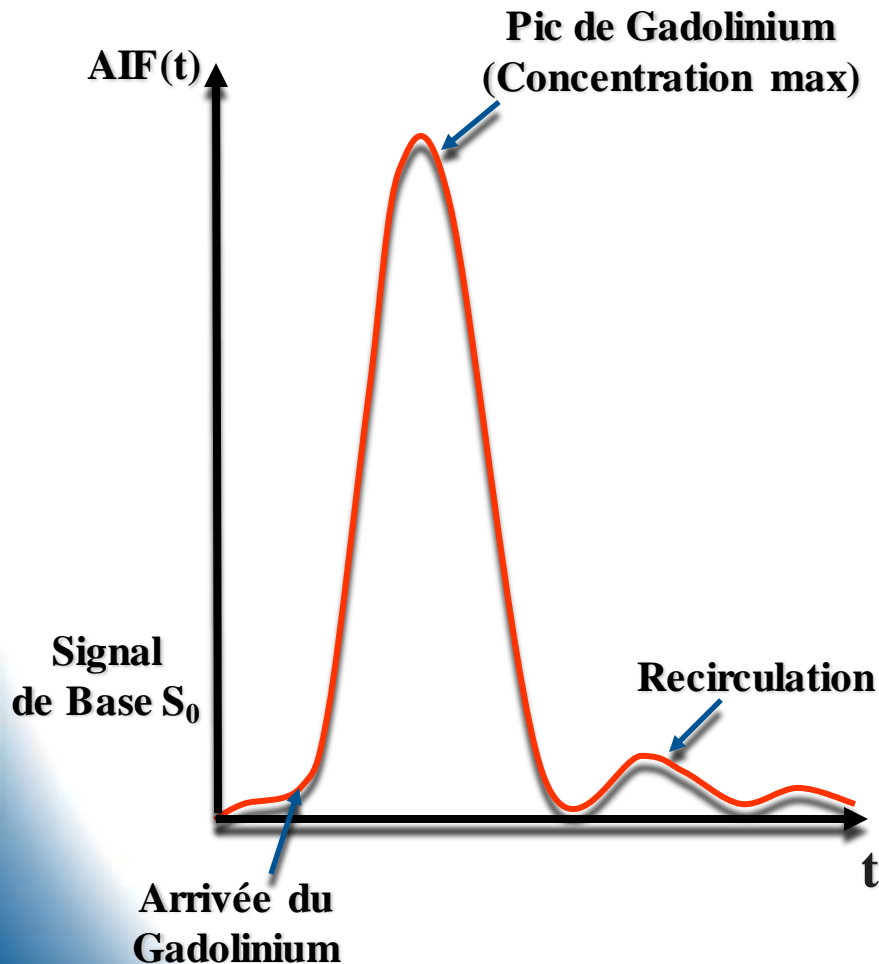
$$c_{ROI}(t) = F_{ROI} c_a(t) \otimes R(t)$$

- détermination de $R(t)$:
 - méthodes de déconvolution :
 - Transformée de Fourier (TF)
 - Décomposition en Valeurs Singulières (SVD)
 - Minimisation et Régularisation
 - extraction de paramètres de flux (**CBF**), de volume (**CBV**) et de temps de transit moyen (**MTT**)

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Fonction d'Entrée Artérielle (AIF)



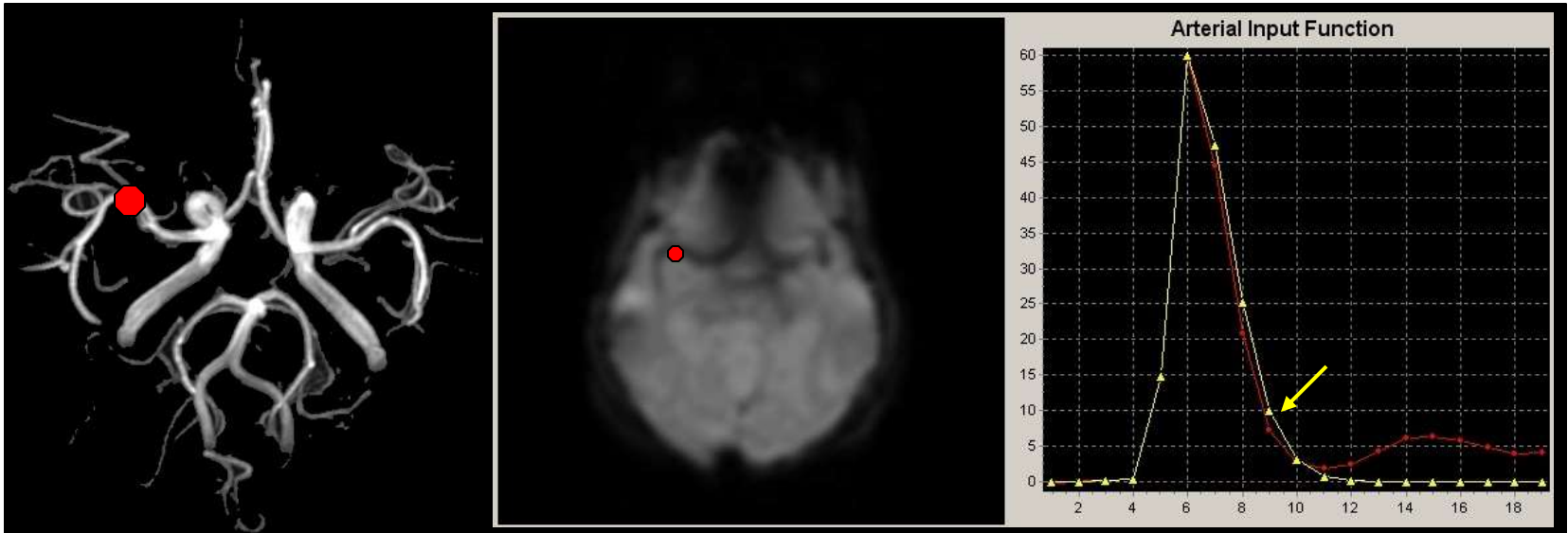
- Voxels au sein desquels est détectée la concentration maximale de Gadolinium, et correspondant aux structures vasculaires.
- Algorithmes permettant la sélection manuelle ou automatique de voxels > à un seuil donné (70% de la valeur max.) à un temps artériel (fonction de coût).
- Phénomènes de volume partiels.
- Susceptibilité magnétique.
- Artéfacts pour les flux non laminaires.
- Variabilité anatomique
- Phénomènes de saturation (début ou fin de bolus)

!! Nécessaire pour quantification !!

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

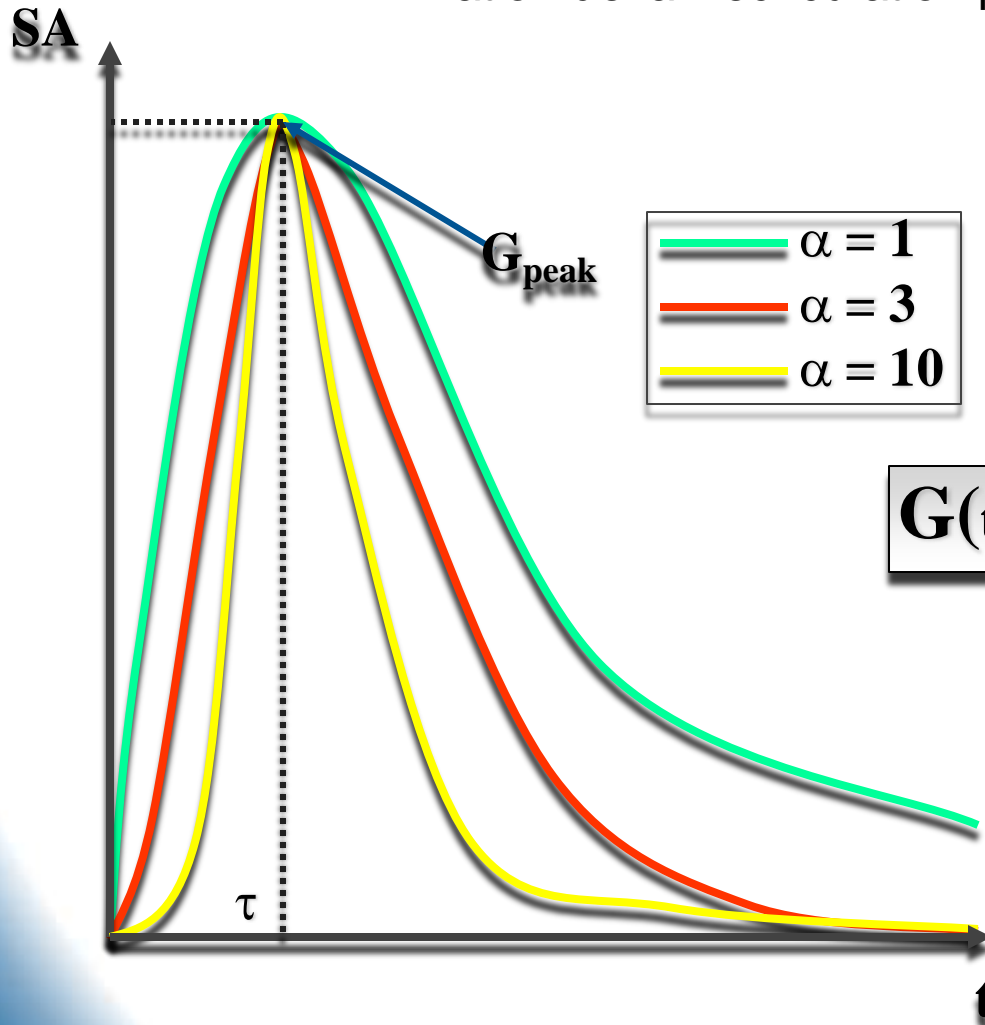
Fonction d'Entrée Artérielle (AIF)



IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Elimination de la Recirculation par Ajustement Gamma



- Modèle physiologique d'ajustement temporel du signal : combinaison fonction puissance et exponentielle.
- Permet d'éliminer la recirculation.

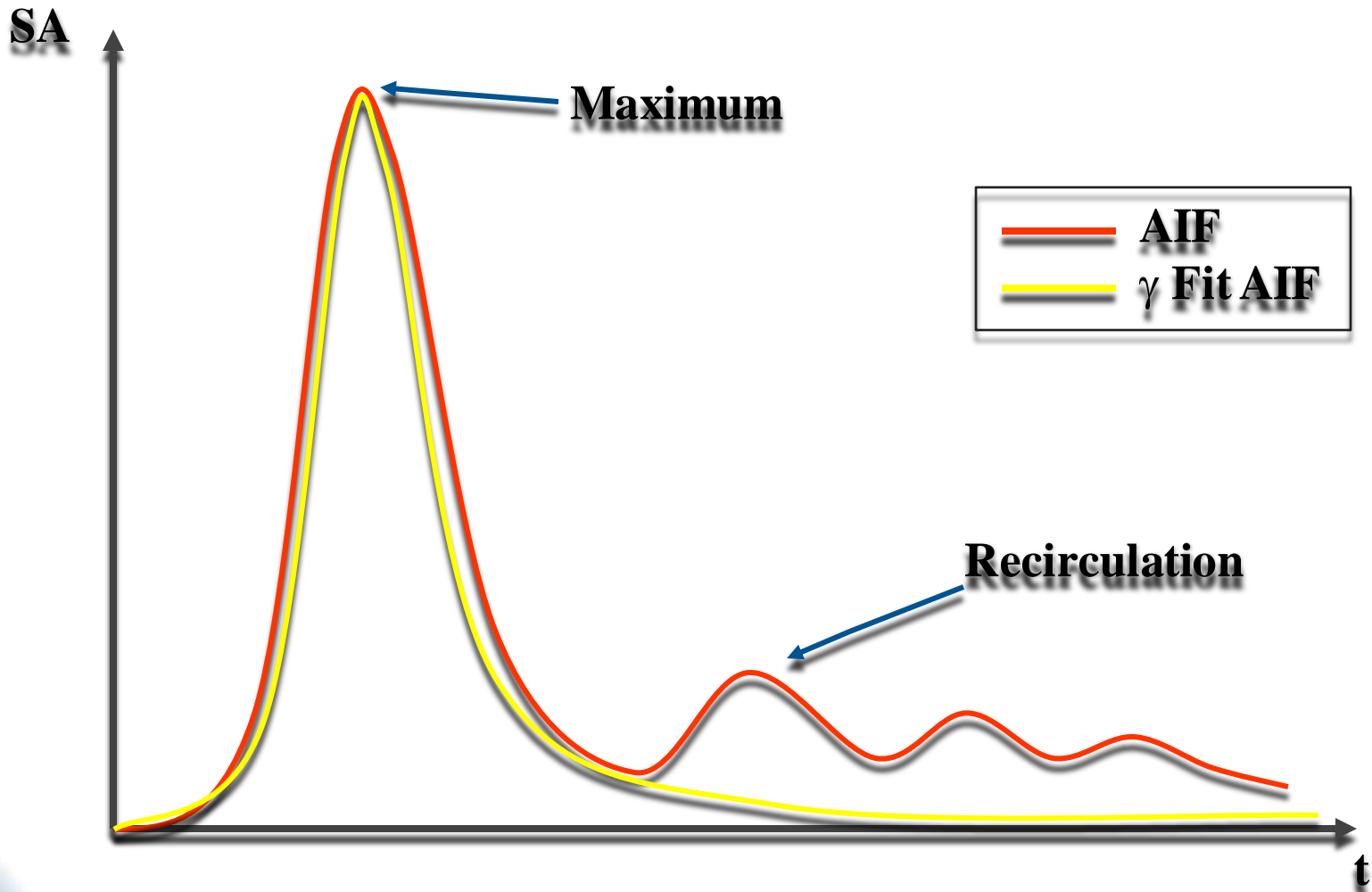
$$G(t, G_{\text{peak}}, \tau, \alpha) = G_{\text{peak}} \left(\frac{t}{\tau}\right)^{\alpha} e^{(-\alpha t/\tau + \alpha)}$$

- G_{peak} : Concentration maximale (AIF ou Cm)
 τ : moment du maximum
 α : constante d'ajustement

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

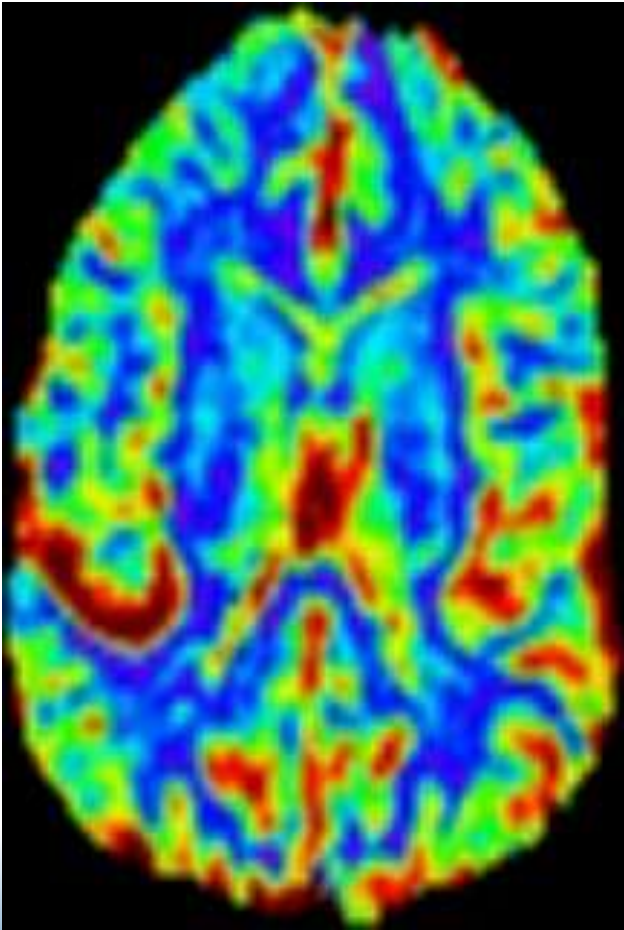
Elimination de la Recirculation par Ajustement Gamma



IRM de Perfusion

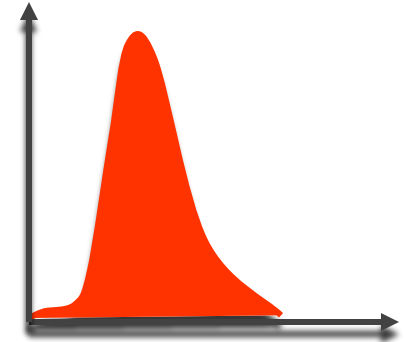
Mesure de la Perfusion cérébrale en IRM T2*

Volume Sanguin Cérébral (CBV)



- Le CBV reflète la masse sanguine locale (en ml/100g).
- Selon la théorie de la dilution des indicateurs, le calcul du Volume Sanguin Cérébral absolu est :

$$\text{CBV}_i = \frac{\kappa}{\rho} \cdot \frac{\int C_i^{\text{fit}}(t) dt}{\int \text{AIF}^{\text{fit}}(t) dt}$$



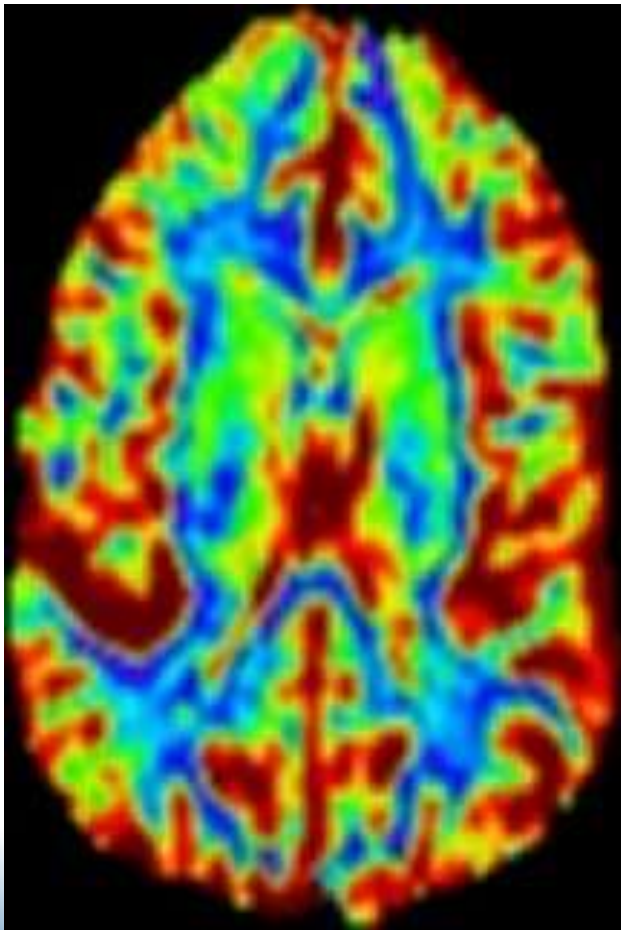
Avec

$C_i^{\text{fit}}(t)$: Concentration de Gadolinium
$\text{AIF}^{\text{fit}}(t)$: Fonction d'Entrée Artérielle
κ	: Facteur de correction de l'hématocrite des vaisseaux
ρ	: Densité du tissu cérébral

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Débit Sanguin Cérébral (CBF)



- Le CBF reflète la perfusion microcapillaire locale (en ml/min/100g).
- Le calcul du CBF n'est possible qu'après déconvolution (TF) de l'AIF (bolus instantané).

$$\text{CBF}_i = \frac{\text{CBV}_i \cdot C_{\max}}{\int C_i(t) dt} \quad C_i(t) = \mathbf{F}^{-1} \left\{ \frac{\mathbf{F} \{C_i^{\text{fit}}(t)\}}{\mathbf{F} \{\text{AIF}^{\text{fit}}(t)\}} \right\}$$

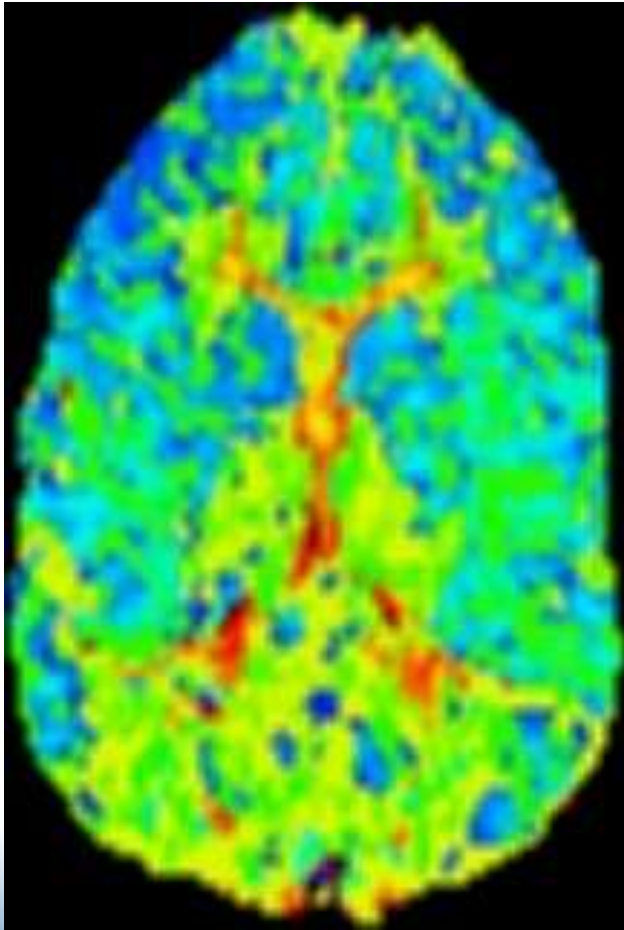
Avec

- $C_i^{\text{fit}}(t)$: Concentration tissulaire mesurée
- $C_i(t)$: Concentration tissulaire idéale
- C_{\max} : Concentration maximale
- $\text{AIF}^{\text{fit}}(t)$: Fonction d'Entrée Artérielle
- \mathbf{F}^{-1} : Déconvolution par FFT inverse

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Temps de Transit Moyen (MTT)



- Le MTT correspond au temps moyen mis par une particule pour parcourir la distance de l'entrée artérielle à la sortie veineuse (en s).
- Reflète la distribution microcapillaire, les résistances périphériques vasculaires.

$$\text{MTT}_i = \frac{\text{CBV}_i}{\text{CBF}_i}$$

- Dépend donc de l'AIF et de la qualité de sa déconvolution.
- Phénomènes de volume partiels ou de susceptibilité magnétiques surestiment le MTT.

IRM de Perfusion

Mesure de la Perfusion cérébrale en IRM T2*

Résultats de précédentes études

Référence	Type d'étude	Substance Grise		Substance Blanche	
		CBV (%)	CBF ml/min/100g	CBV (%)	CBF ml/min/100g
<i>Smith 2000</i>	PWI	9,6 ± 1,9	65,5 ± 16,3	3,9 ± 1,2	28,1 ± 6,9
<i>Remp 1994</i>	PWI	8,0 ± 3,1	69,7 ± 29,7	4,2 ± 0,9	33,6 ± 11,5
<i>Hagen 1999</i>	PWI	NA	52,2 ± 16,4		27,4 ± 6,8
<i>Ye 1997</i>	MR ASL	NA	81,0 ± 20,0		23,0 ± 7,0
<i>Yang 1998</i>	MR ASL	NA	58,5 ± 7,2		20,7 ± 2,3
<i>Frackowiak 1980</i>	TEP	NA	65,3 ± 11,0		21,4 ± 9,0
<i>Greenberg 1978</i>	TEP	5,0 ± 0,7	NA	3,5 ± 0,2	NA
<i>Leenders 1990</i>	TEP	3,8 ± 0,5	42,0 ± 8,0	2,7 ± 0,6	22,2 ± 4,9
<i>Hamberg 1996</i>	TDM	4,5 ± 0,6	NA	2,5 ± 0,6	NA

3.3 Rappels Méthodologiques

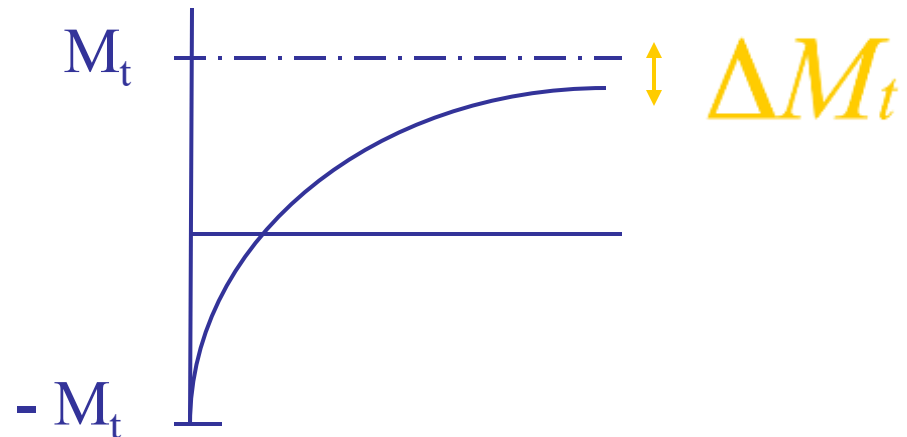
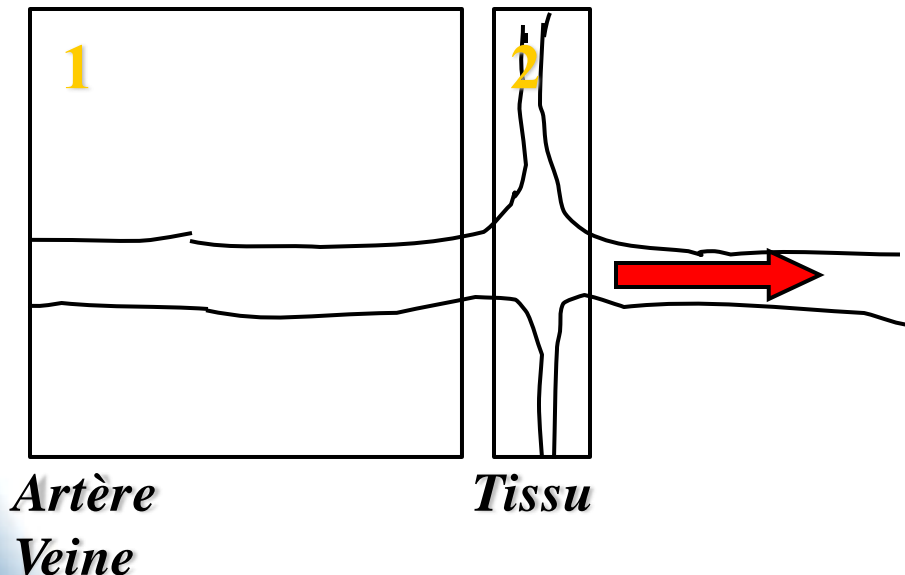
IRM de Perfusion en ASL

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Définition

- région de marquage : artères (1)
- région à imager : tissu (2)



- Les protons du sang sont marqués à $t=0$ avec une impulsion RF 180°
- Relaxation avec T_{1a}
- Relaxation avec T_{1t} après perfusion
- Acquisition de l'image à $t=TI$ (EPI ou spiralée)

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Technique

• 2 acquisitions:

- une première **avec marquage** ('image marquée' $\propto IM_m$)
- une seconde **sans marquage** ('image de contrôle' $\propto IM_c$)

• **Limites :**

- Faible SNR à 1.5 T : une image de perfusion = $IM_c - IM_m$ (faible signal : $0.9\% \pm 0.13$ pour ASL contre $1.44\% \pm 0.13$ pour BOLD)
- Nombre limité de coupes (4-8 max.)
- L'image de perfusion finale est la moyenne d'un nombre important d'images soustraites.
- Possibilité utiliser ASL pour IRMf d'activation

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Quantification : Equations de Bloch

Traduit l'évolution de l'aimantation du tissu par rapport au temps.

$$\frac{dM_t(t)}{dt} = \frac{M_t^0 - M_t(t)}{T_{1t}} + f (M_a(t) - M_v(t))$$
$$\Delta M_t(TI) = 2M_a^0 f \int_0^{TI} e^{-t/T_{1a}} \times e^{-f(TI-t)/\lambda} \times e^{-(TI-t)/T_{1t}} dt$$

- 3 composantes: -apport de sang artériel marqué
- drainage par les veines
- relaxation longitudinale

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Séquences

EPISTAR : Echo Planar Imaging and Signal Targeting with Alternating Radio Frequency

-> 90° dans plan image

-> 180° dans plan artériel proximal

-> EPI

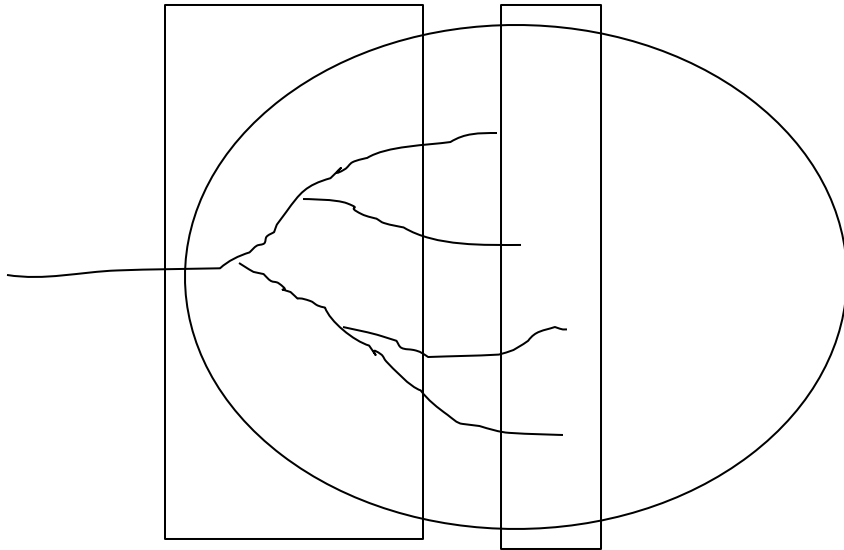
FAIR : Flow-Sensitive Alternating Inversion Recovery

PICORE

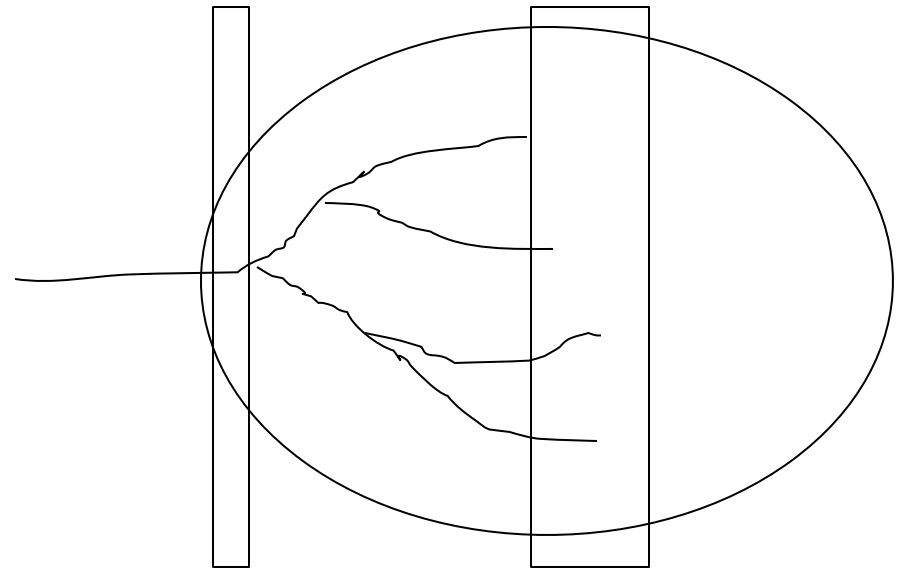
IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Pulsé vs Continu



Continu



Pulsé

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Quantification du DSC

Image de perfusion

- 4 coupes adjacentes de 7mm d'épaisseur
- région de marquage = 10cm
- espace entre marquage/image = 1cm
- FOV= 200mm
- taille de la matrice = 64*64
- taille d'un voxel = 3.125*3.125*7mm
- $TI_1/TI_s/TI_2 = 700/1050/1400ms$
- TR=2.5s
- 150 images EPI spiralées (75 marquée et 75 contrôle) en 6min 15s

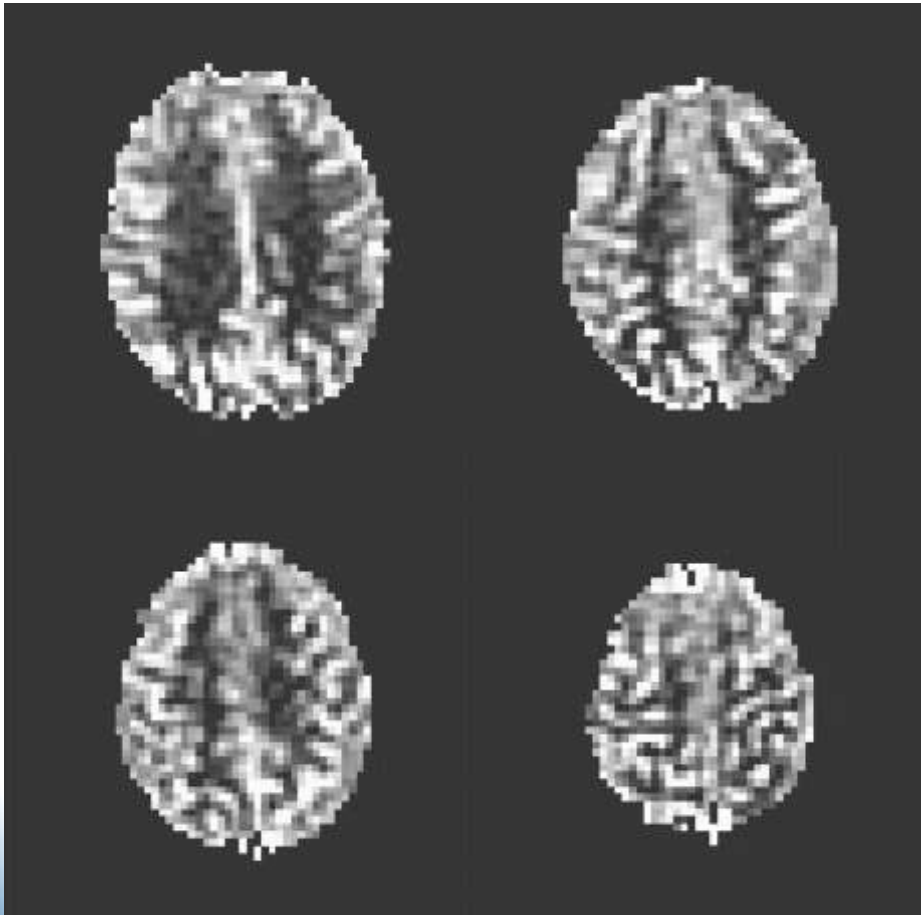
Image T_1

24 images Inversion / Récupération à 24 \square TI pour la correction q

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Quantification du DSC



Carte T_1 :

- différencier la substance grise ($T_{1t} > 0.65s$)
de la substance blanche ($T_{1t} < 0.65s$)
- calcul du flux corrigé (9% SB, 5% SG)

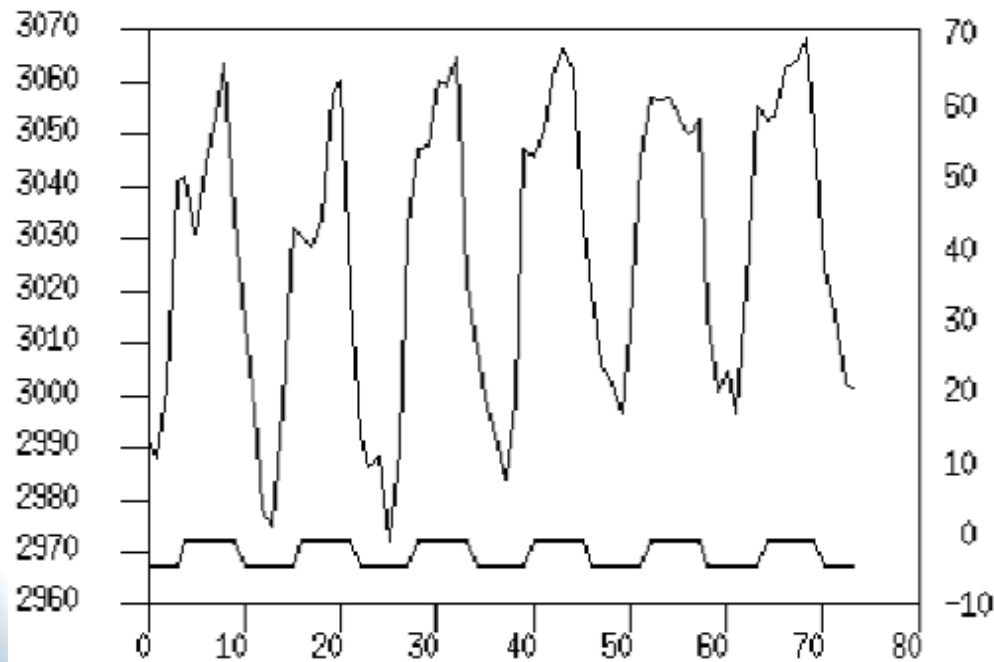
	Substance grise	Substance blanche
T_1 (s)	0.74	0.56
f corrigé ml/100g/min	75.6	24.6
f non-corrigé ml/100g/min	71.7	22.4

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

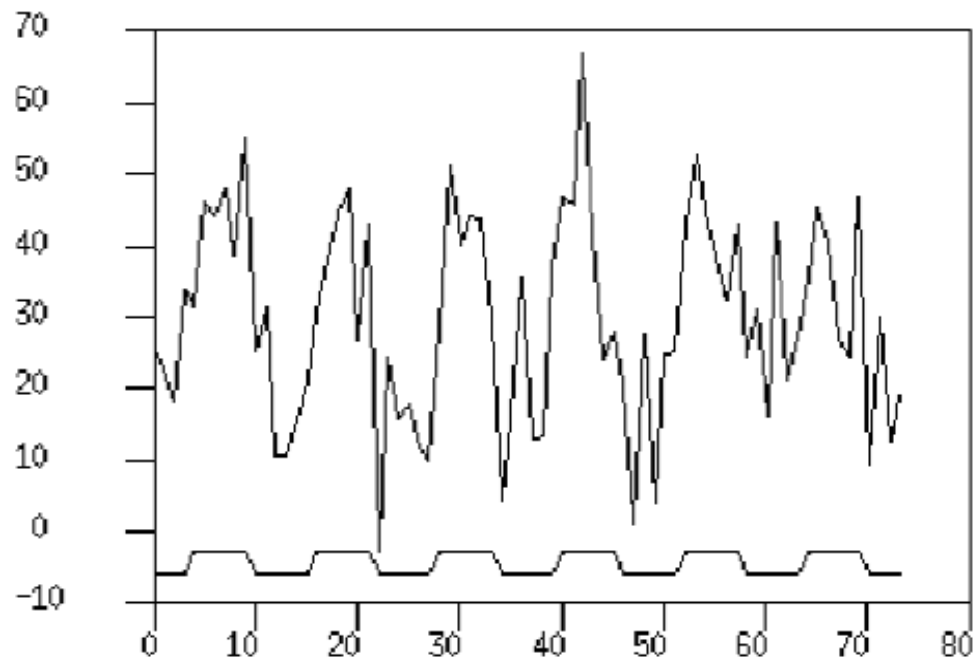
Analyse du Signal

ROI Activation Average Intensity (Time: 0, 73)



BOLD

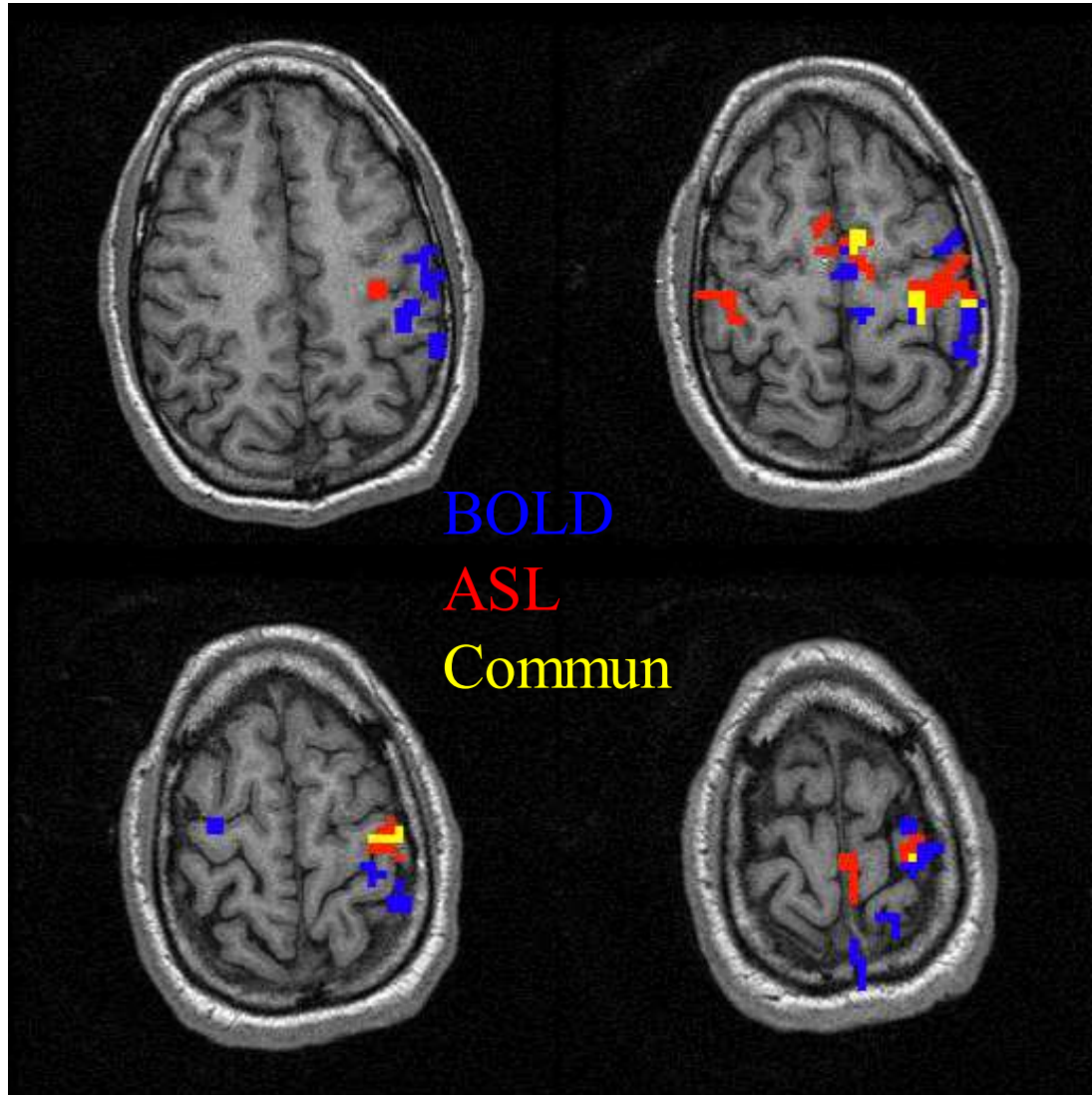
ROI Activation Average Intensity (Time: 0, 73)



ASL

IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL



IRM de Perfusion

Mesure de la Perfusion cérébrale en ASL

Avantage : pas d'injection de contraste

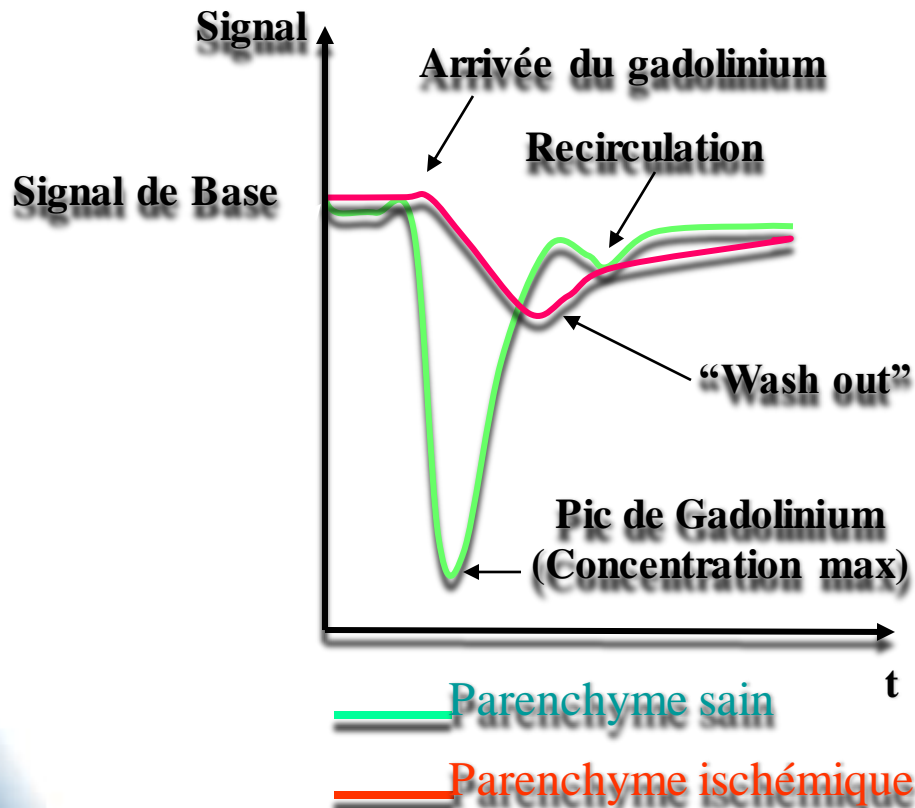
Inconvénients :

- **Très faible SNR : 3 T**
- **Marquage avec pulse stable**
- **Approximation de l'échange interstitiel**
- **Mesure uniquement CBF**

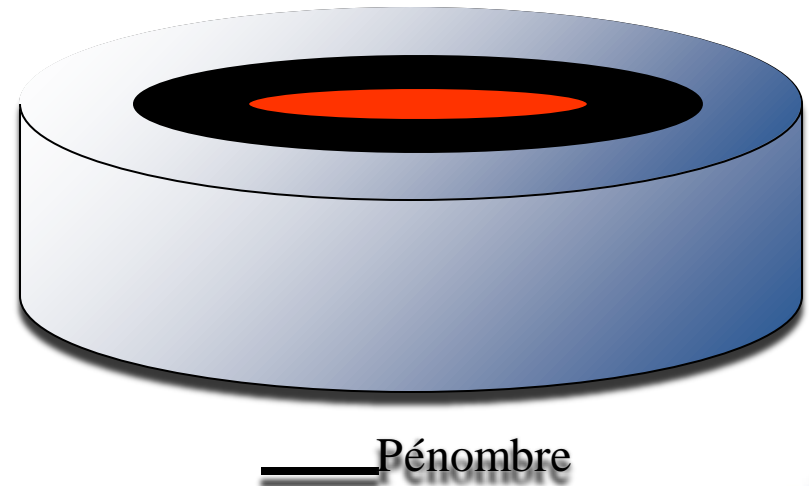
3.4 Applications Cliniques

IRM de Perfusion

Ischémie cérébrale au Stade Aigu

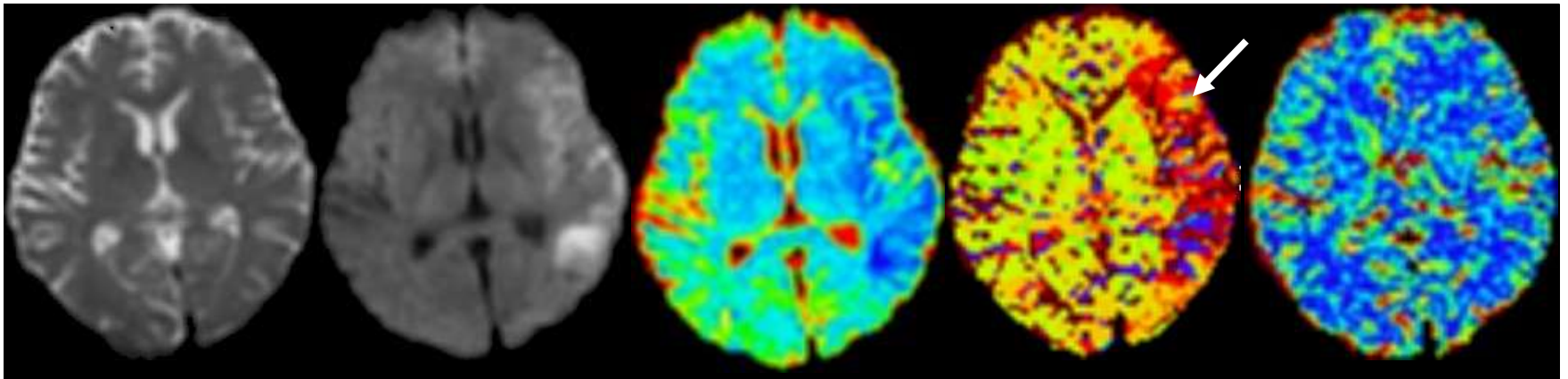
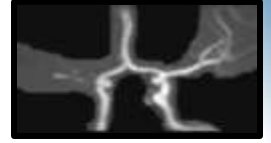


- *Pénombre* : zone de fragilité hémodynamique vasculaire, hypoperfusée.
- Extension de l'ischémie.
- Discordance diffusion-perfusion.



IRM de Perfusion

Mismatch en IRM



T2

DWI

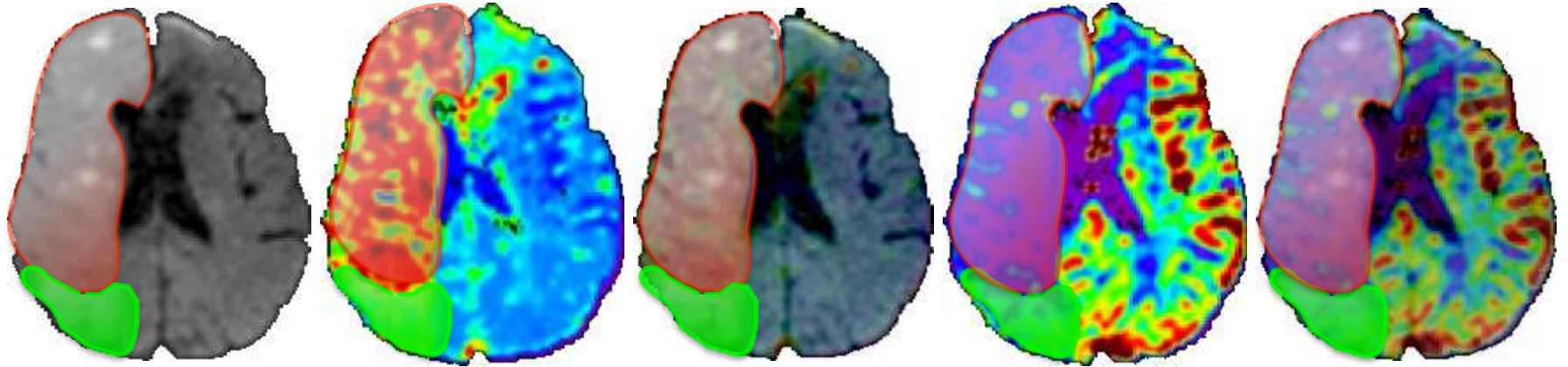
ADC

MTT

CBV

IRM de Perfusion

Mismatch en IRM

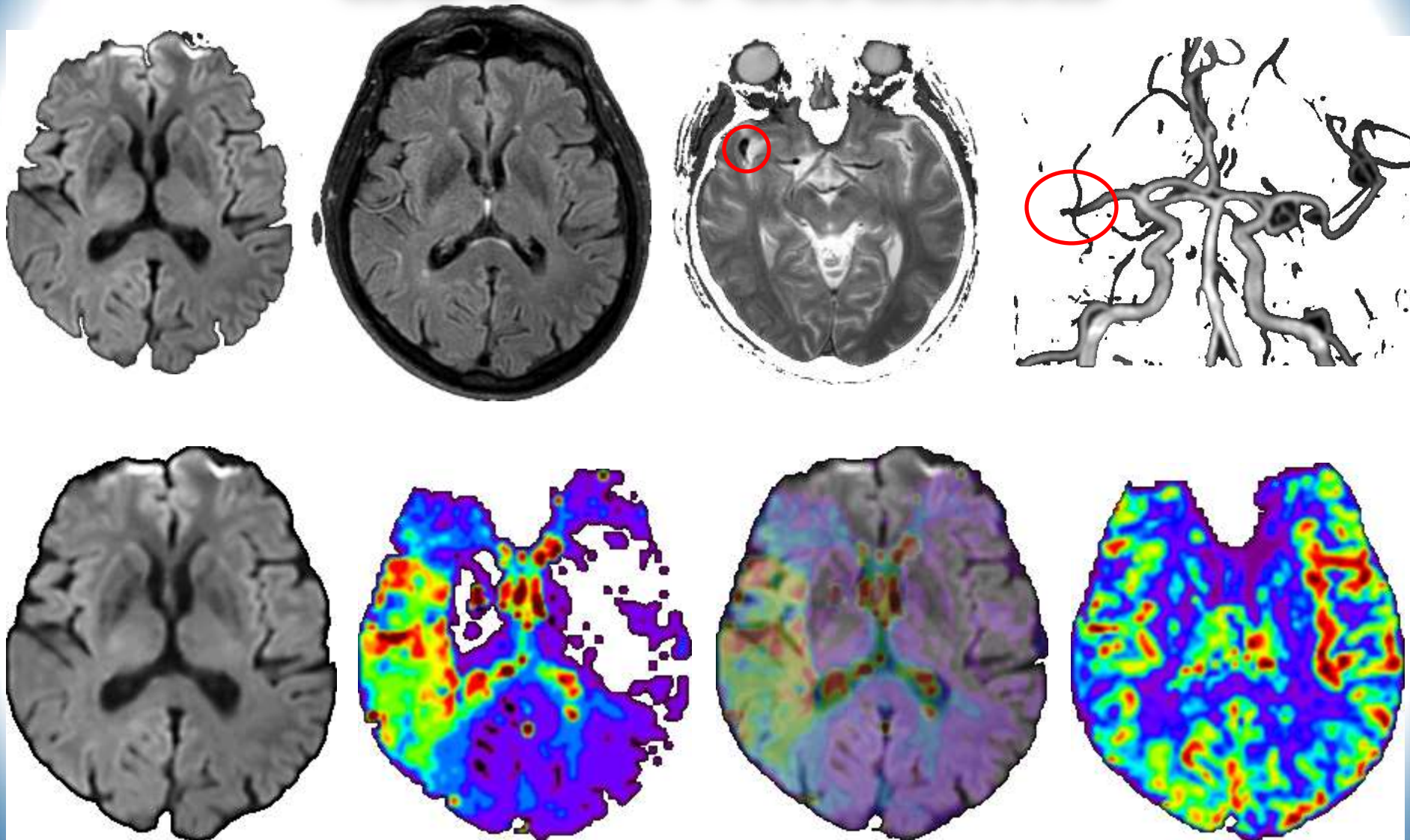


DWI

MTT

CBF

IRM de Perfusion



TMAX

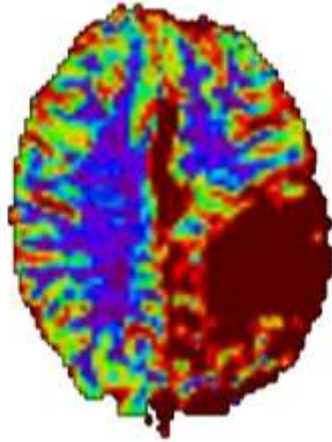
CBF

IRM de Perfusion

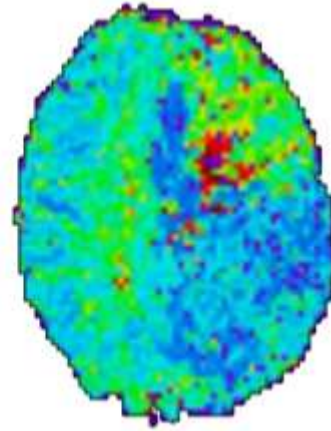
Malformations Artério-Veineuses Cérébrales



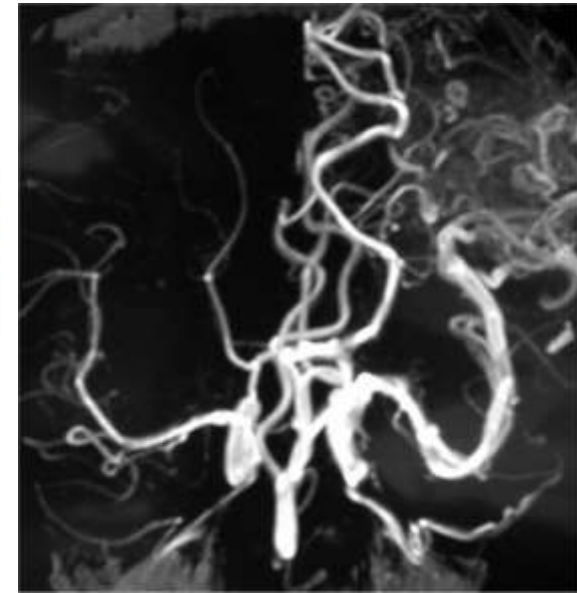
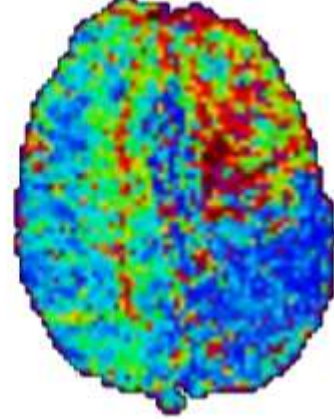
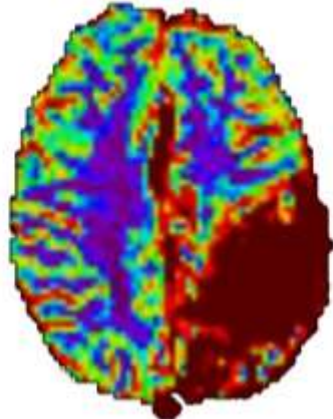
T2



CBV

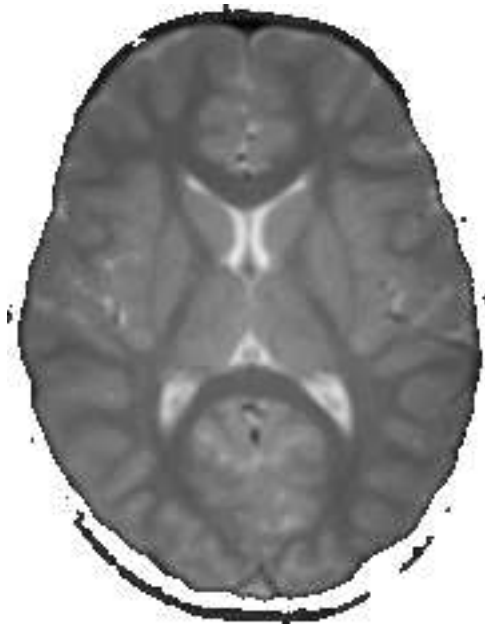


MTT

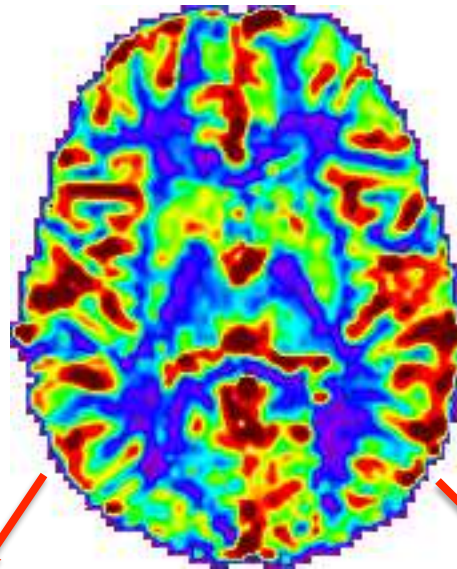


IRM de Perfusion

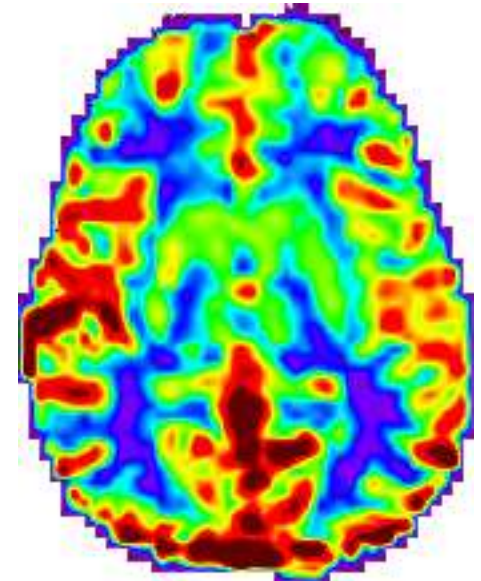
Malformations Artériovoineuses Cérébrales



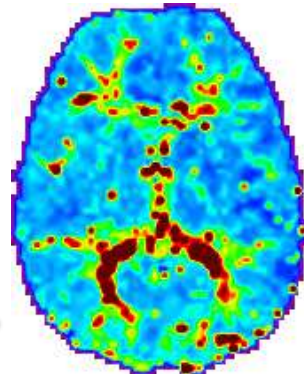
T2*



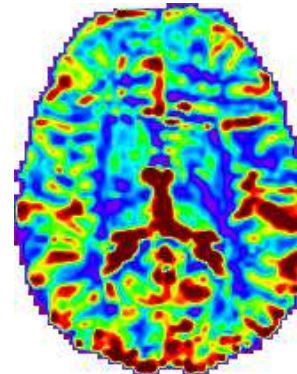
**CBF
T2***



**CBF
ASL**



MTT

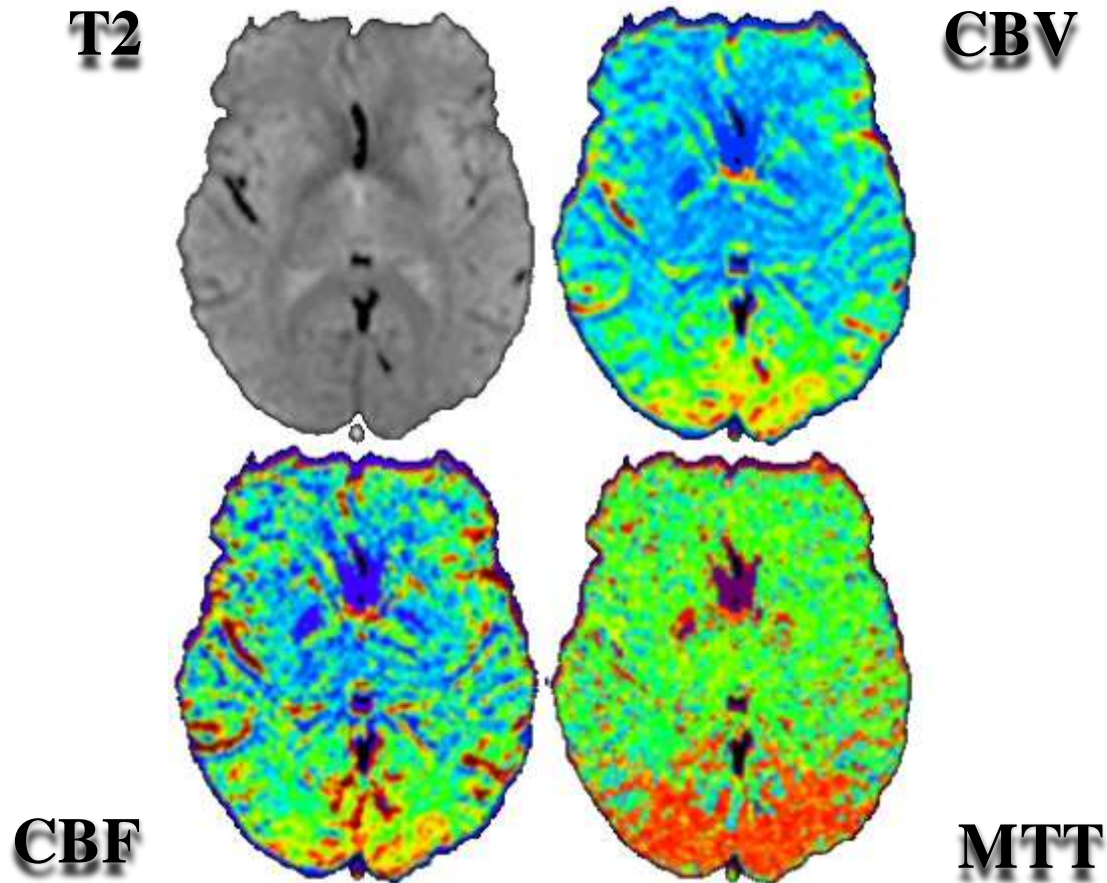


CBV

IRM de Perfusion

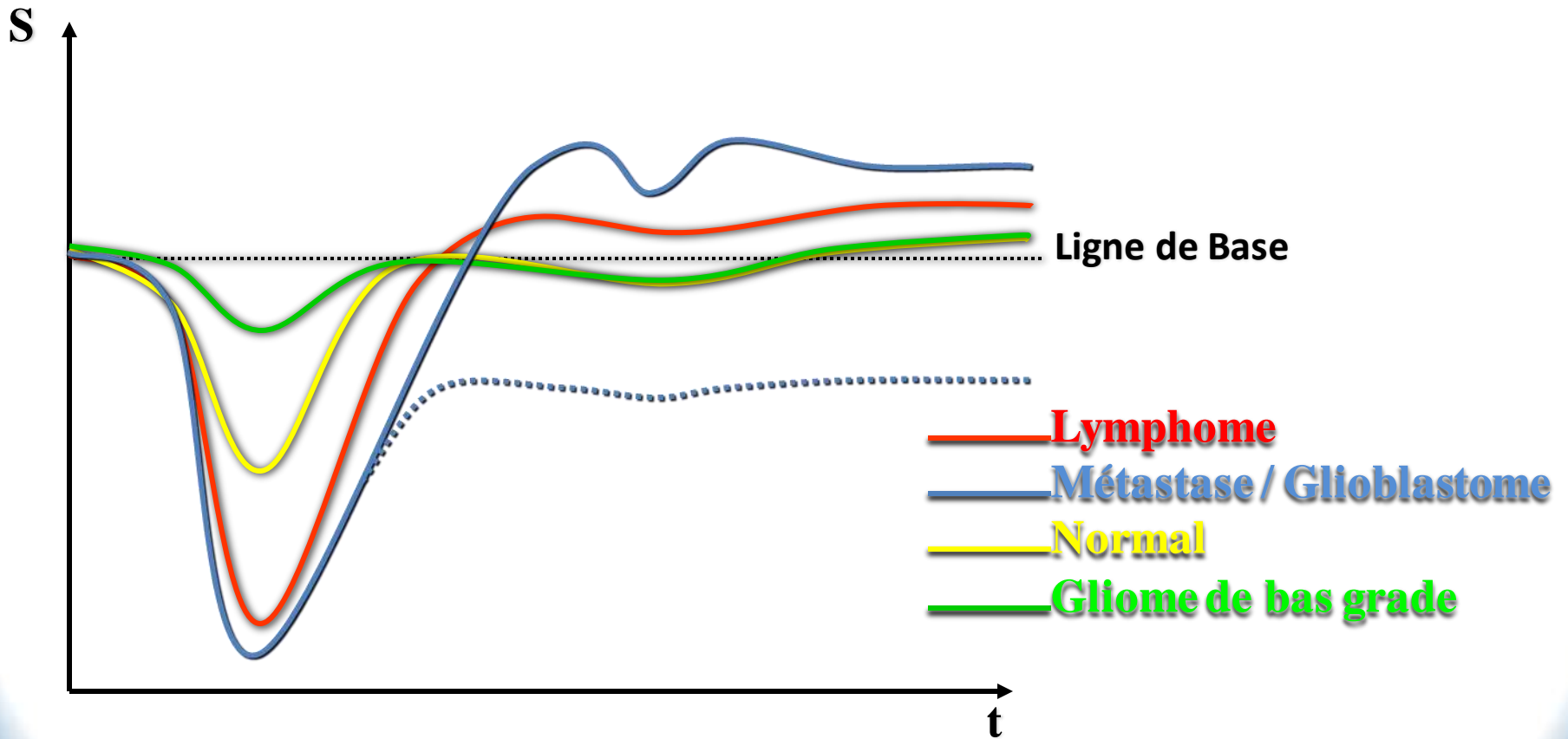
Epilepsie

- Recherche zone corticale d'hypo ou d'hyperperfusion inter-ictale



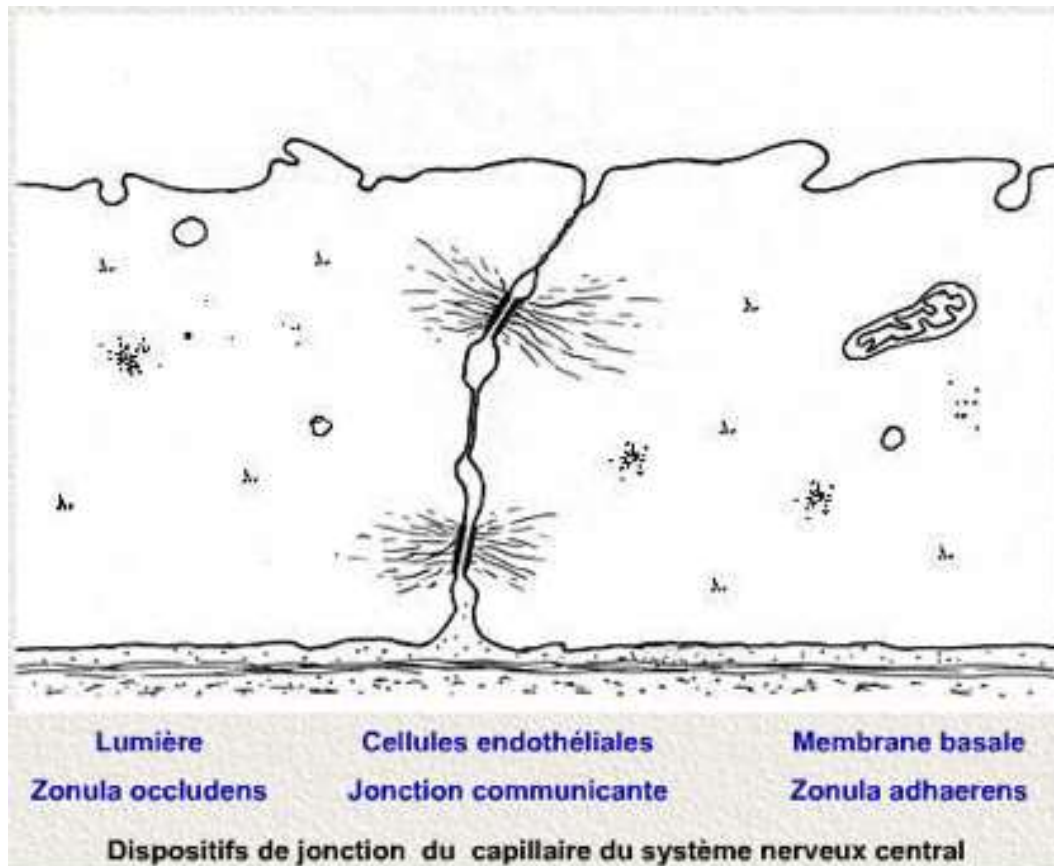
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



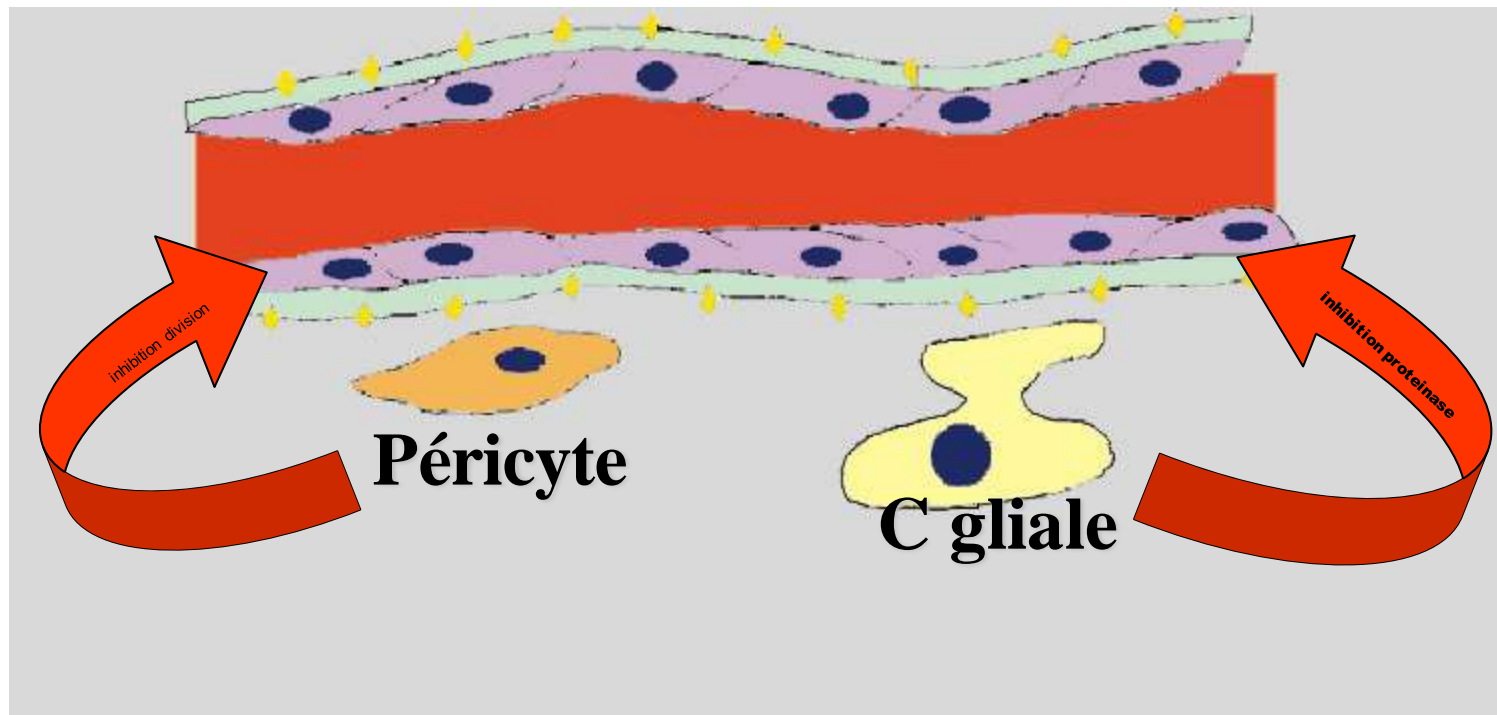
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



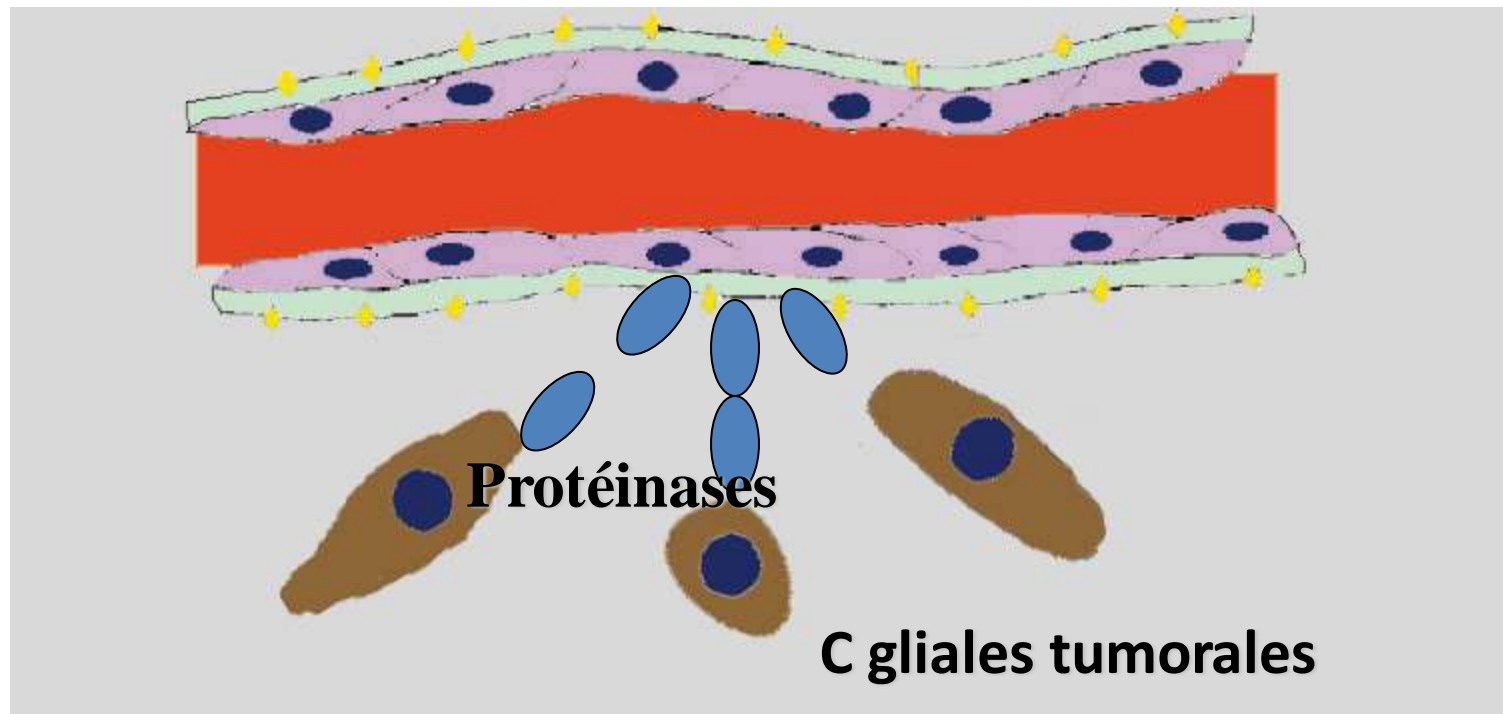
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



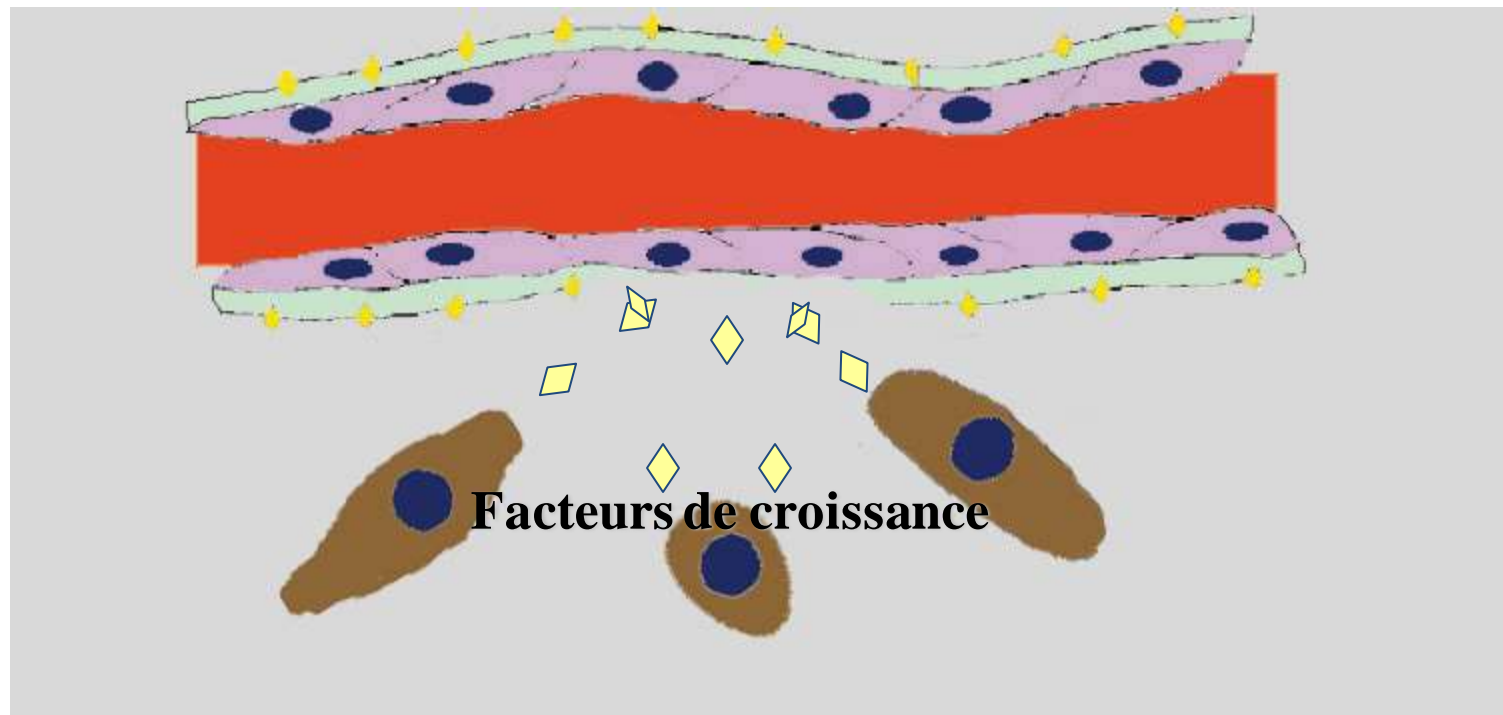
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



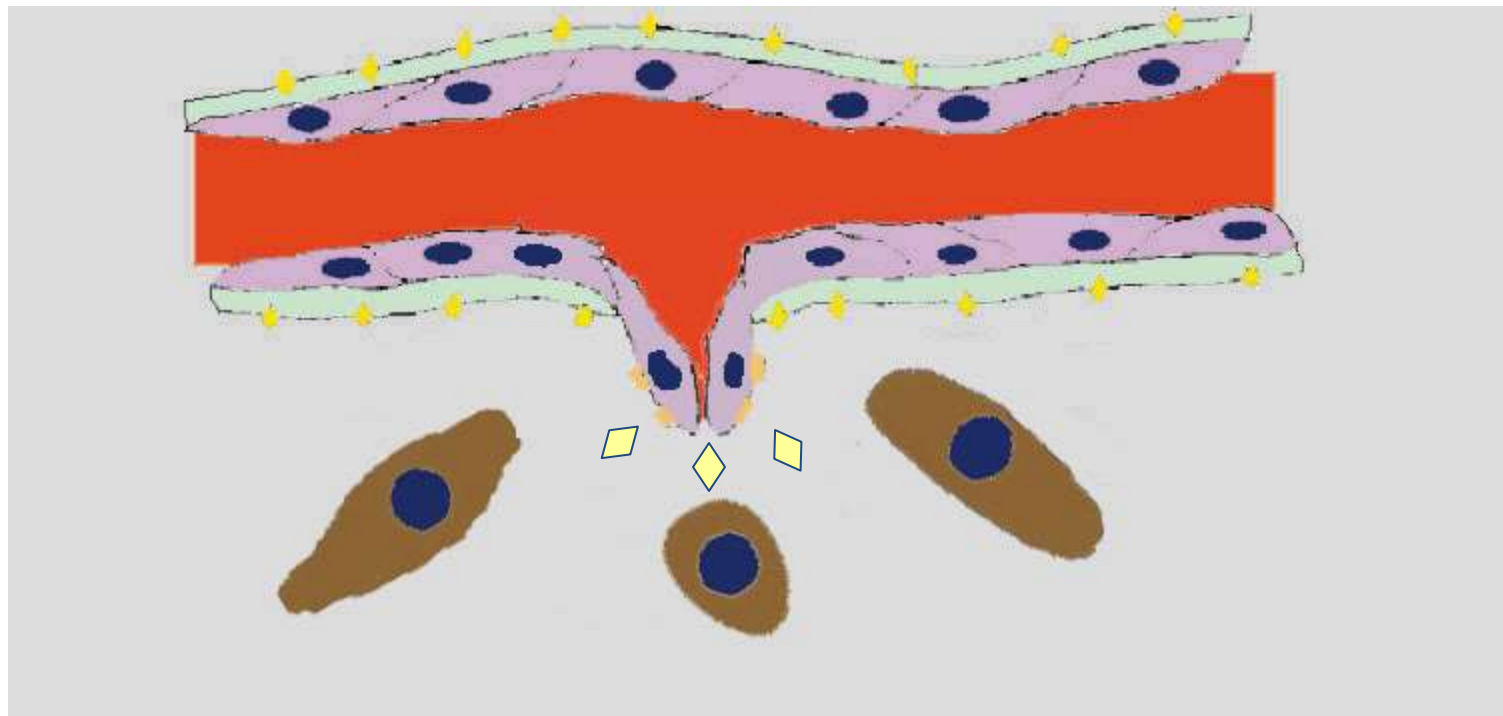
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



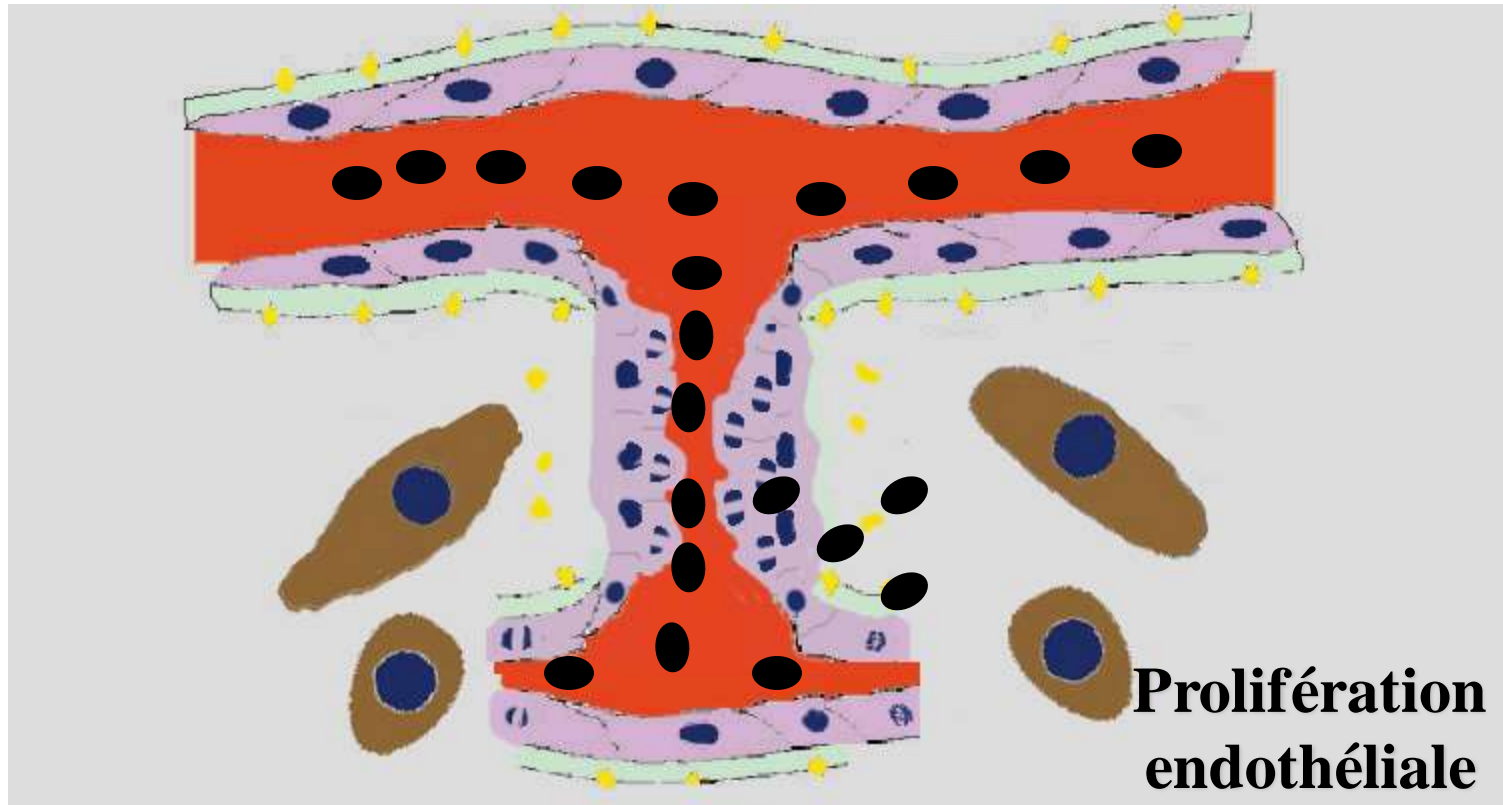
IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



IRM de Perfusion

Tumeurs - Néovascularisation et Rupture de BHE



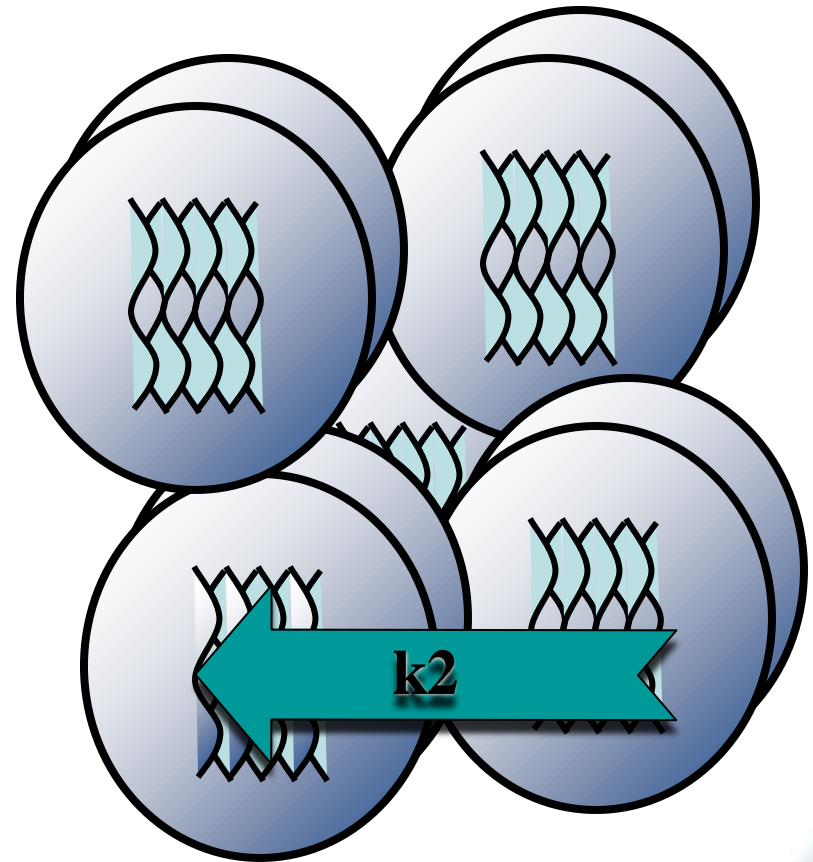
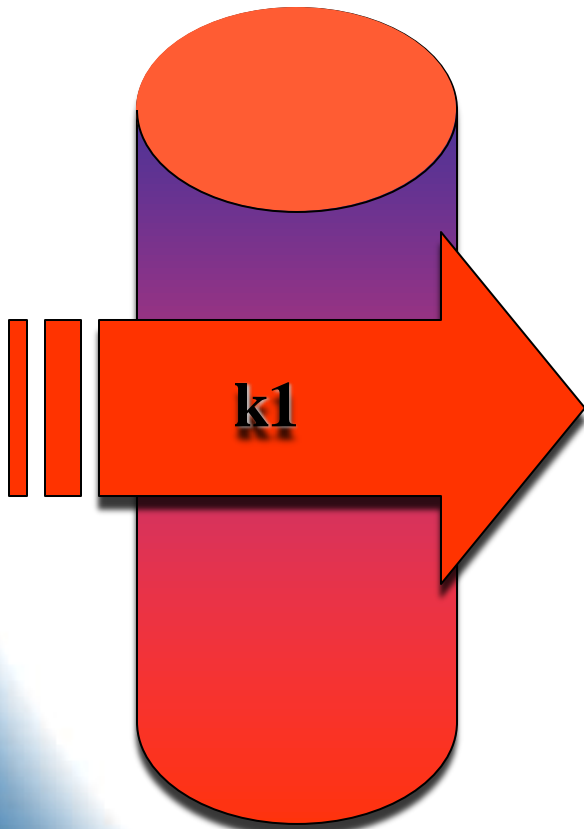
4. IRM de Perméabilité

4.1 Principles

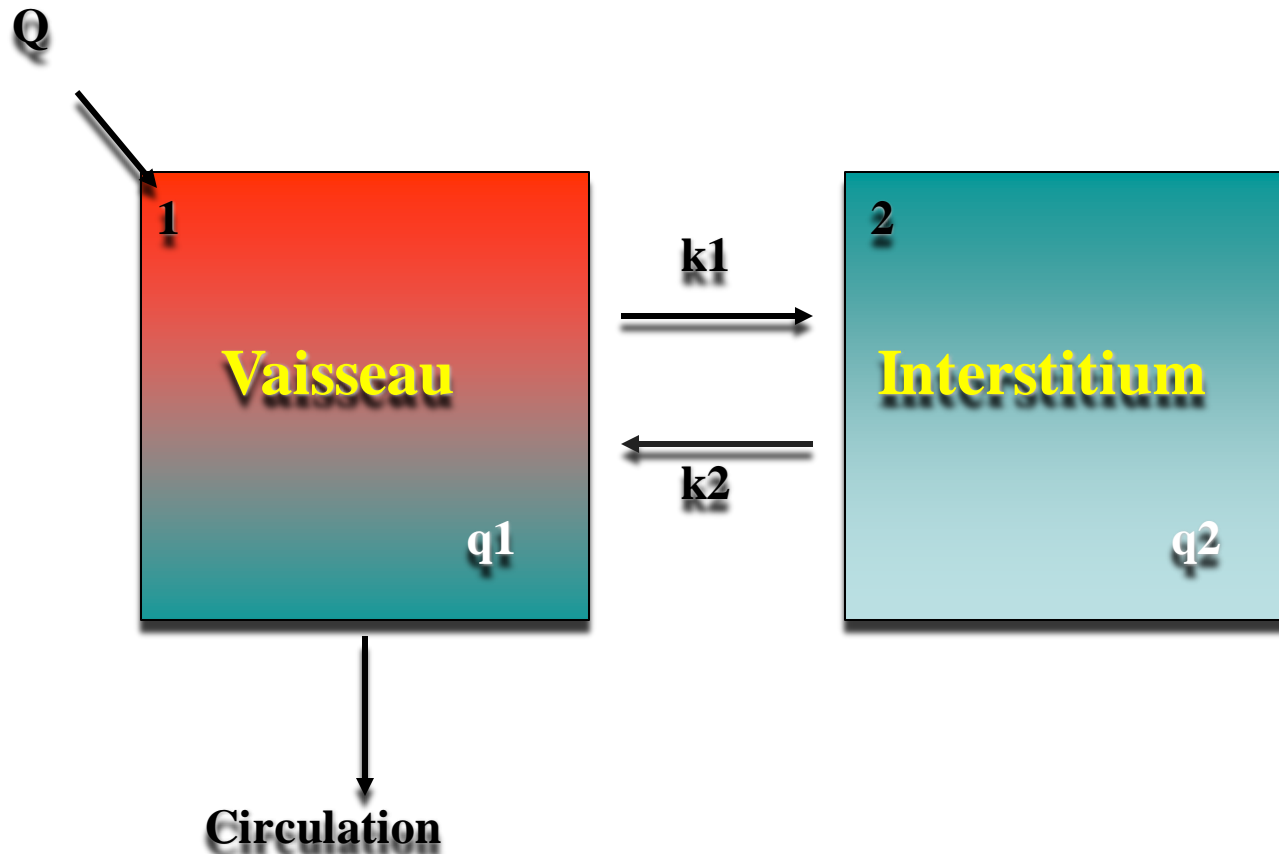
IRM de Perméabilité

Définition

Etude de la diffusion d'un traceur dans l'interstitium

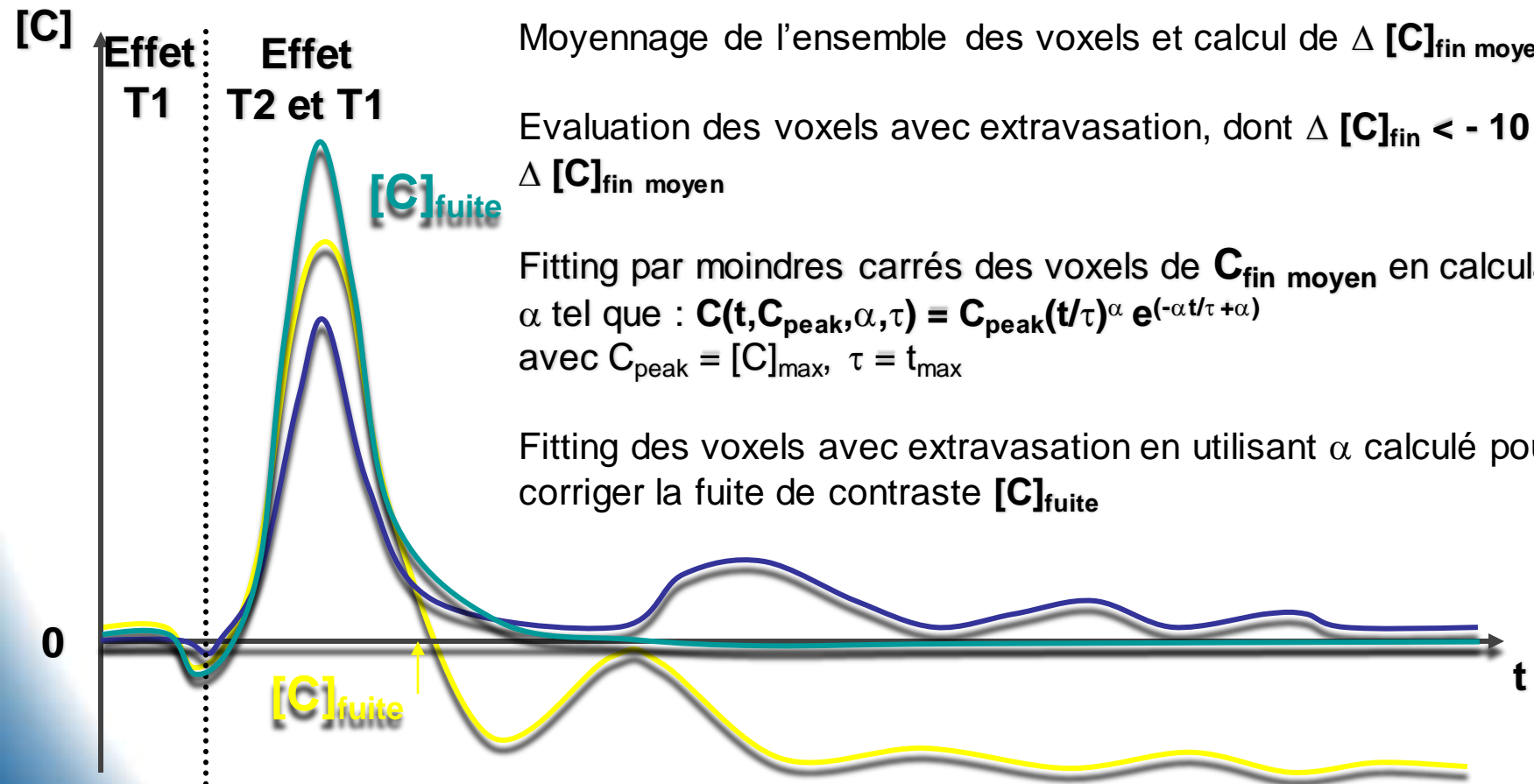


IRM de Perméabilité



IRM de Perméabilité

Méthode de correction de la fuite de contraste



Moyennage de l'ensemble des voxels et calcul de $\Delta [C]_{fin\ moyen}$

Evaluation des voxels avec extravasation, dont $\Delta [C]_{fin} < - 10 \%$

$\Delta [C]_{fin\ moyen}$

Fitting par moindres carrés des voxels de $C_{fin\ moyen}$ en calculant

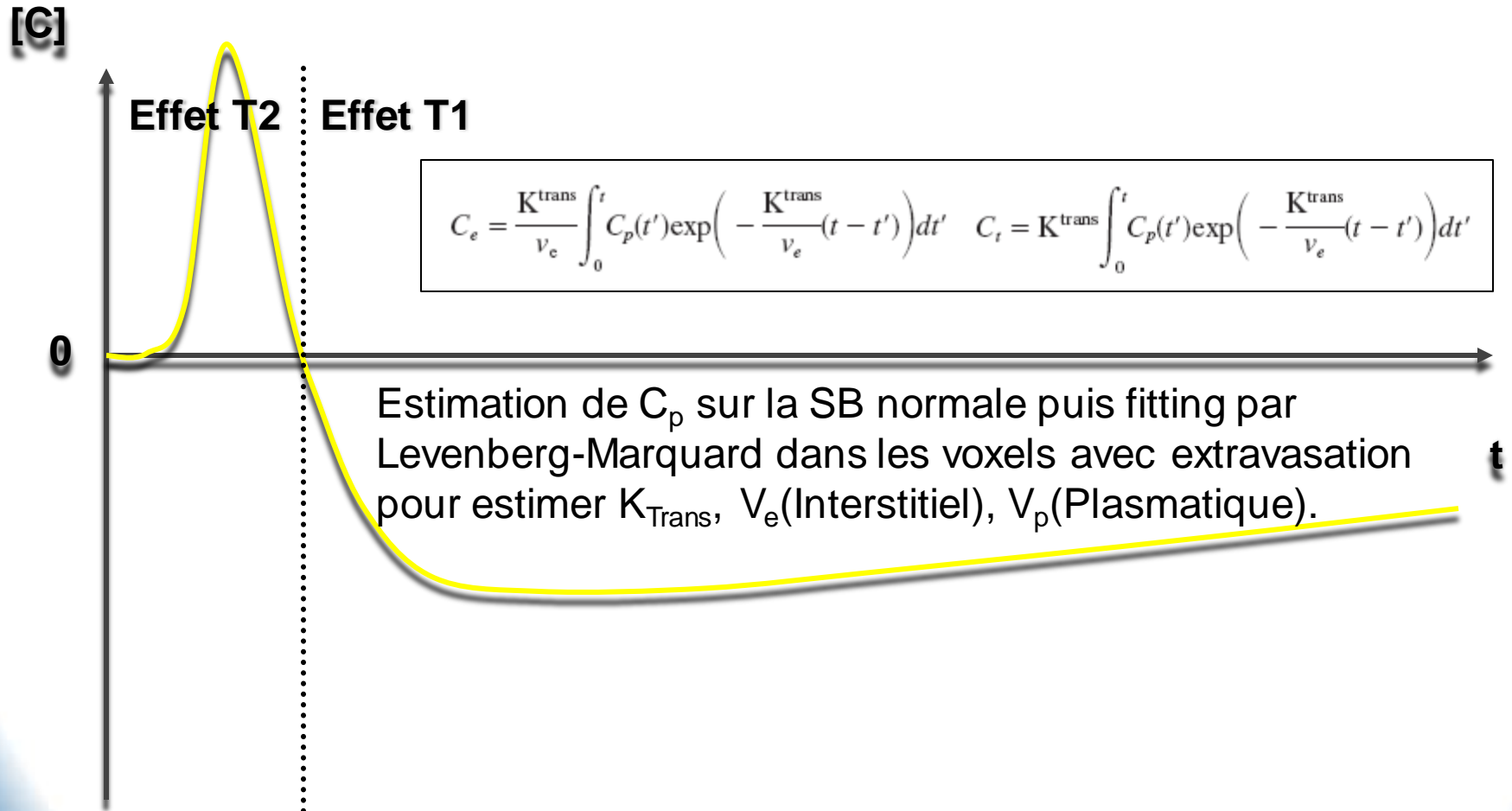
α tel que : $C(t, C_{peak}, \alpha, \tau) = C_{peak} (t/\tau)^\alpha e^{(-\alpha t/\tau + \alpha)}$

avec $C_{peak} = [C]_{max}$, $\tau = t_{max}$

Fitting des voxels avec extravasation en utilisant α calculé pour corriger la fuite de contraste $[C]_{fuite}$

IRM de Perméabilité

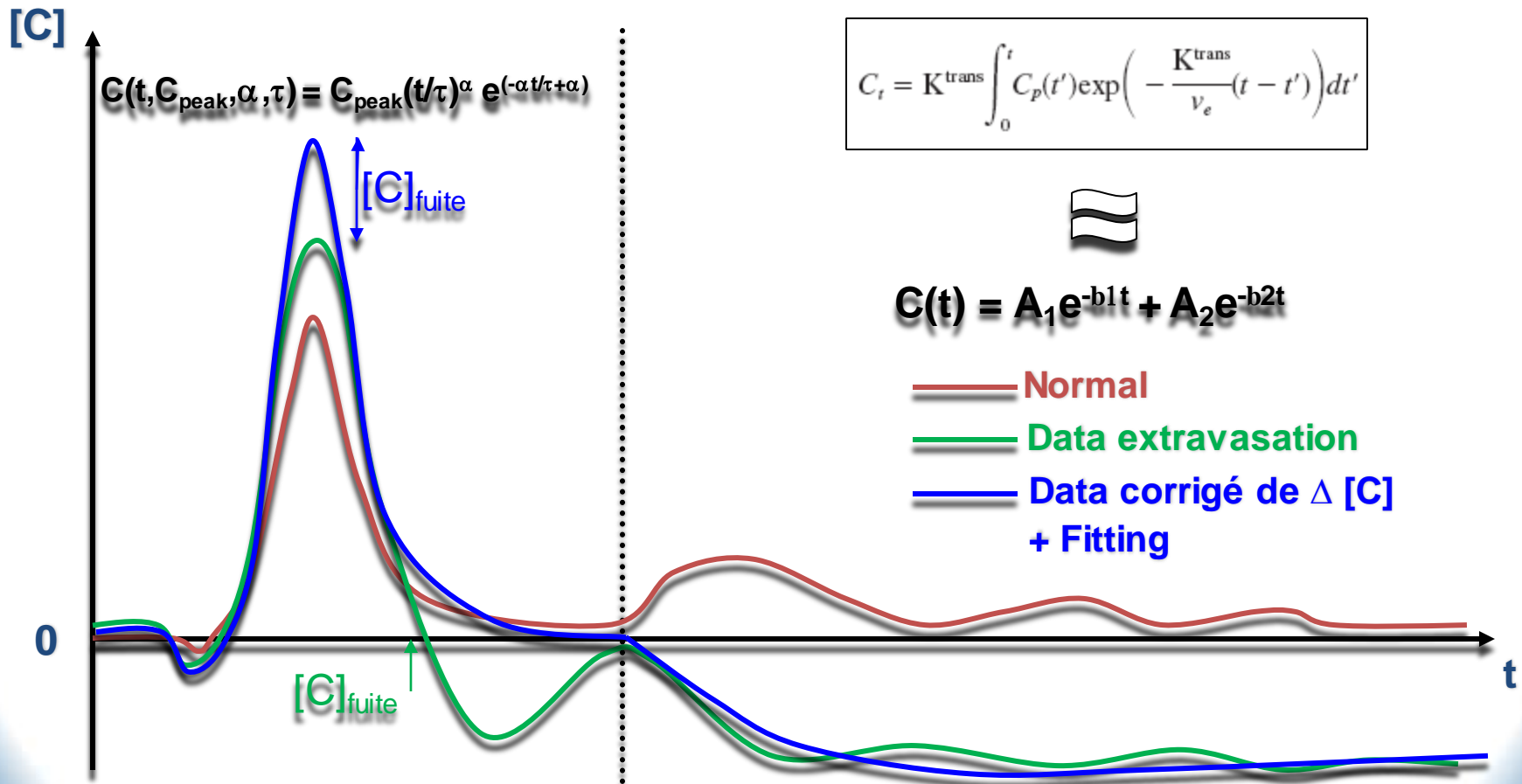
Calcul de la Perméabilité en T2*



IRM de Perméabilité

Perfusion et Perméabilité simultanées en T2*

Brevet WO/2008/132386



IRM de Perméabilité

Calculs Paramétriques

$$\text{CBV}_i = \frac{\kappa}{\rho} \frac{\int \text{Ccorr}_i(t) dt}{\int \text{AIF}(t) dt}$$

$$\text{CBF}_i = \frac{\text{CBV}_i \cdot \text{C}_{i\text{max}}}{\int \text{C}_i(t) dt} \text{ avec } \text{C}_i(t) = \text{FFT}^{-1} \left\{ \frac{\text{FFT} \{ \text{Ccorr}_i(t) \}}{\text{FFT} \{ \text{AIF}(t) \}} \right\}$$

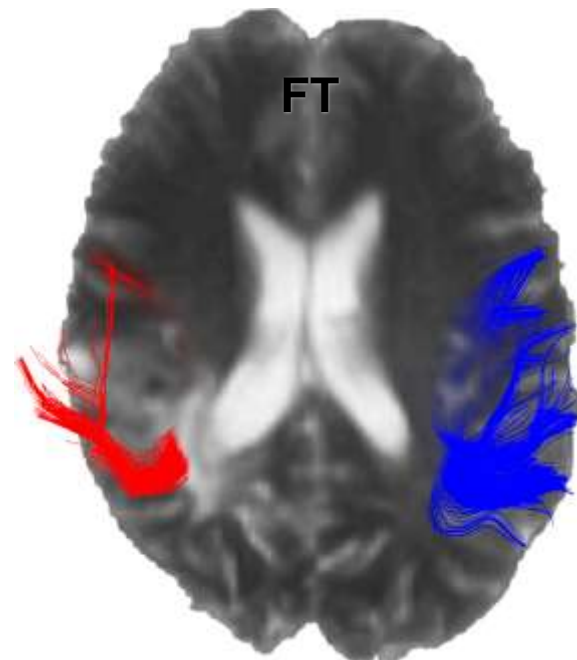
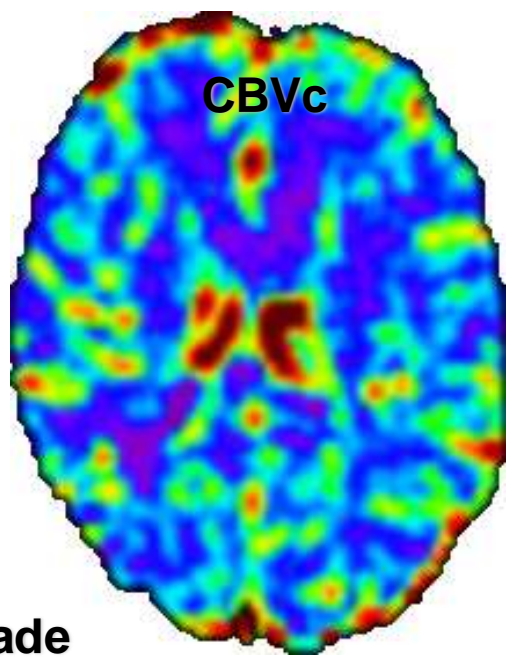
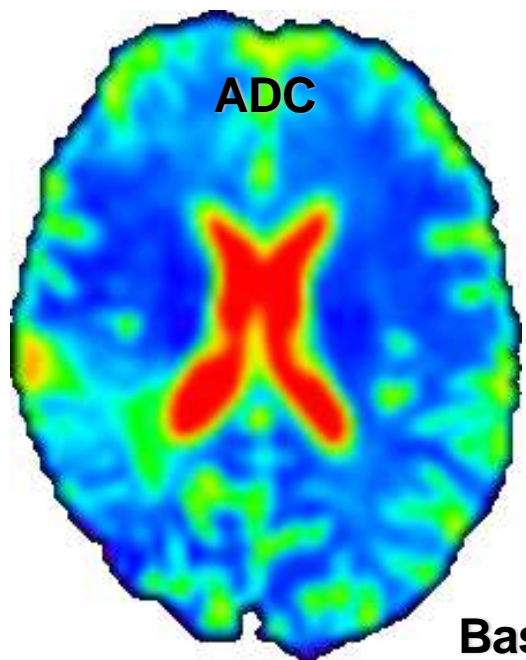
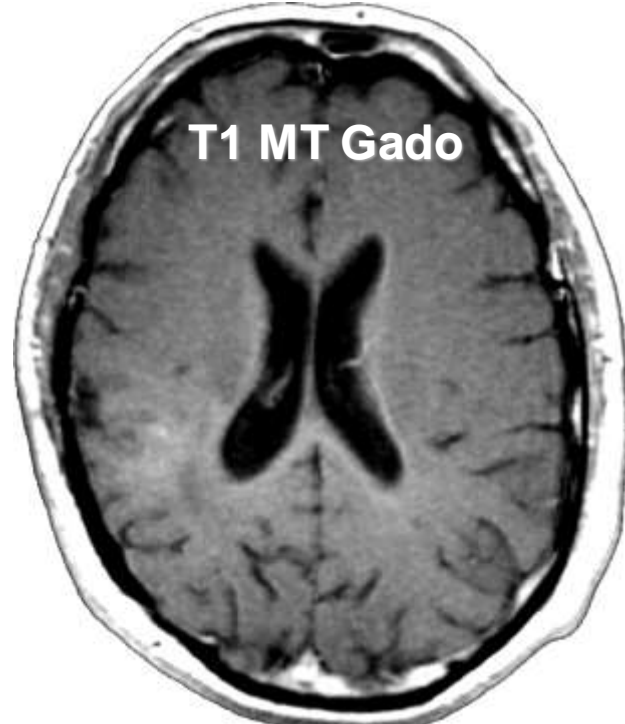
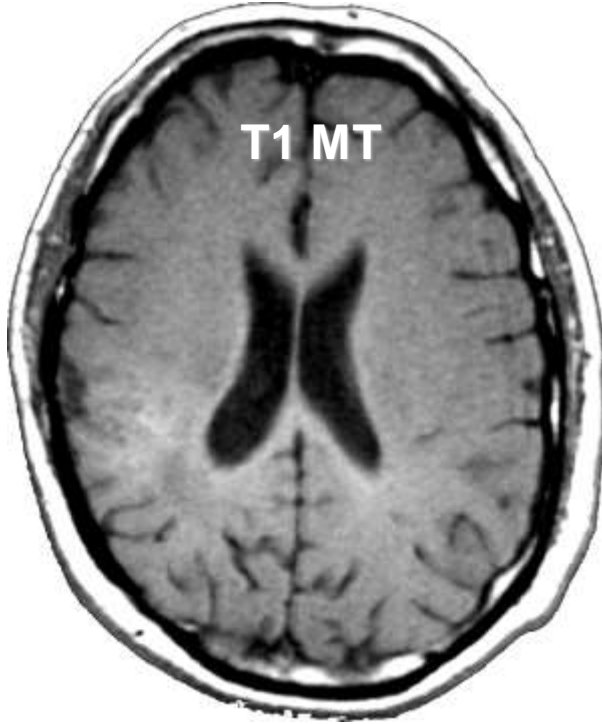
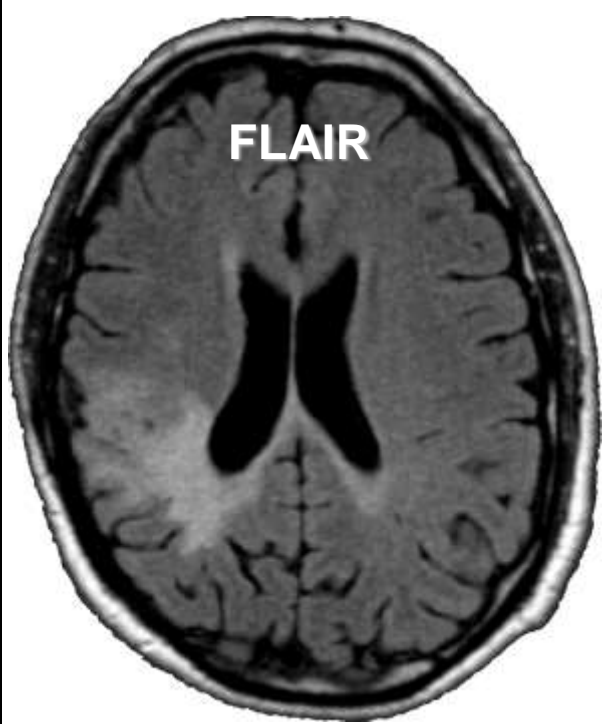
$$\text{MTT}_i = \frac{\text{CBV}_i}{\text{CBF}_i}$$

$$\text{fBV}_i = \int_0^t \frac{A_1(1-e^{-b_1t}) + A_2e^{-b_2t}}{A_{1v}(1-e^{-b_1vt}) + A_{2v}e^{-b_2vt}}$$

$$\text{kPS}_i = \text{Surf}_i \text{ fBV}_i \frac{\kappa}{\rho} \frac{A_1b_1 + A_2b_2 - b_1b_2}{b_1(1-A_1) + b_2(1-A_2)}$$

4.2 Enjeux

Enjeu n°1 :
Détecter la néo-angiogénèse



Bas Grade

FLAIR

T1 MT

T1 MT Gado

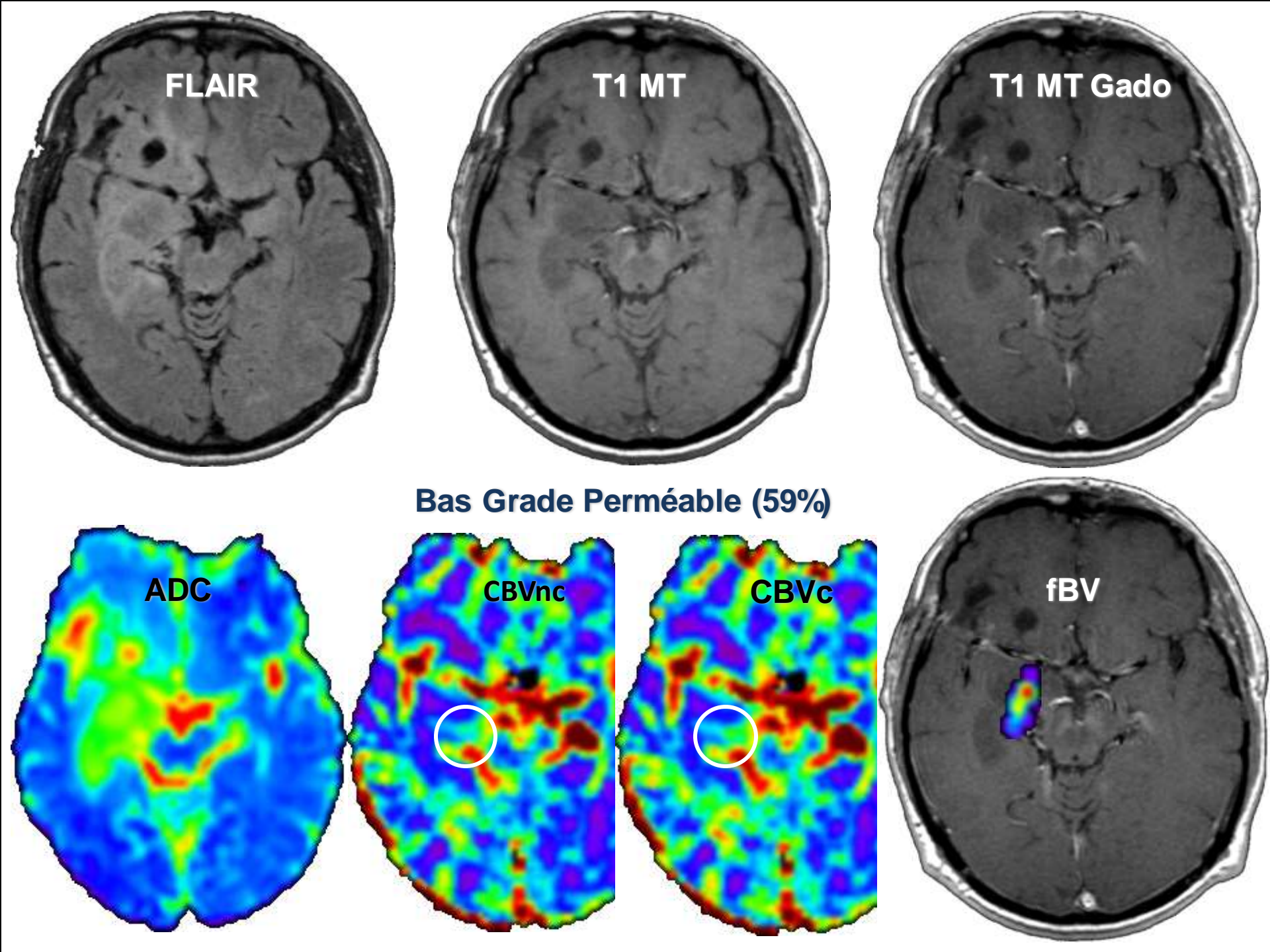
Bas Grade Perméable (59%)

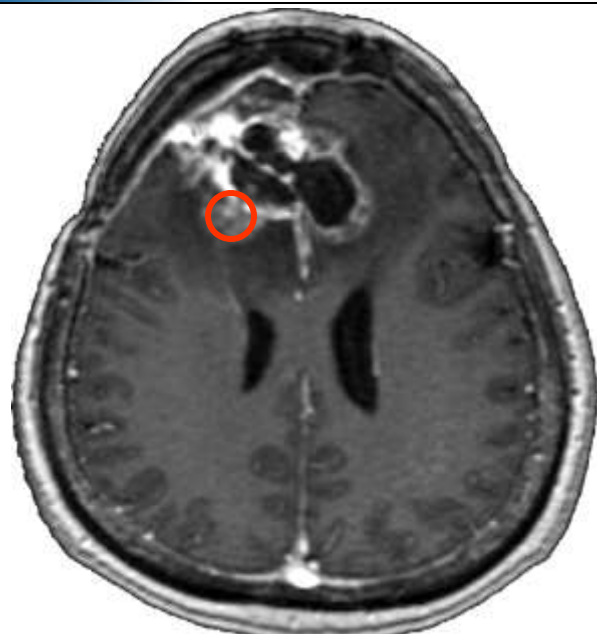
ADC

CBVnc

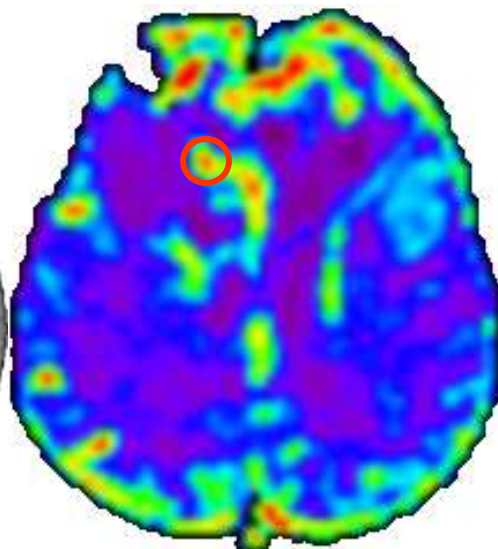
CBVc

fBV

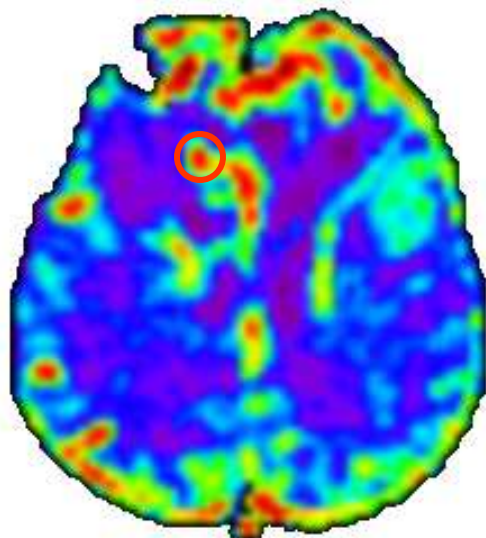




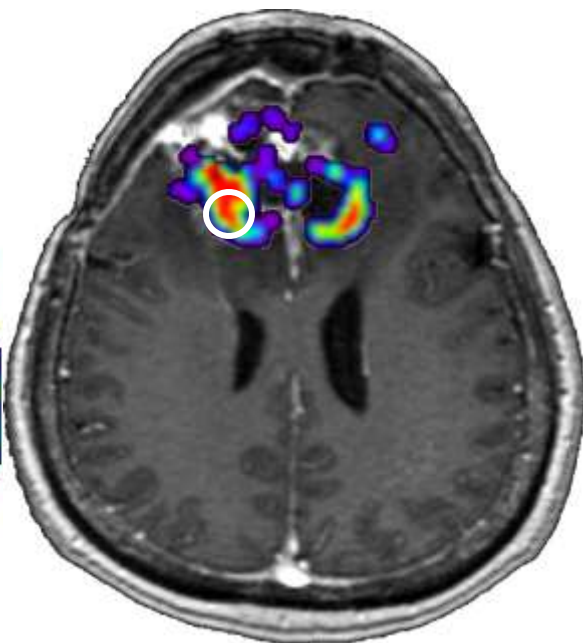
T1 Gado



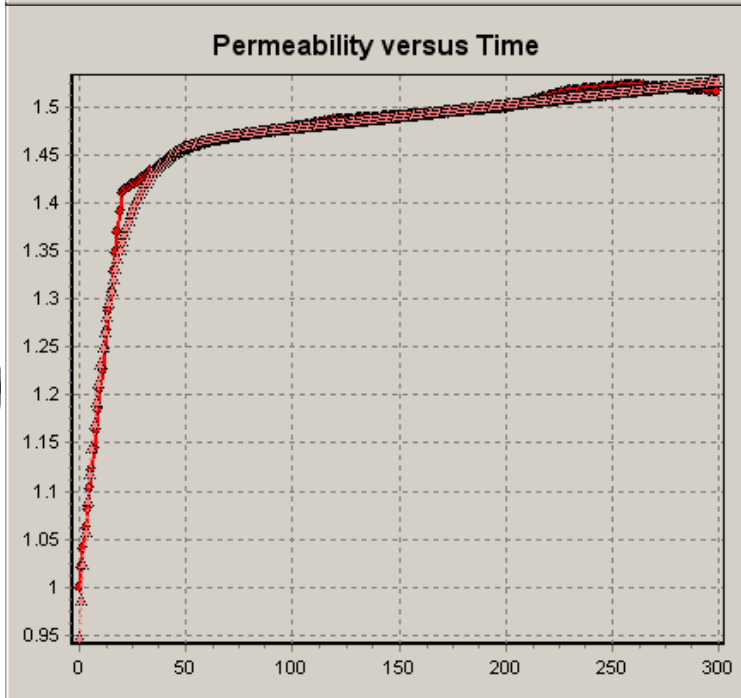
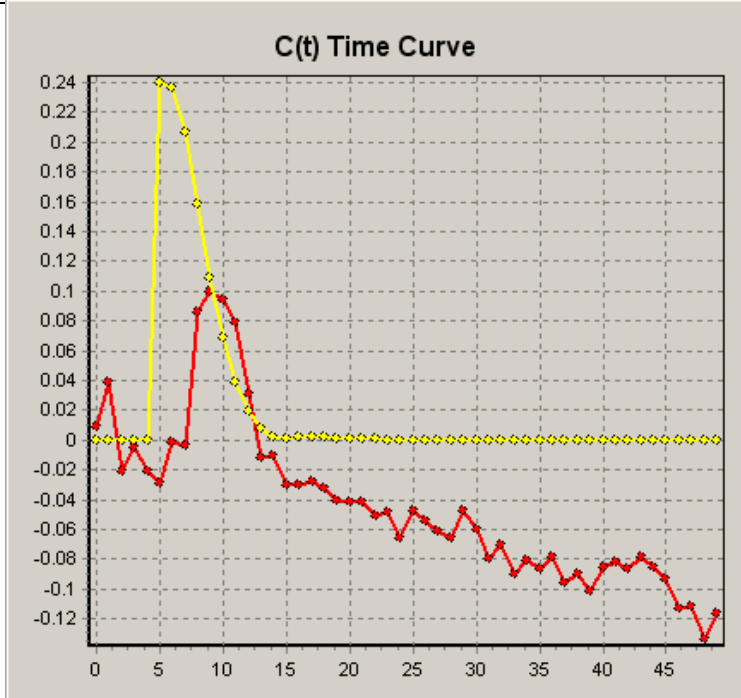
CBVnc = 5.45 ± 0.95

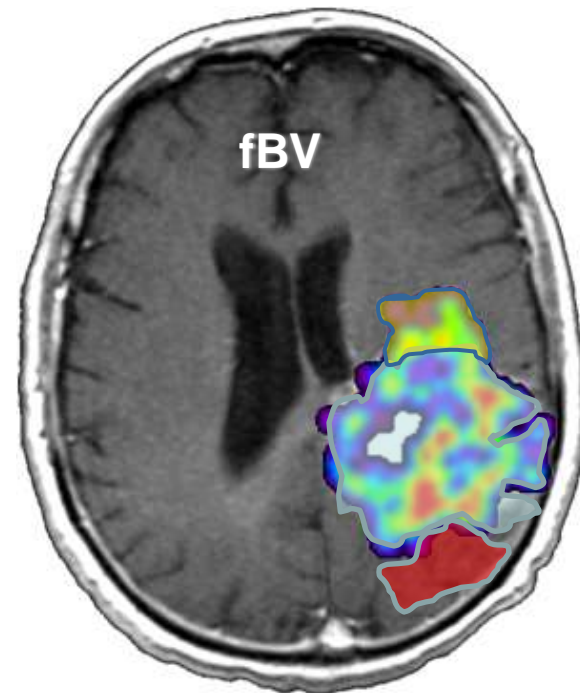
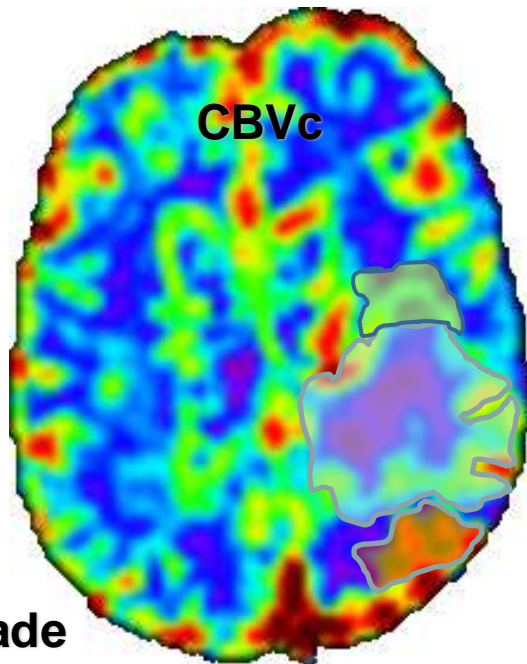
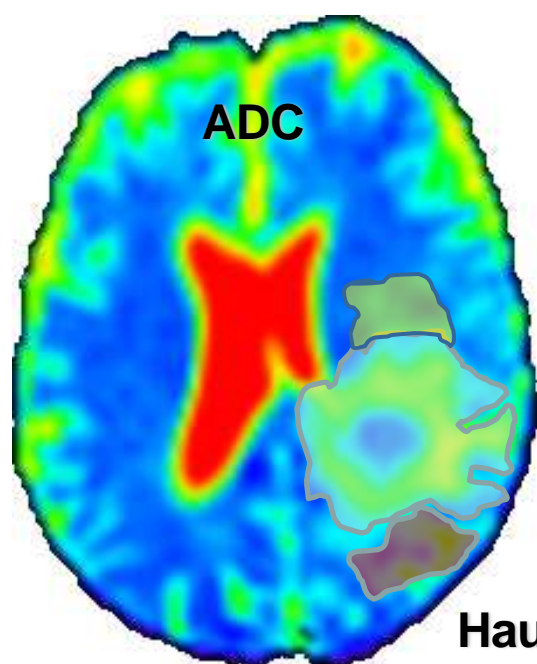
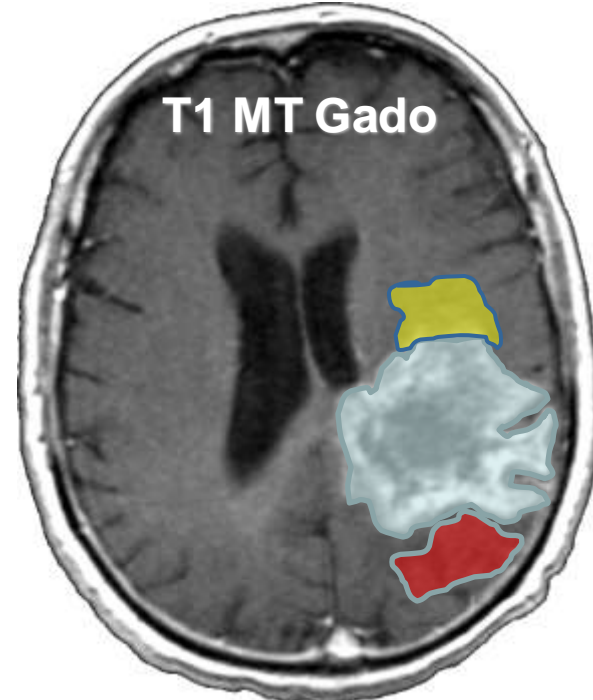
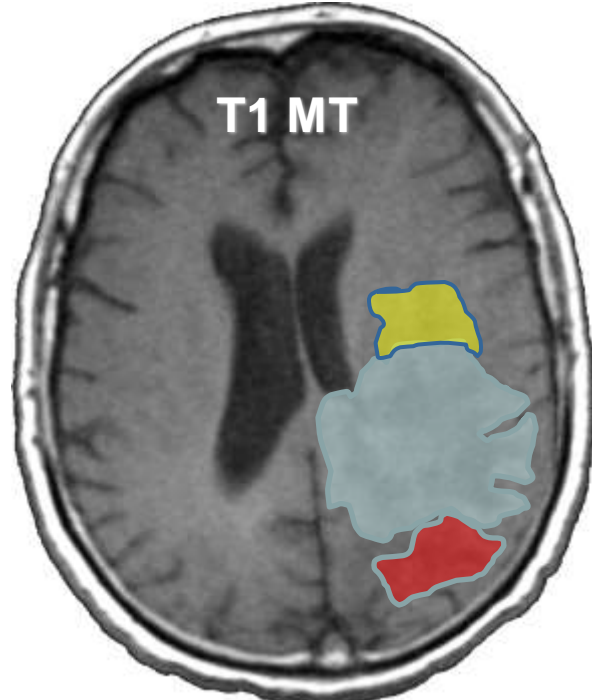
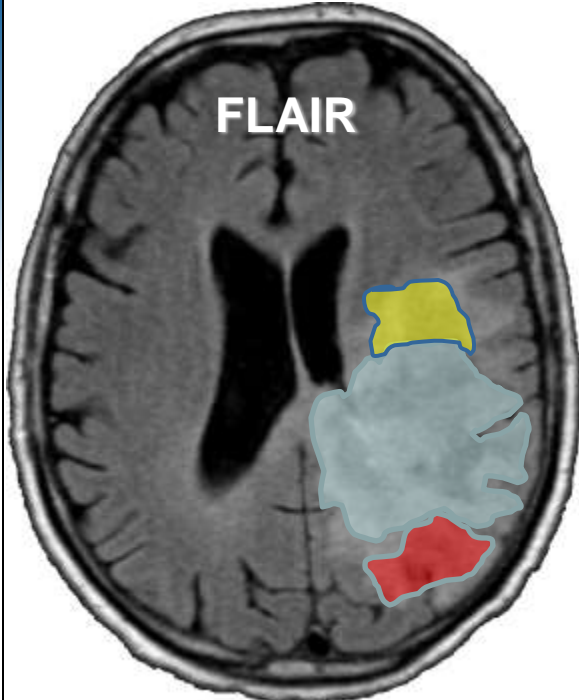


CBVc = 6.96 ± 0.75

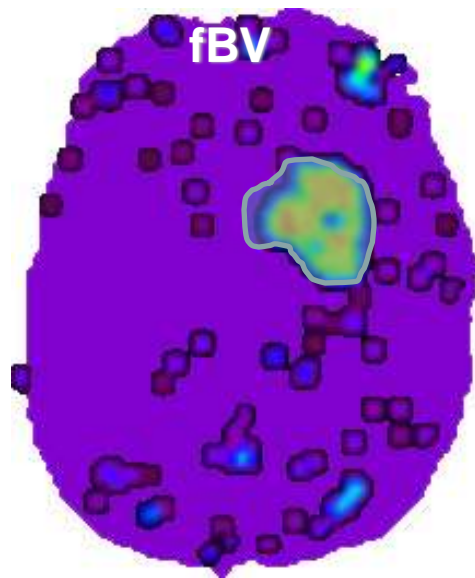
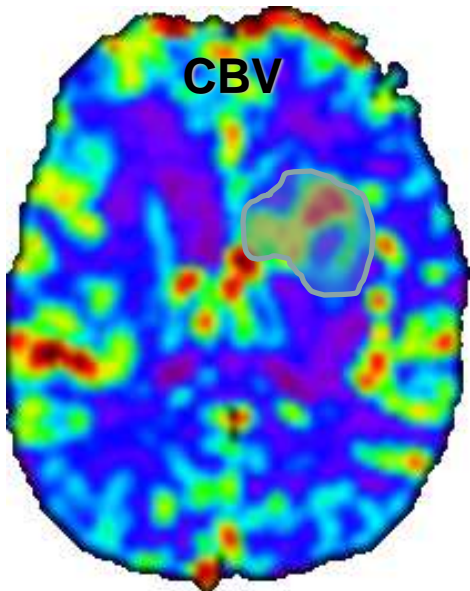
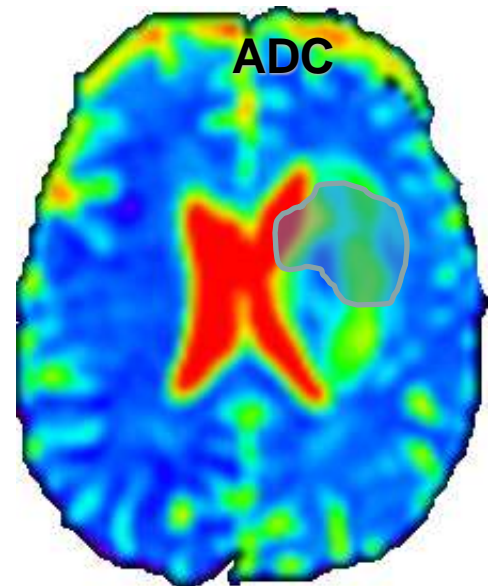
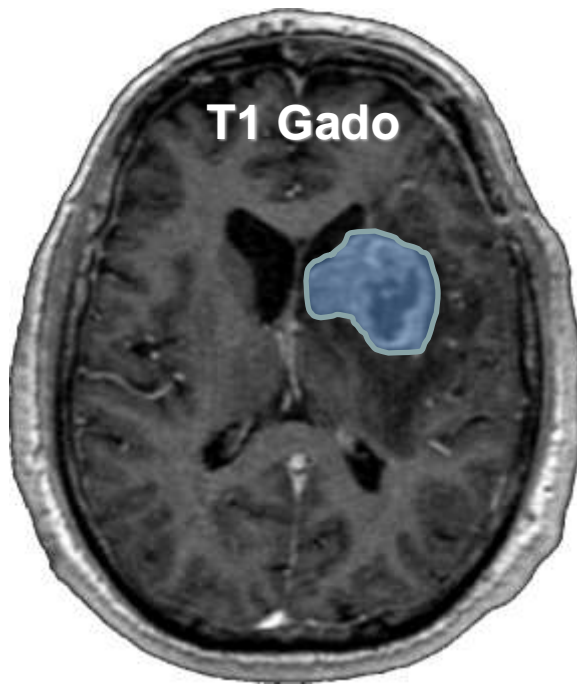
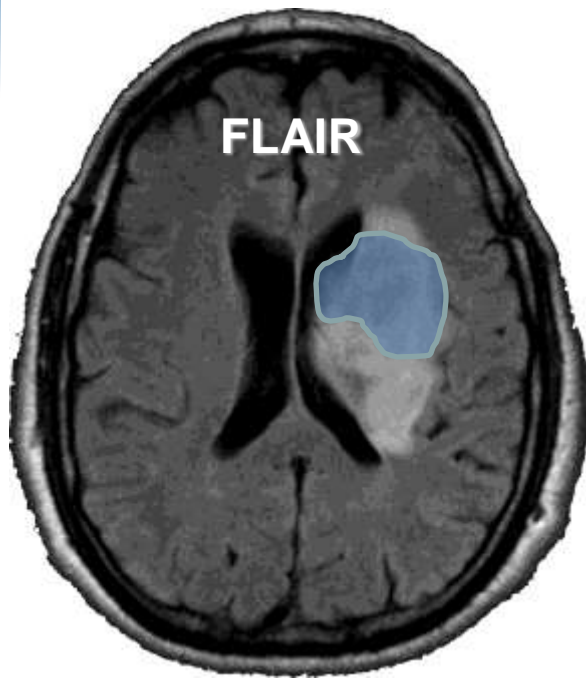


kPS / fBV = 0.2 / 23



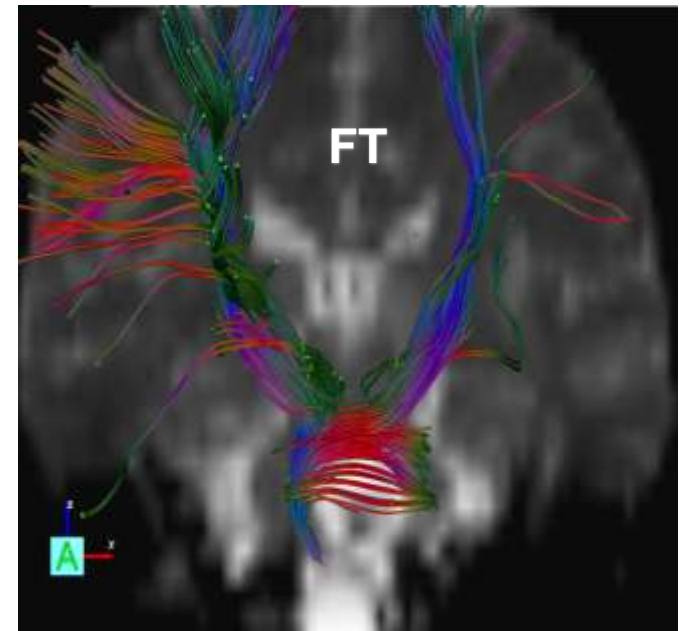
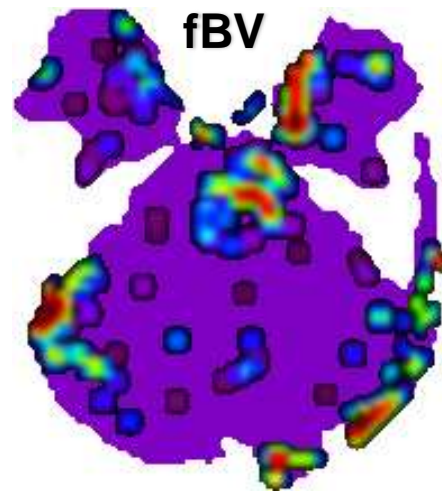
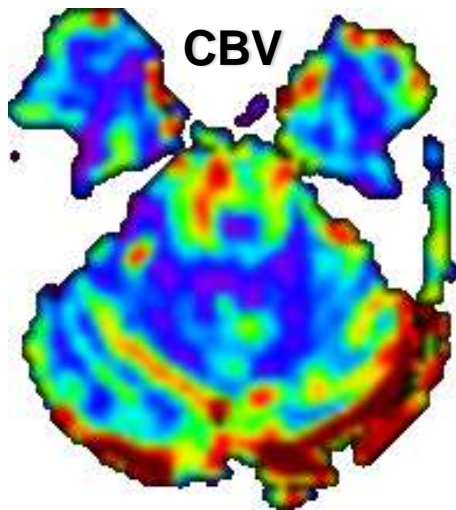
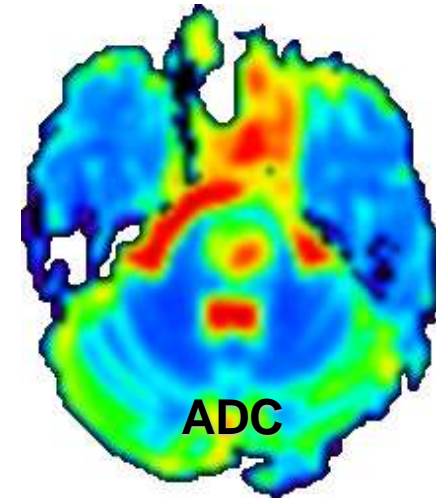
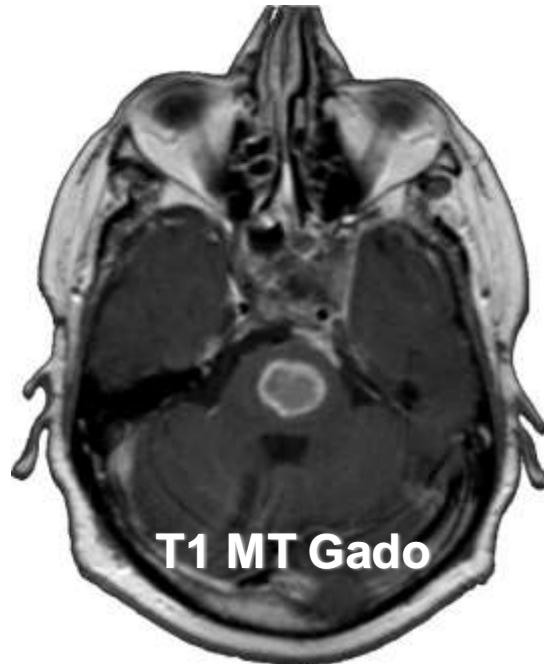
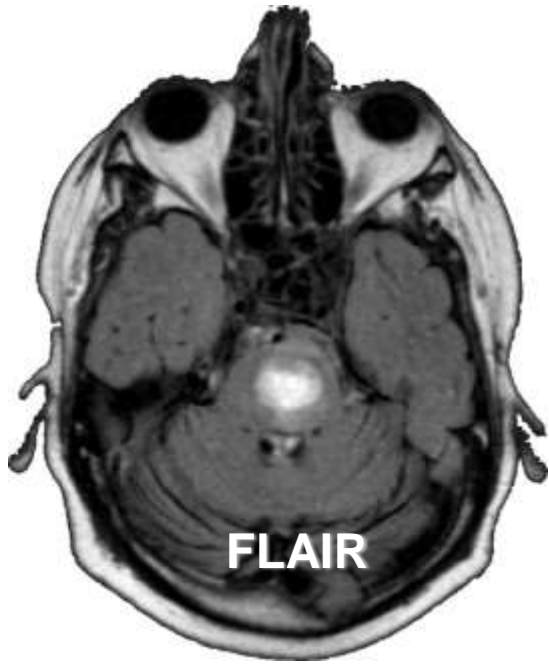


Haut Grade

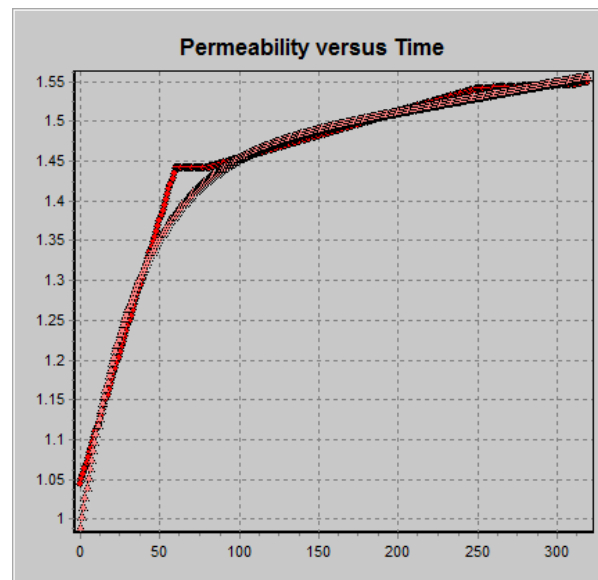
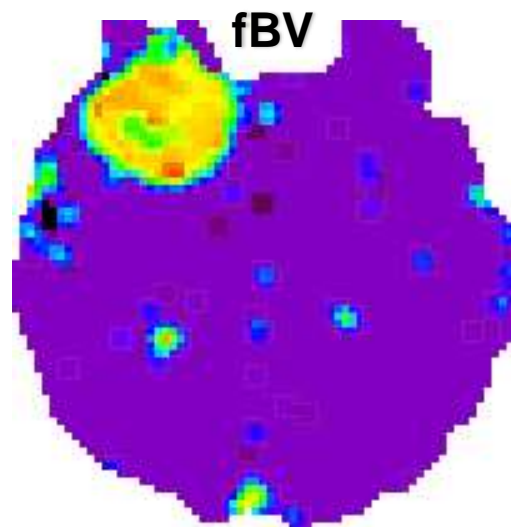
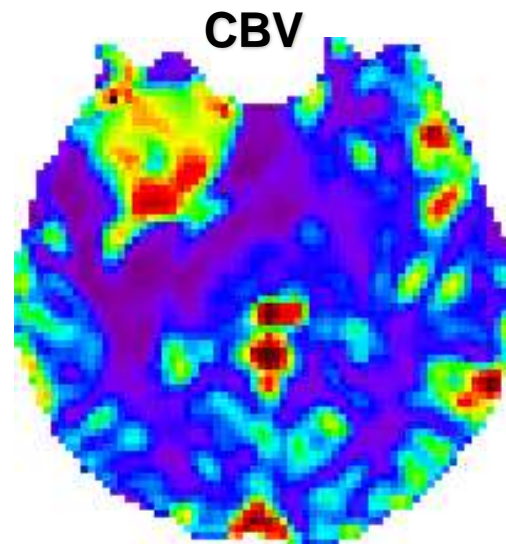
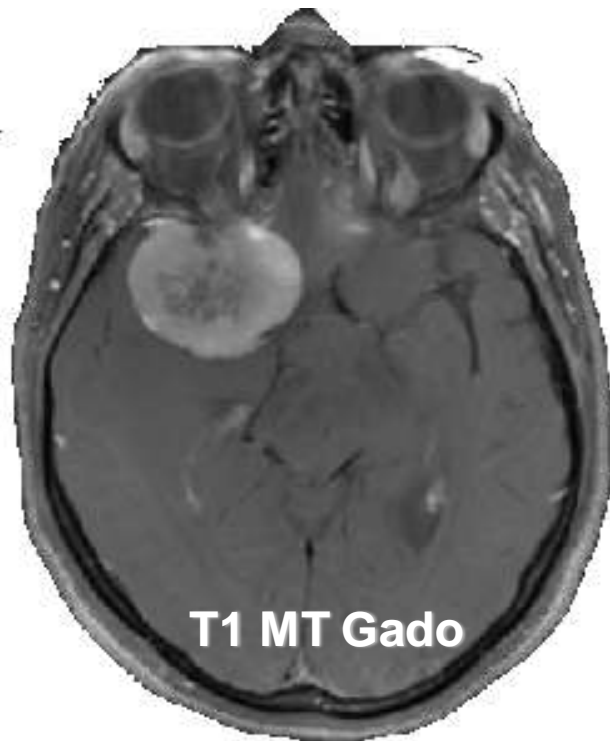


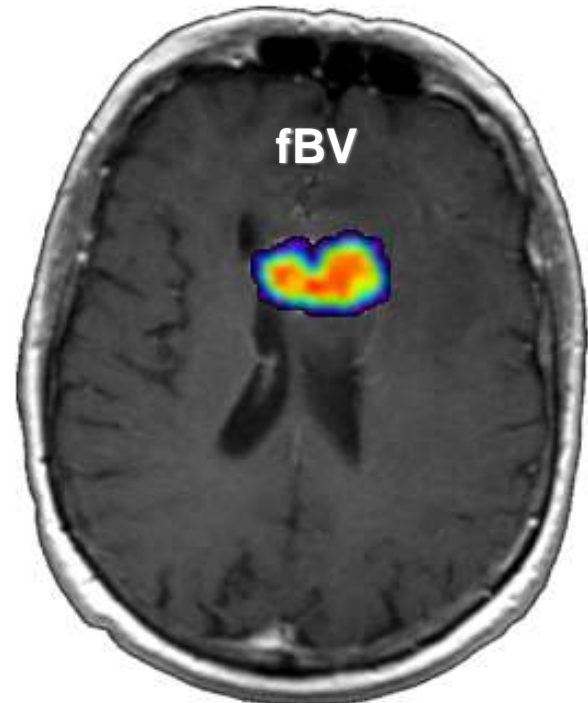
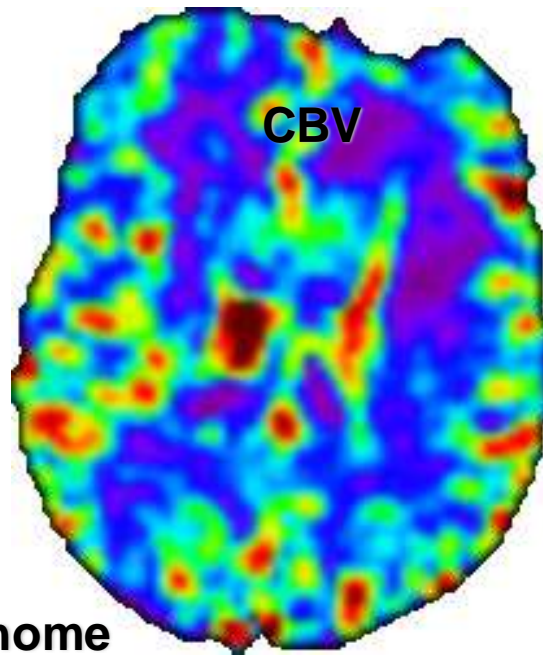
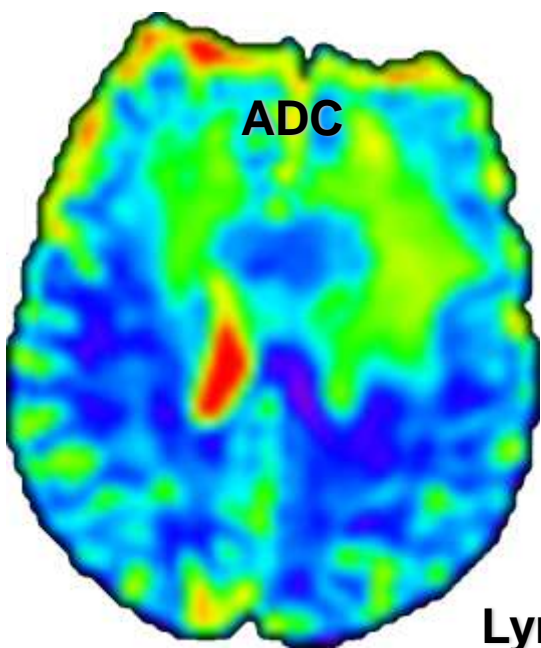
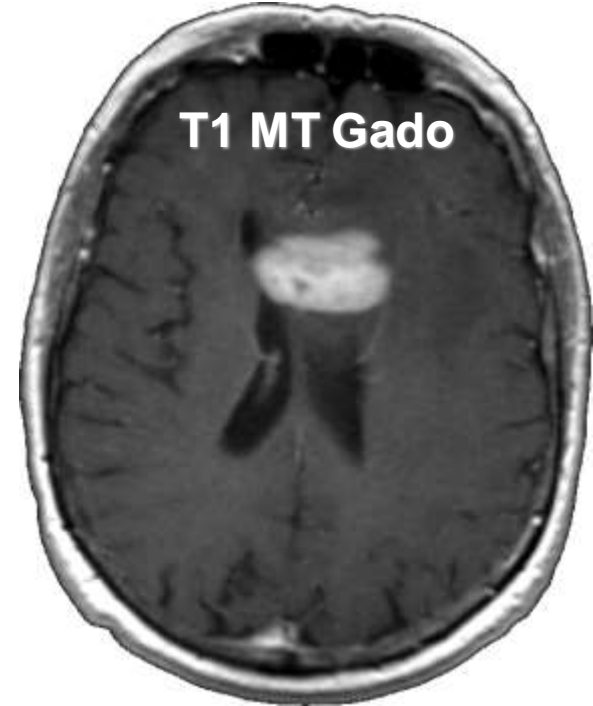
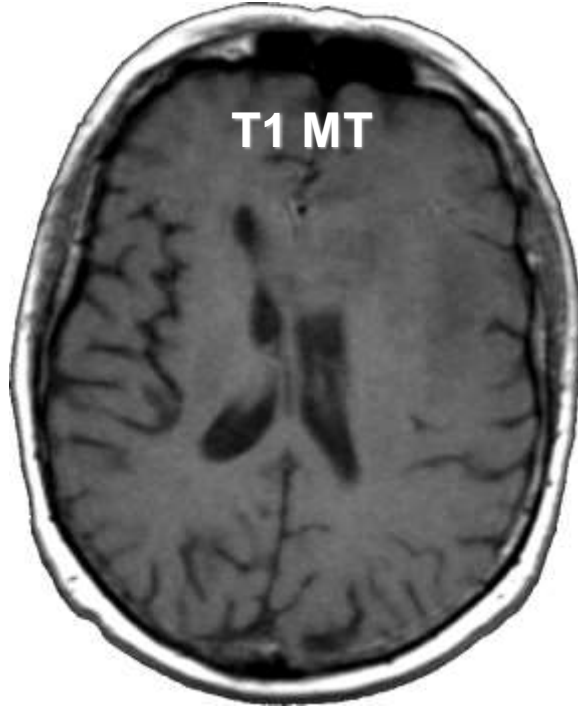
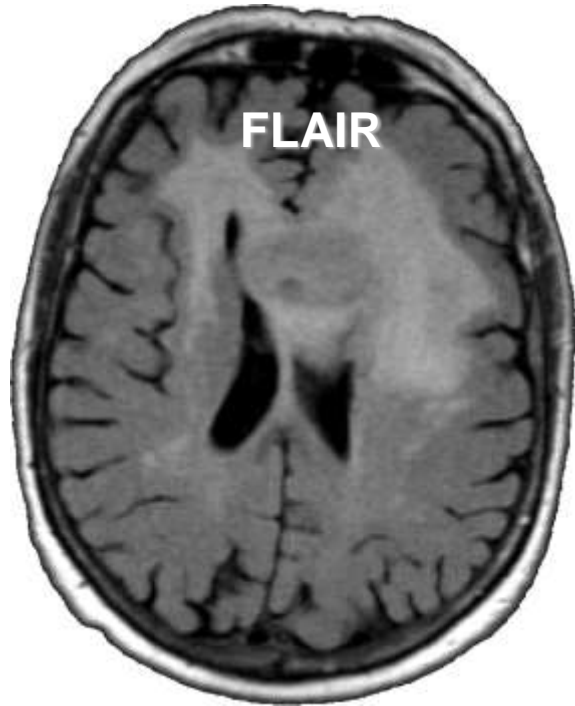
Métastase

Abcès



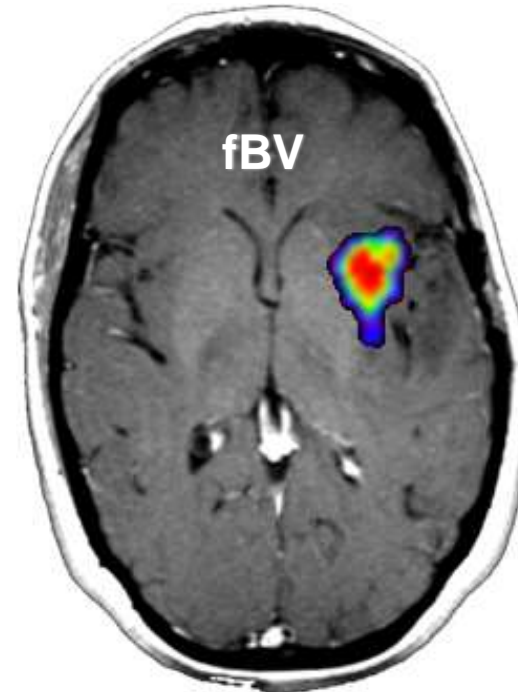
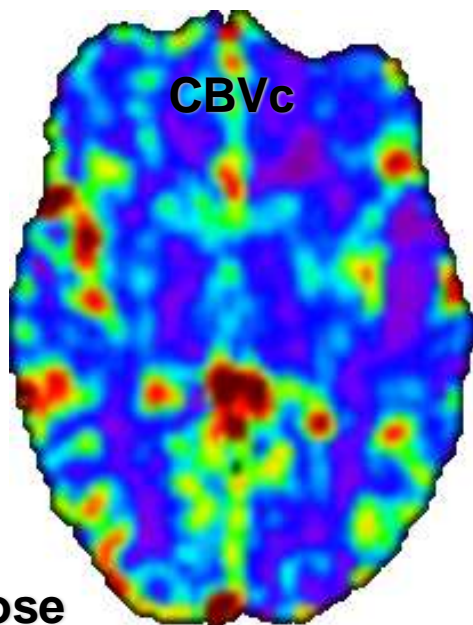
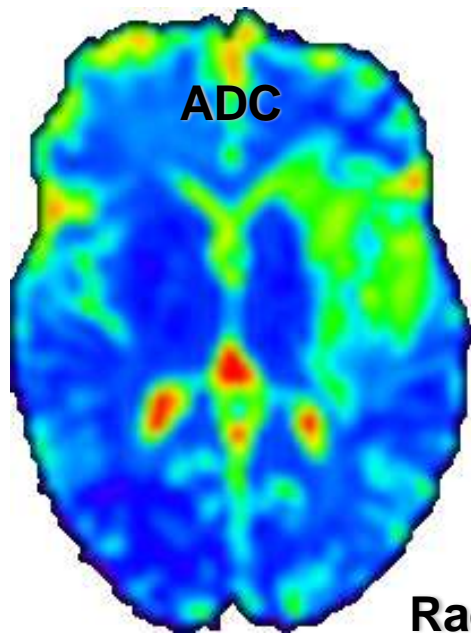
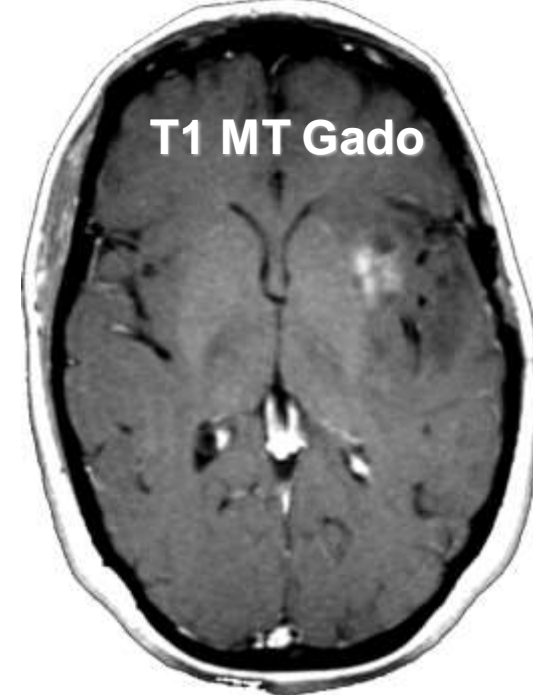
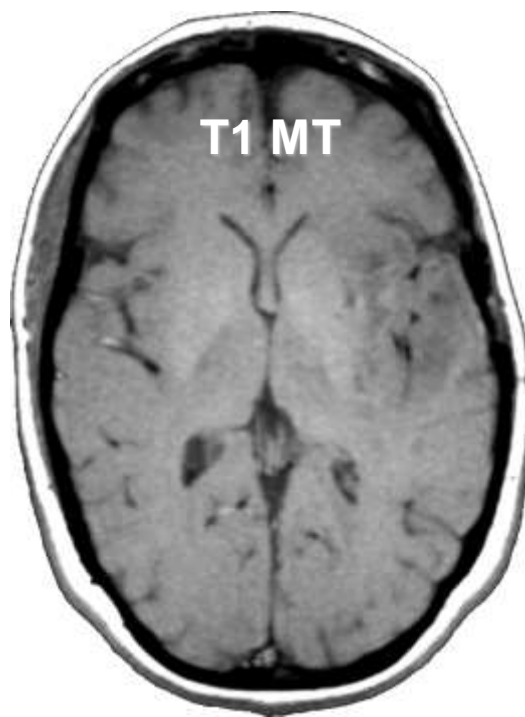
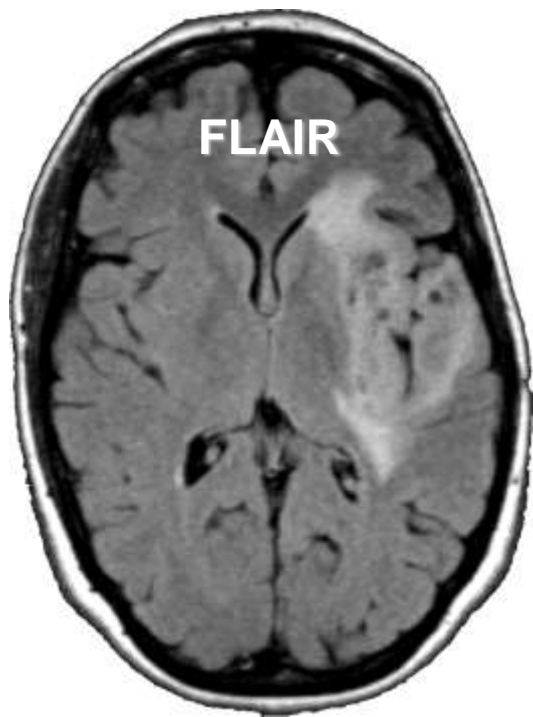
Méningiome





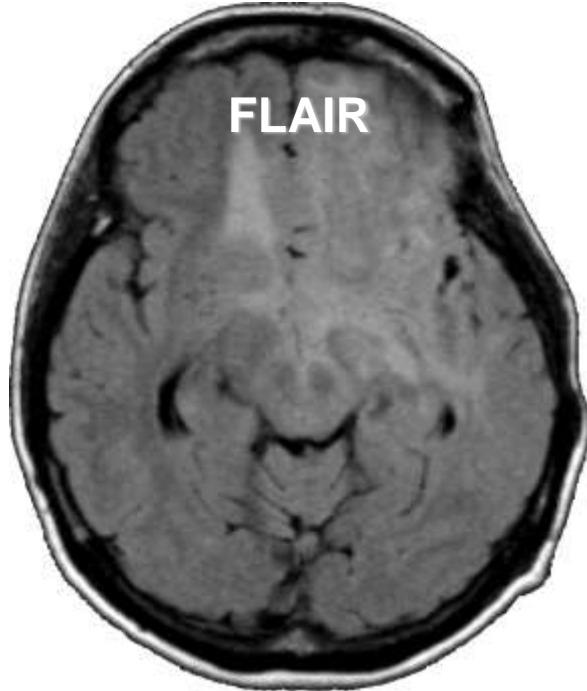
Lymphome

Enjeu n°2 :
Différencier Récidive et Radionécrose

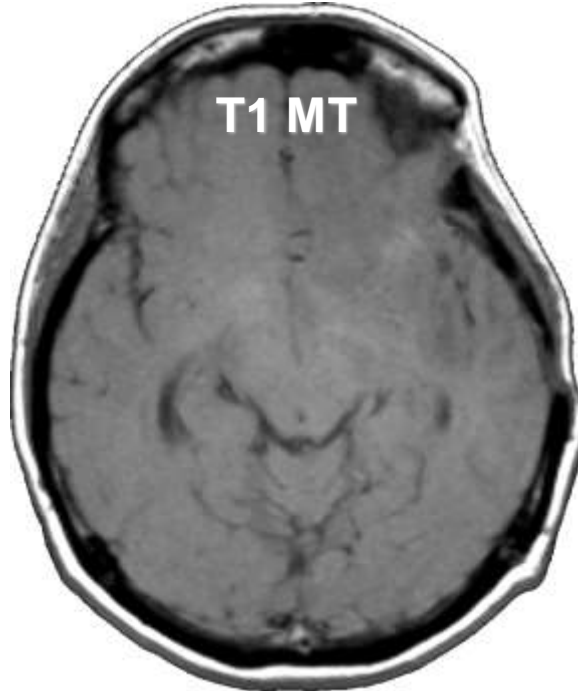


Radionécrose

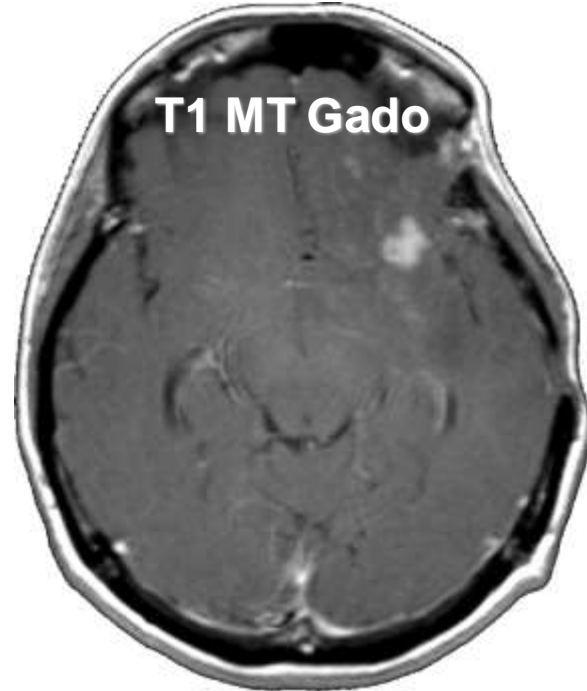
FLAIR



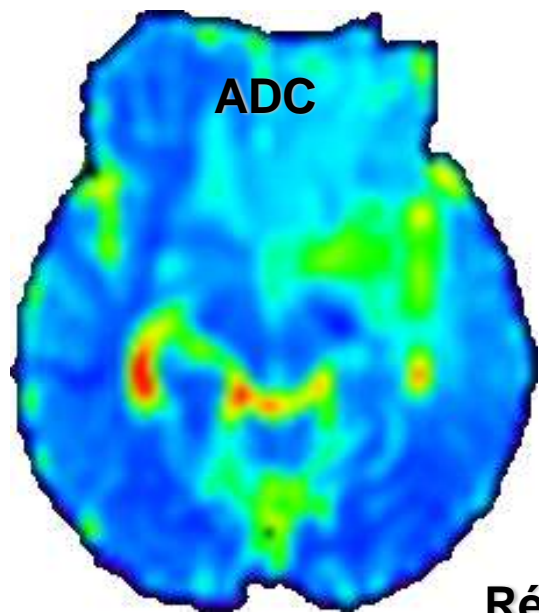
T1 MT



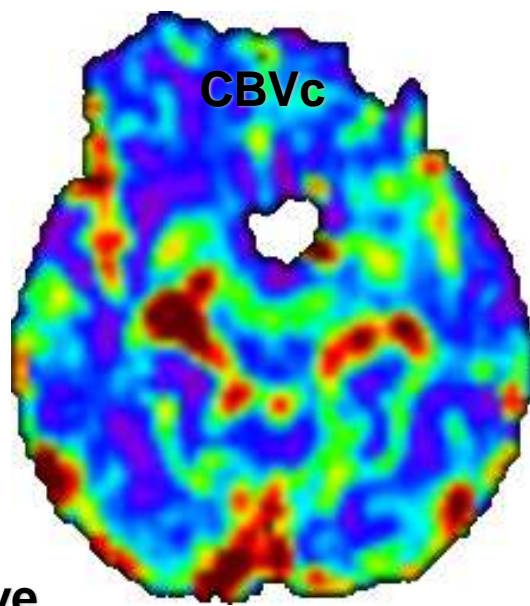
T1 MT Gado



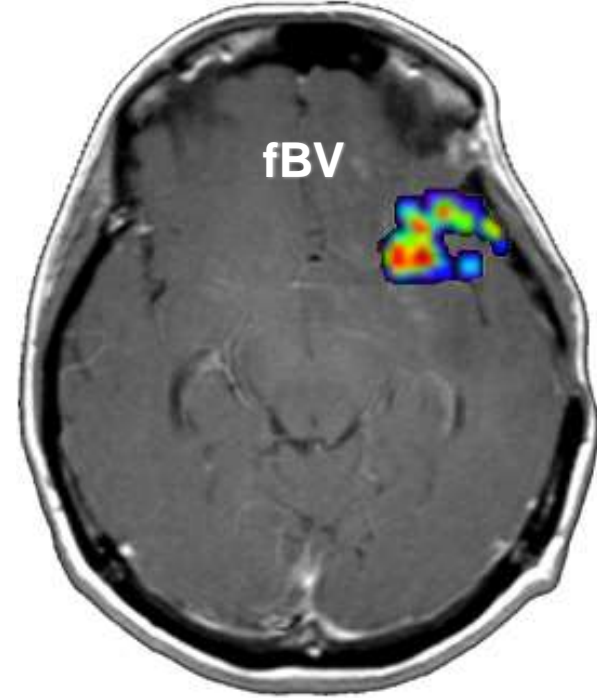
ADC



CBVc

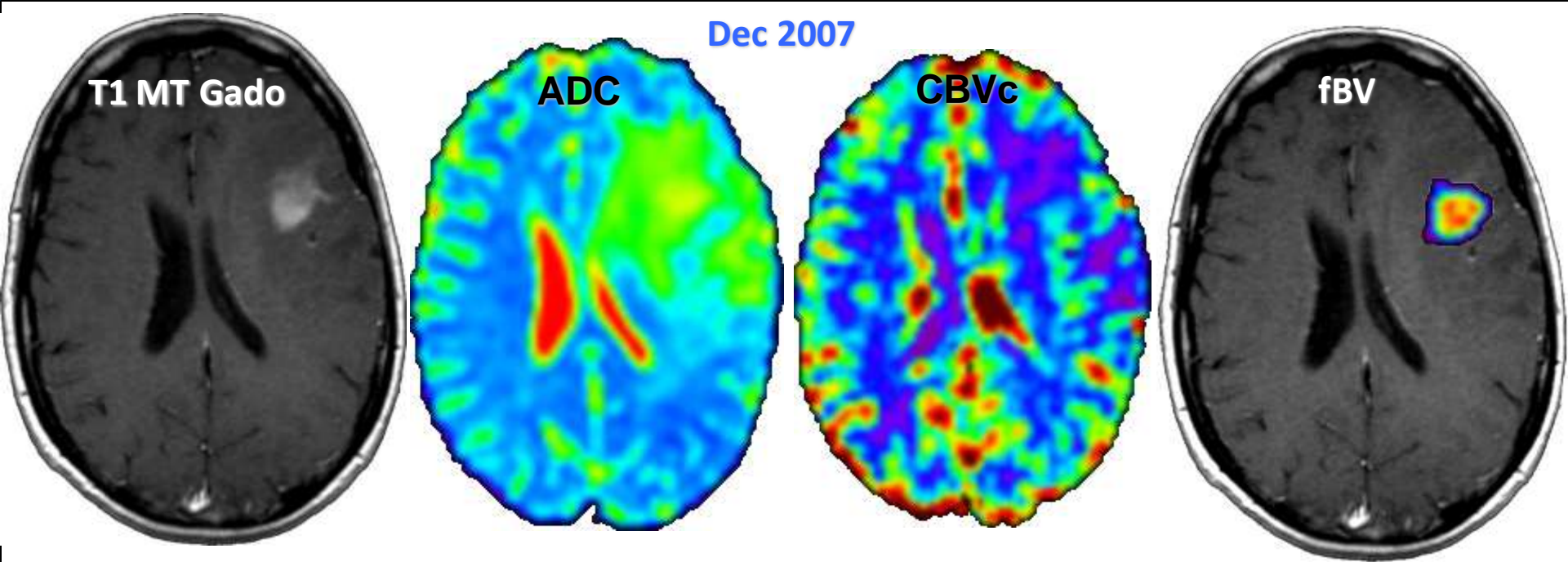


fBV

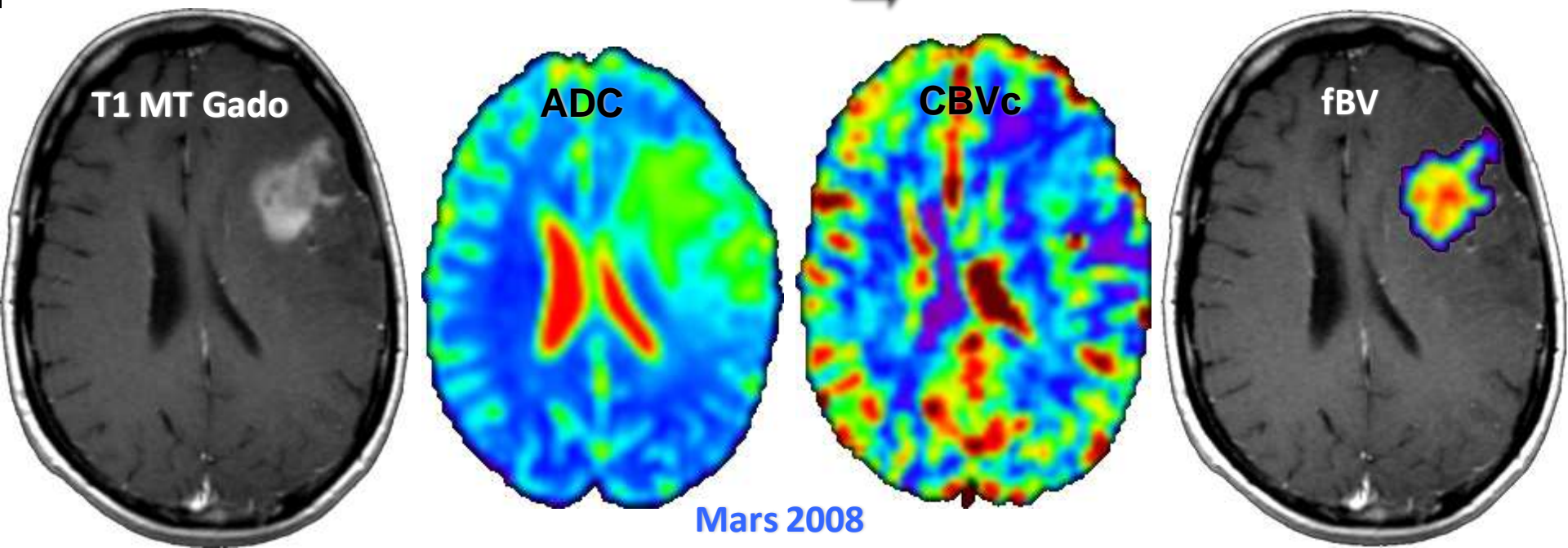


Récidive

Dec 2007



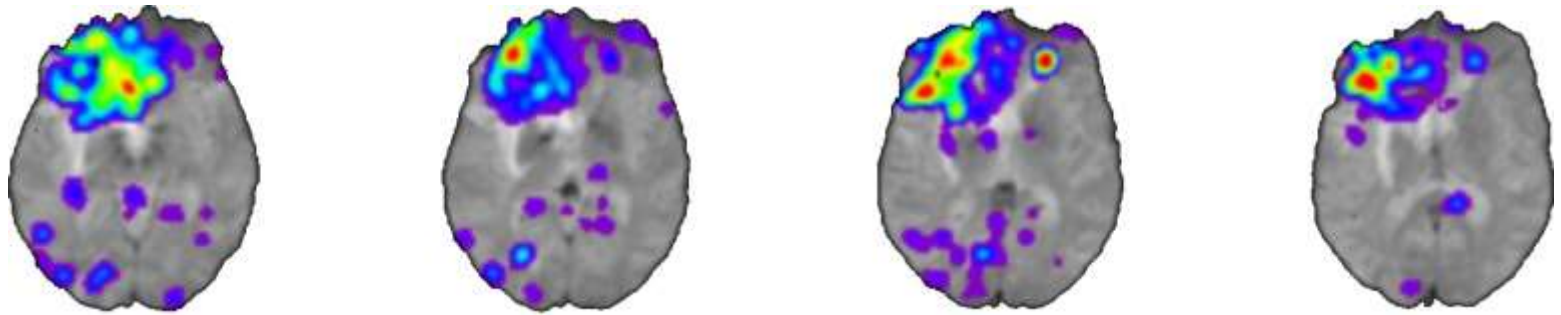
Douteux = 50 % → Suivi



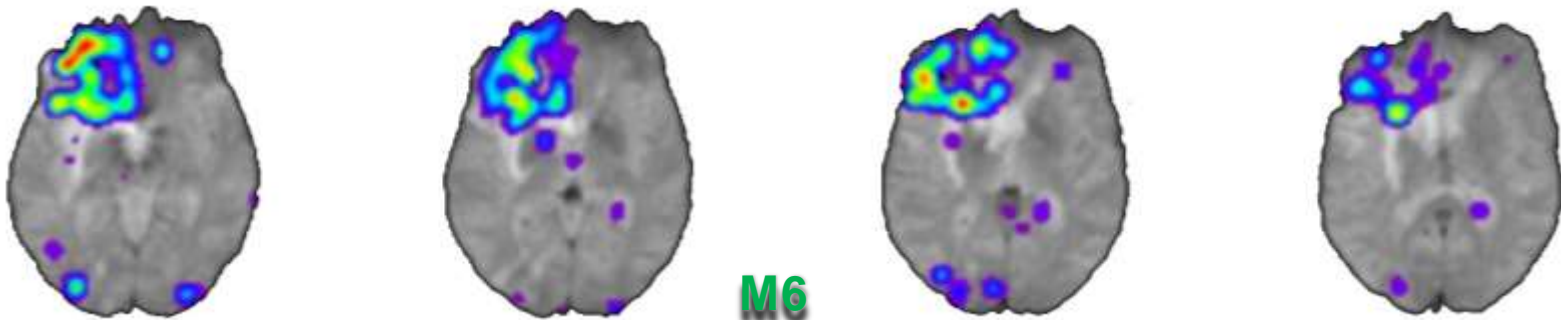
Enjeu n°3 :

Evaluer l'efficacité thérapeutique

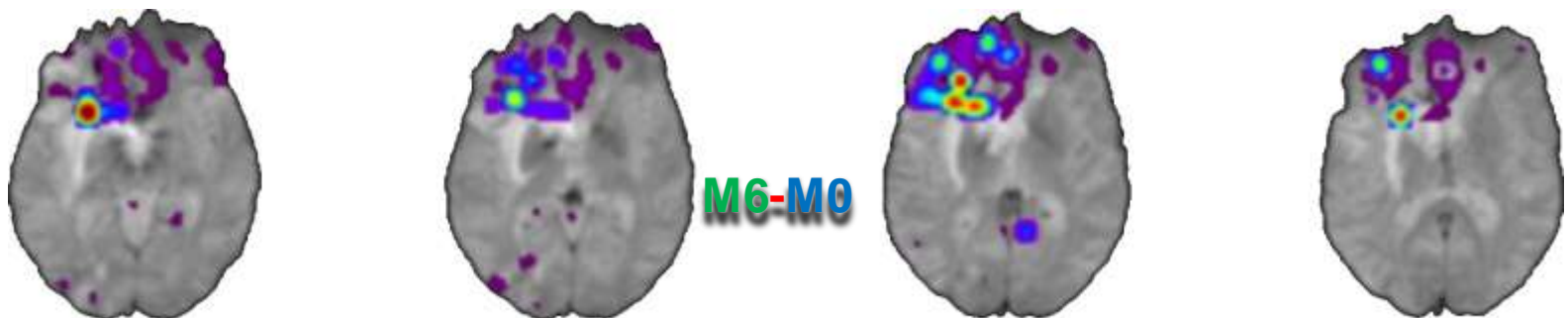
Traitements Anti-angiogéniques



M0



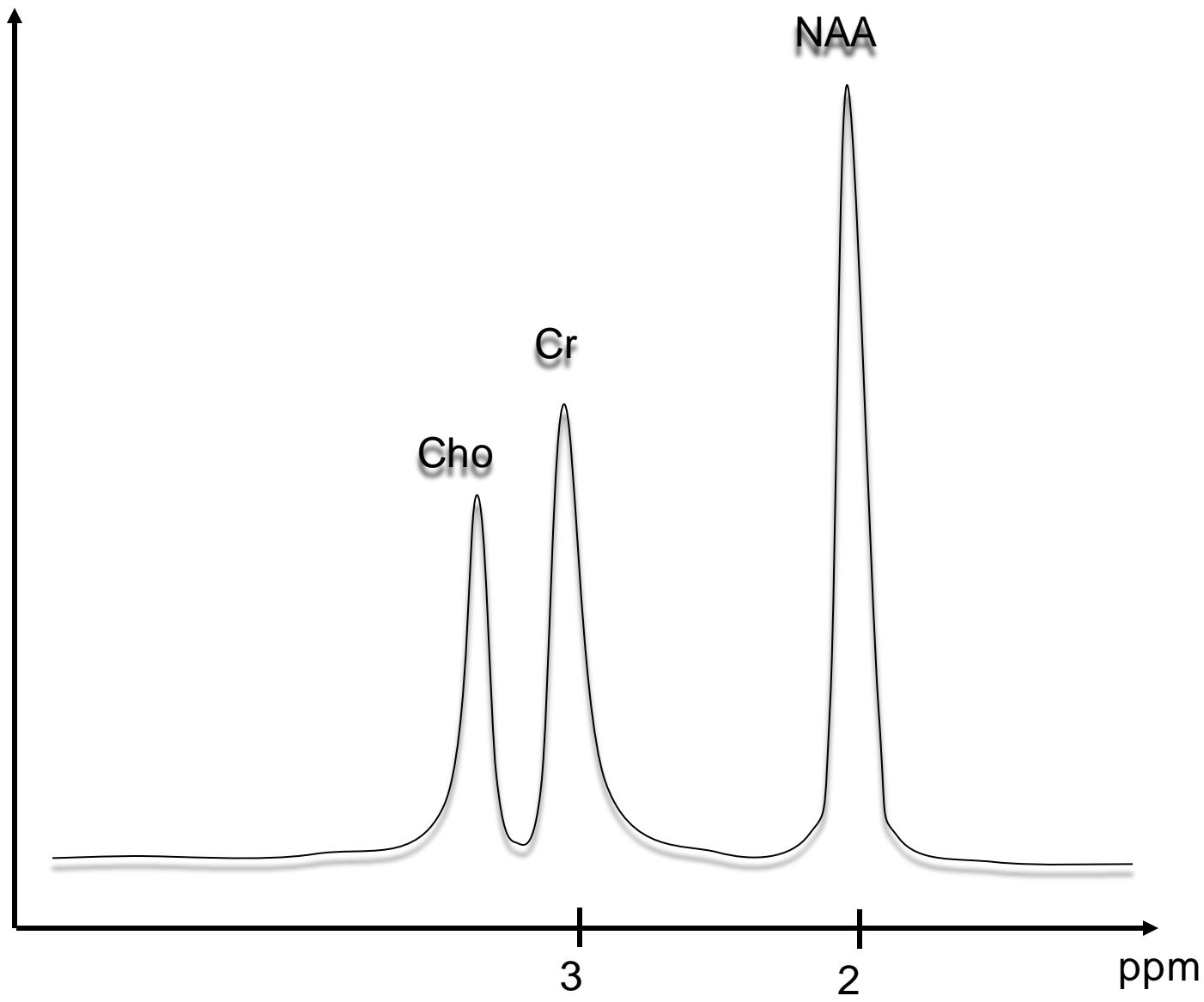
M6



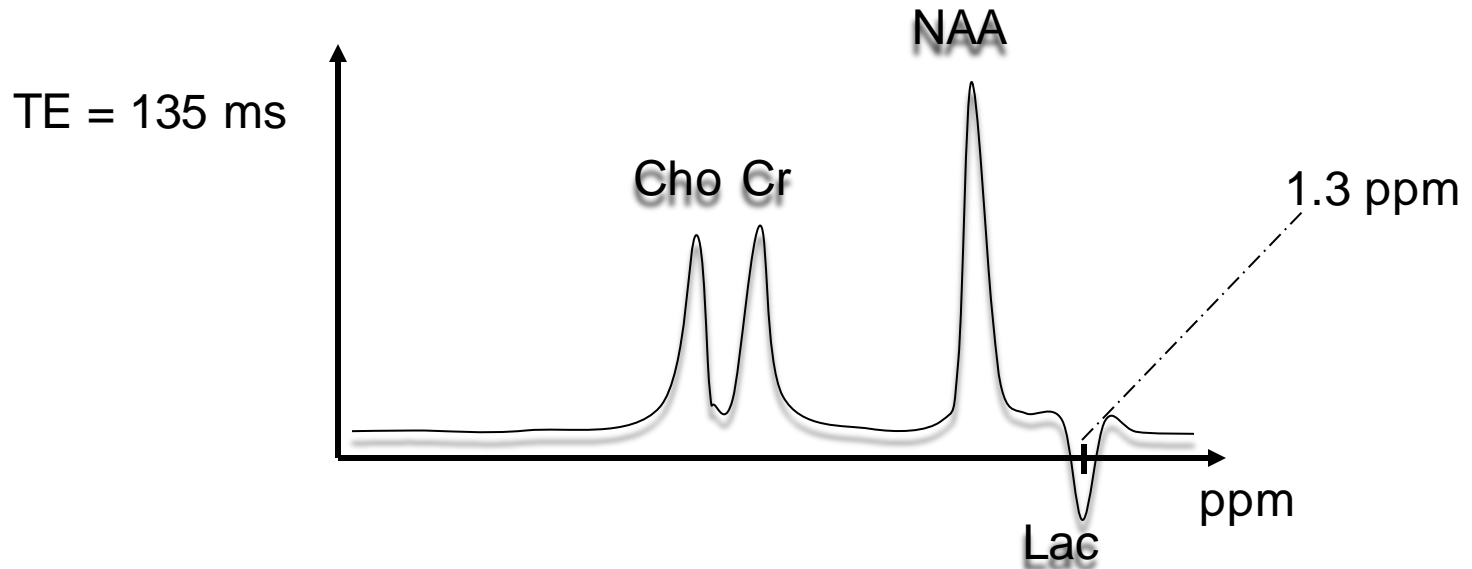
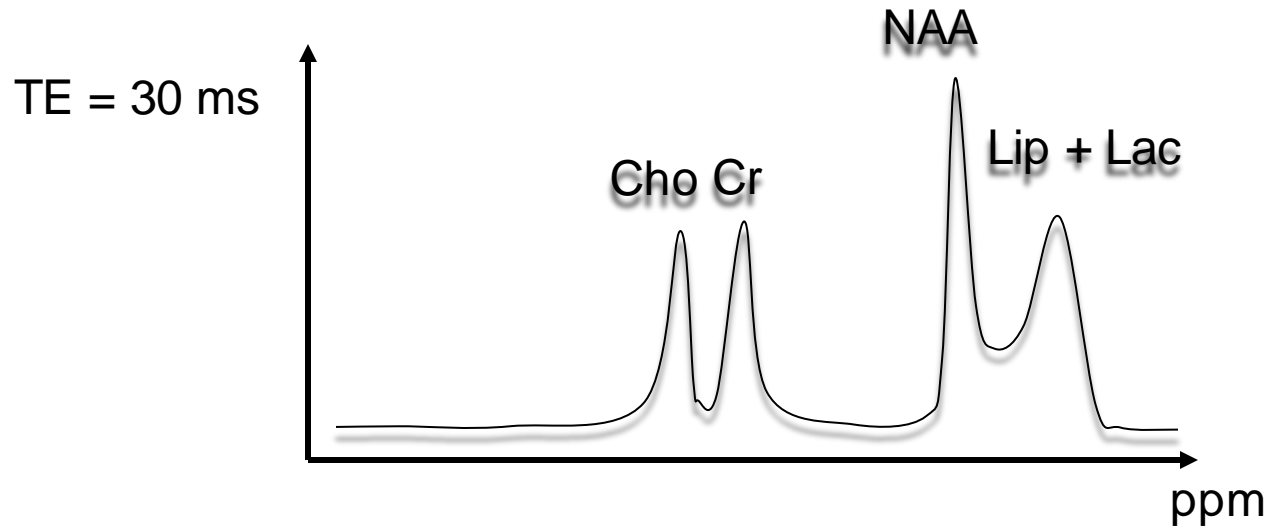
M6-M0

5. Spectro IRM

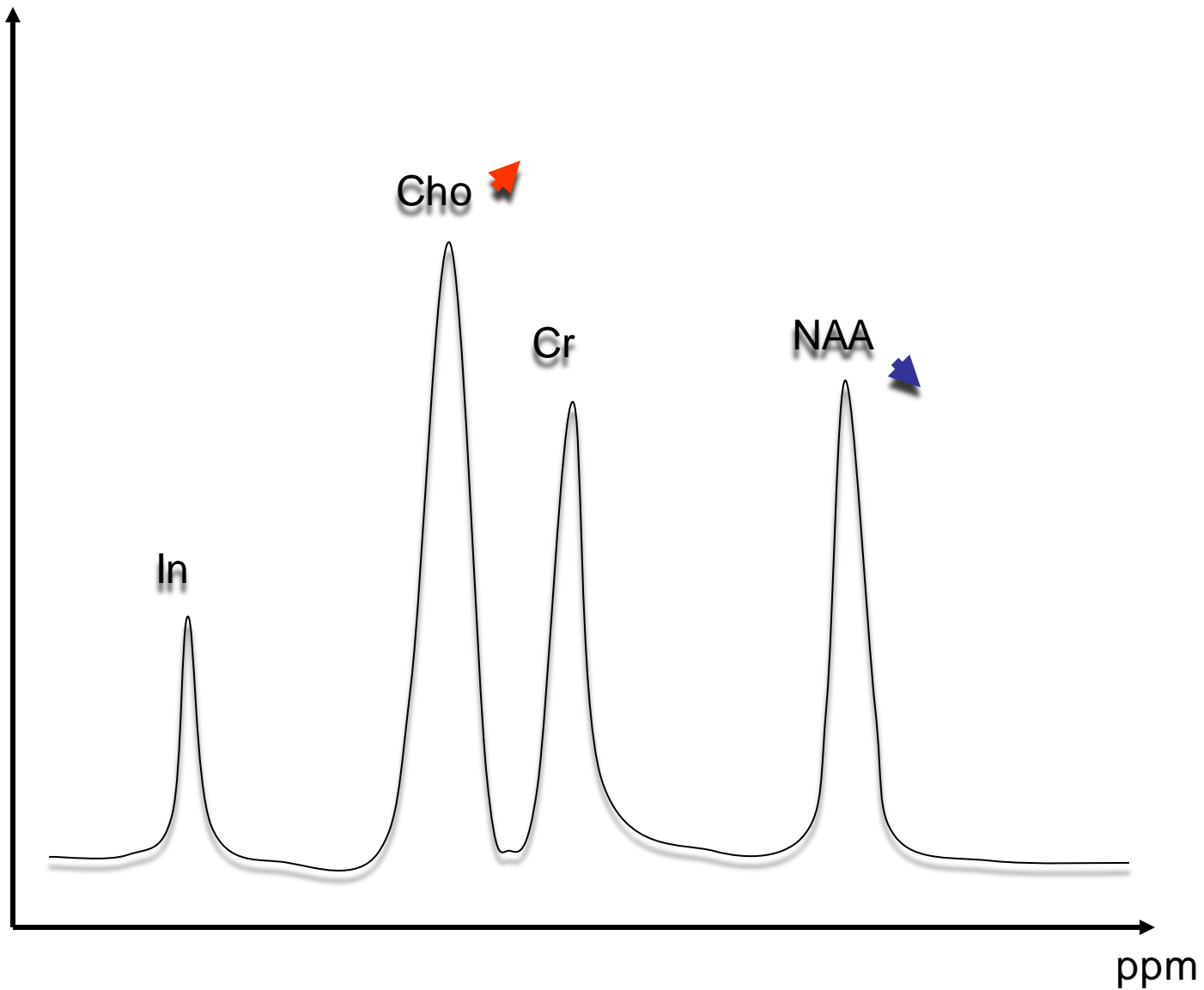
Spectre Normal



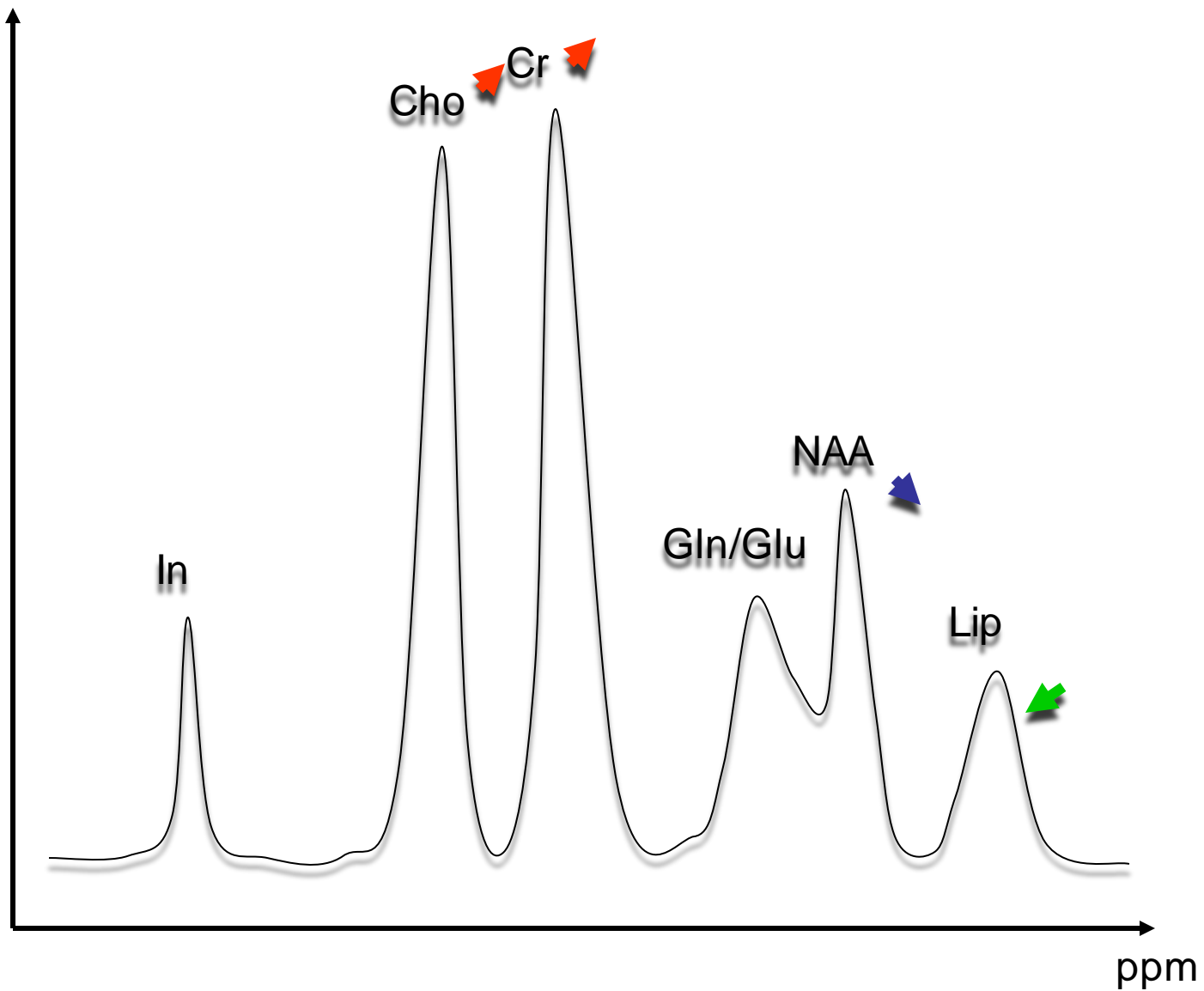
Lactates



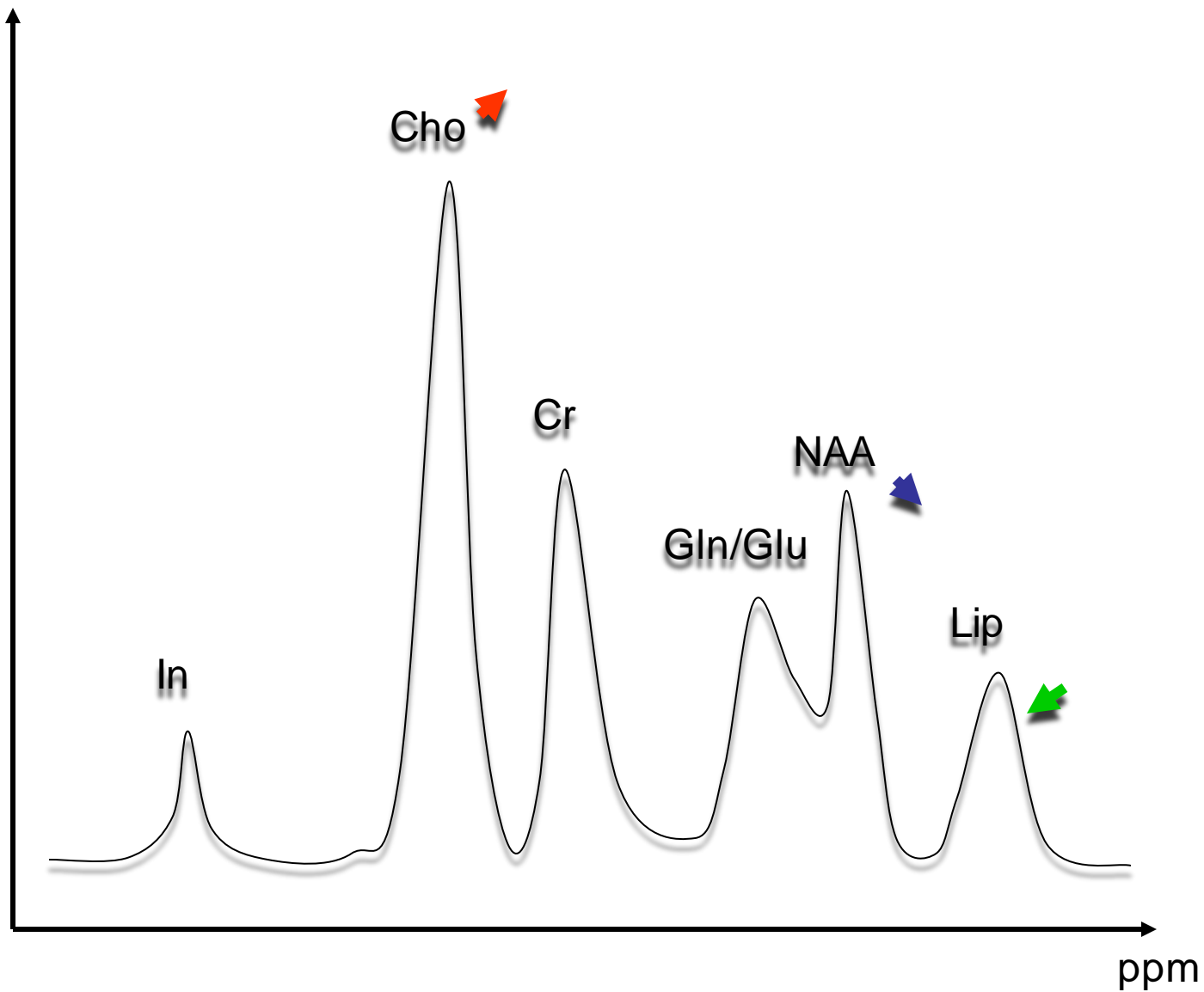
Gliome de Bas Grade



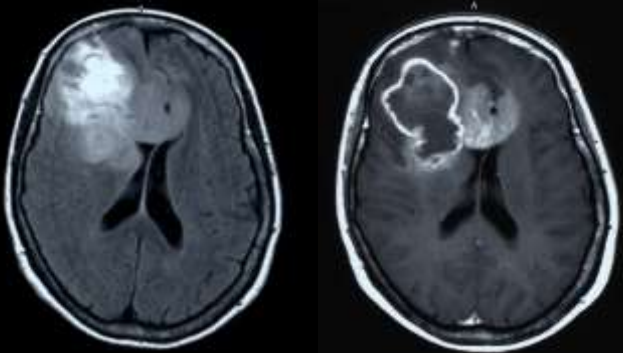
Gliome de Haut Grade



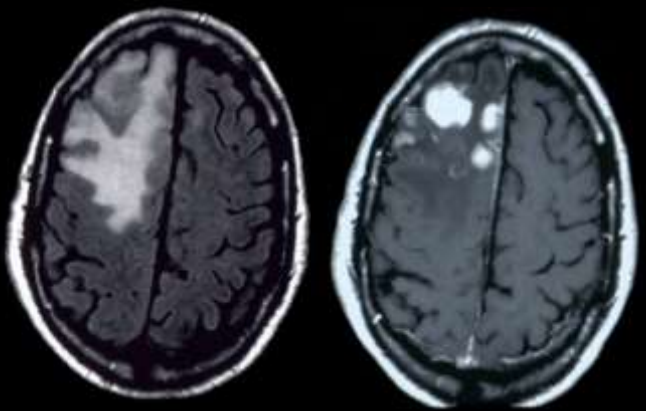
Lymphomes et Métastases



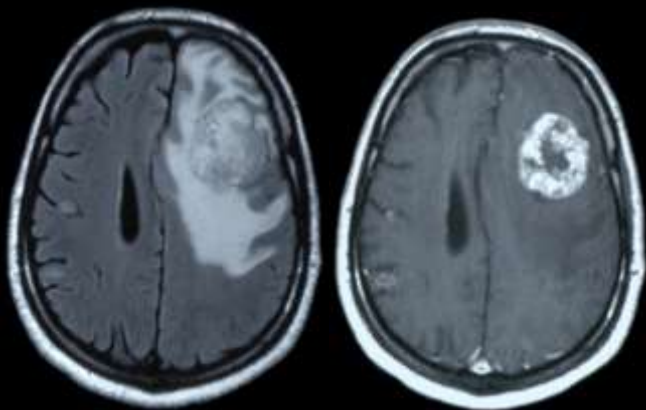
Glioblastome



Lymphome

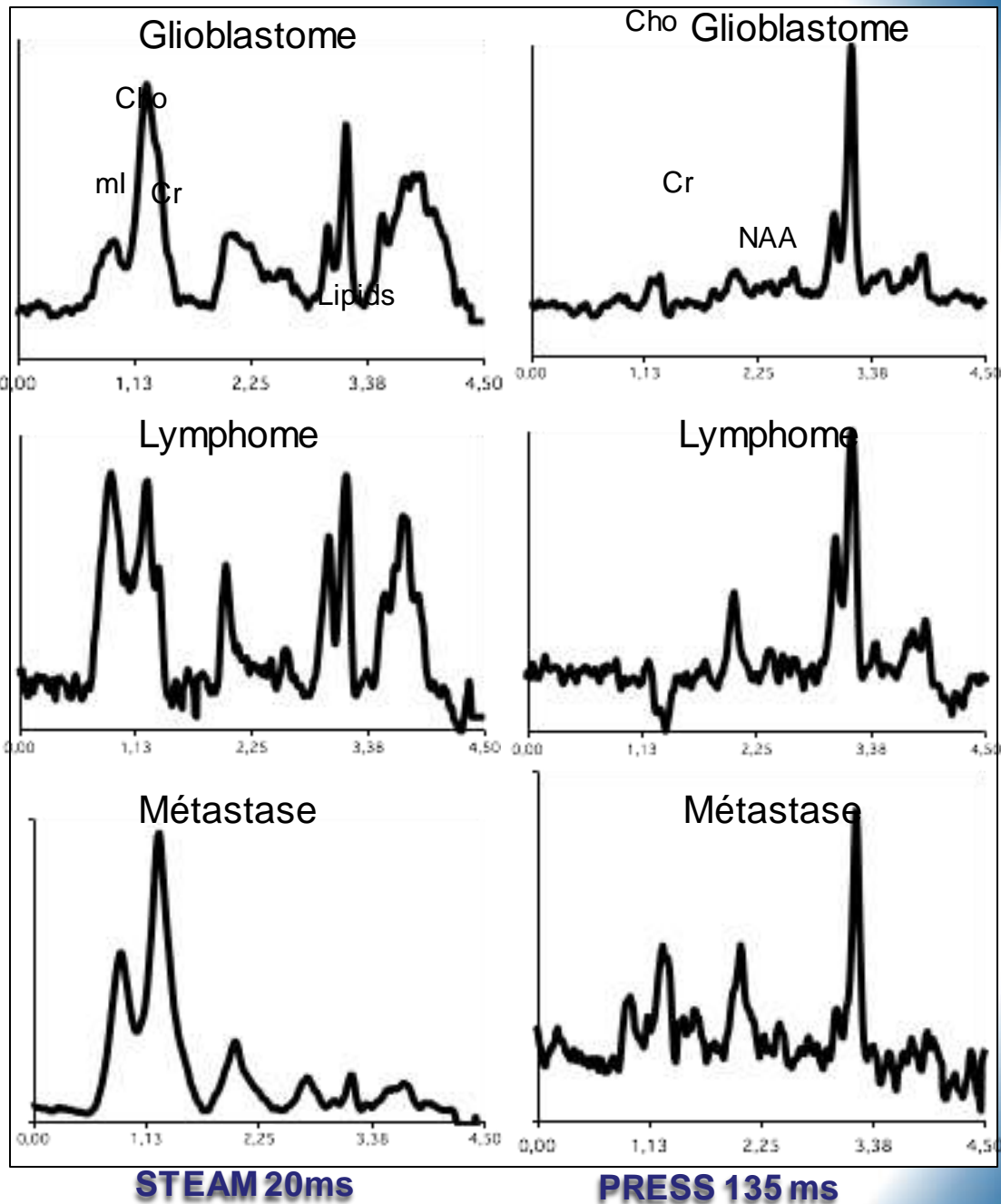


Métastase

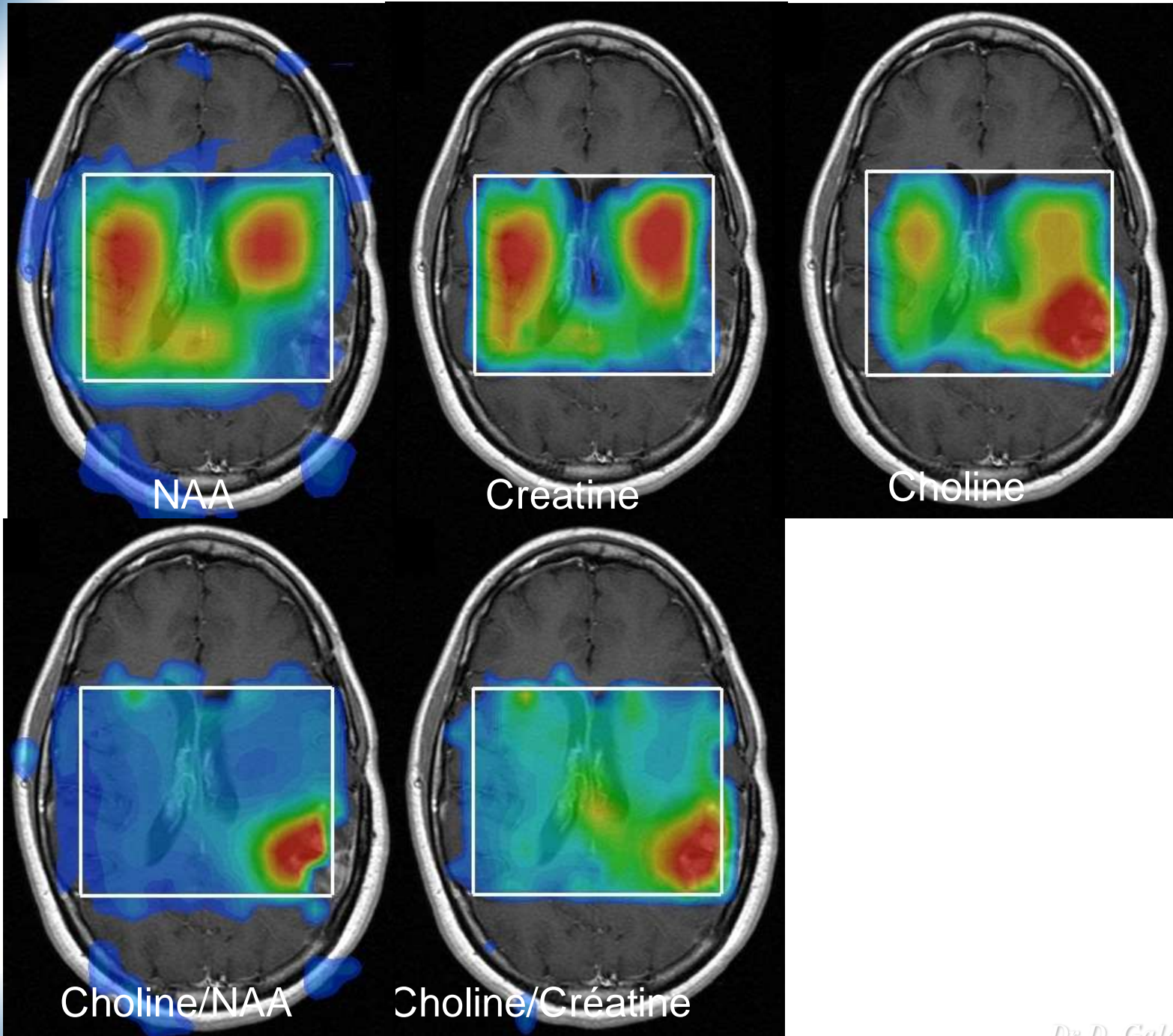


FLAIR

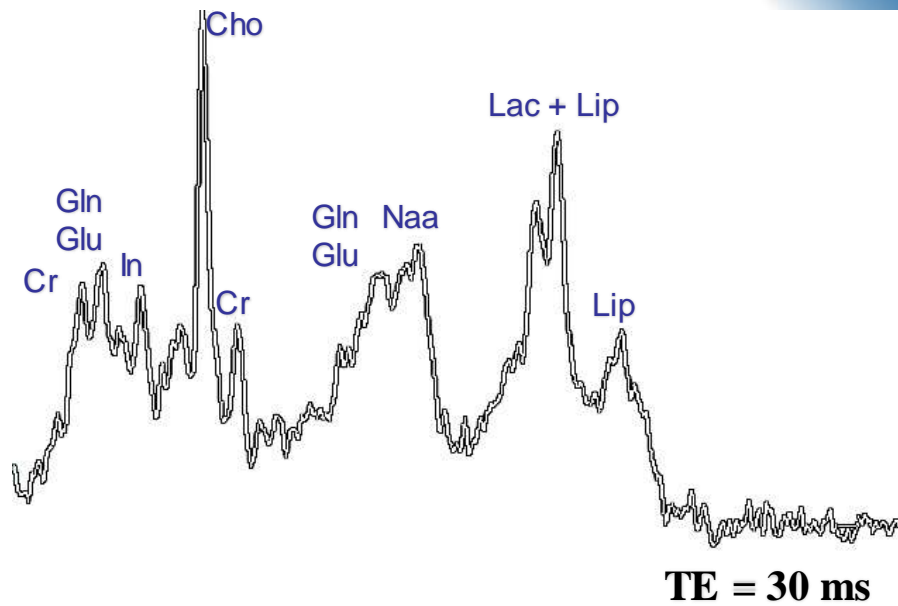
T1Gd



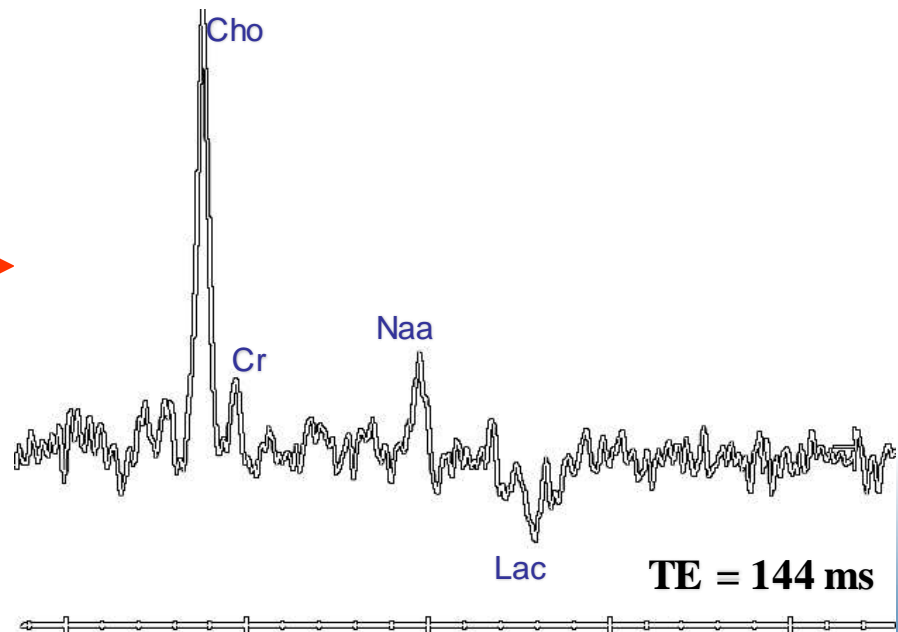
Dr D. Galanaud, PSL



SE T2

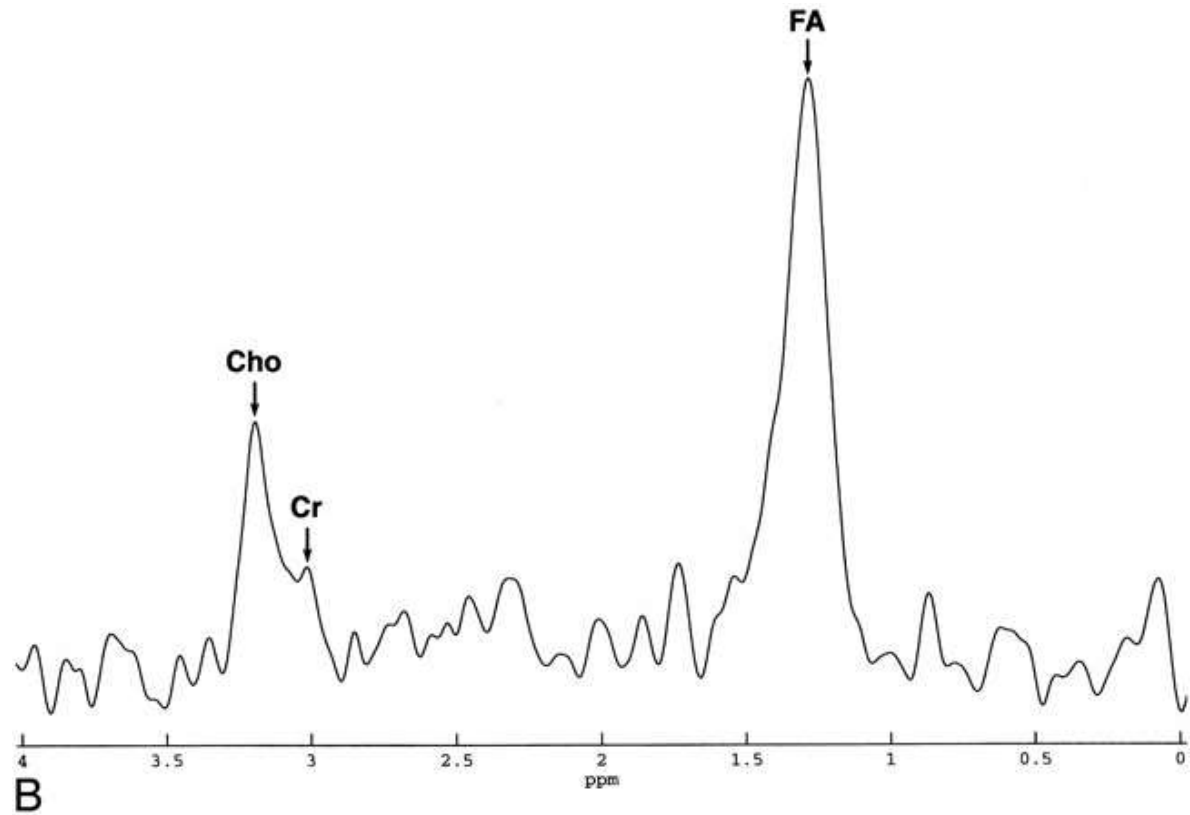
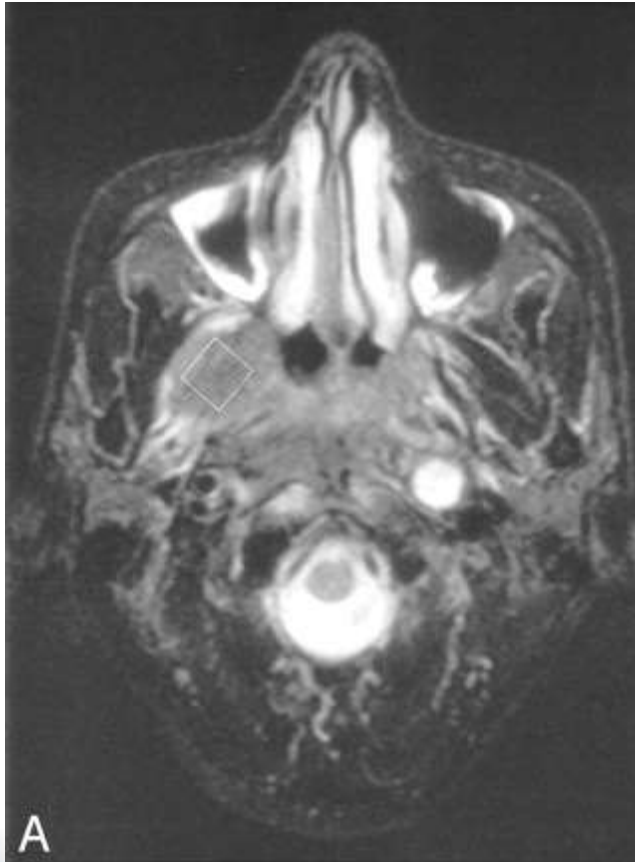


TE = 30 ms

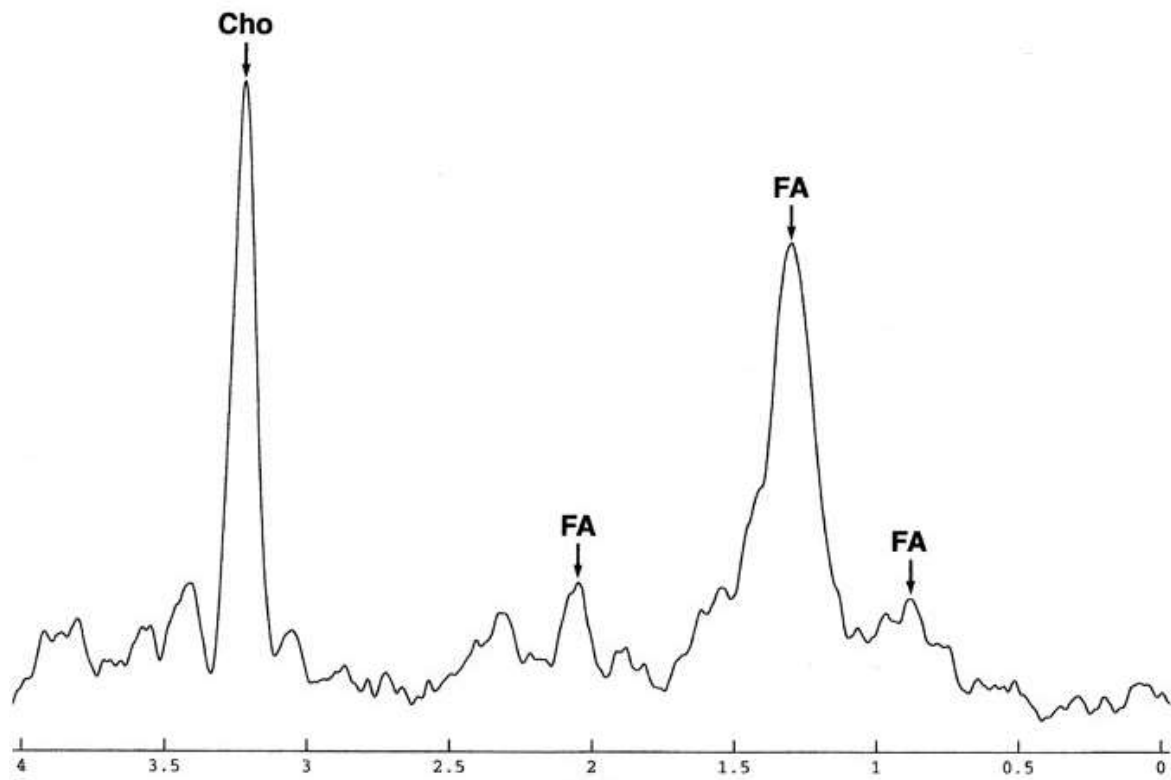
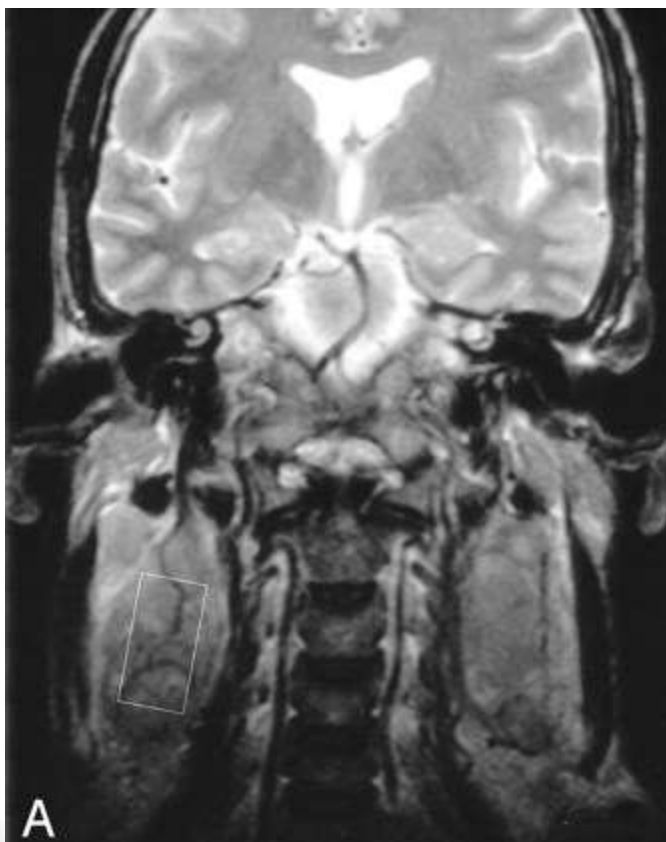


TE = 144 ms

Adénocarcinomes



Adénopathies

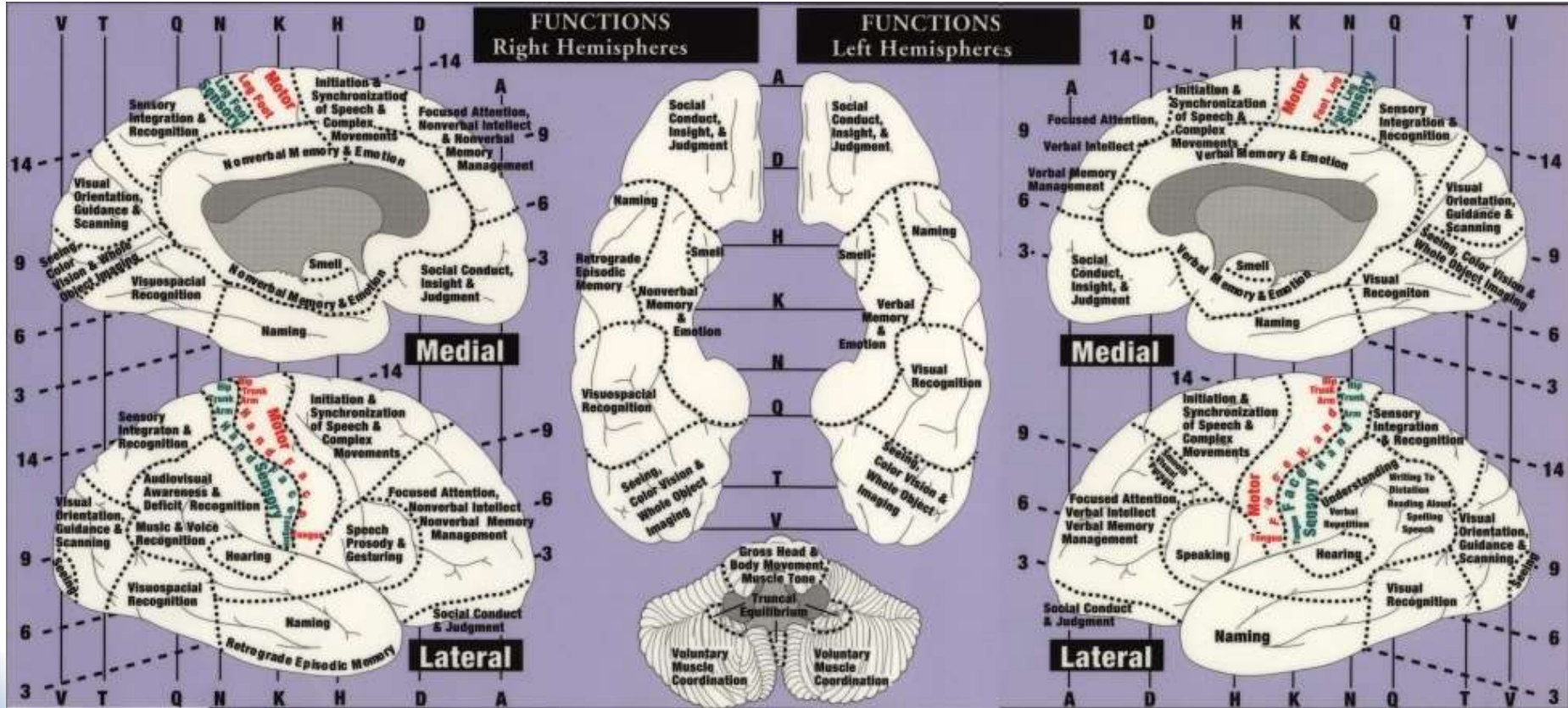


6. IRM d'Activation

6.1 Rappels Physiologiques

IRM d'Activation

Neuro-Anatomie Fonctionnelle



I. Couche Molec

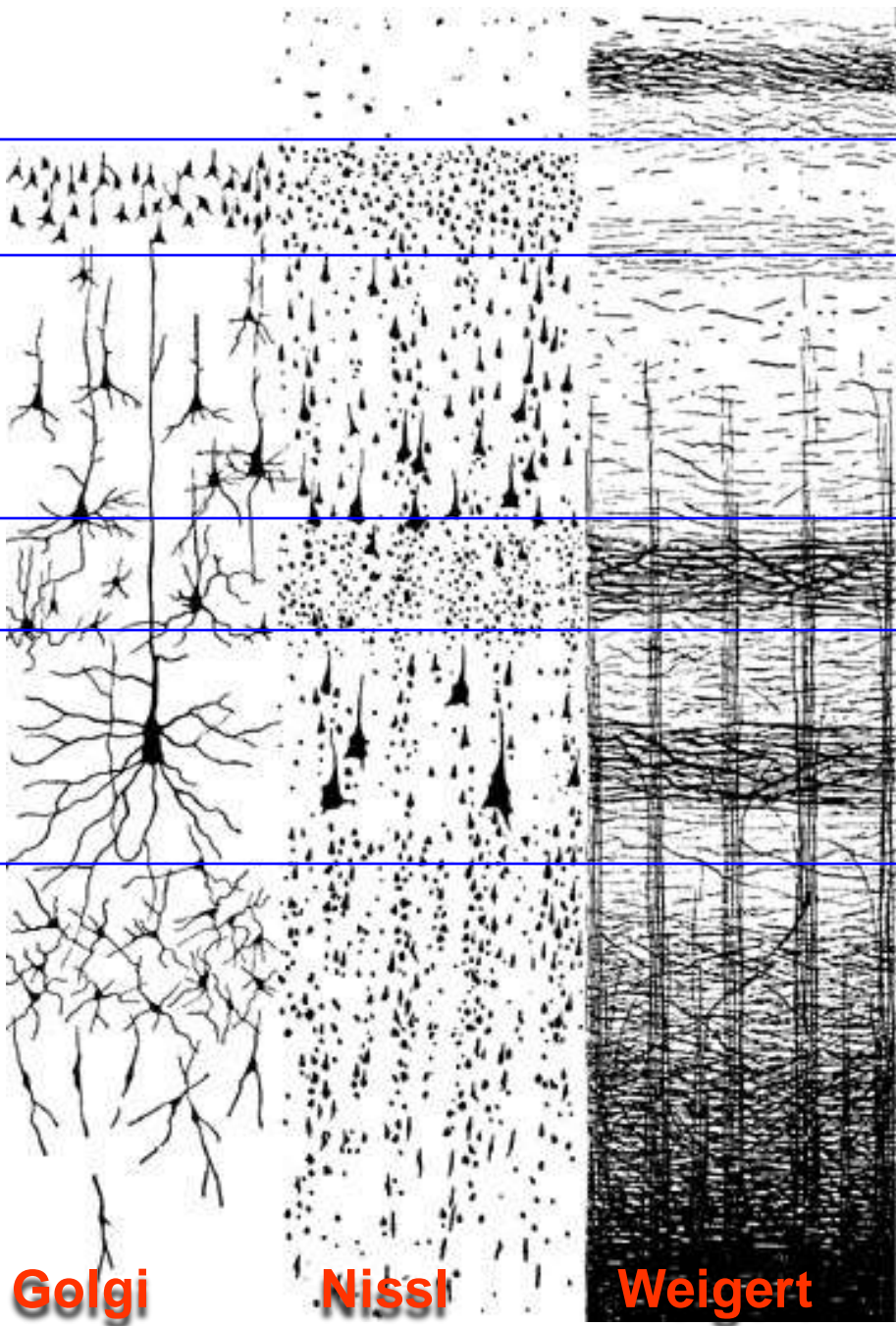
II. Granulaire ext

III. Pyramidale ext

IV. Granulaire int

V. Pyramidale int

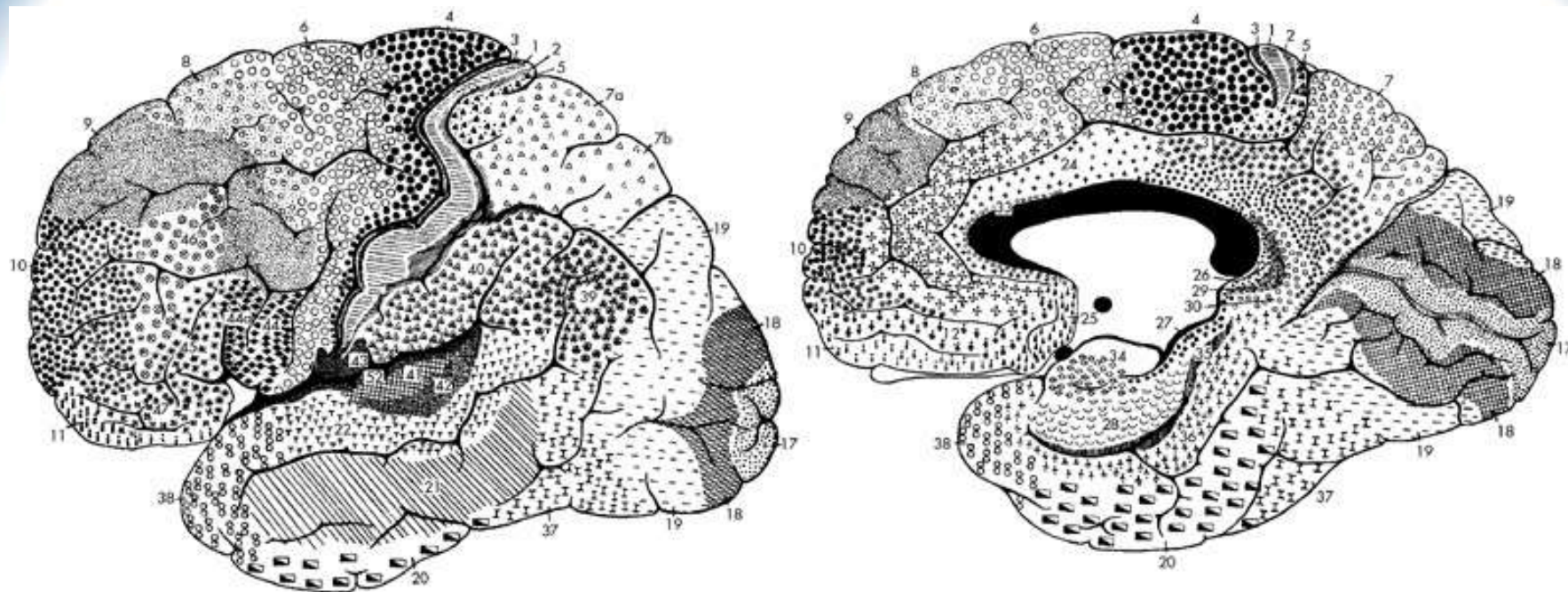
VI. Couche Mltform



Golgi

Nissl

Weigert



Aires de Brodmann :

Area 17 – Scissure Calcarine, Aire visuelle Primaire

Areas 18,19 – Aires Visuelles Associatives

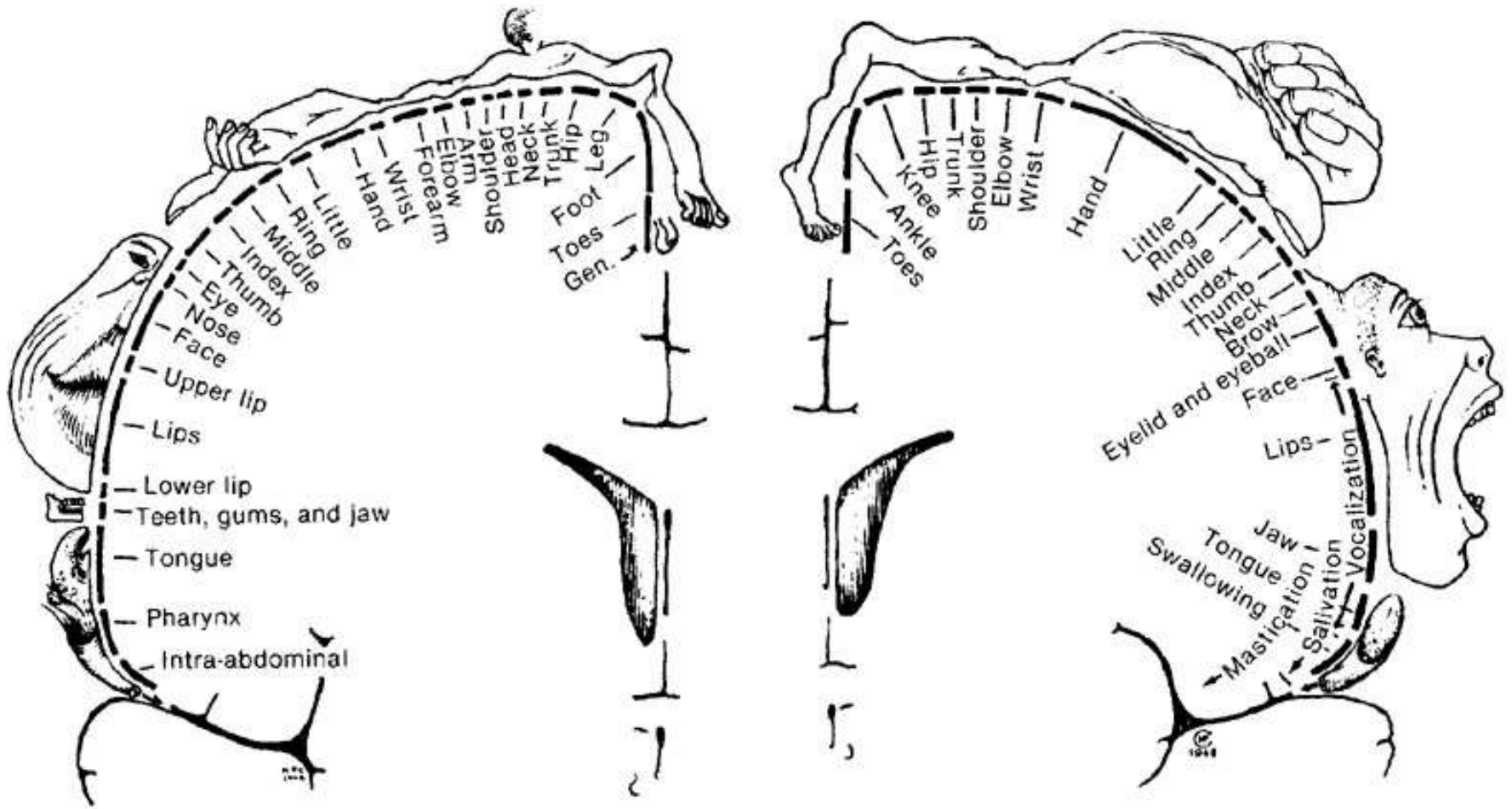
Areas 4,6 – Aires Motrices Primaires et Supplémentaires

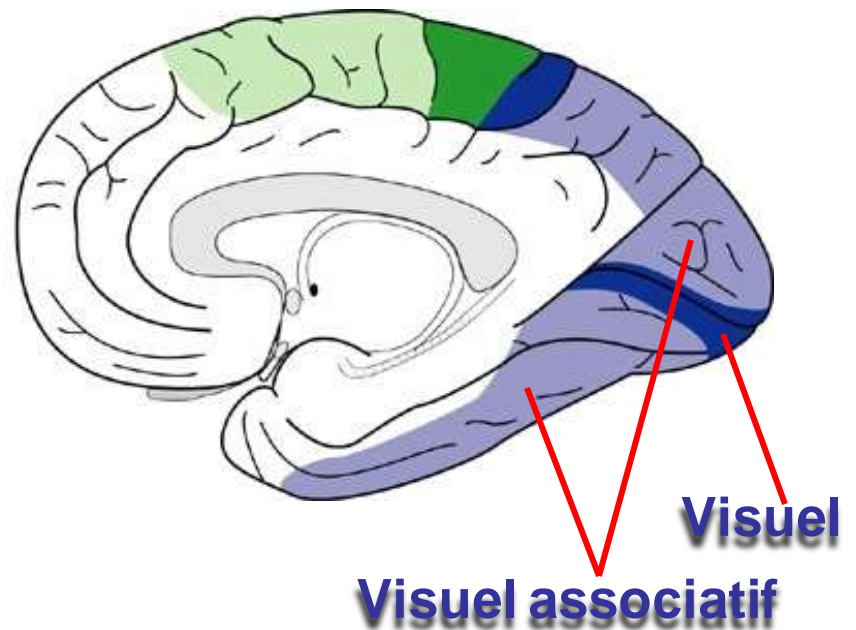
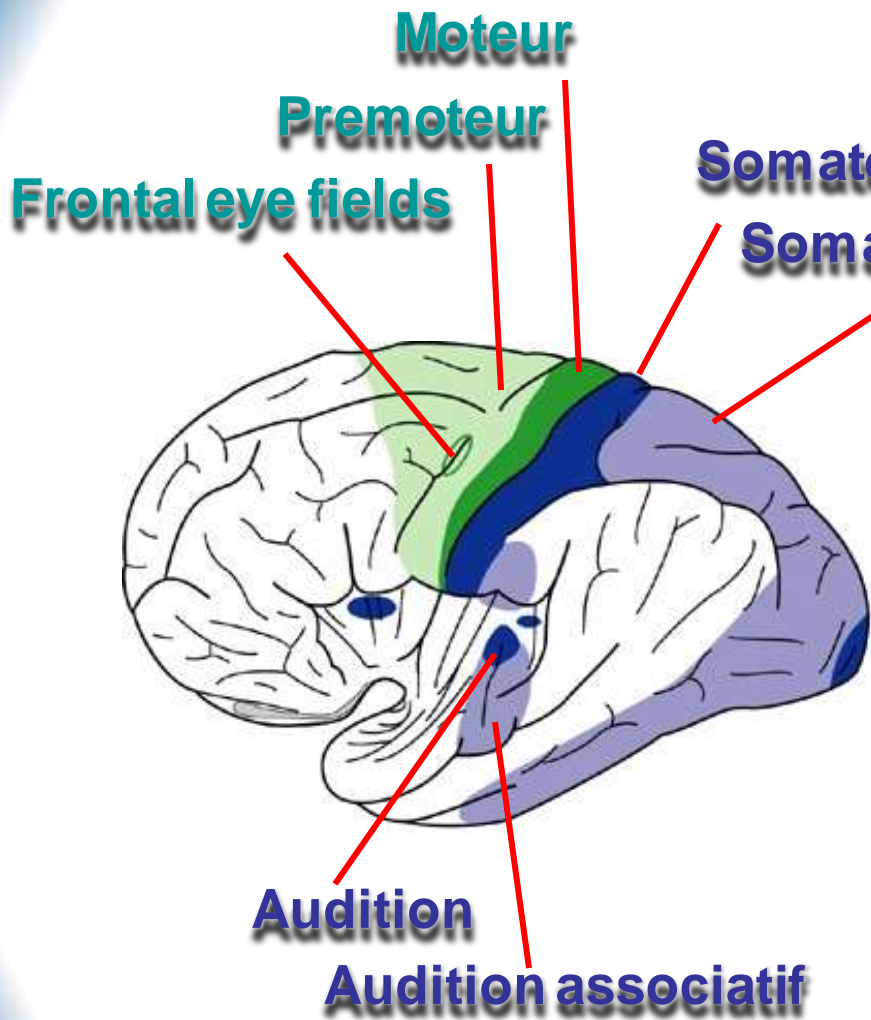
Areas 44,45 – Aires de Broca

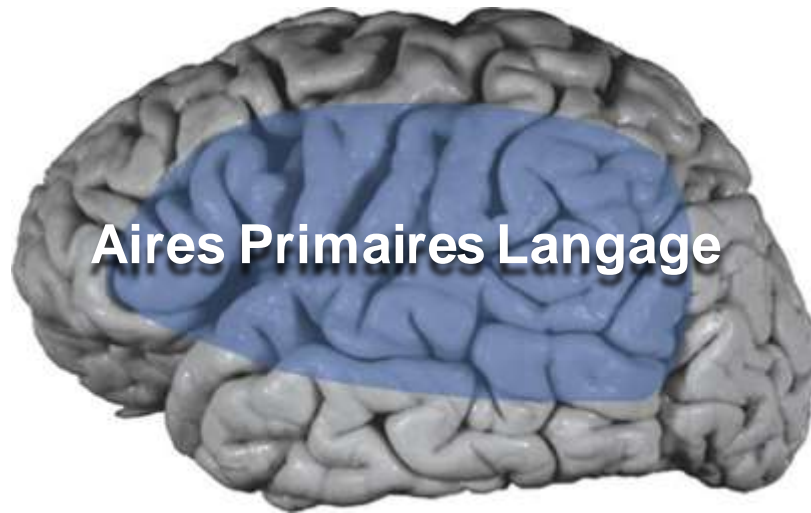
Areas 41,42,22 – Aires Auditives Primaires et Associatives

IRM d'Activation

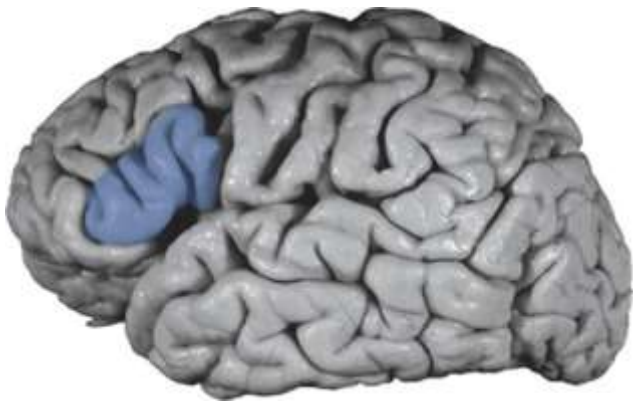
Neuro-Anatomie Fonctionnelle



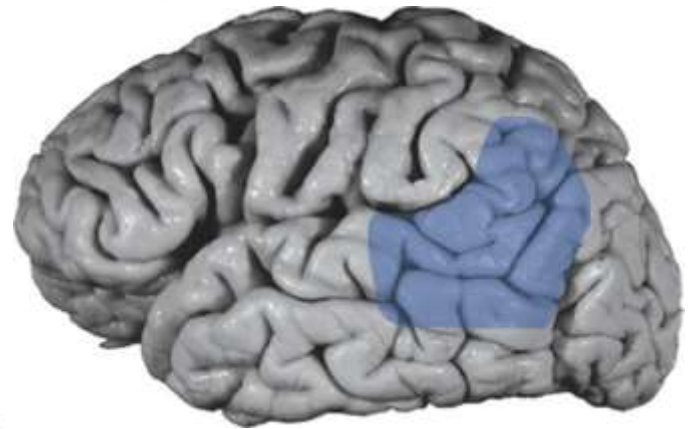




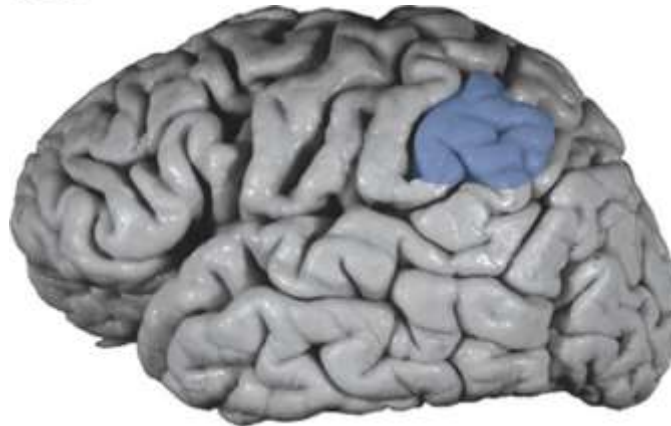
Aires Primaires Langage



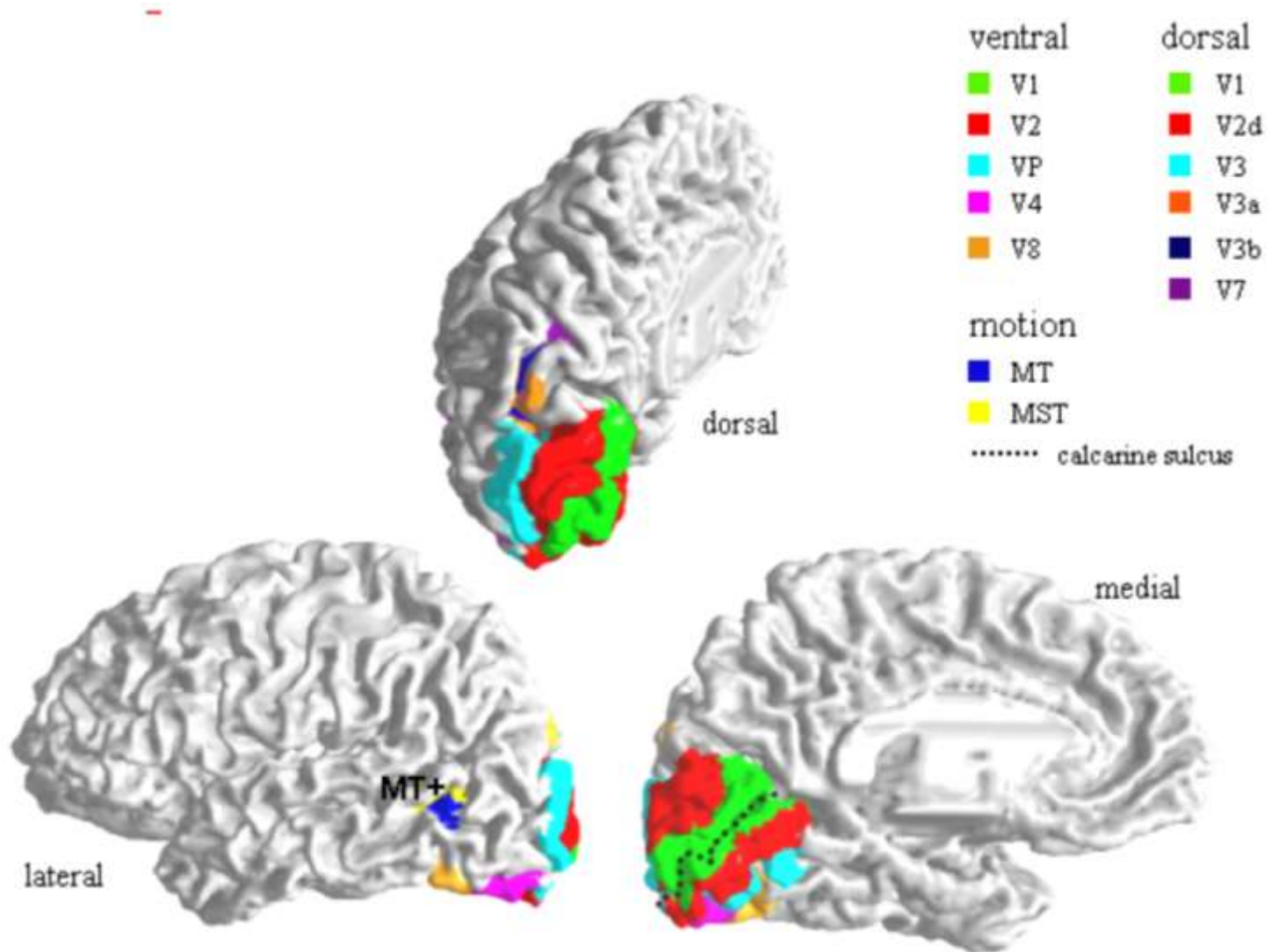
Broca



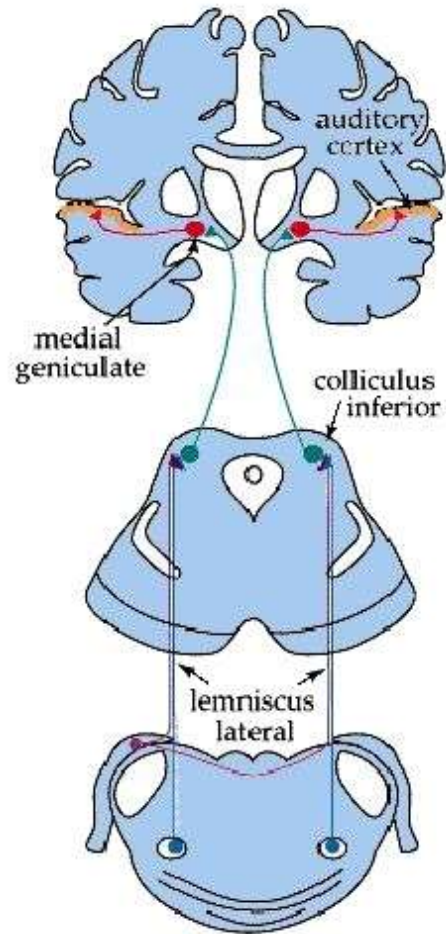
Wernicke



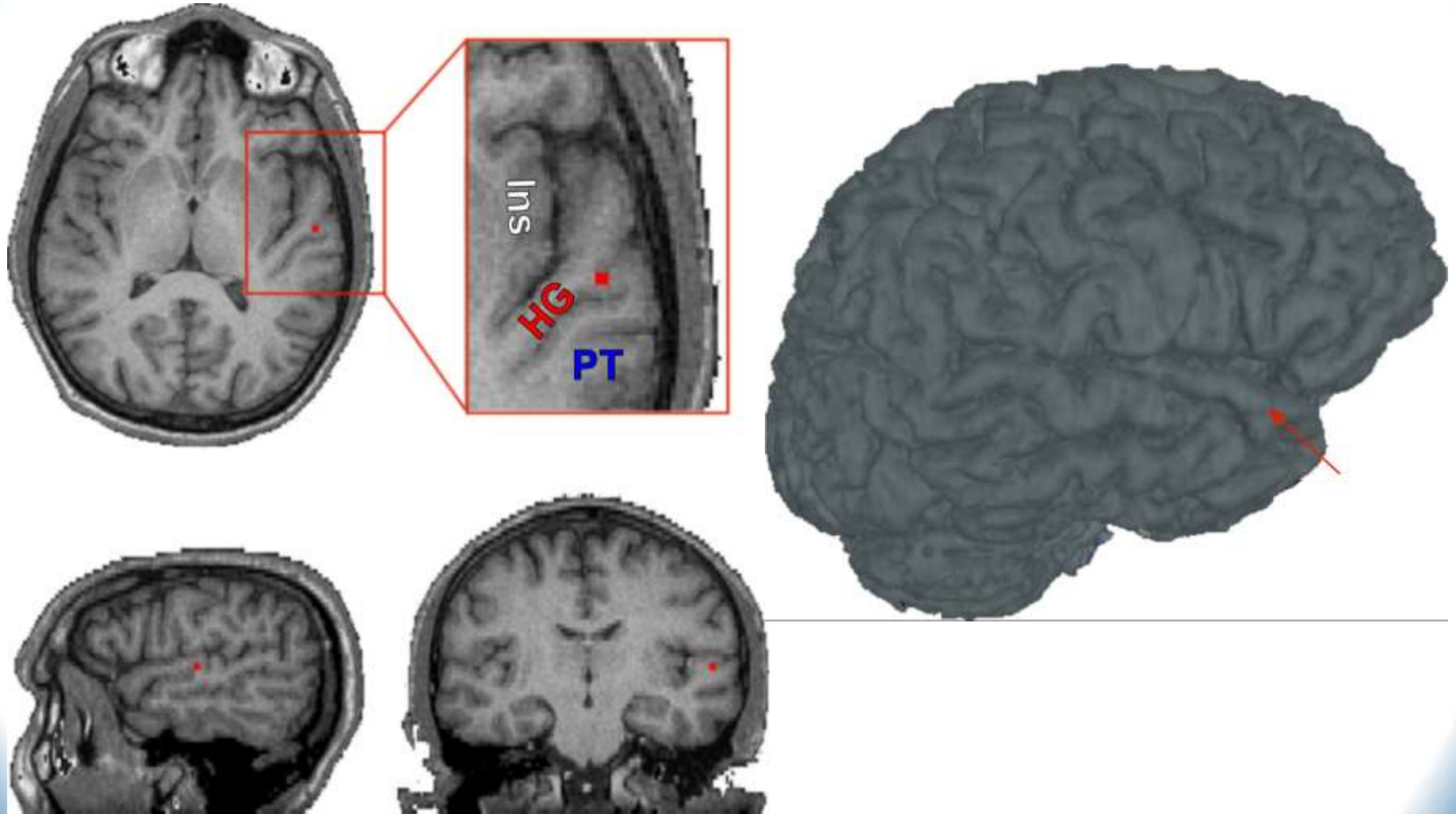
Cortex Visuel



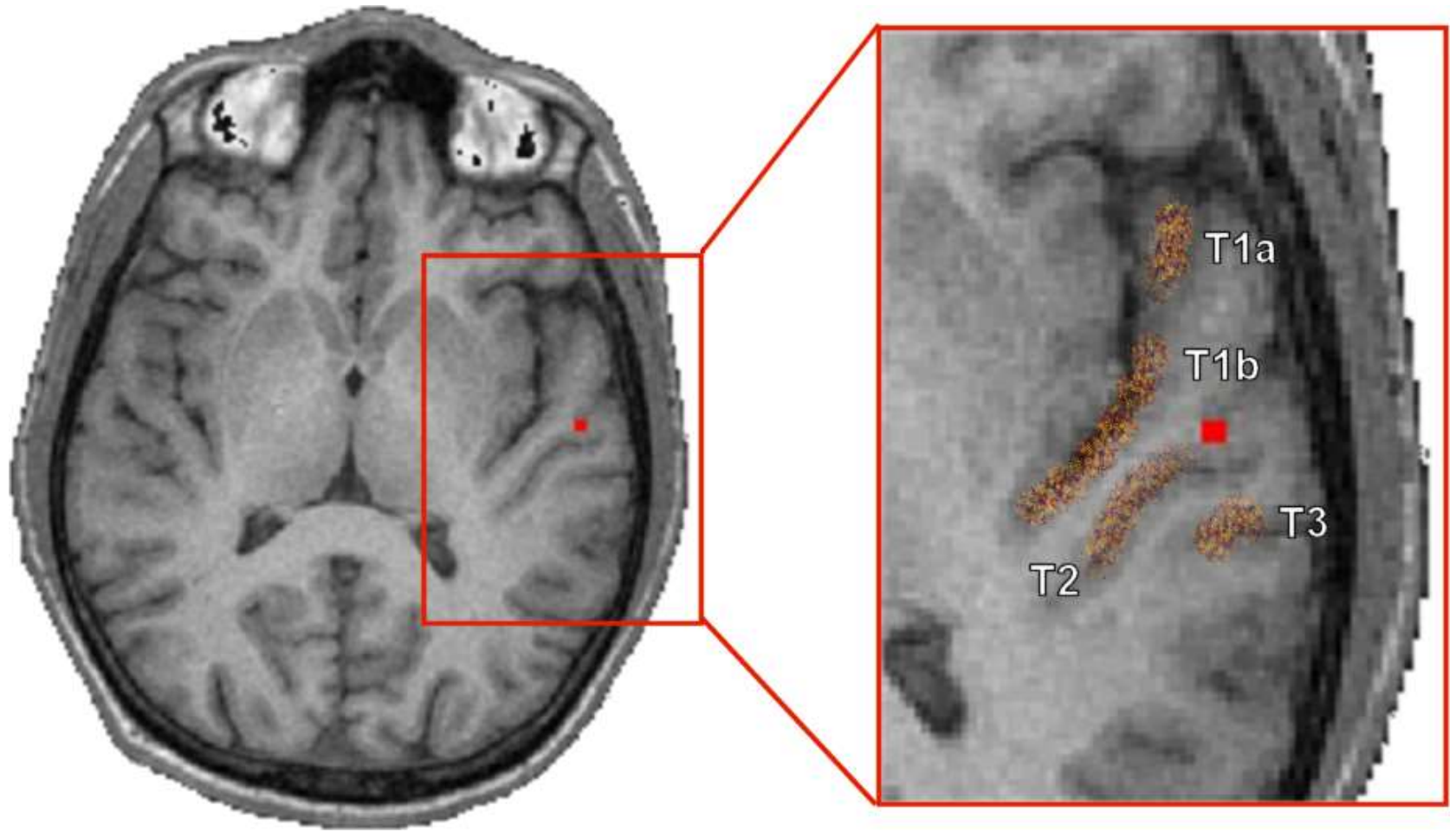
Voies Auditives



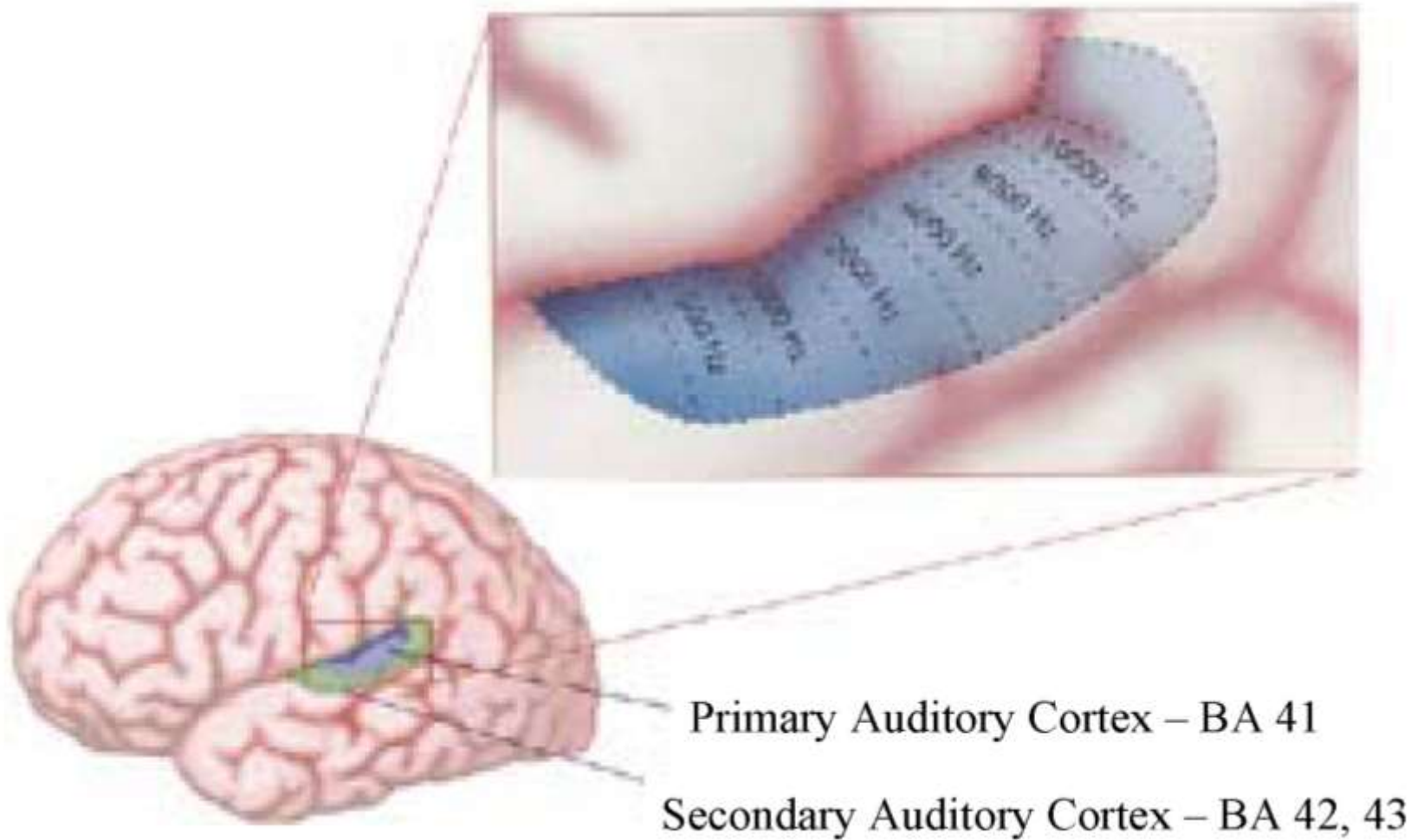
Voies Auditives



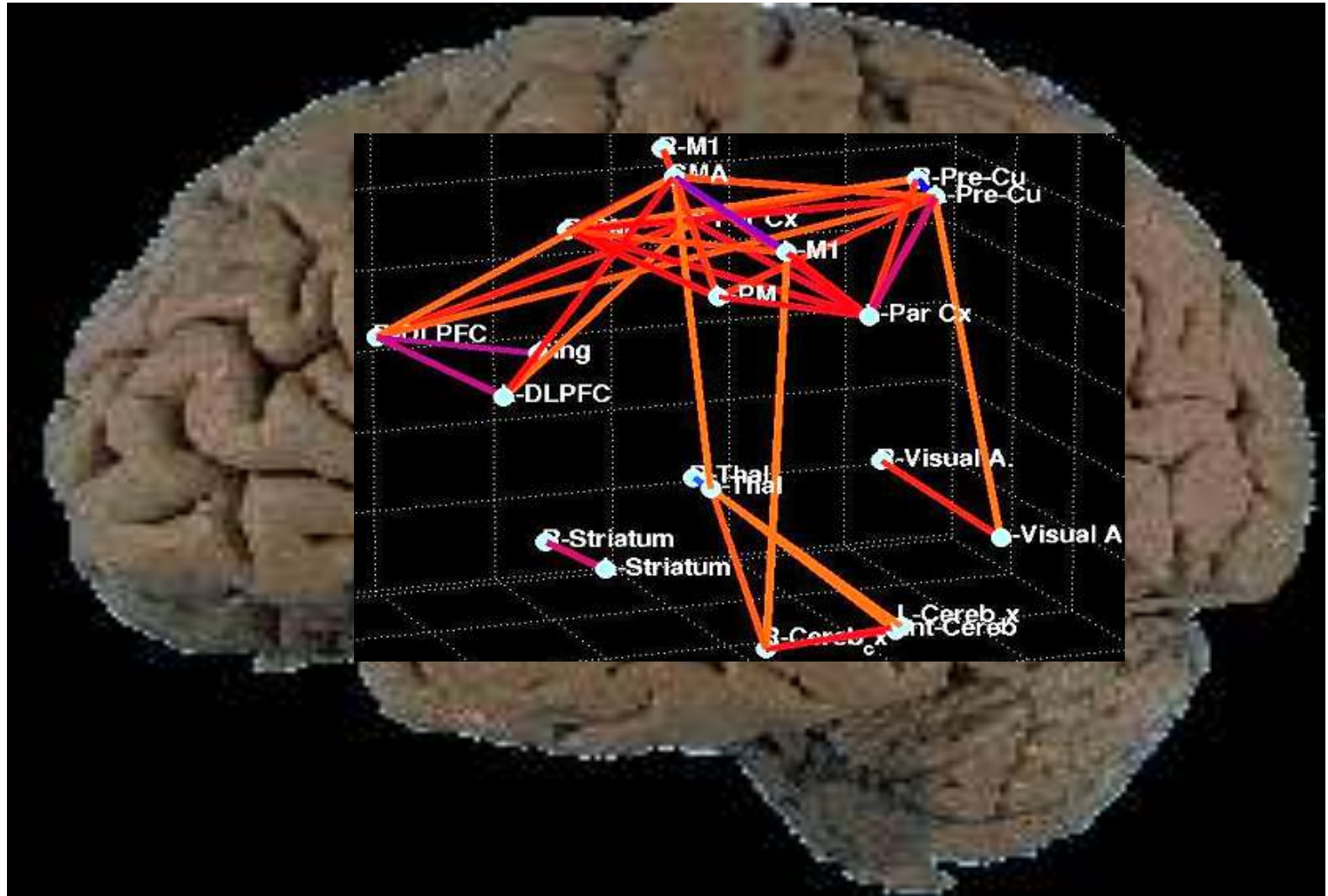
Voies Auditives

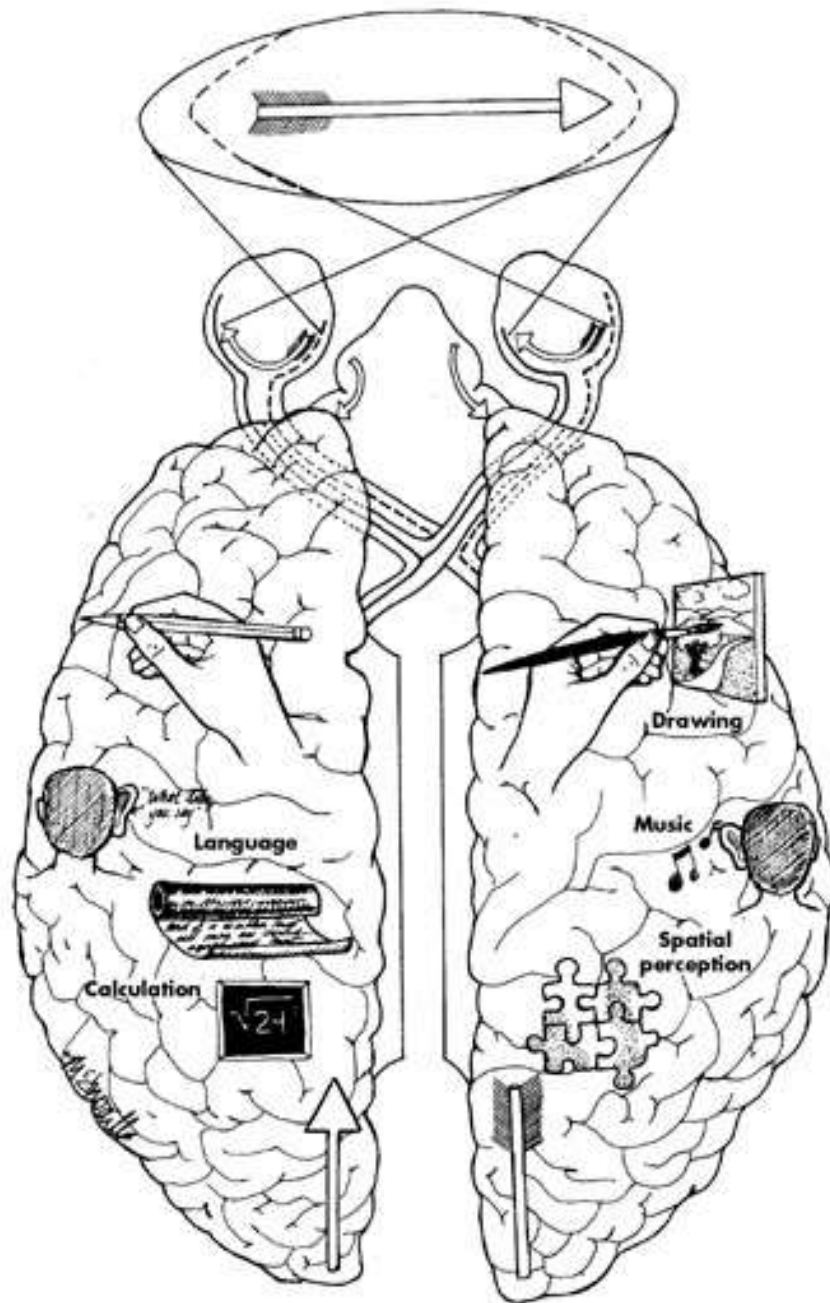


Voies Auditives



Réseaux Neuronaux

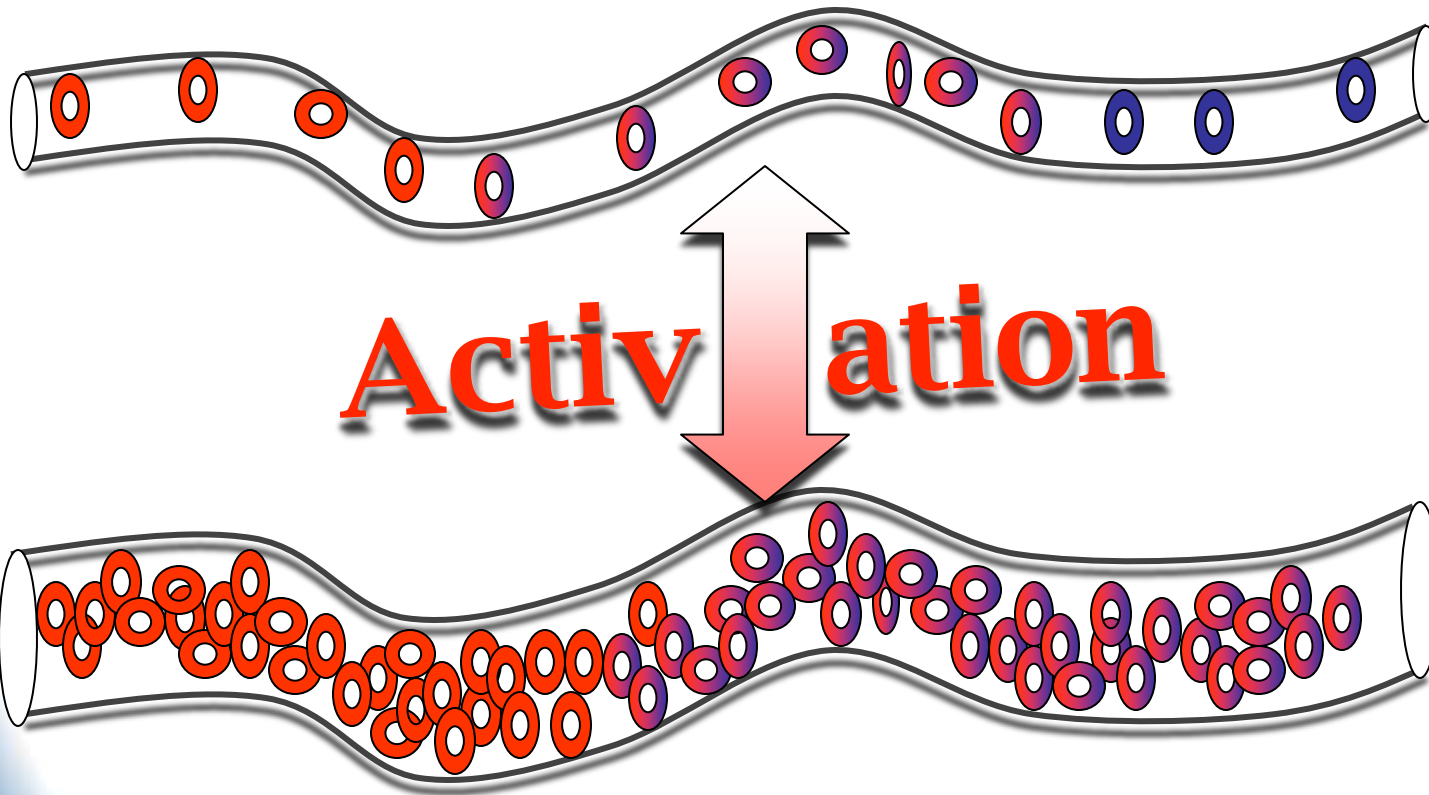




6.2 Rappels Méthodologiques

IRM d'Activation

Couplage Activation - Perfusion



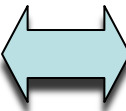
DSC



O² In



O² Ext



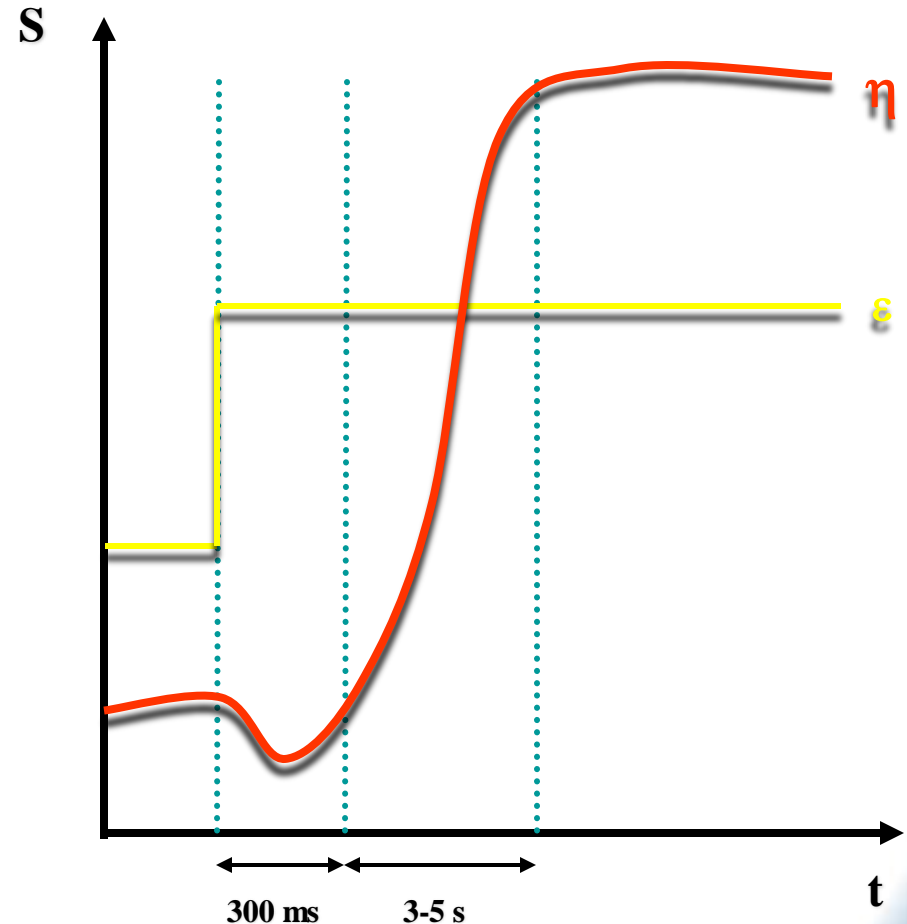
O² Out



IRM d'Activation

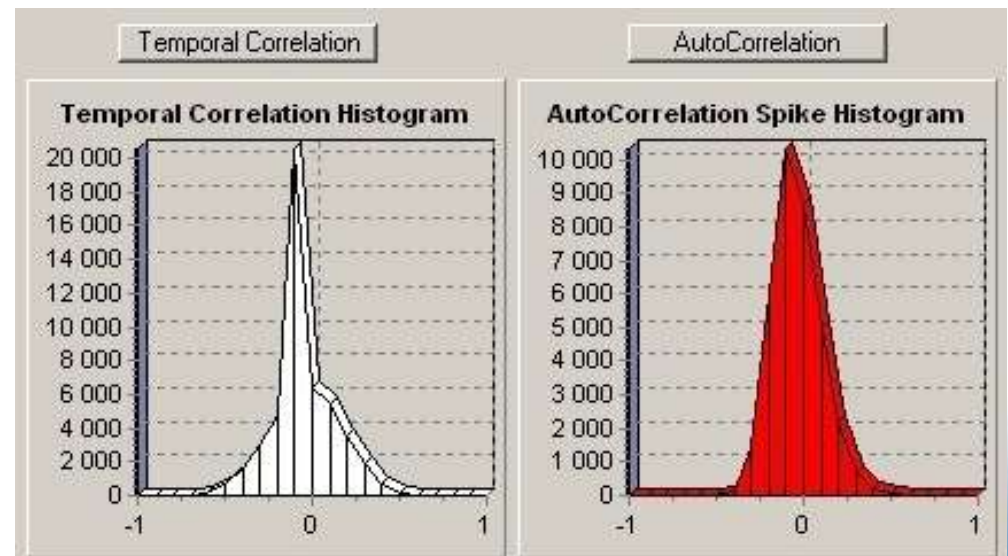
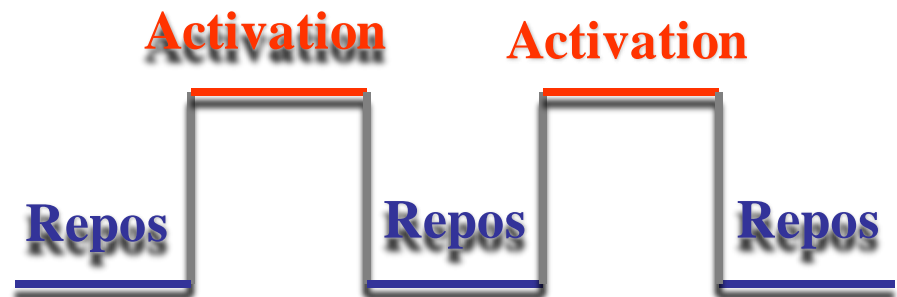
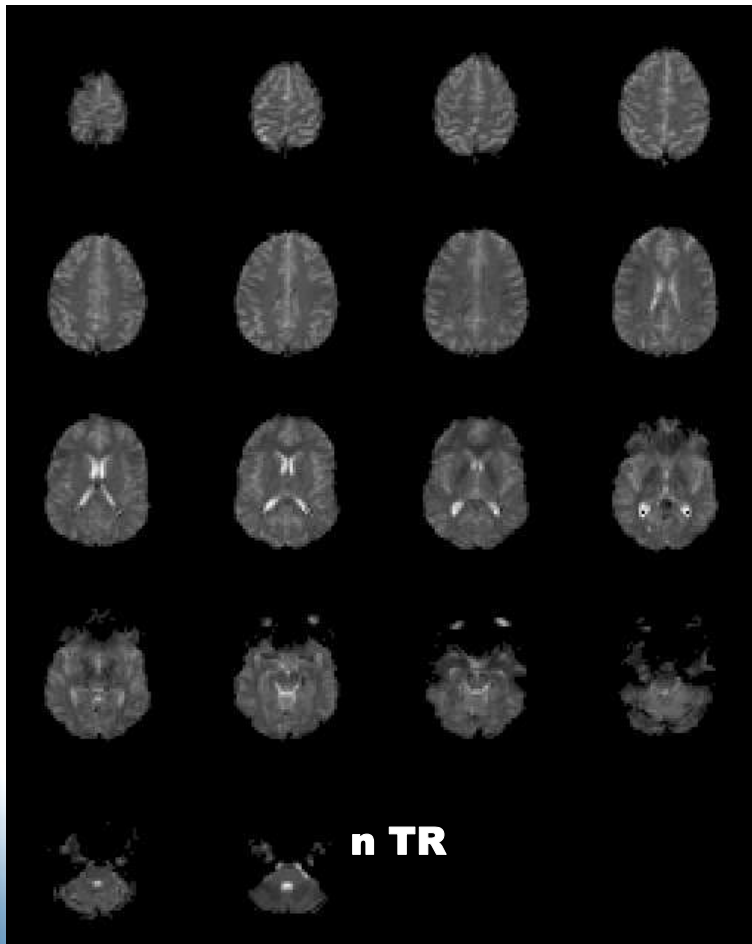
Couplage Activation - Perfusion

Blood
Oxygenation
Level
Dependent



IRM d'Activation

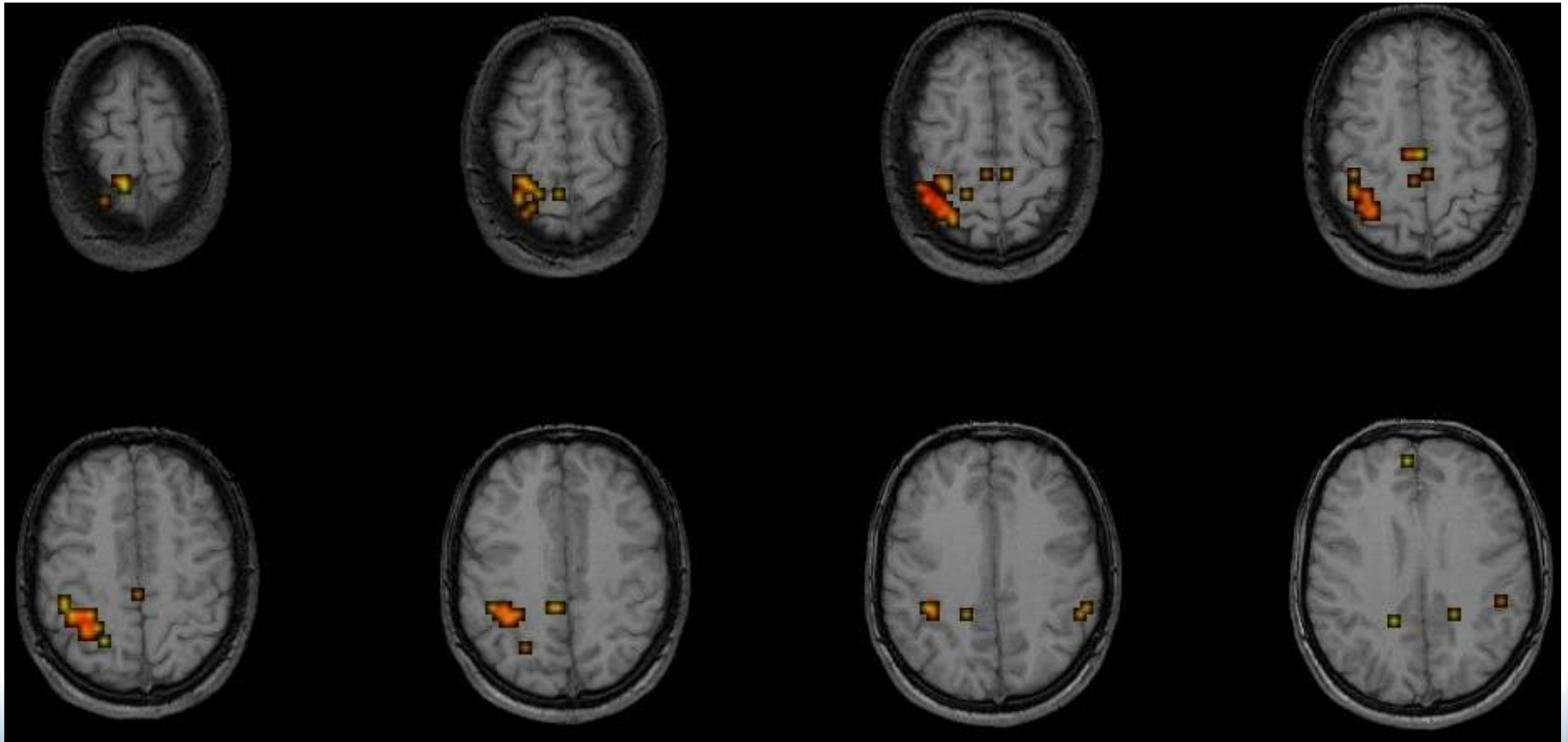
Traitement des Images



6.3 Applications Cliniques

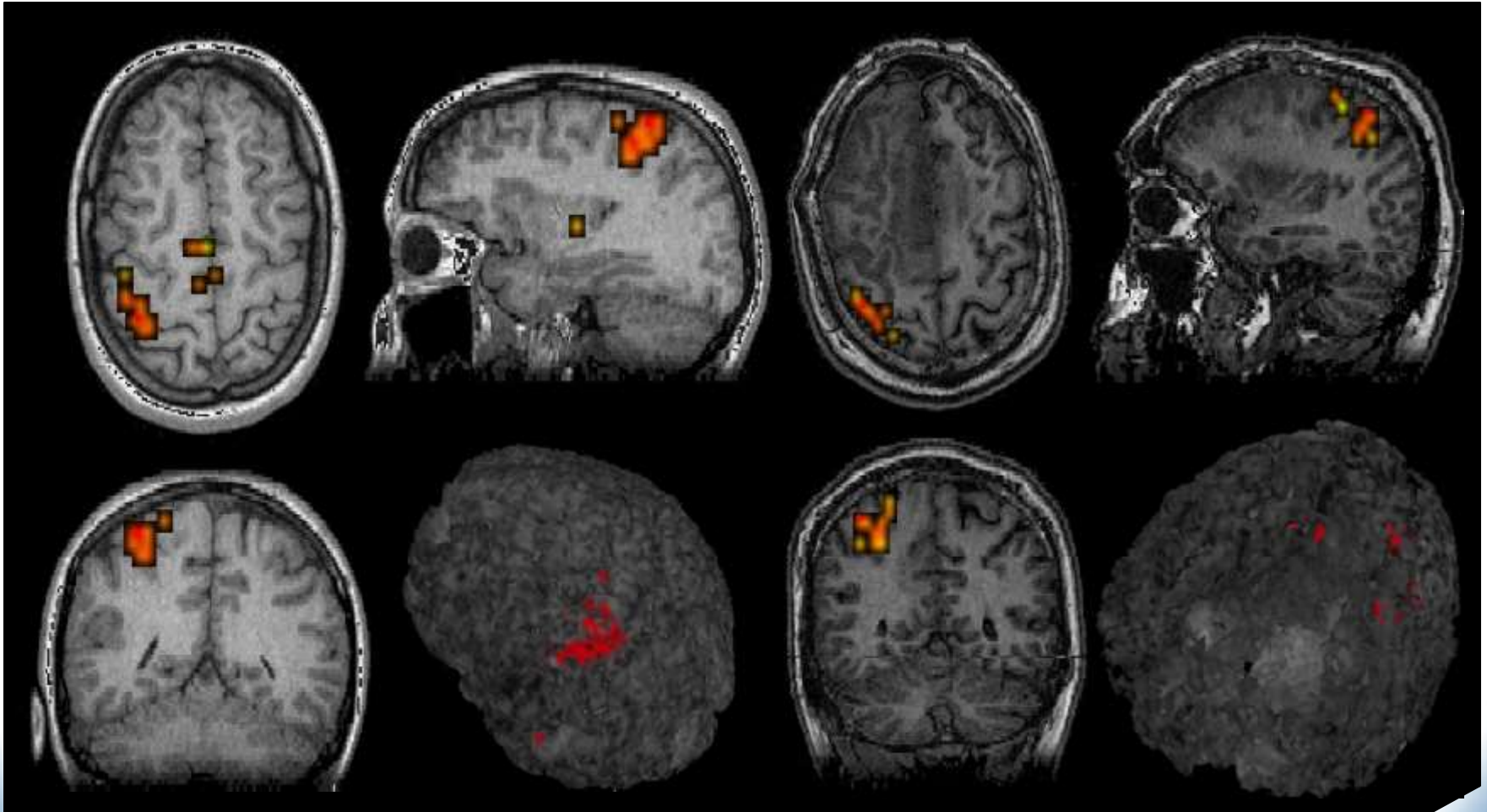
IRM d'Activation

Motricité



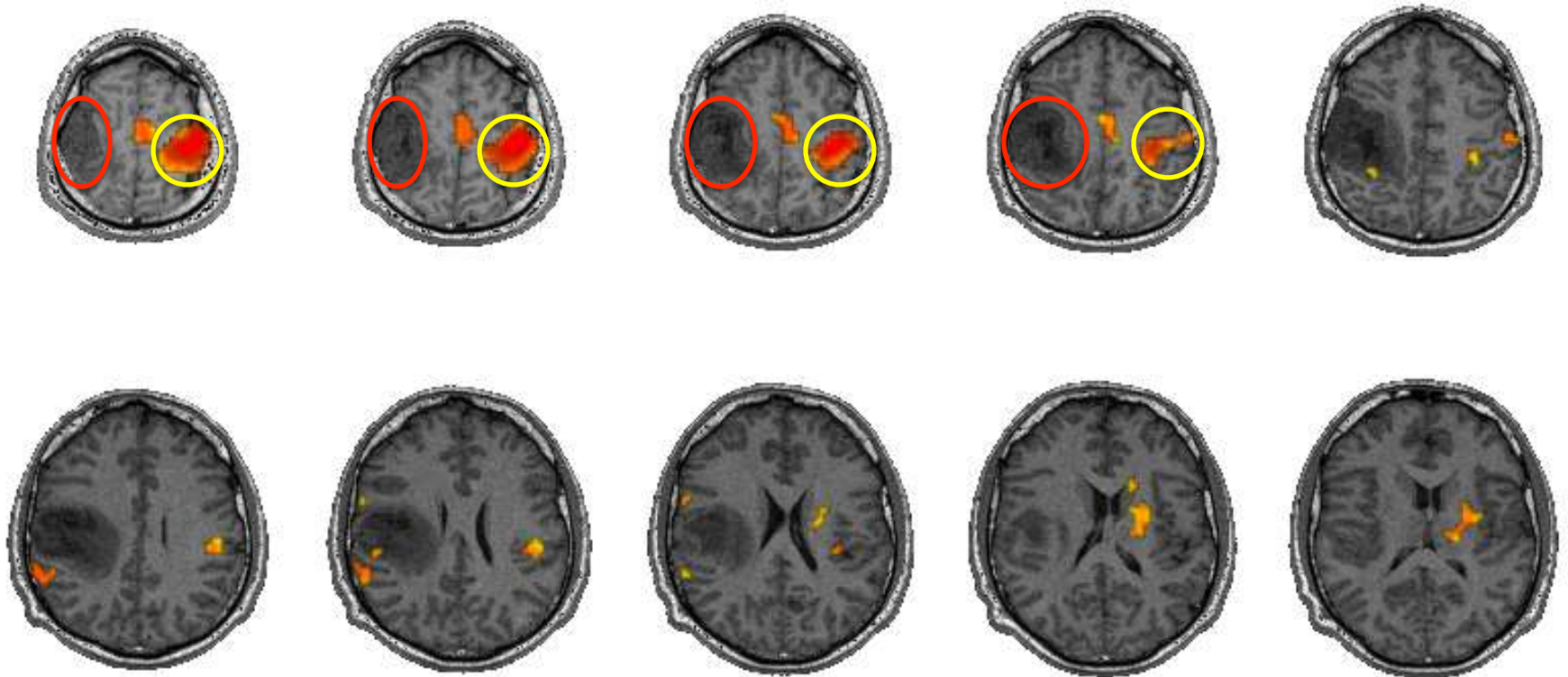
IRM d'Activation

Motricité - Bilan Tumoral



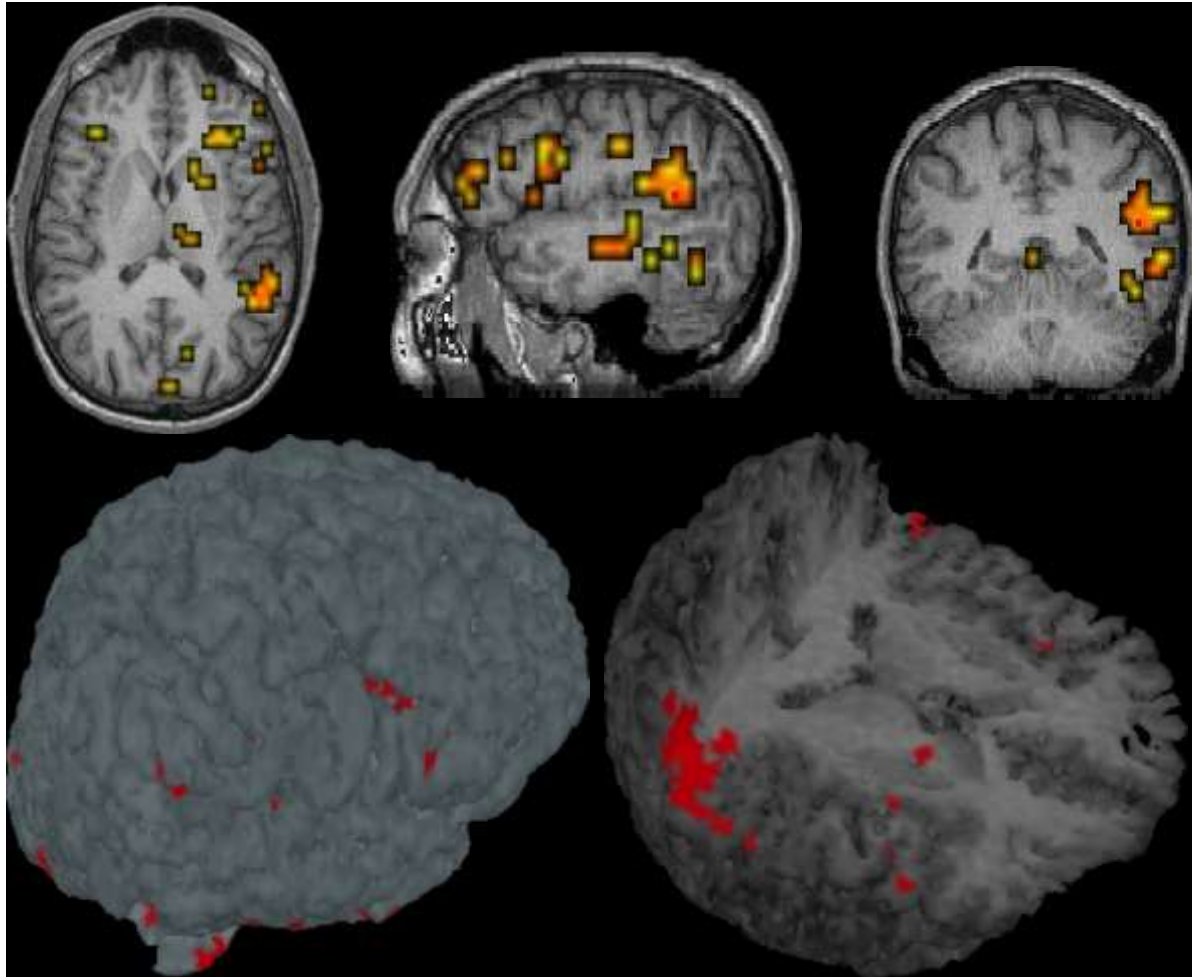
IRM d'Activation

Motricité - Bilan Tumoral



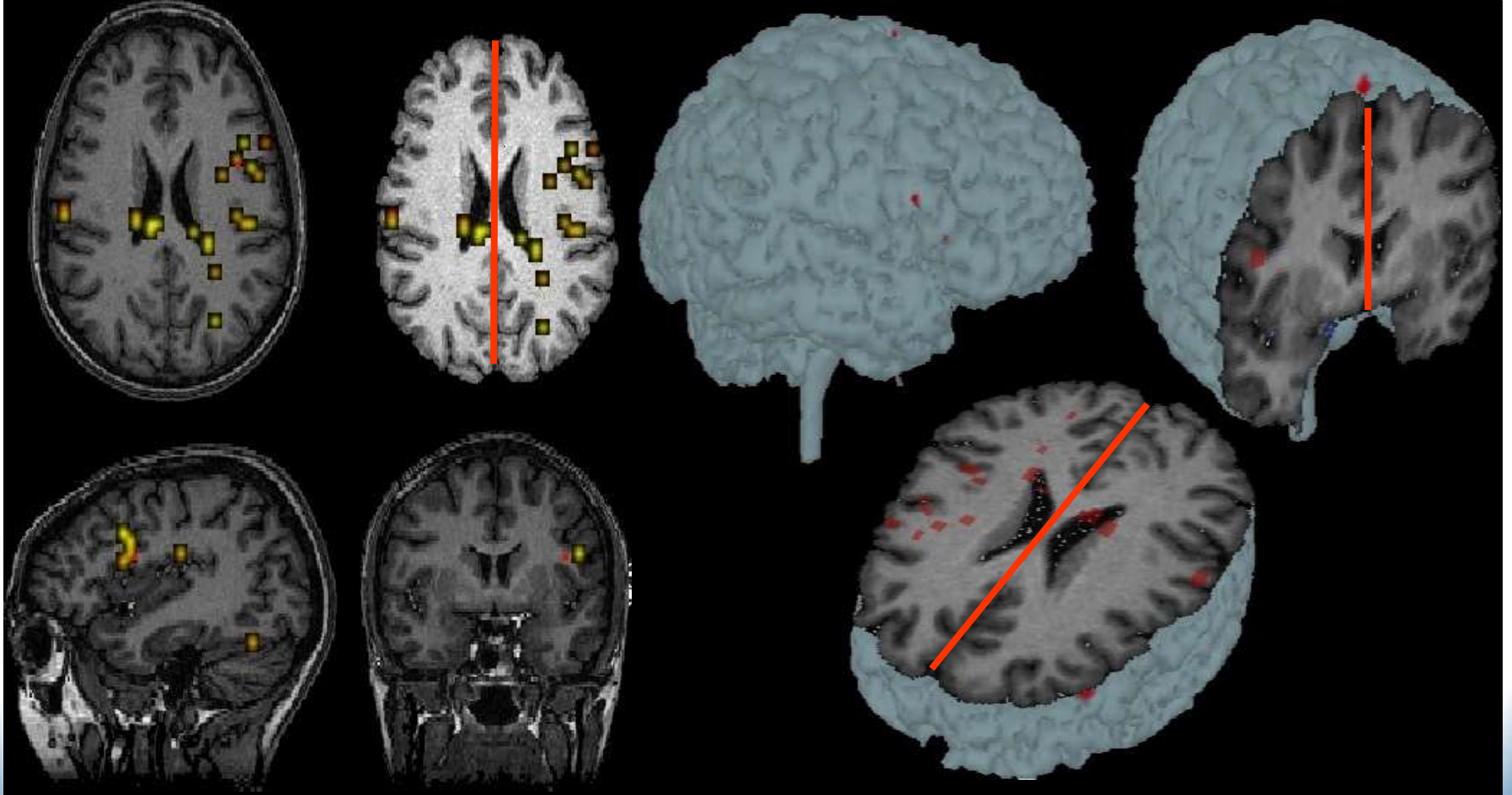
IRM d'Activation

Langage - Fluence Verbale



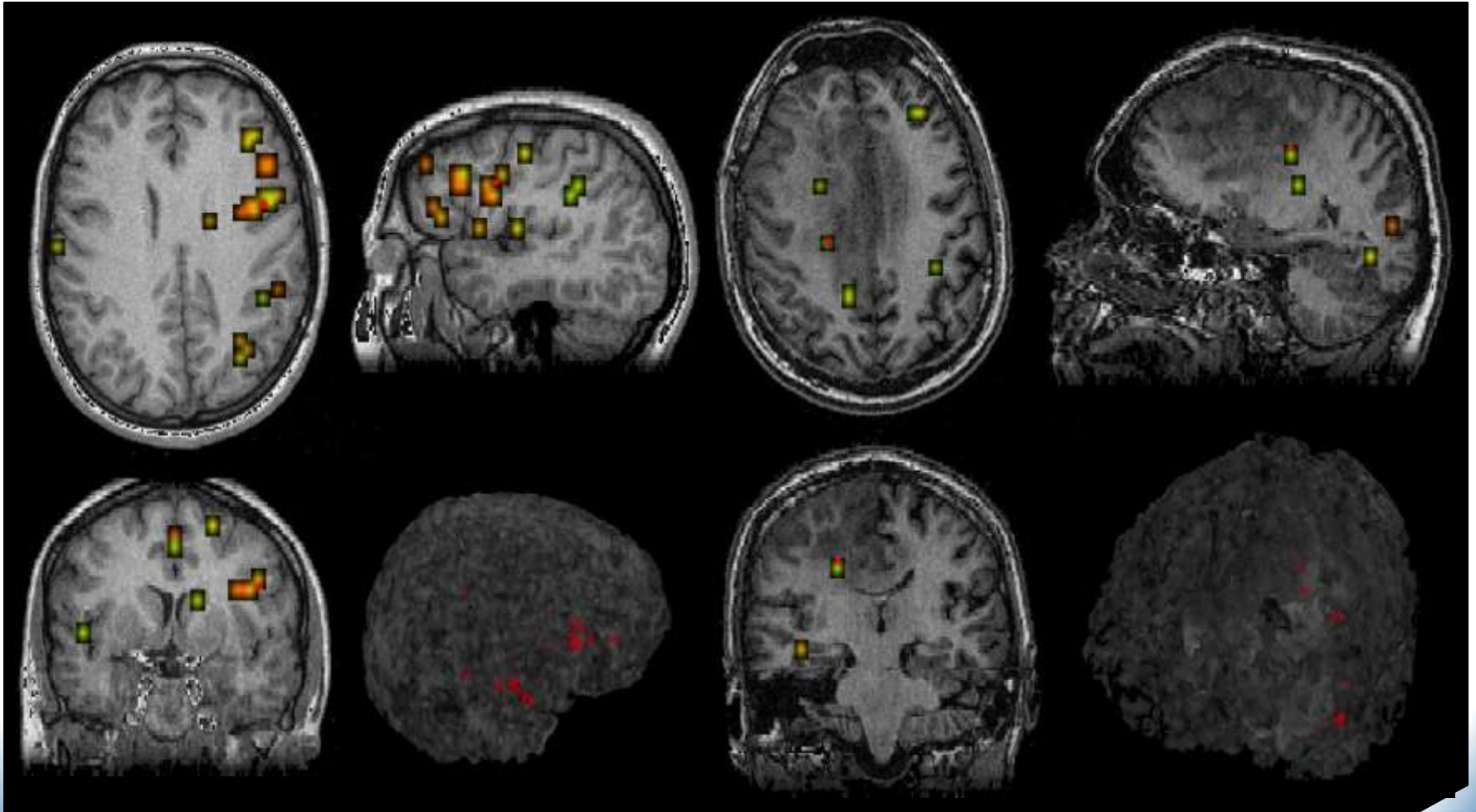
IRM d'Activation

Langage - Latéralisation



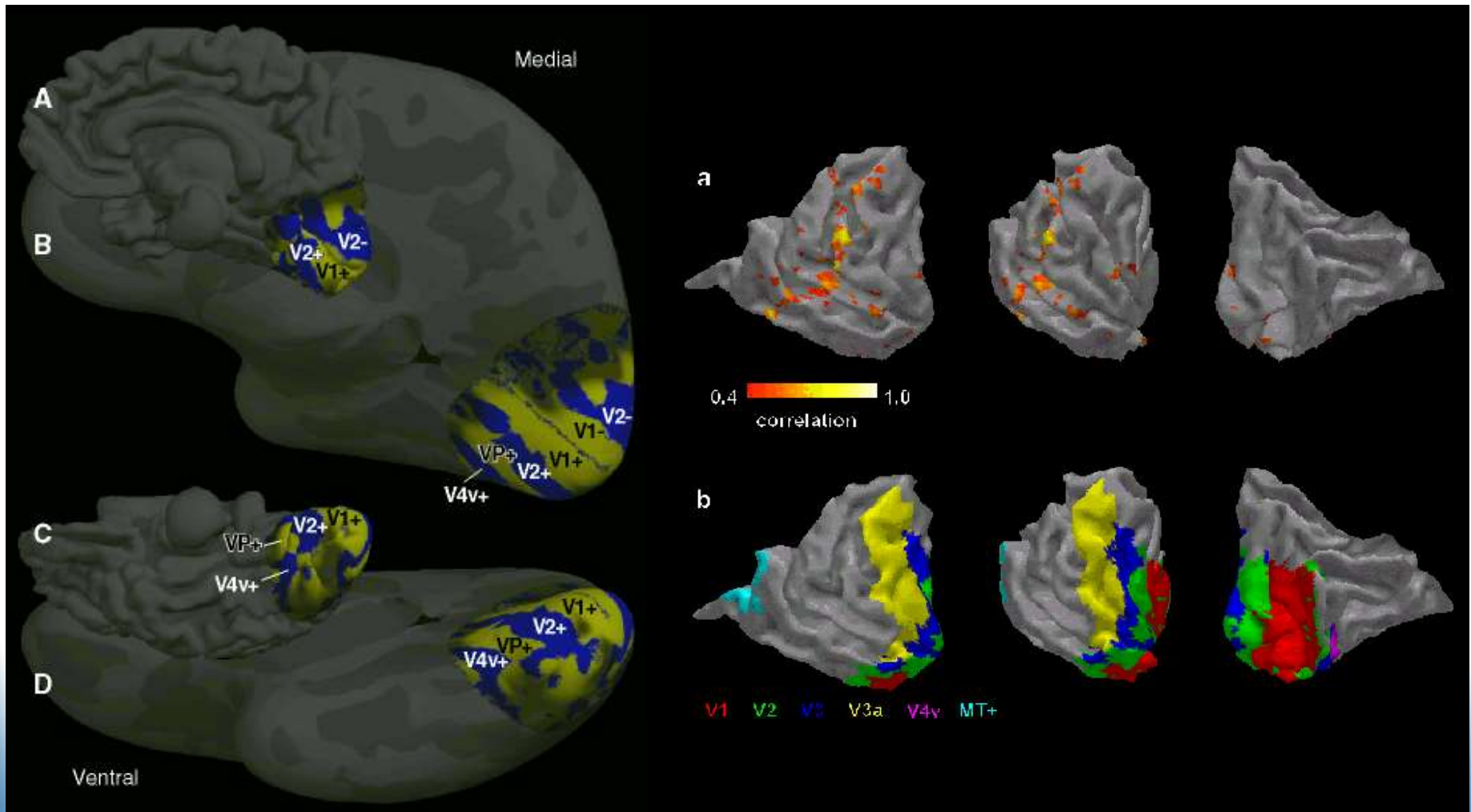
IRM d'Activation

Langage - Bilan Tumoral



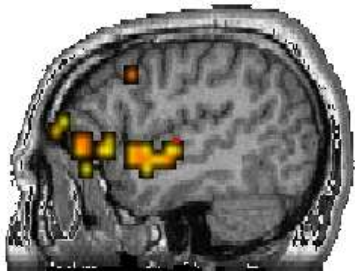
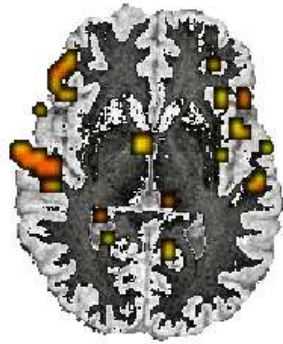
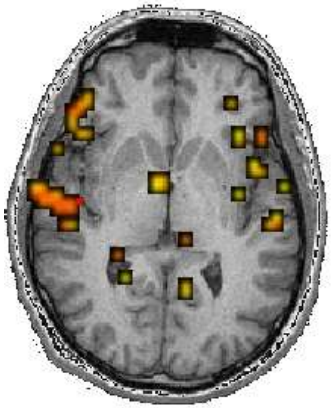
IRM d'Activation

Fonctions Visuelles

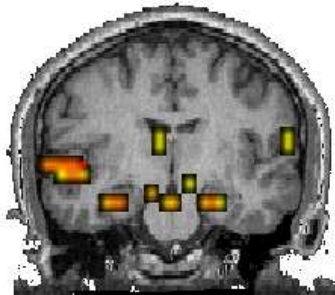


IRM d'Activation

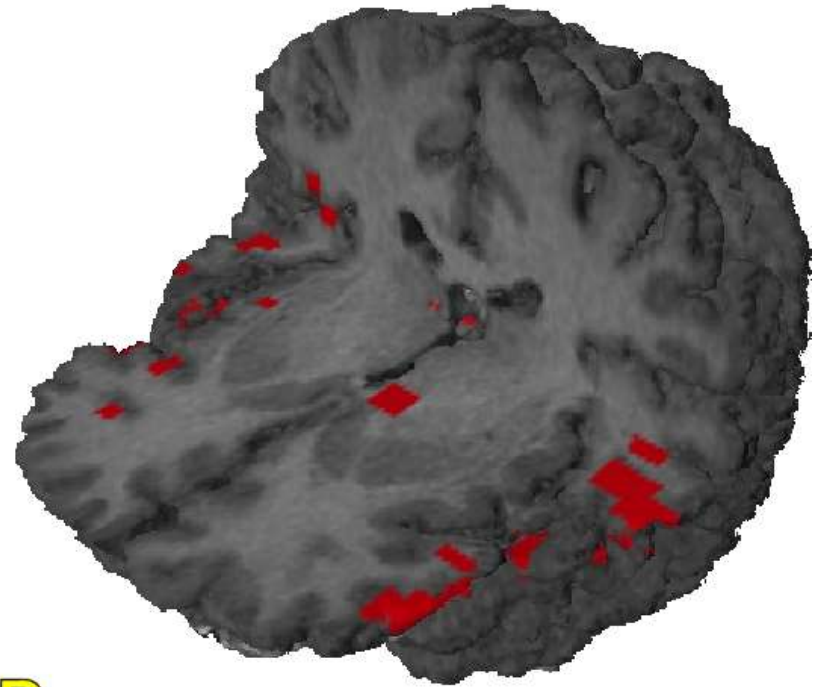
Fonctions Auditives



C

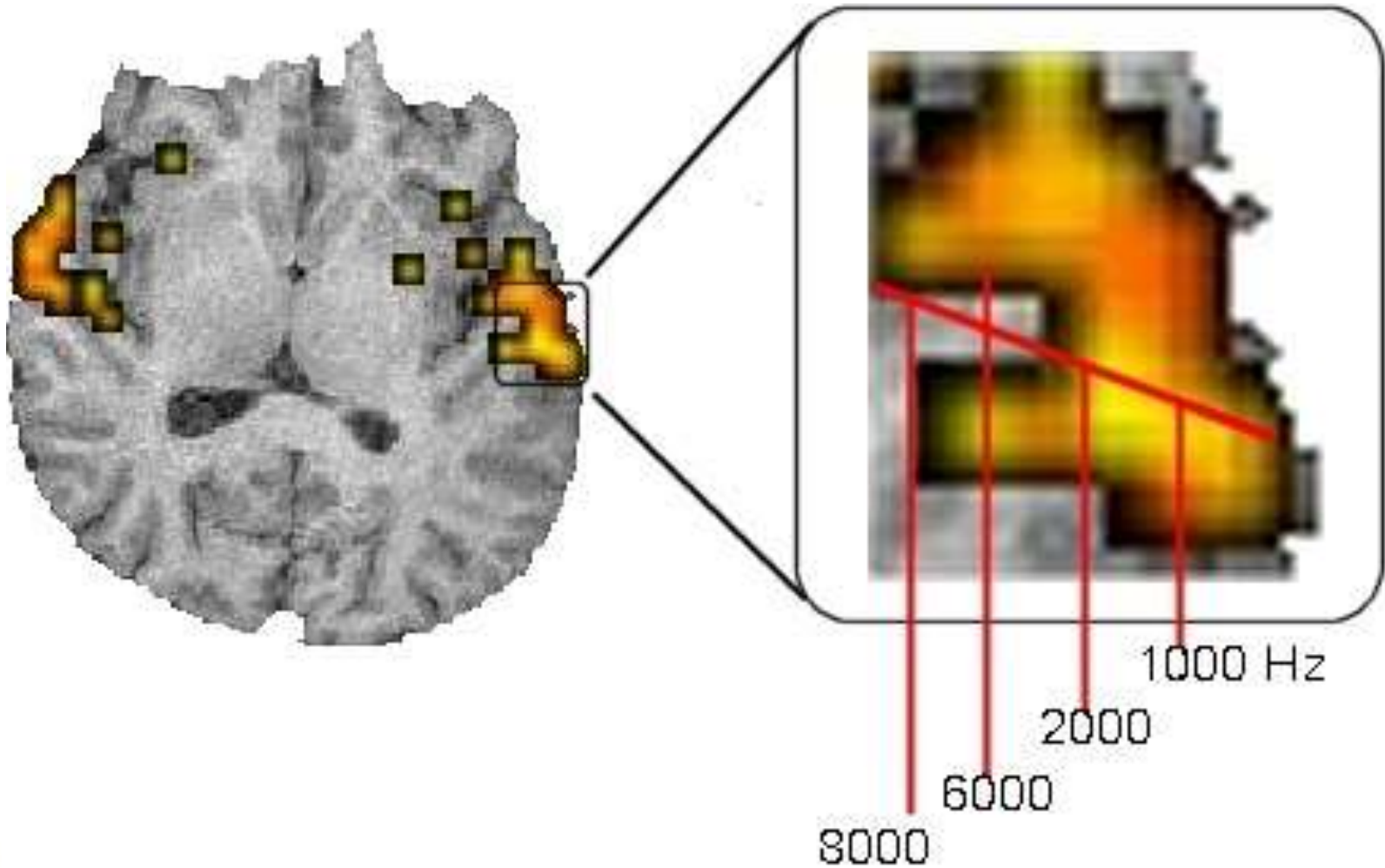


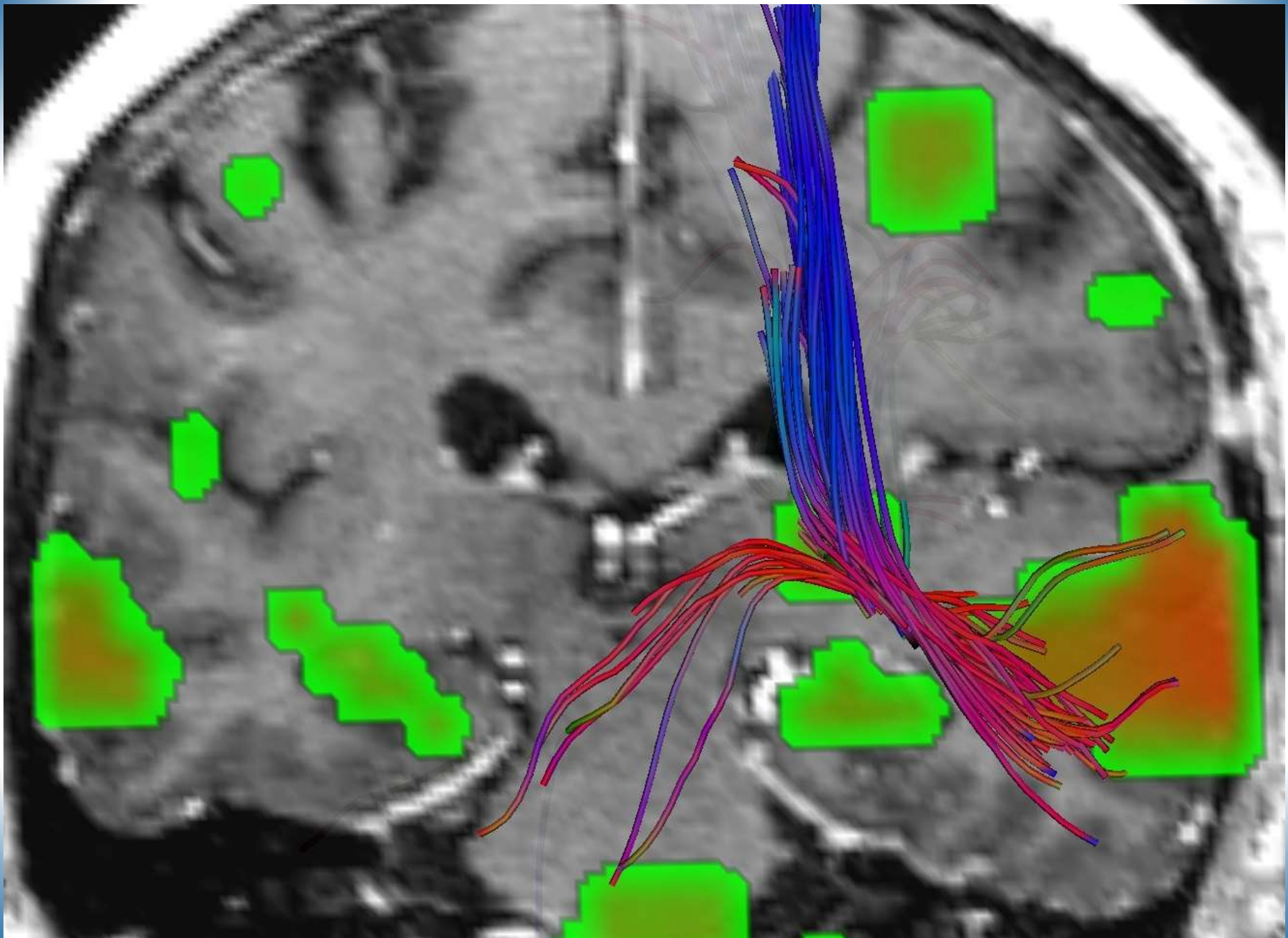
D

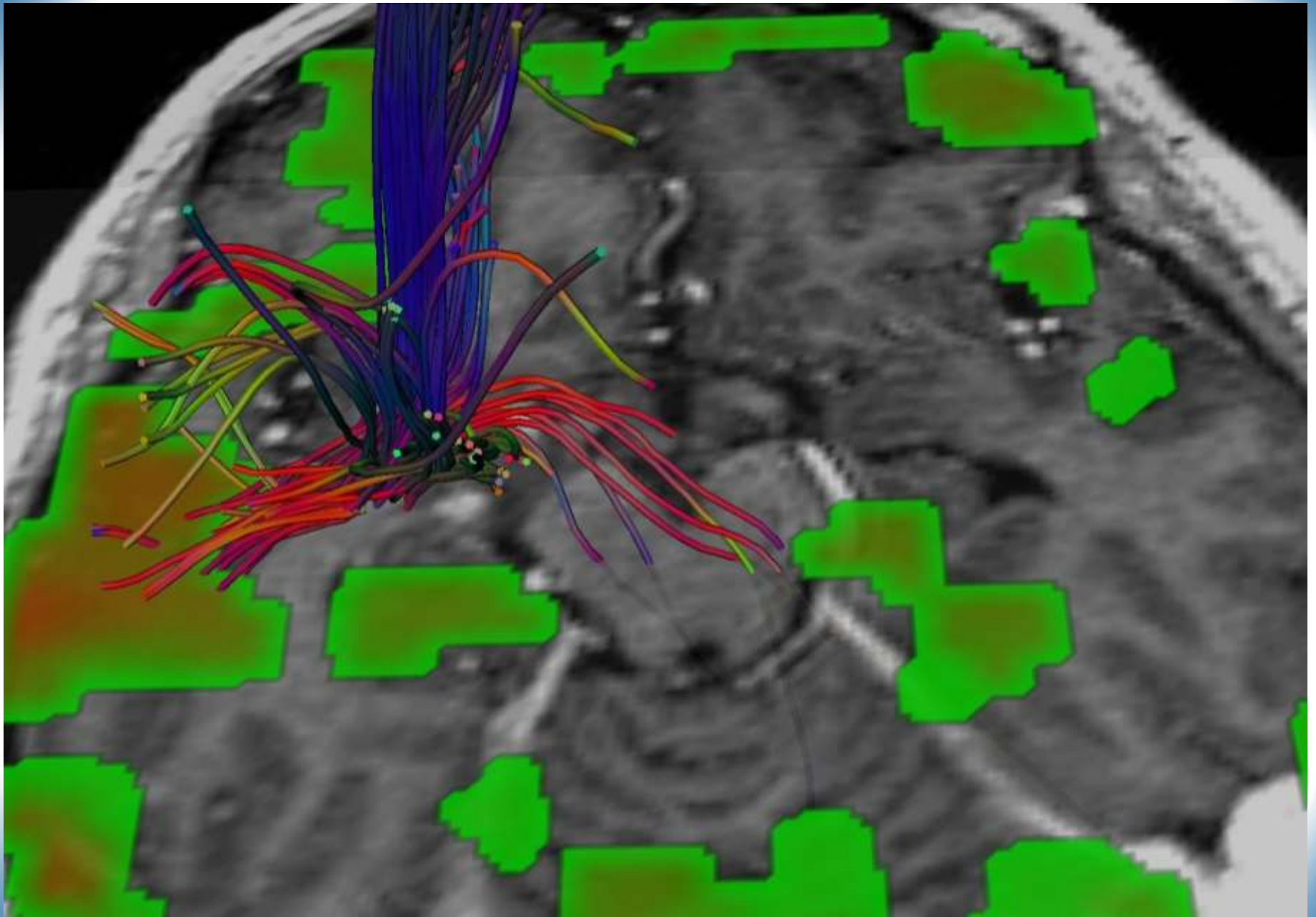


IRM d'Activation

Fonctions Auditives

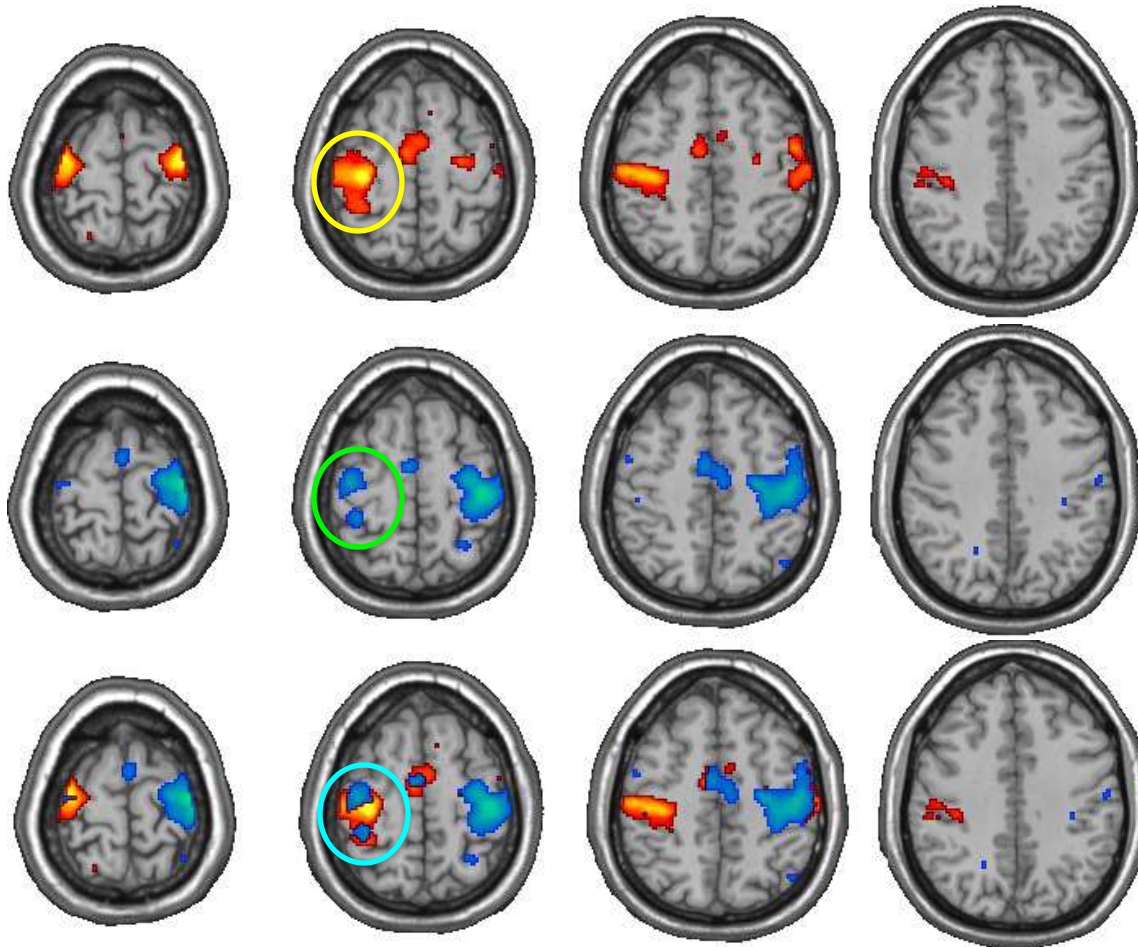






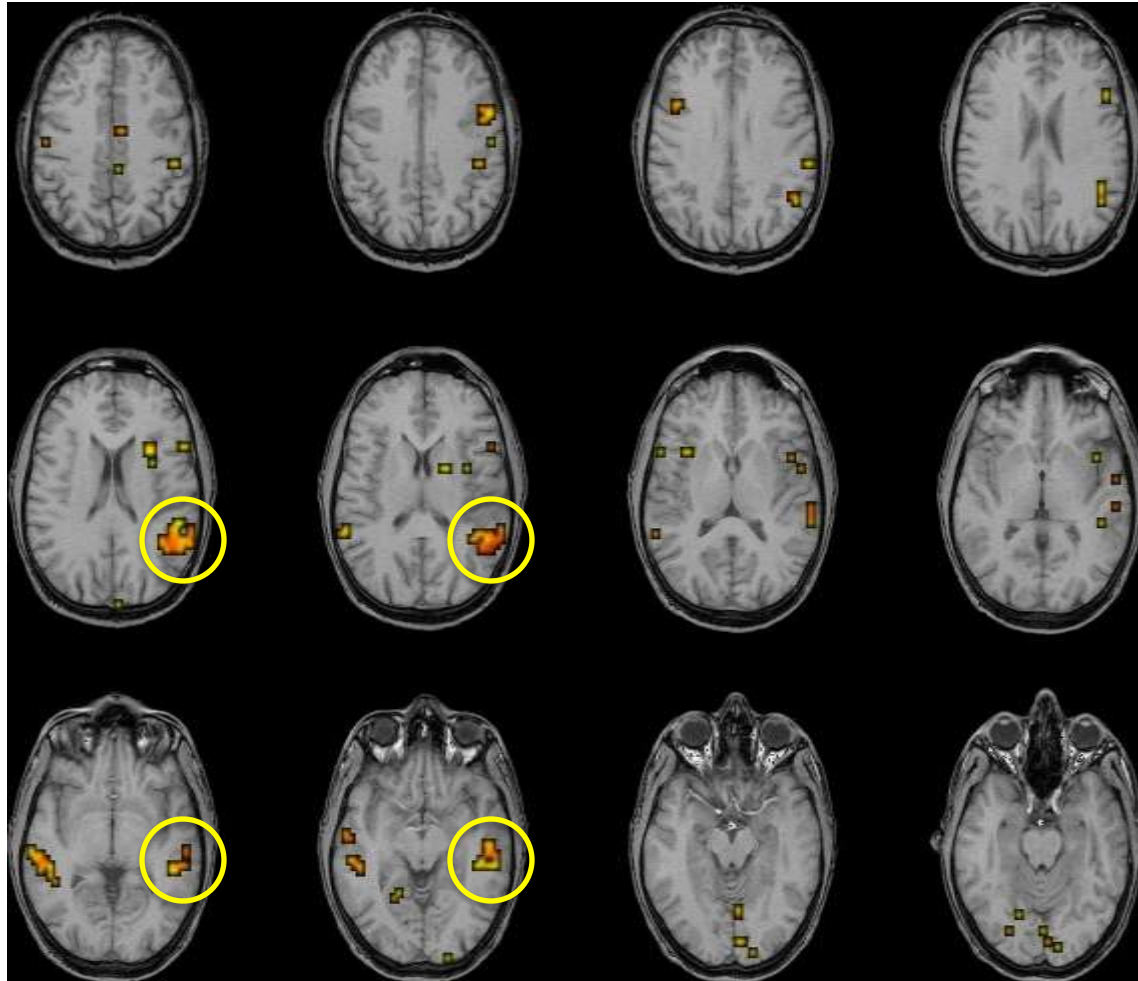
IRM d'Activation

Imagerie Mentale Motrice



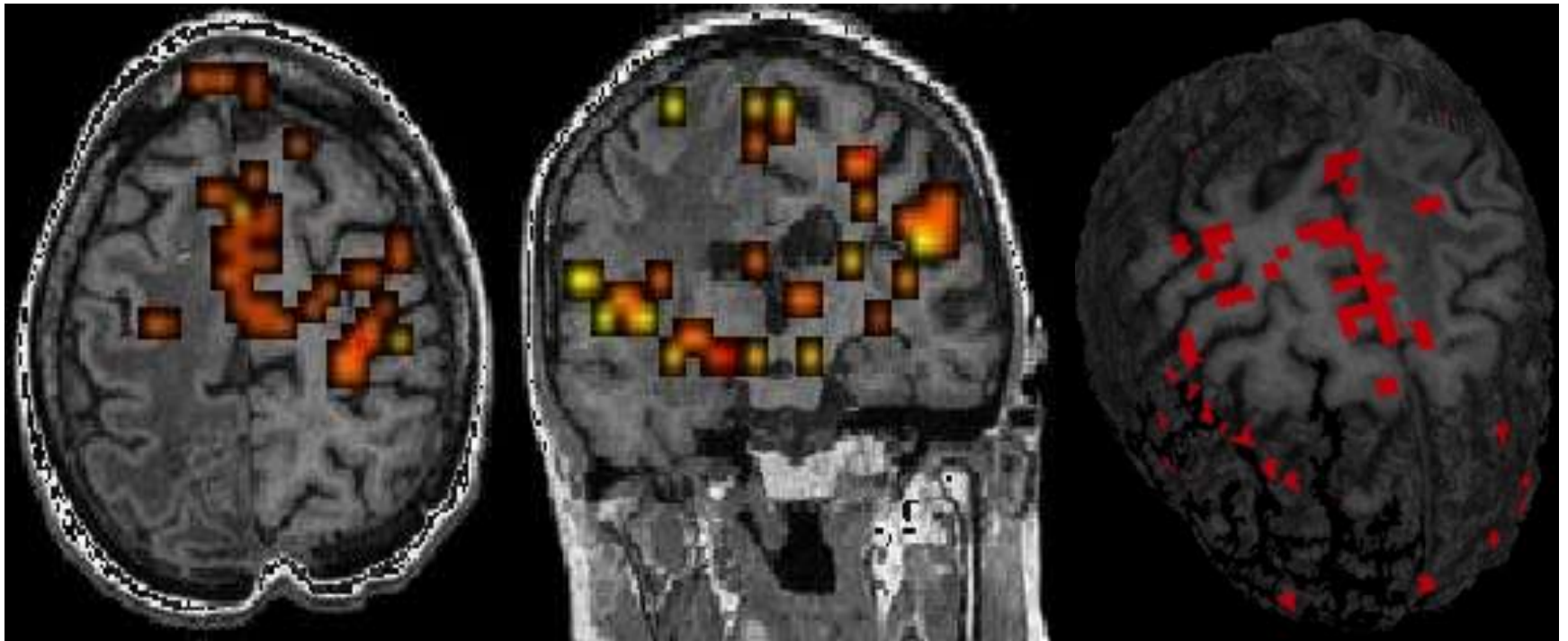
IRM d'Activation

Imagerie Mentale Auditive

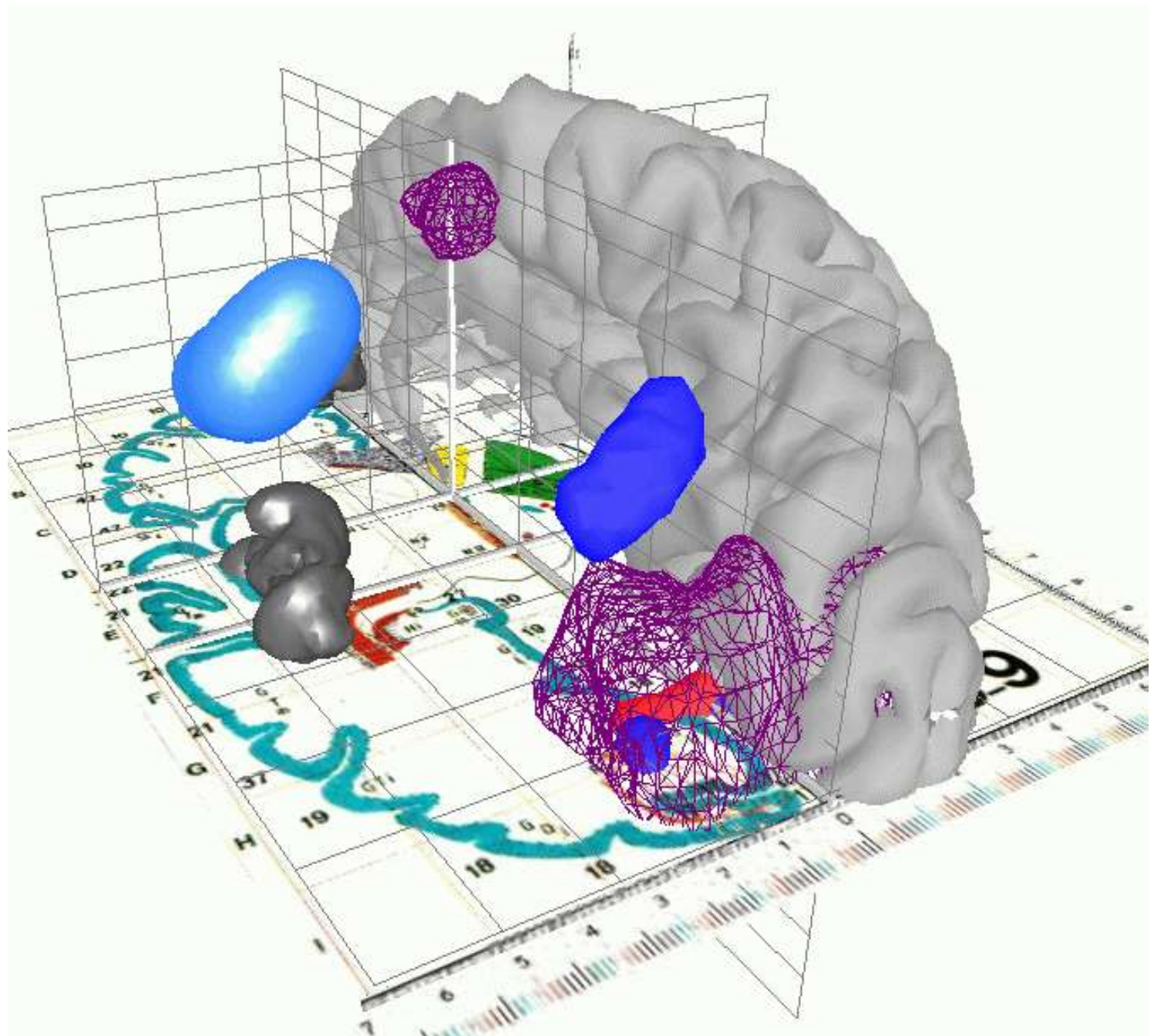


IRM d'Activation

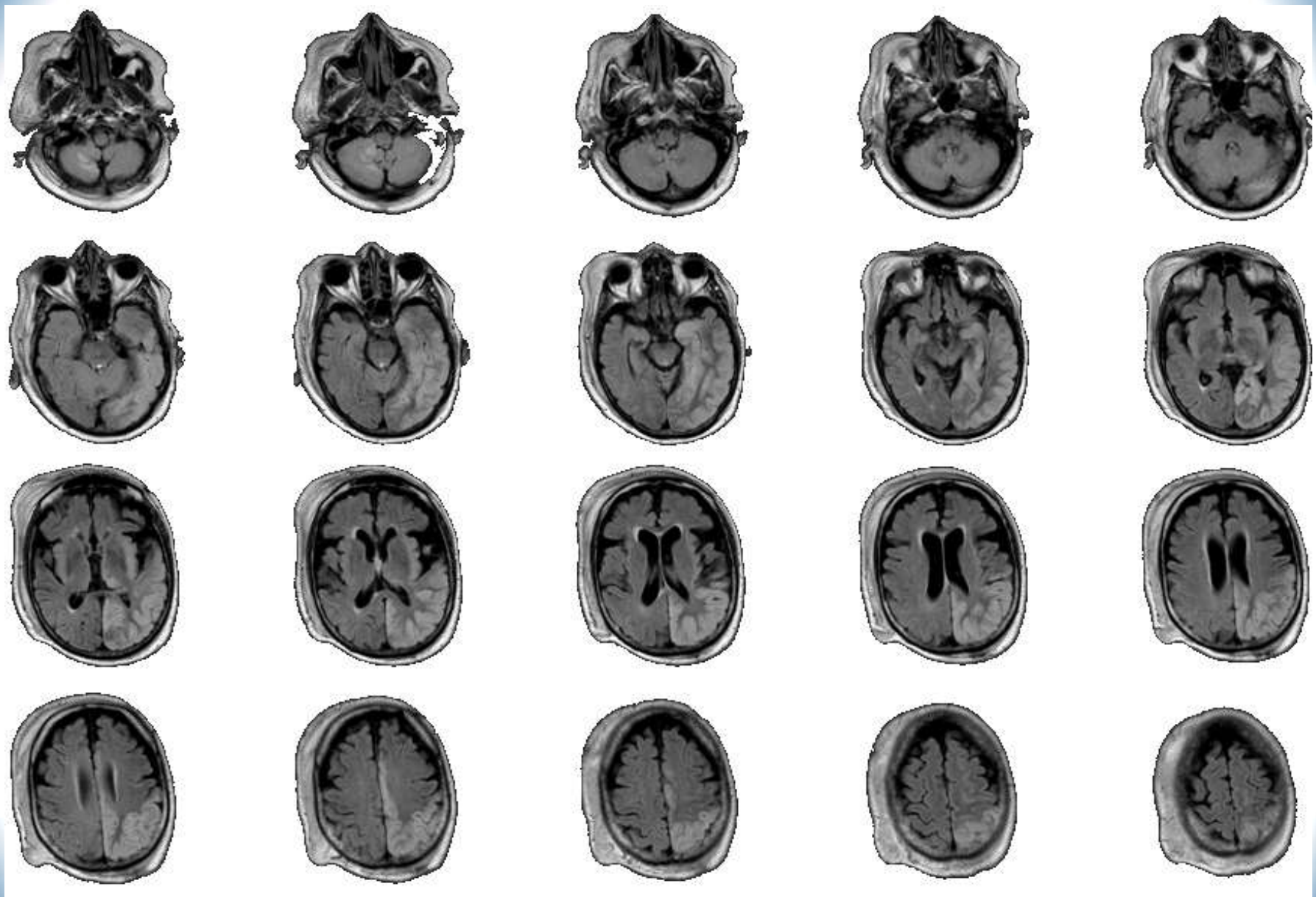
Evaluations Thérapeutiques



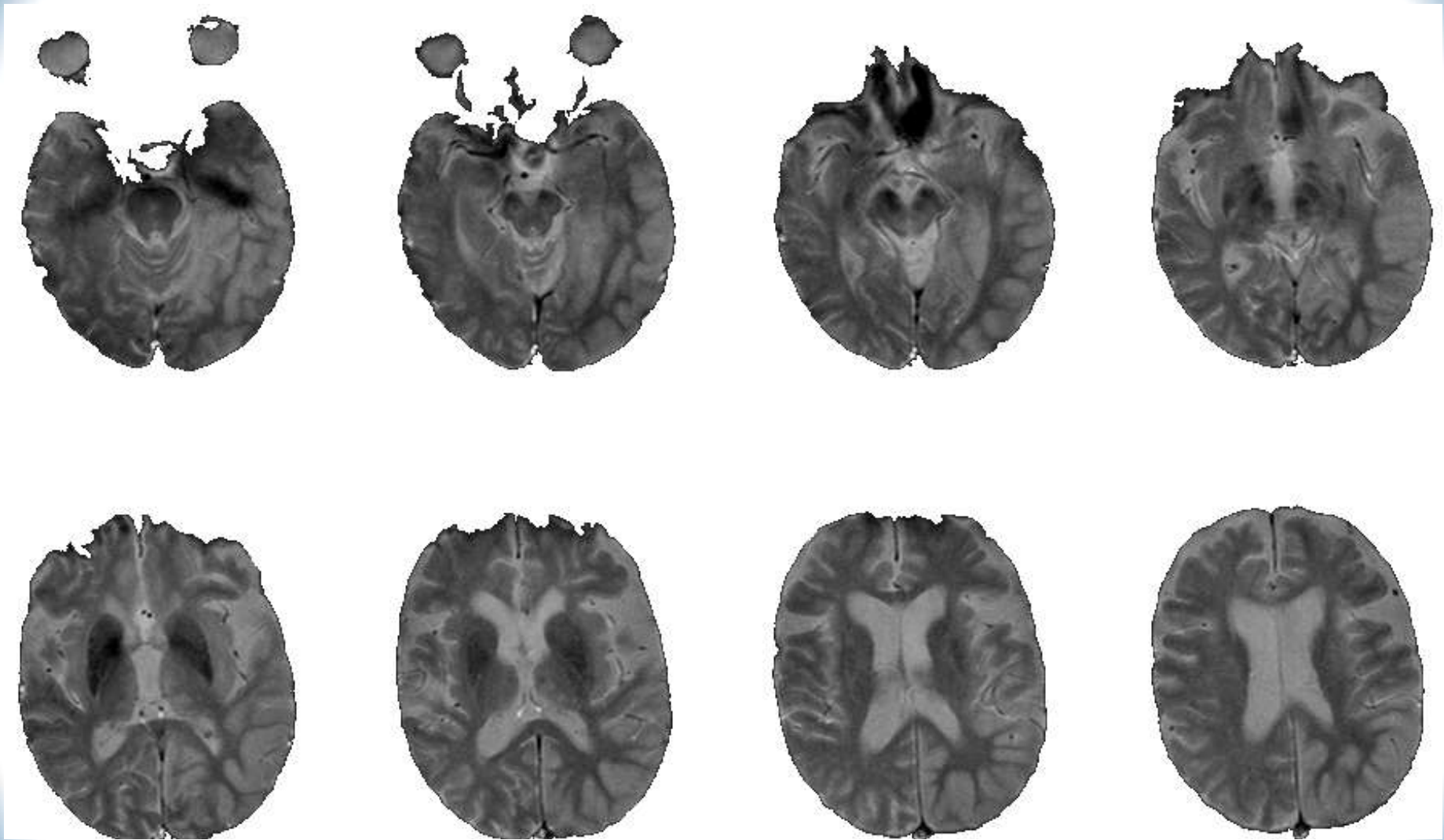
7. Bilan Fonctionnel



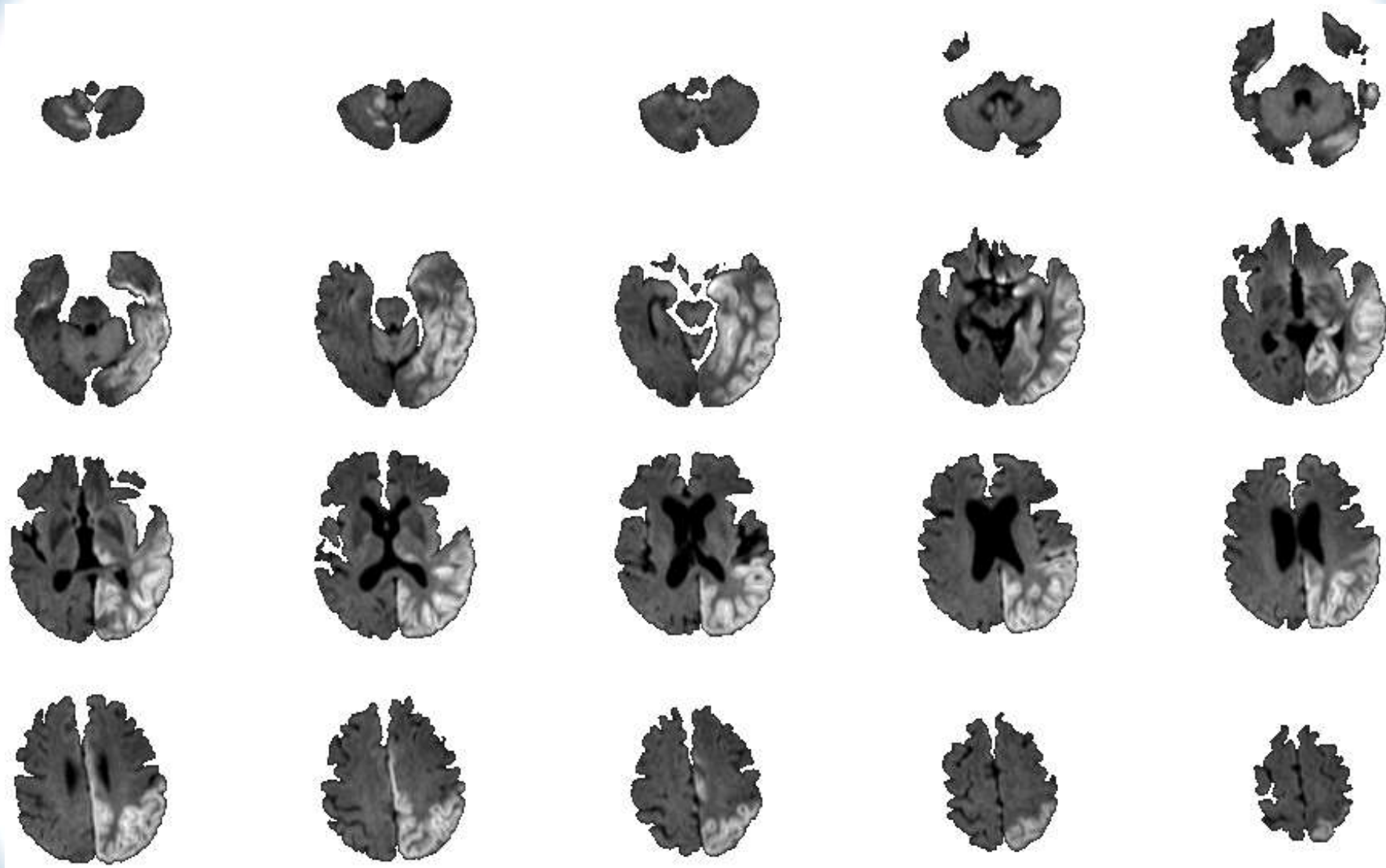
7.1 Status Epilepticus

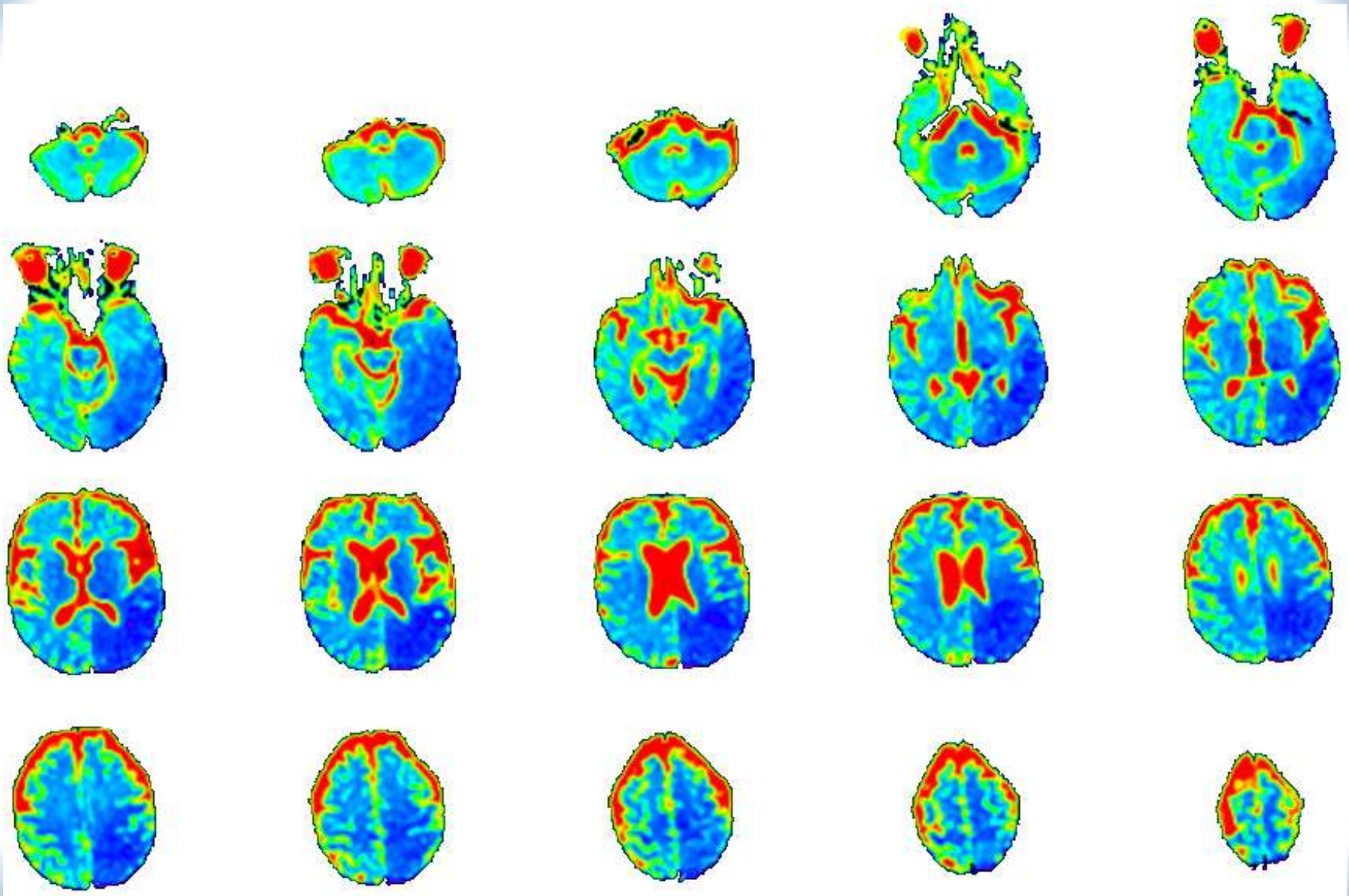


FLAIR

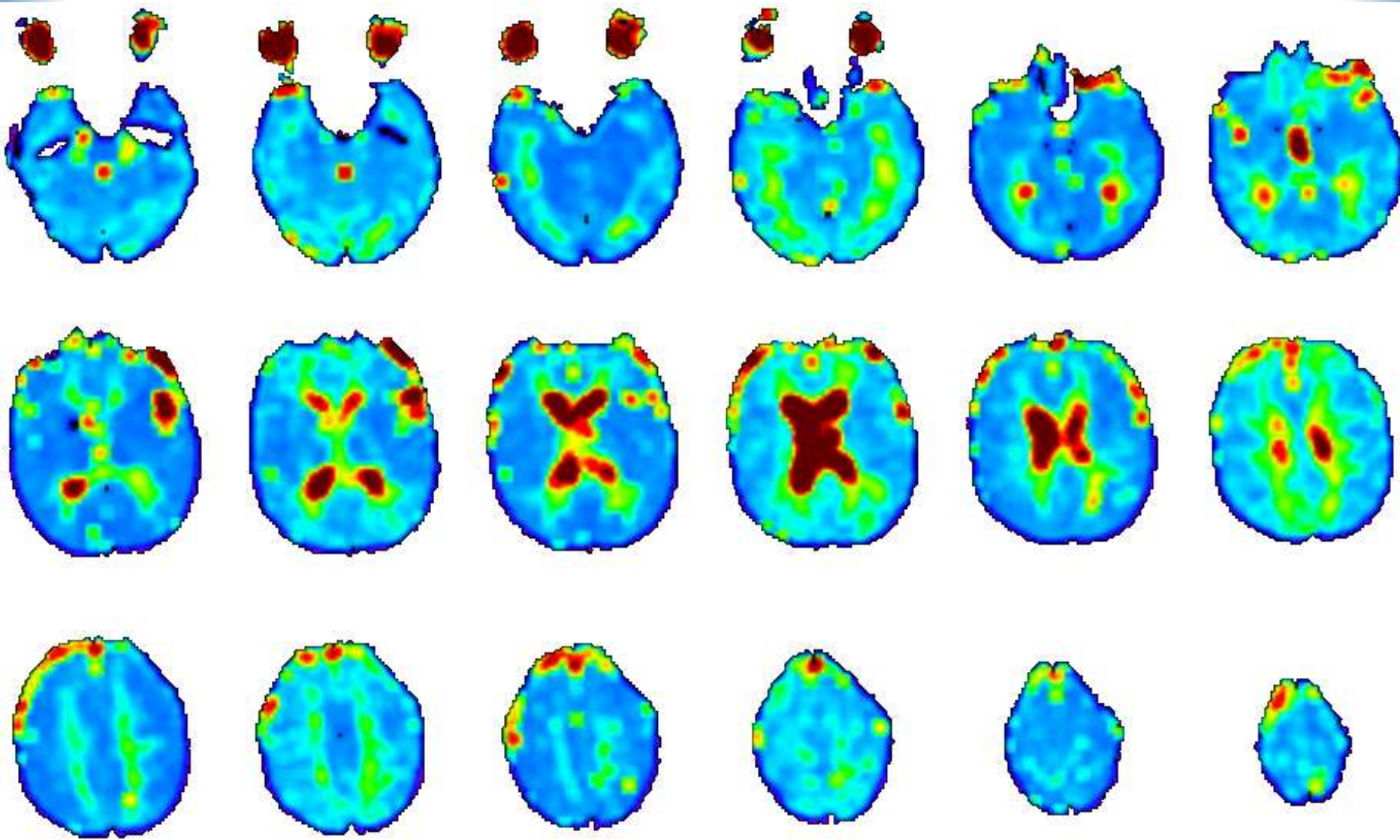


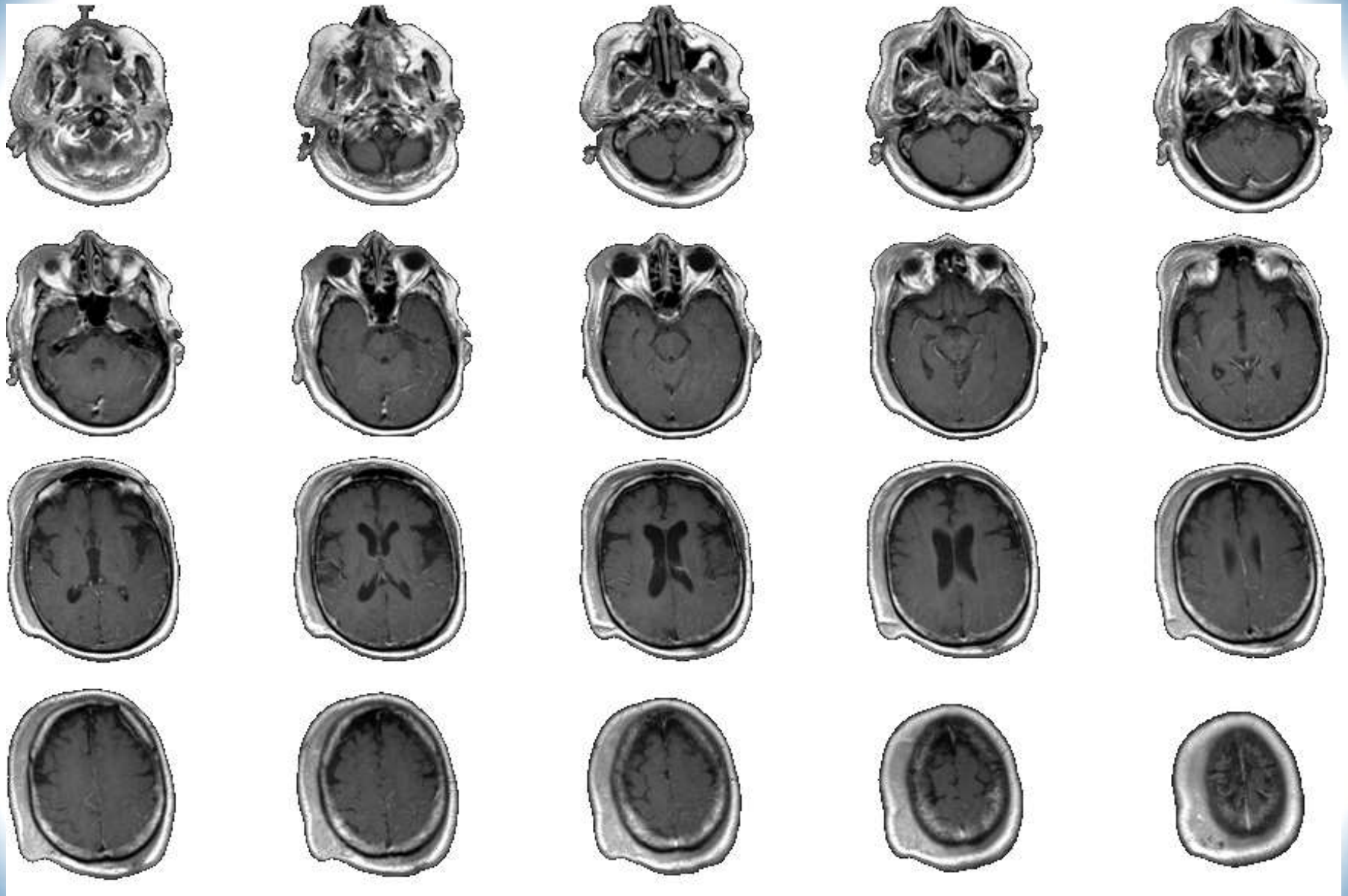
T2*





ADC

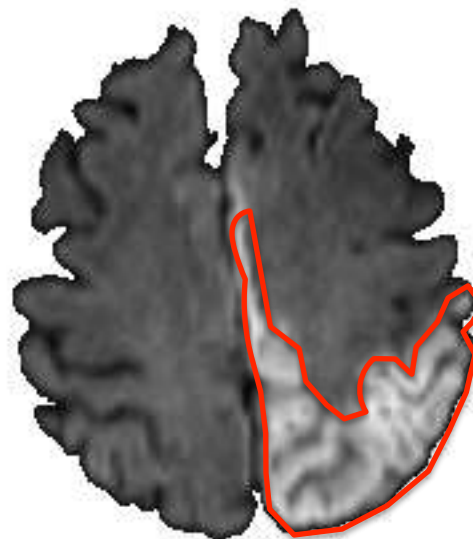
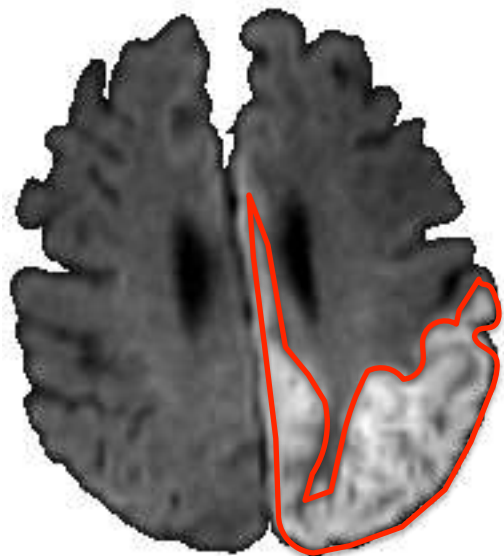


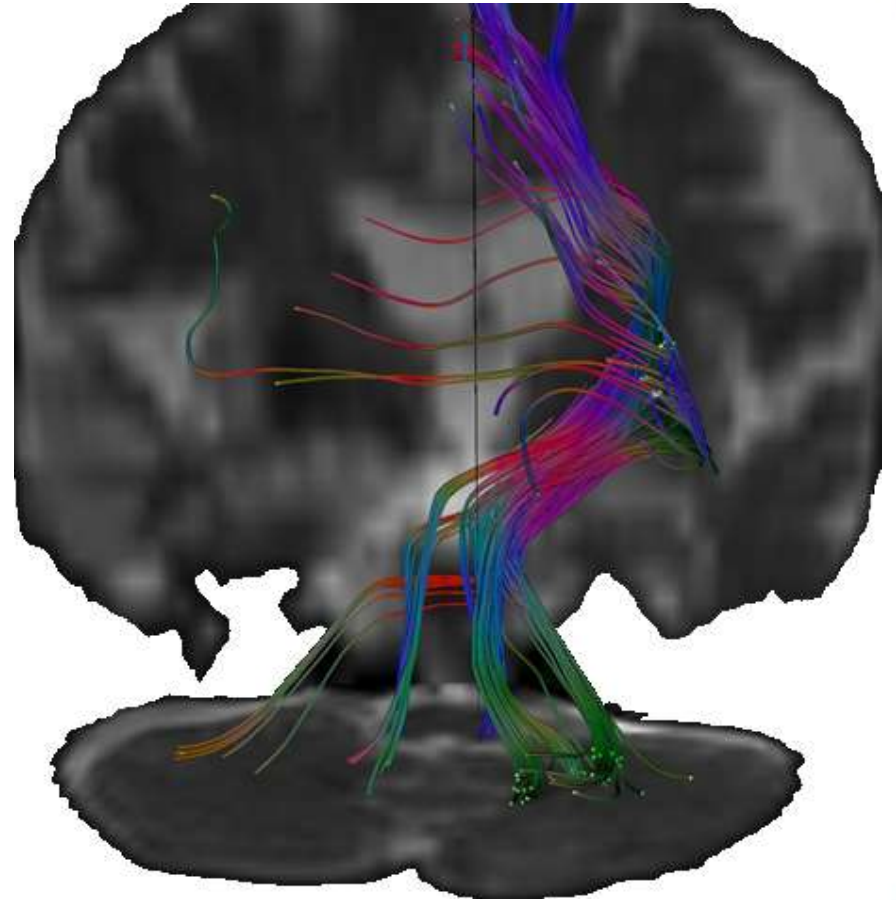
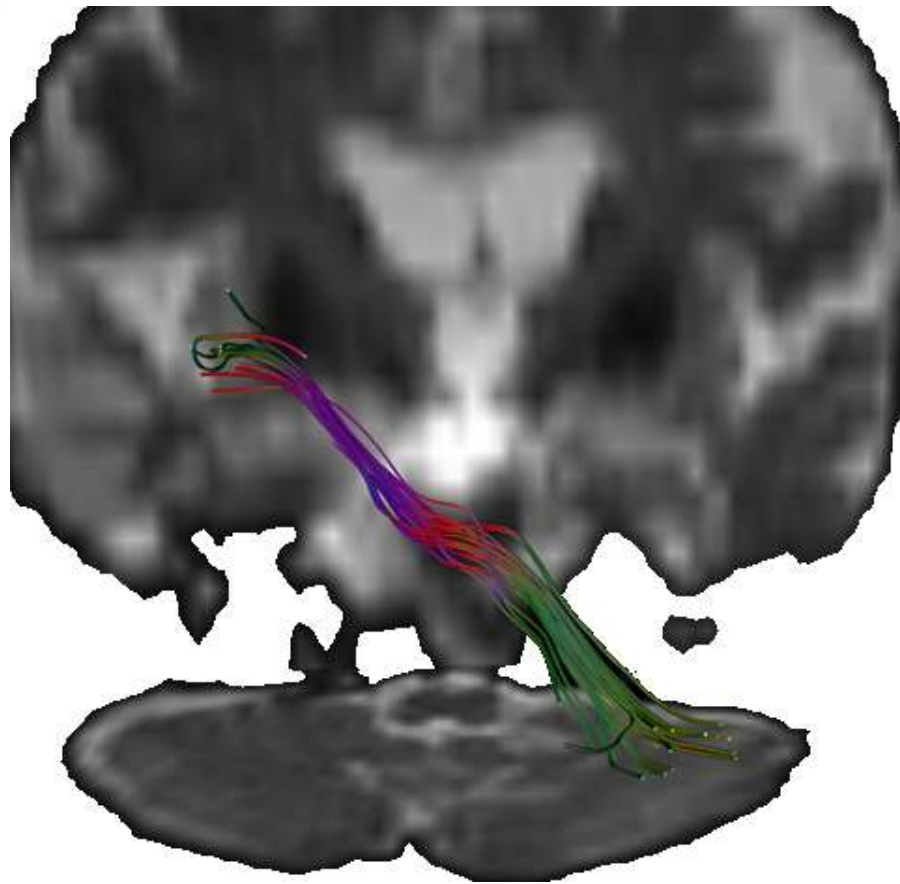


T1 Gado

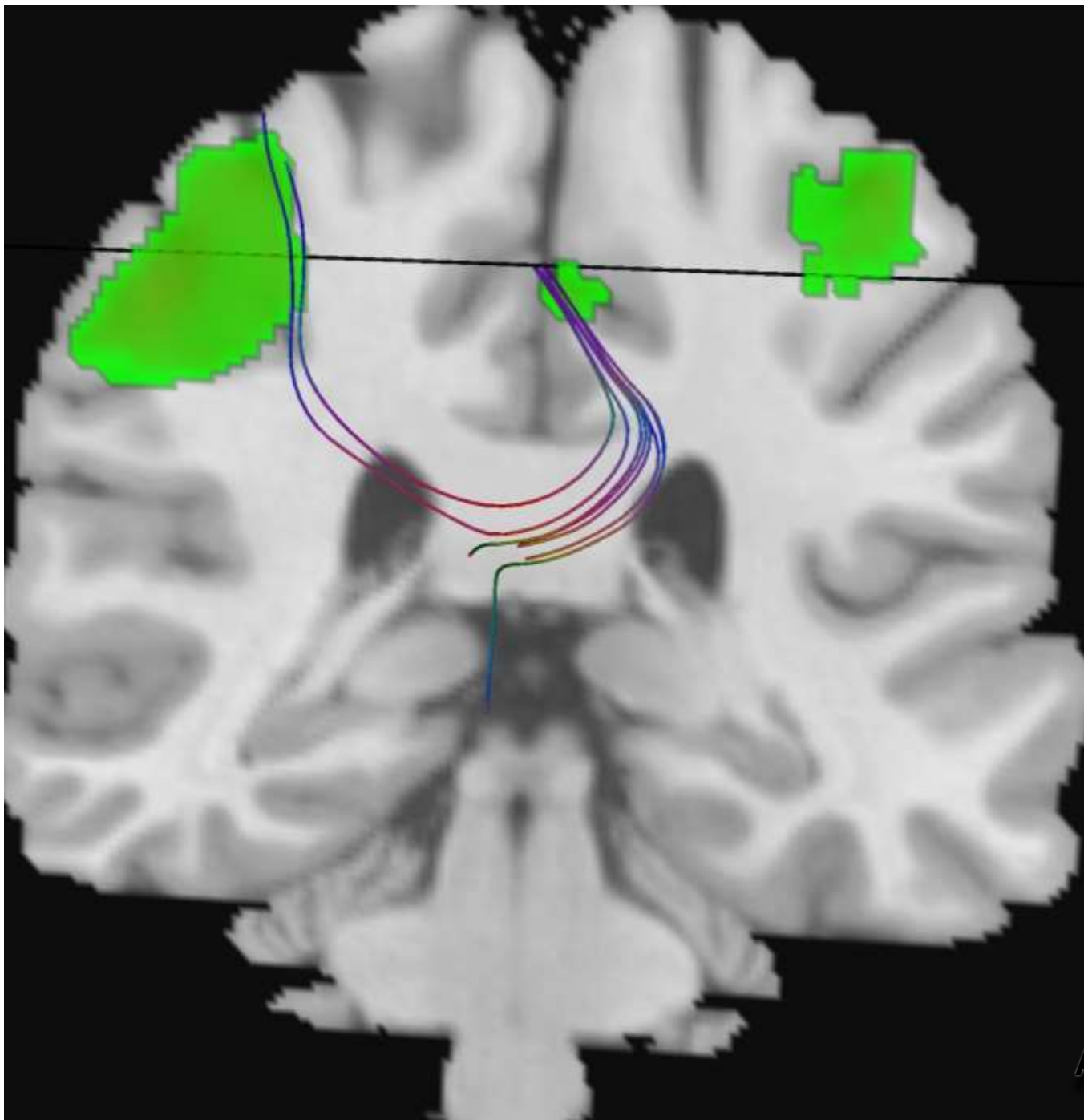


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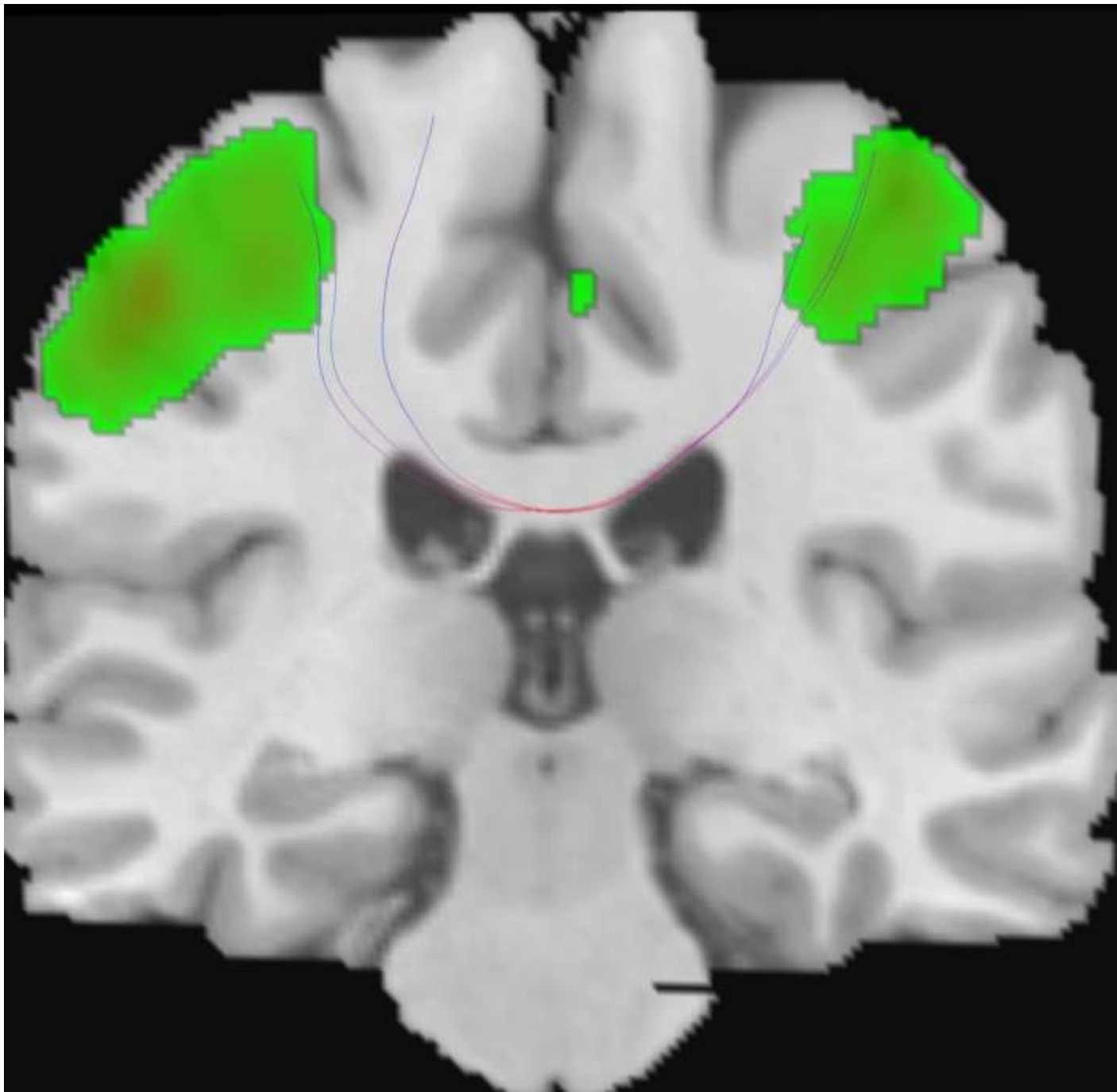




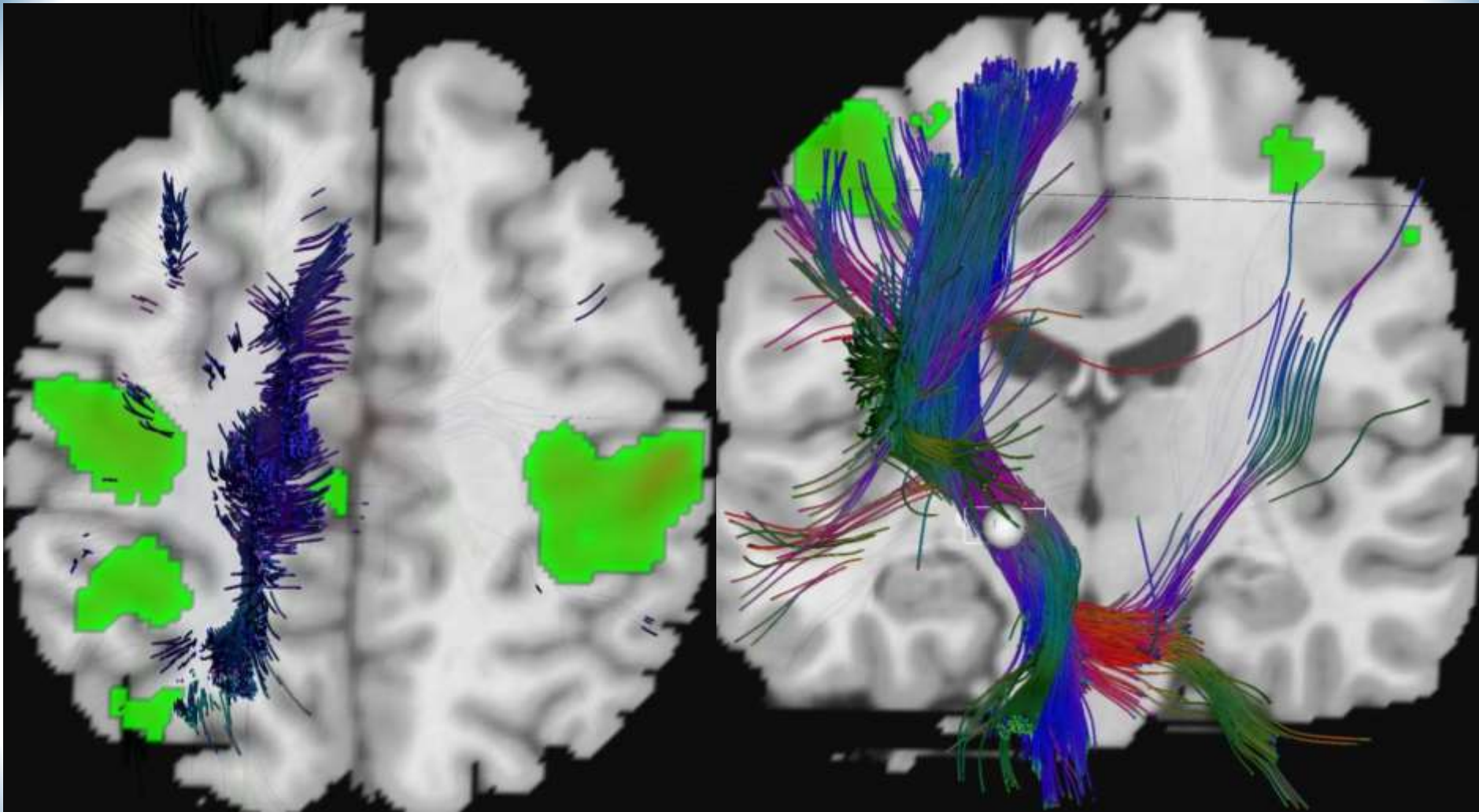
7.2 Syncinésies sur Kallmann de Morsier



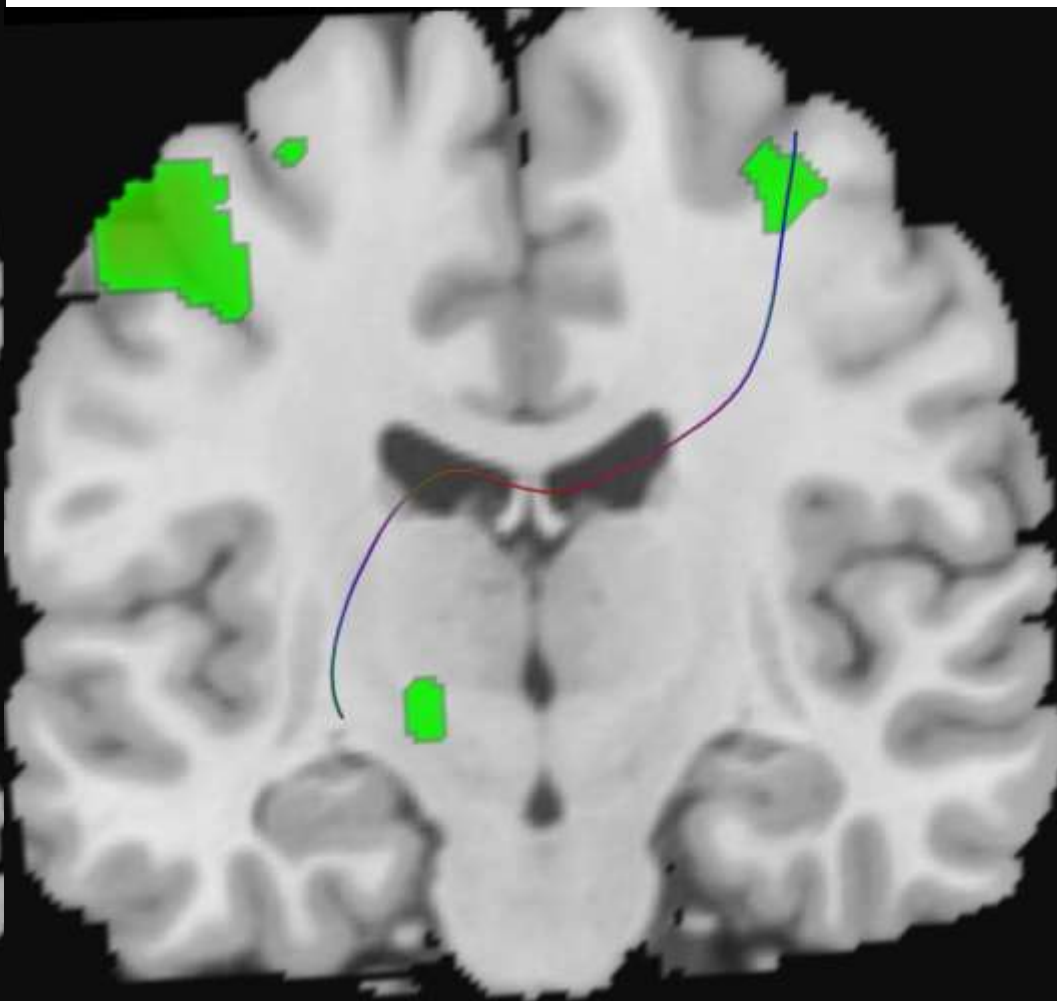
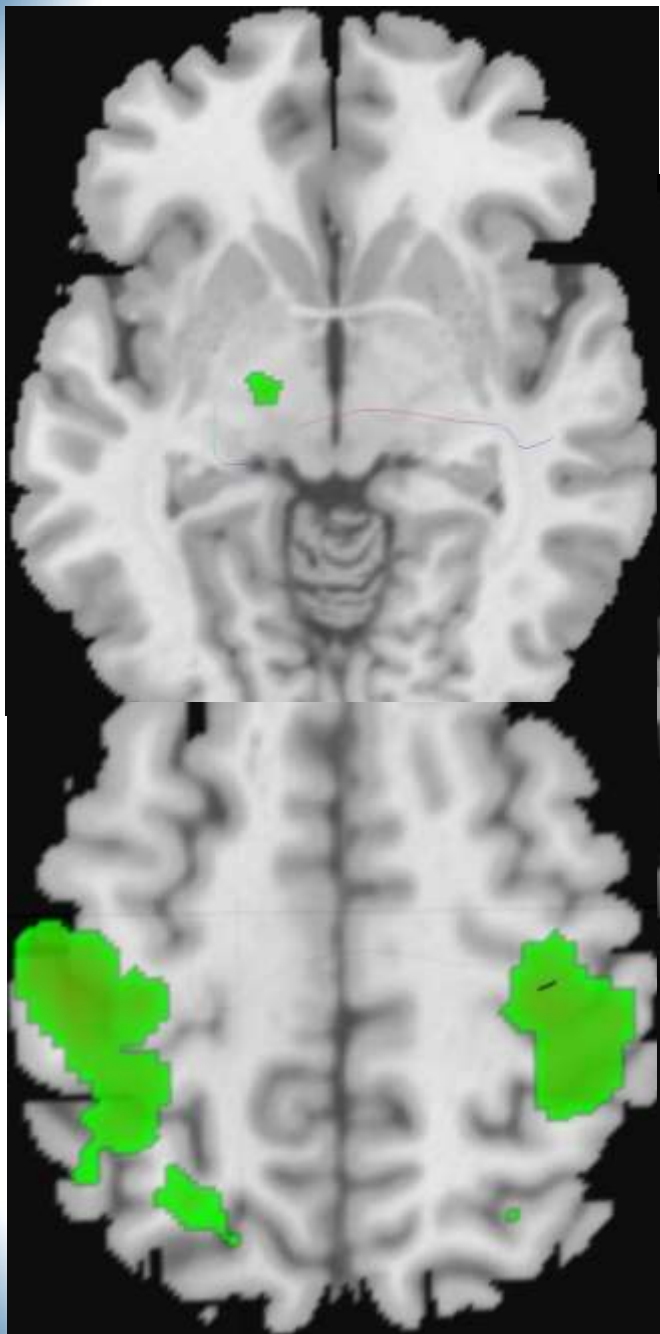
AMP + AMS



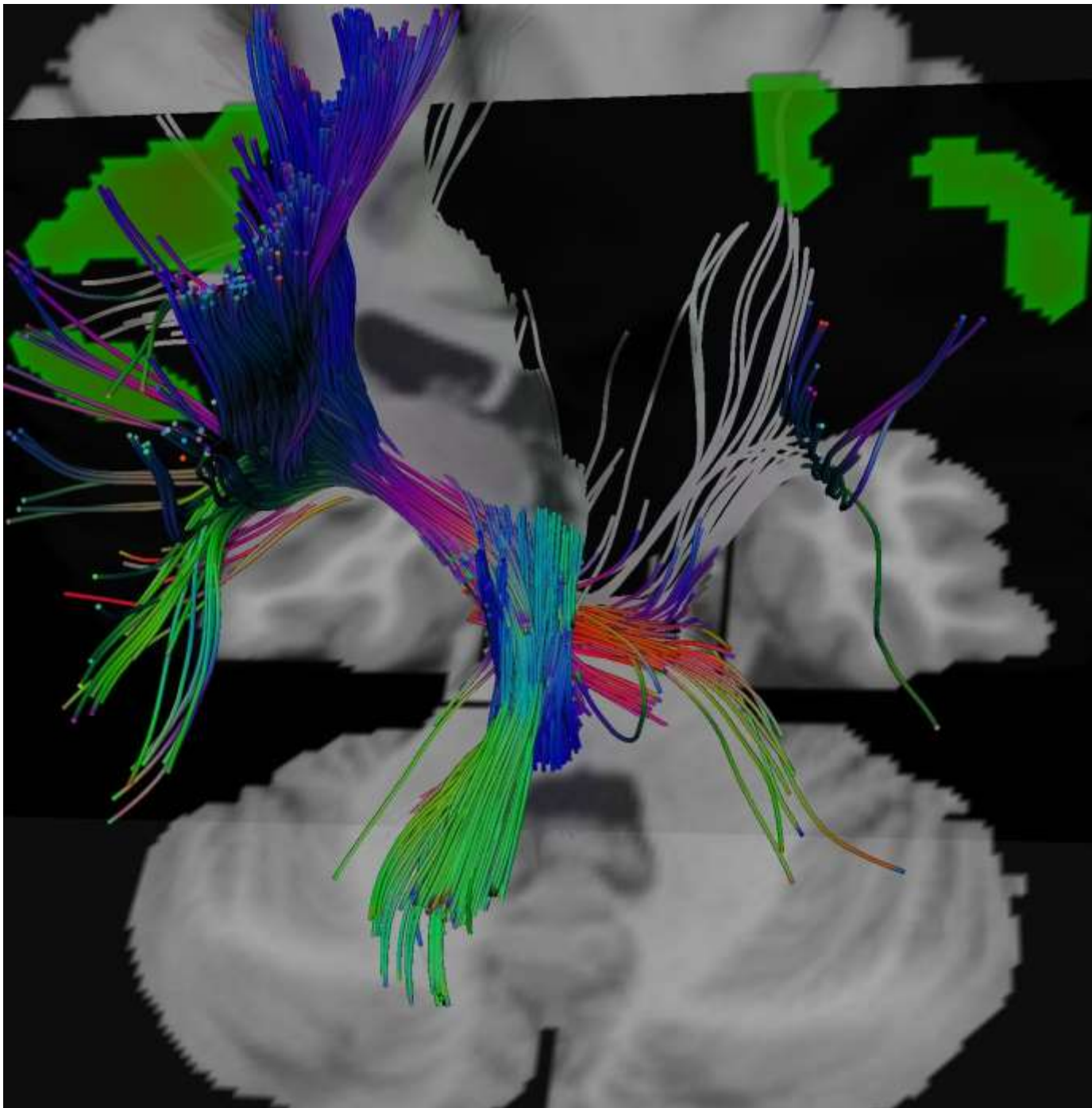
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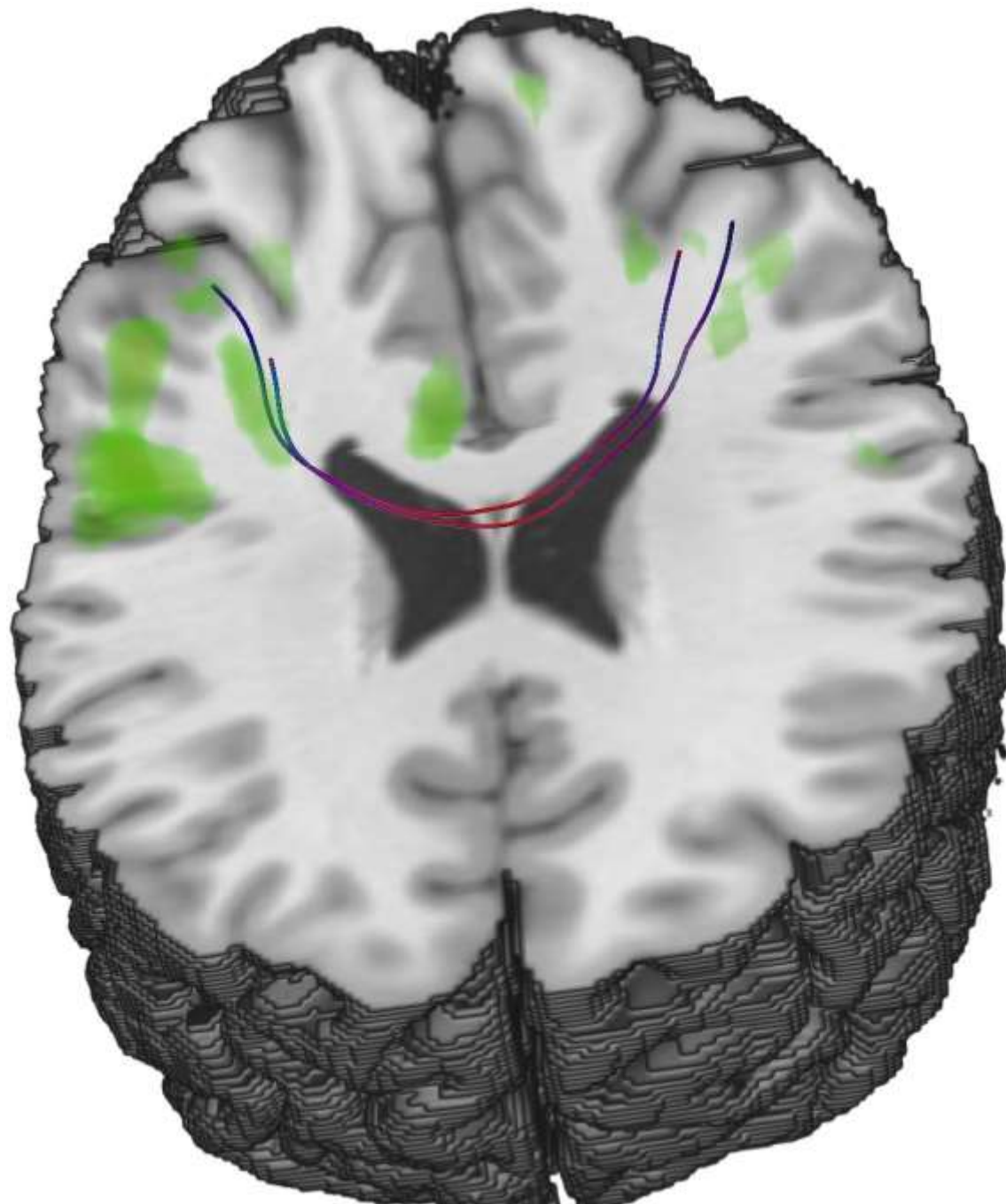


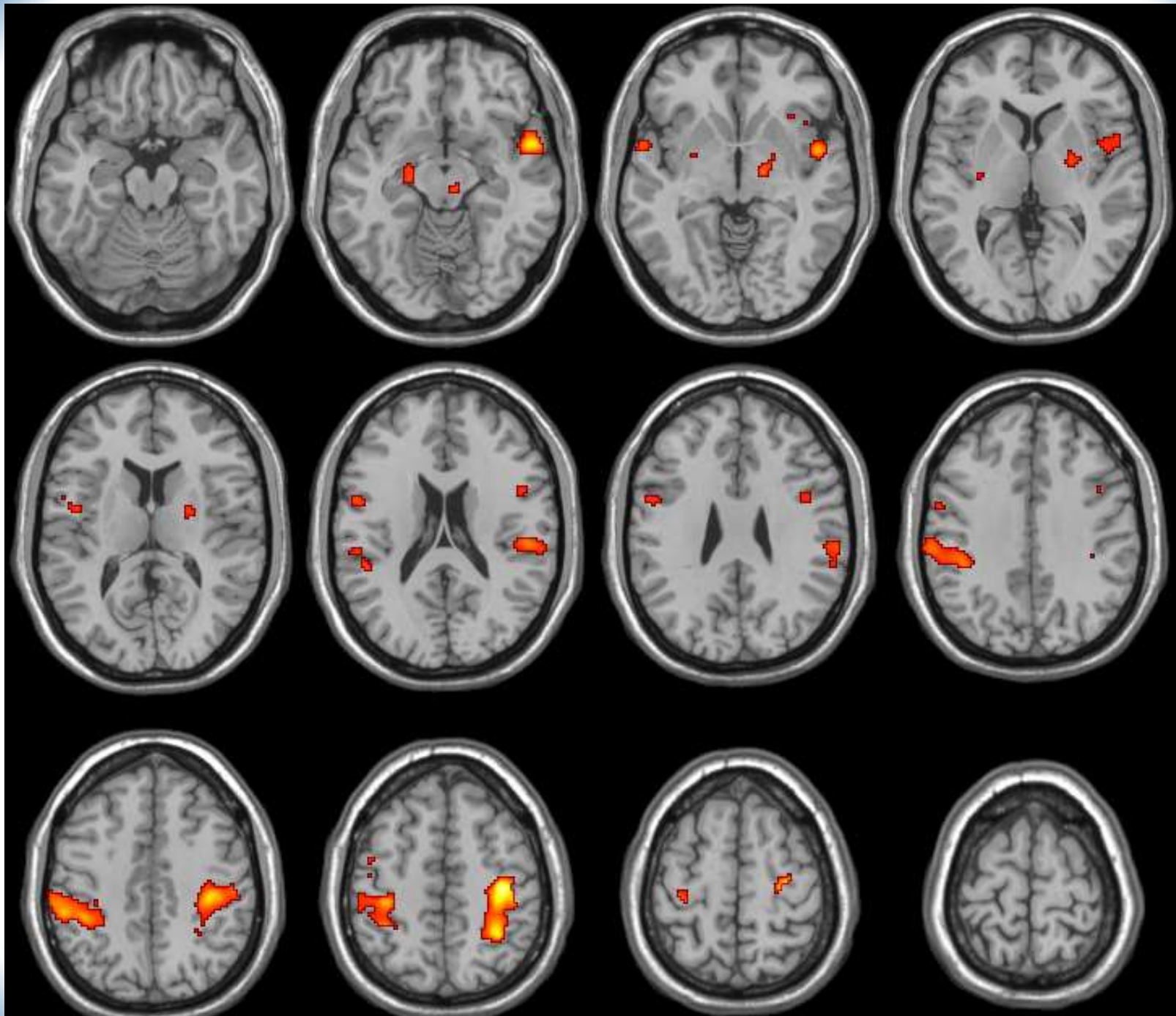
CST + Th

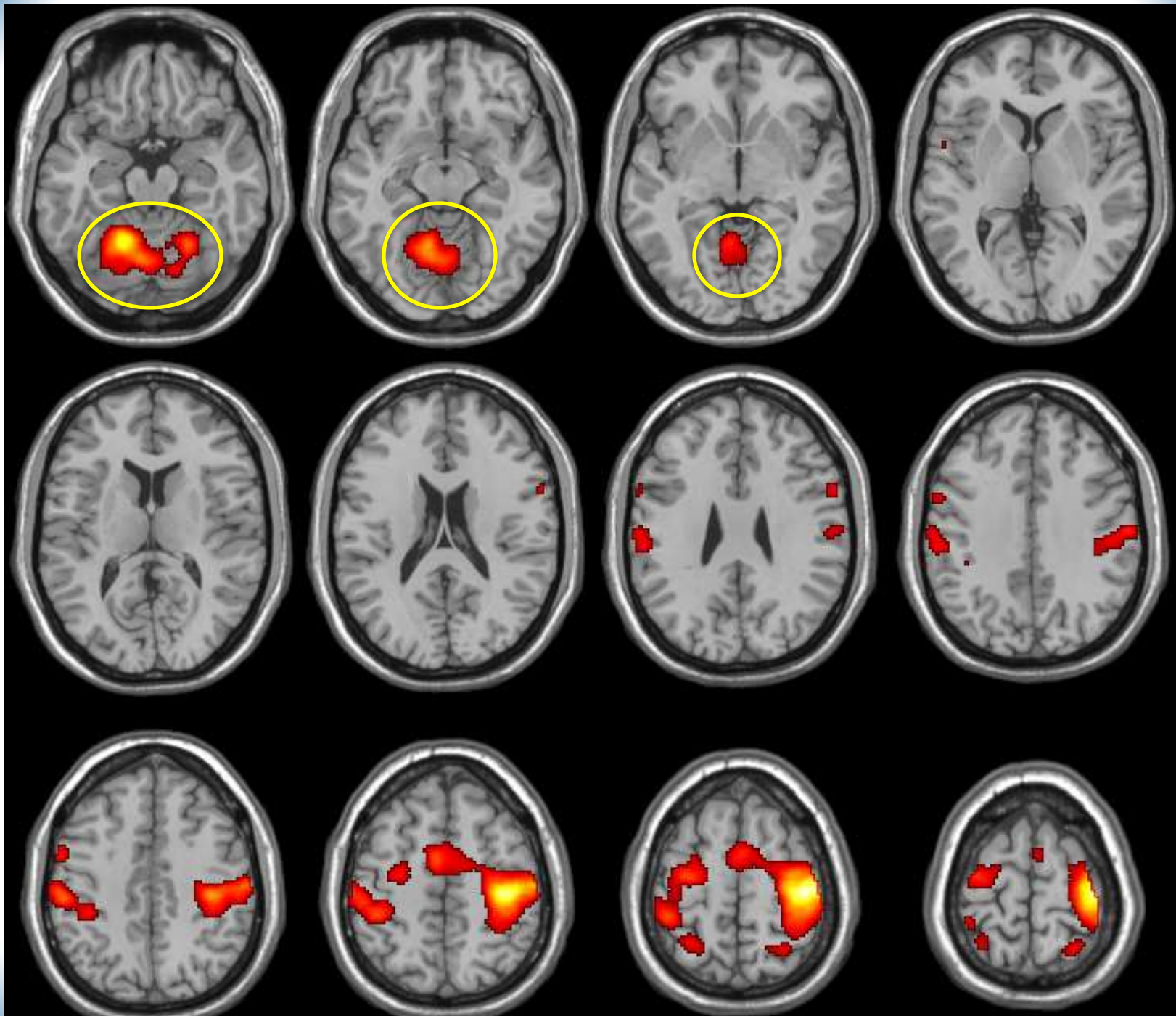


CST + Th

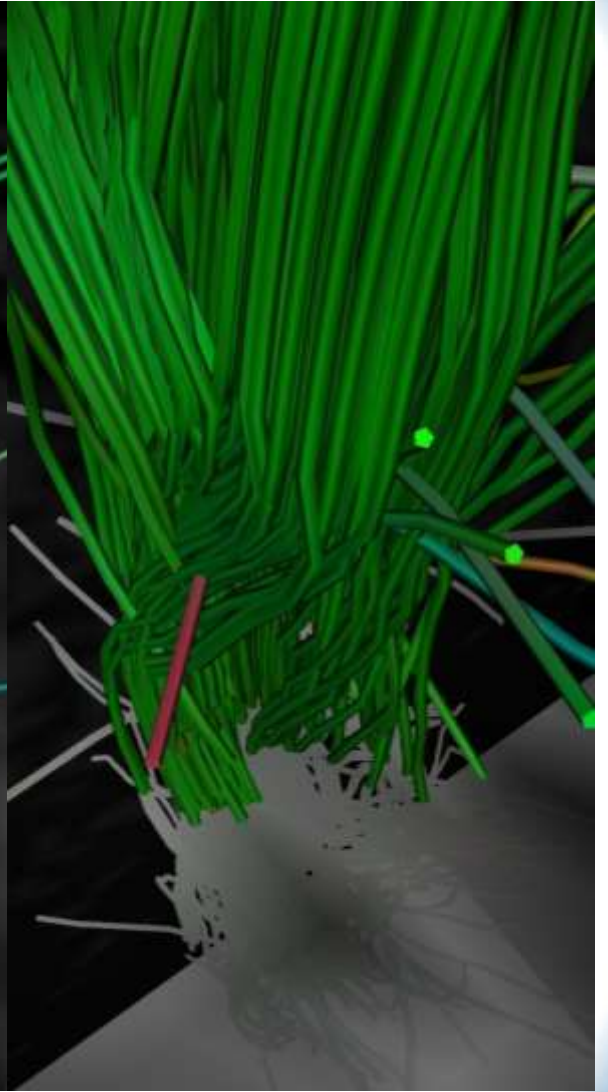
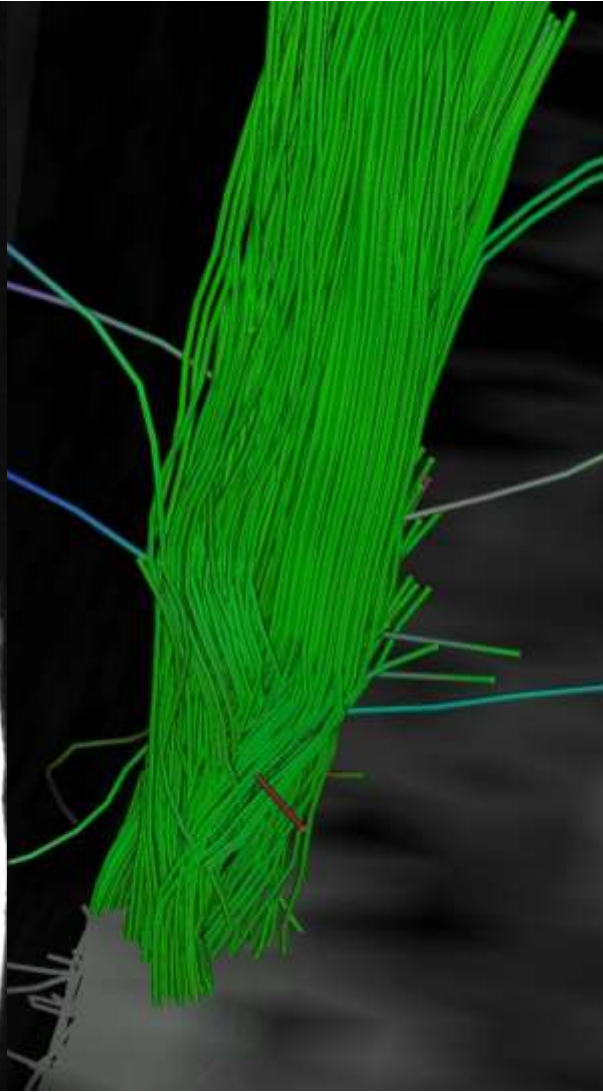


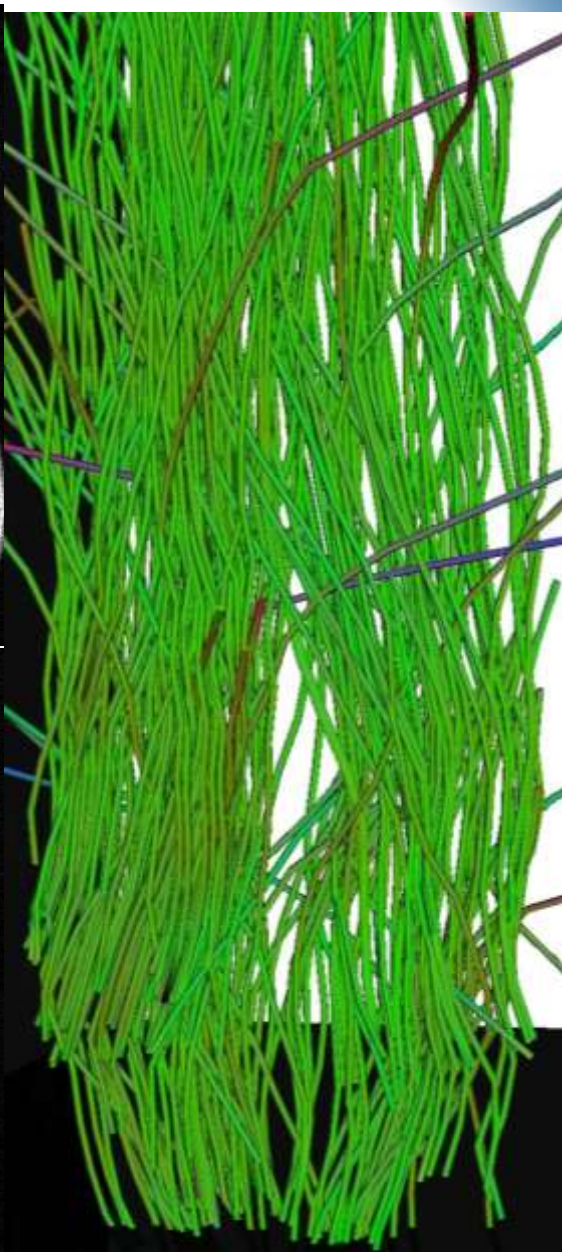
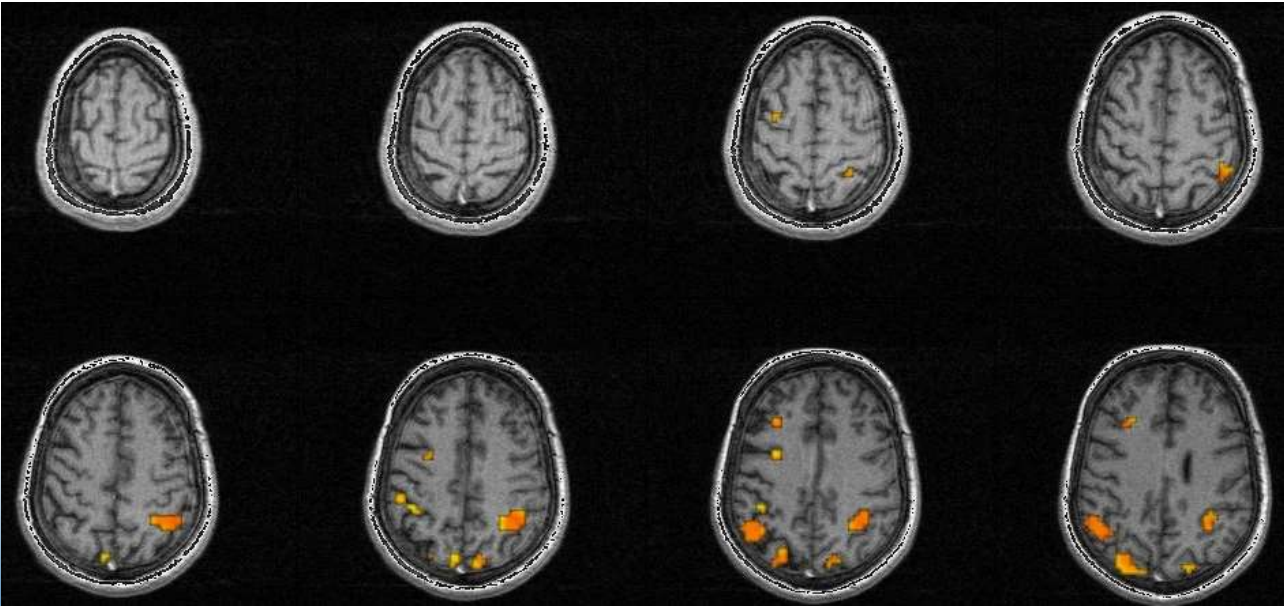
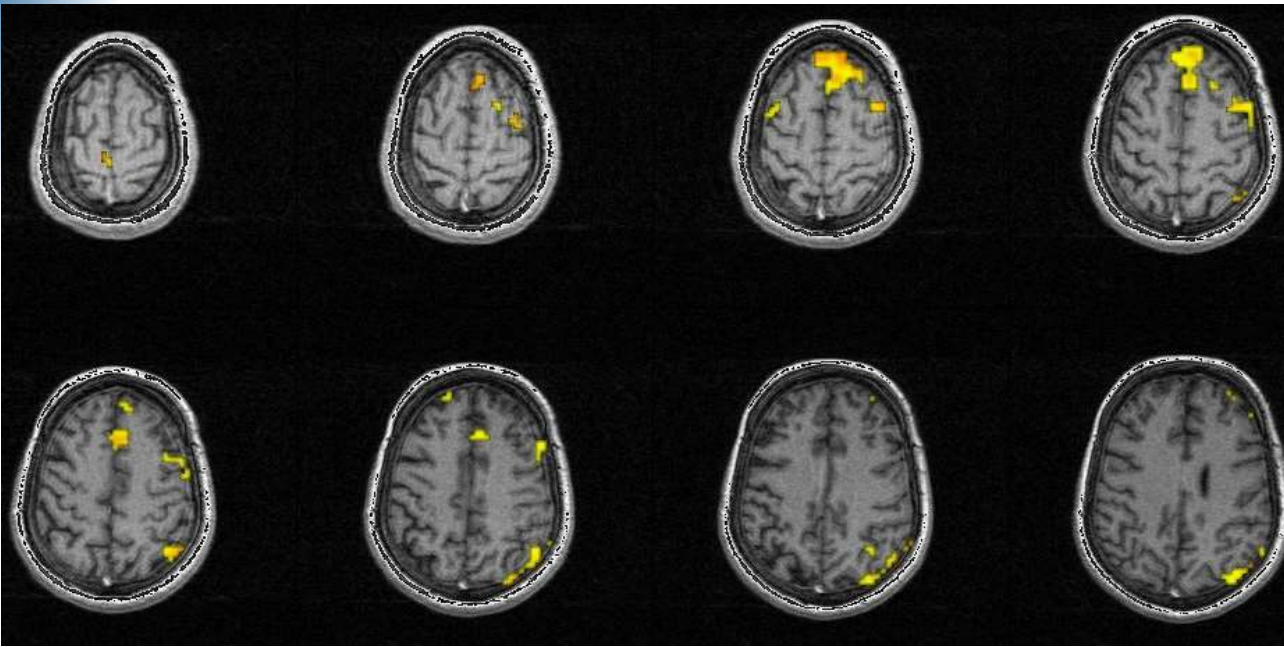




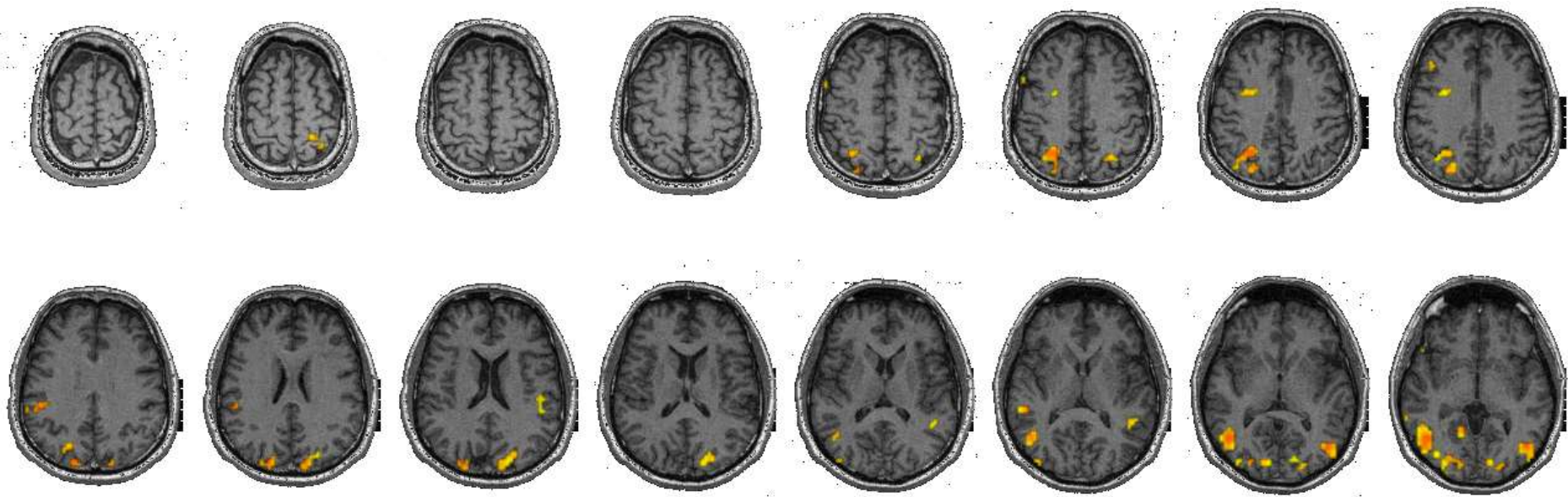


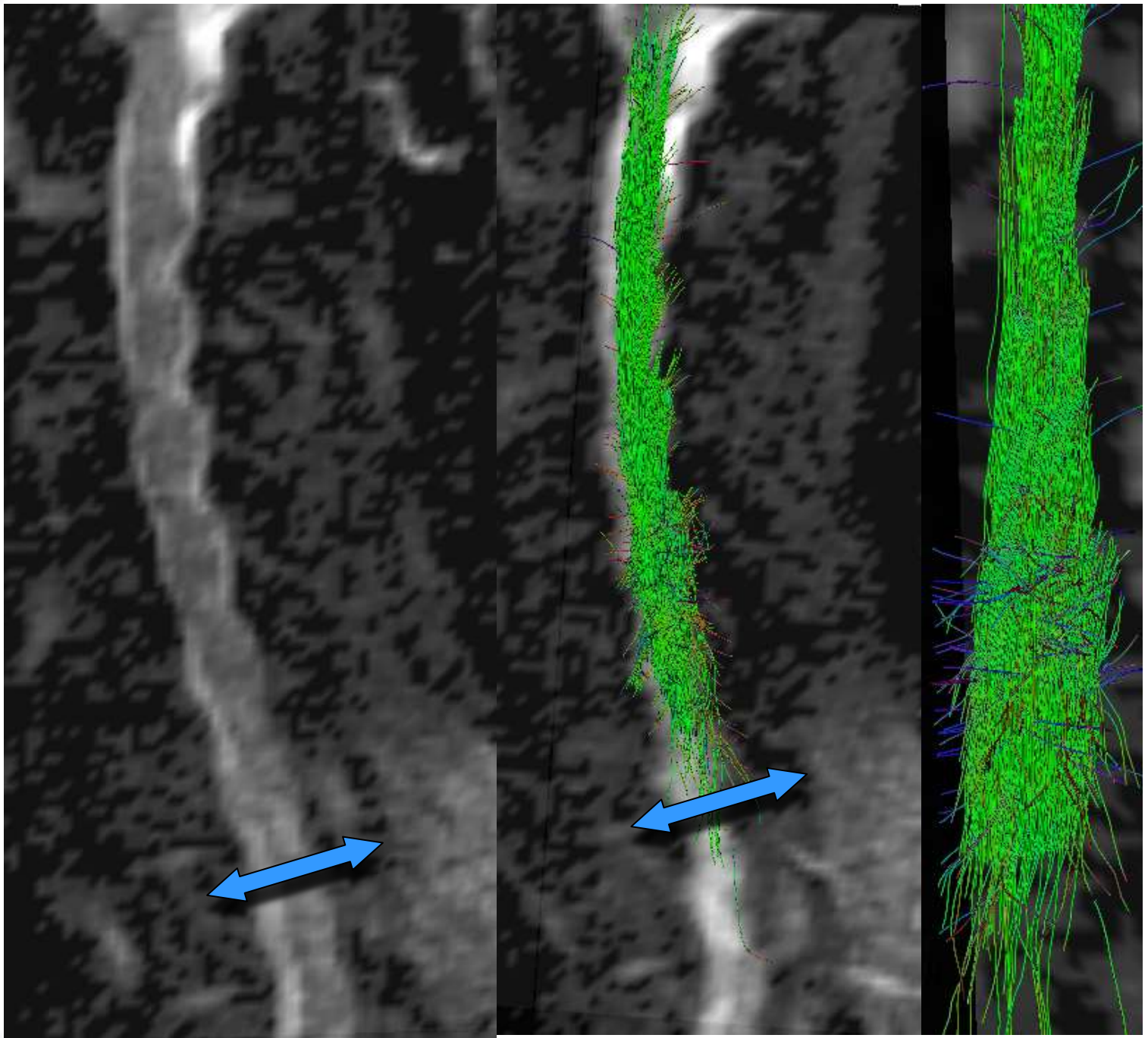
7.3 Syringomyélie et Récupération Sensorielle

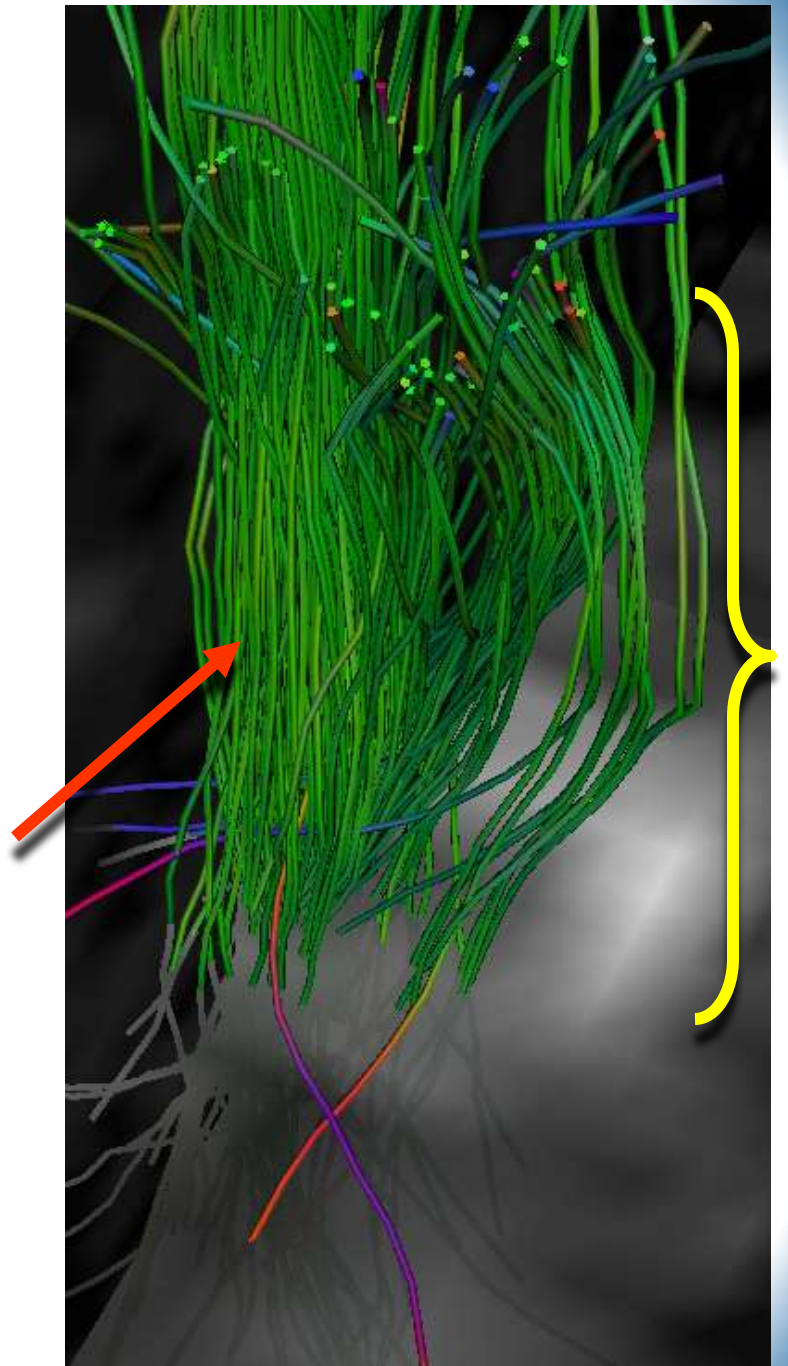
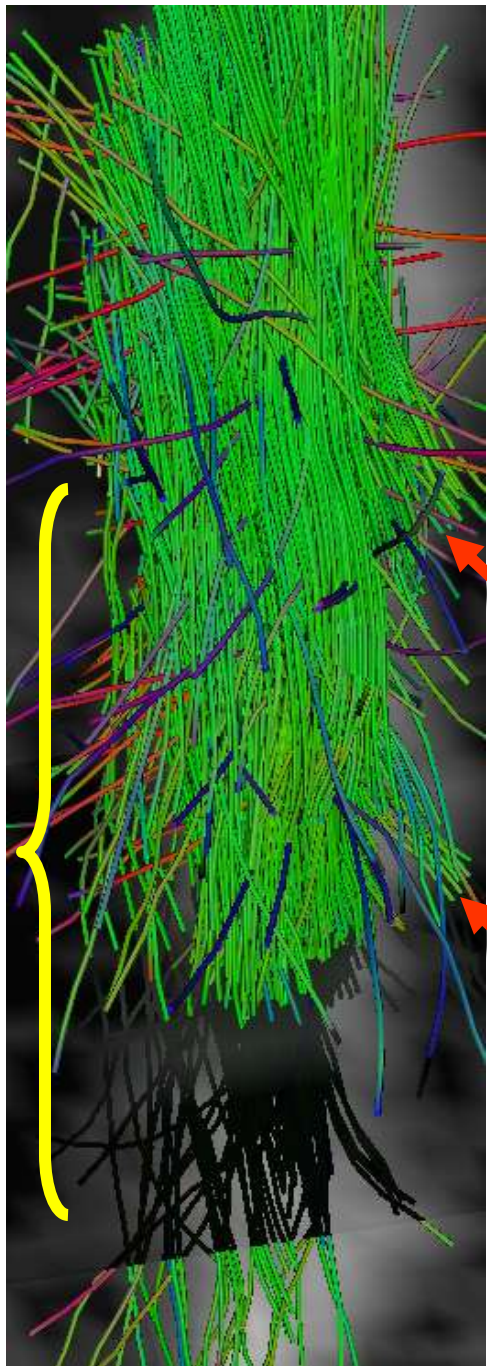




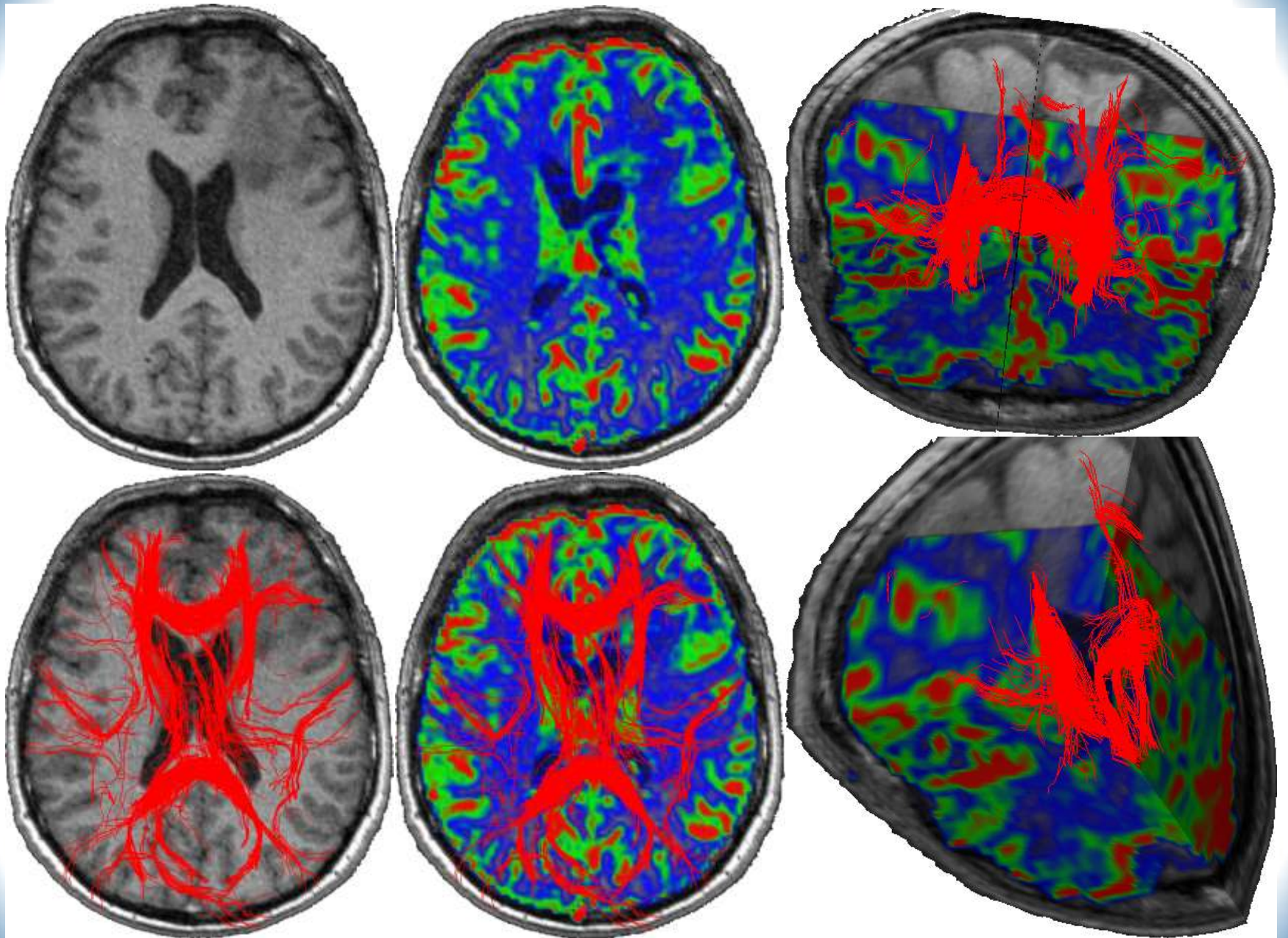
7.4 Régénération Axonale et Greffe de Moelle

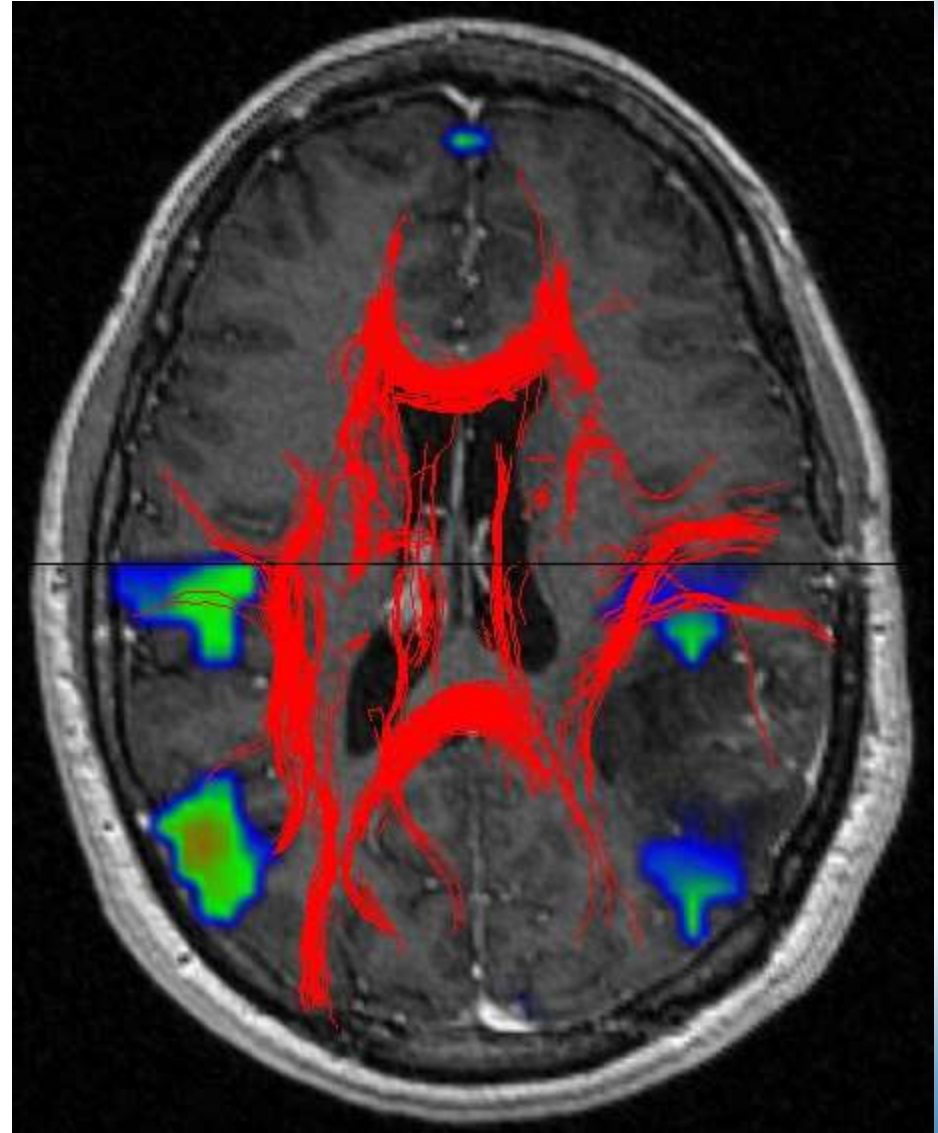
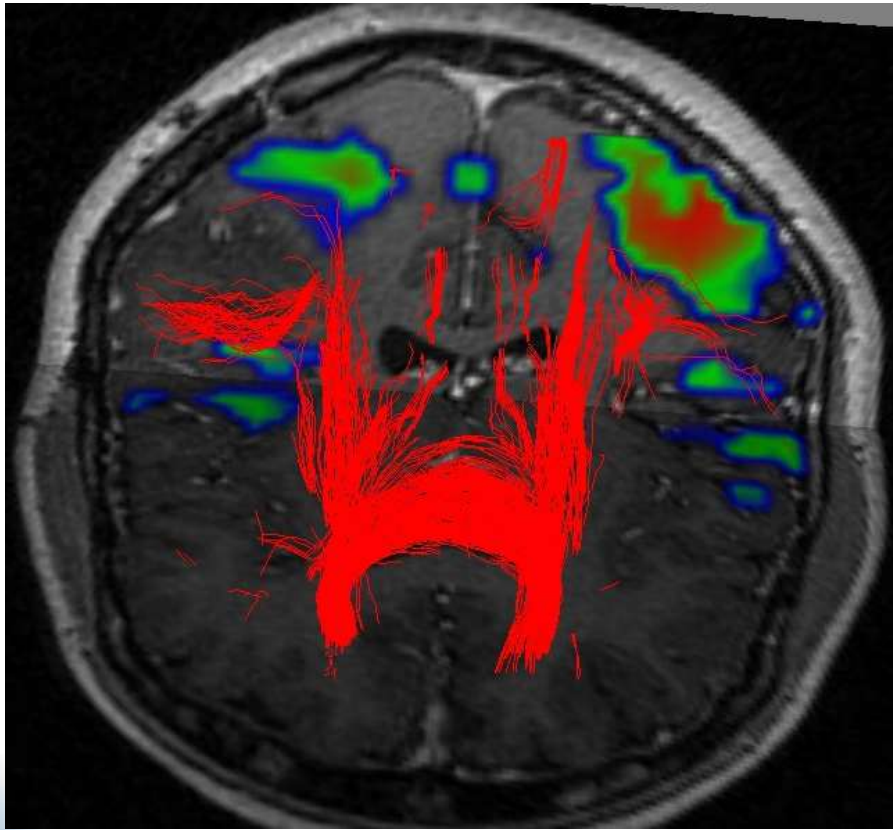


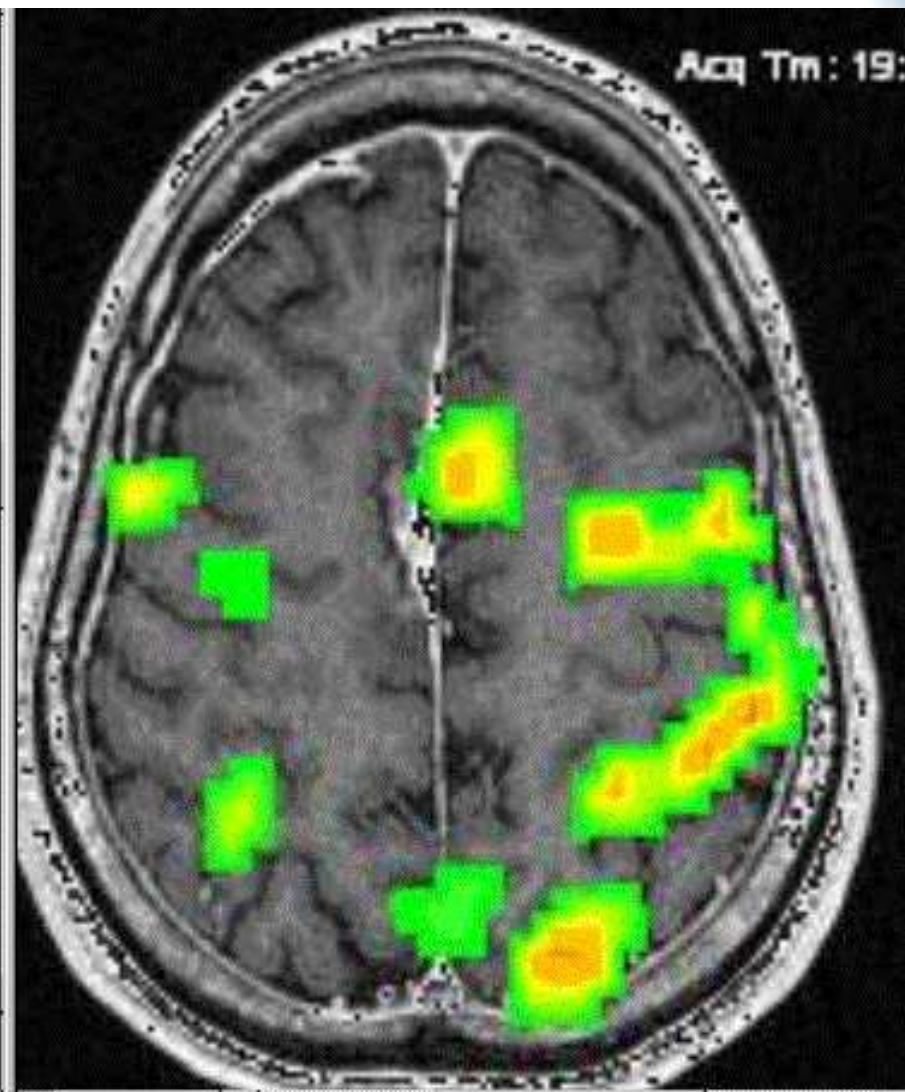
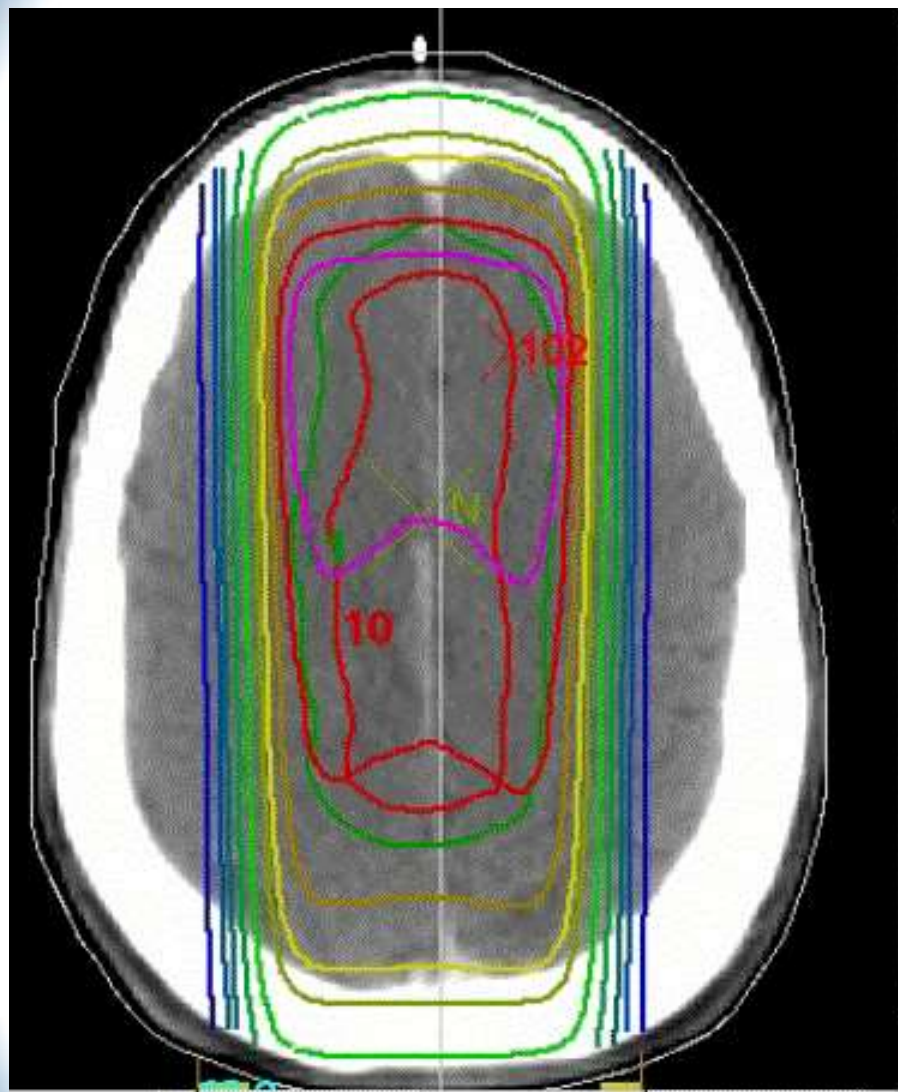


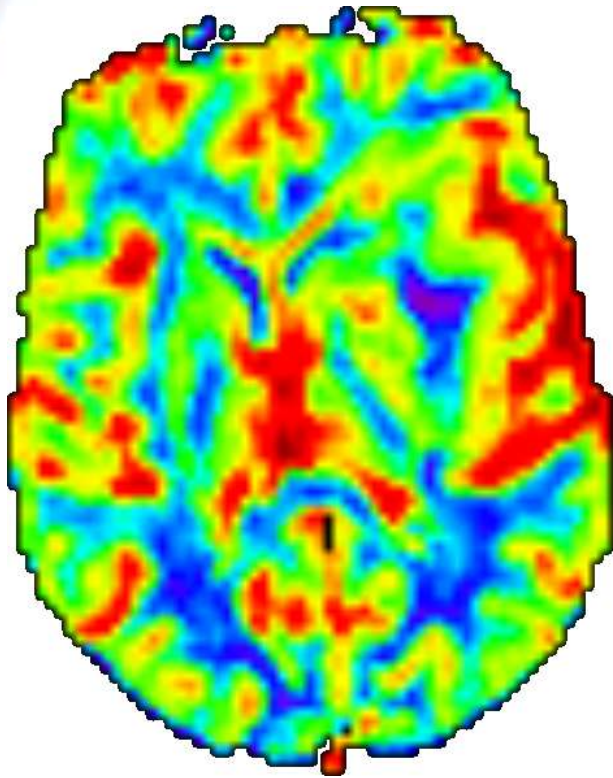


7.5 Bilan Pré-Radiothérapie

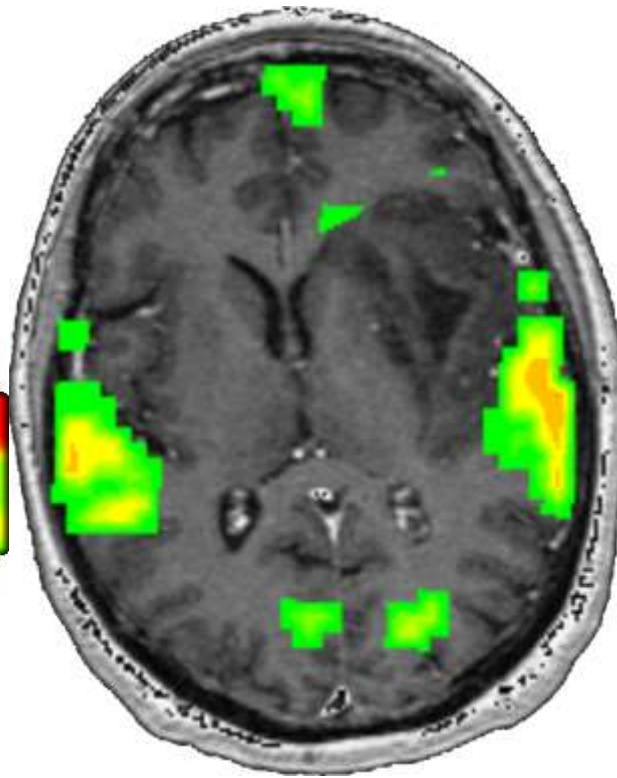




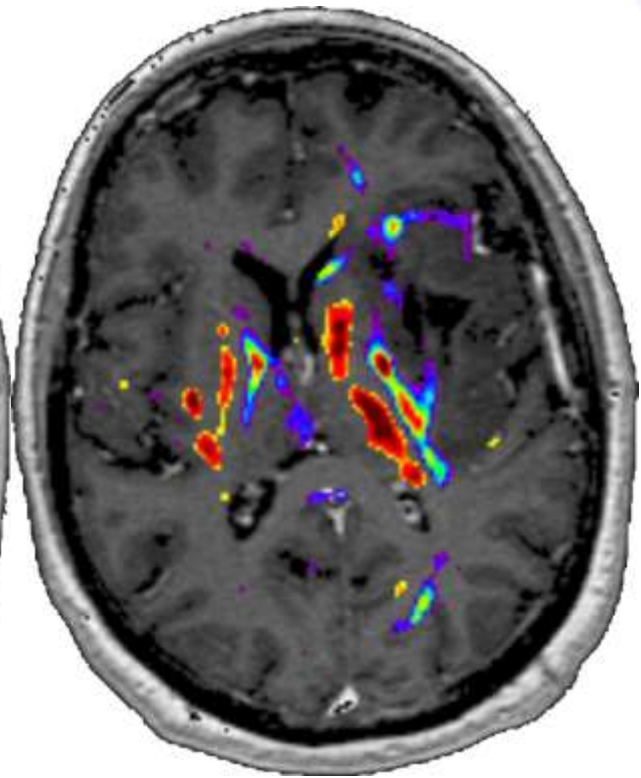




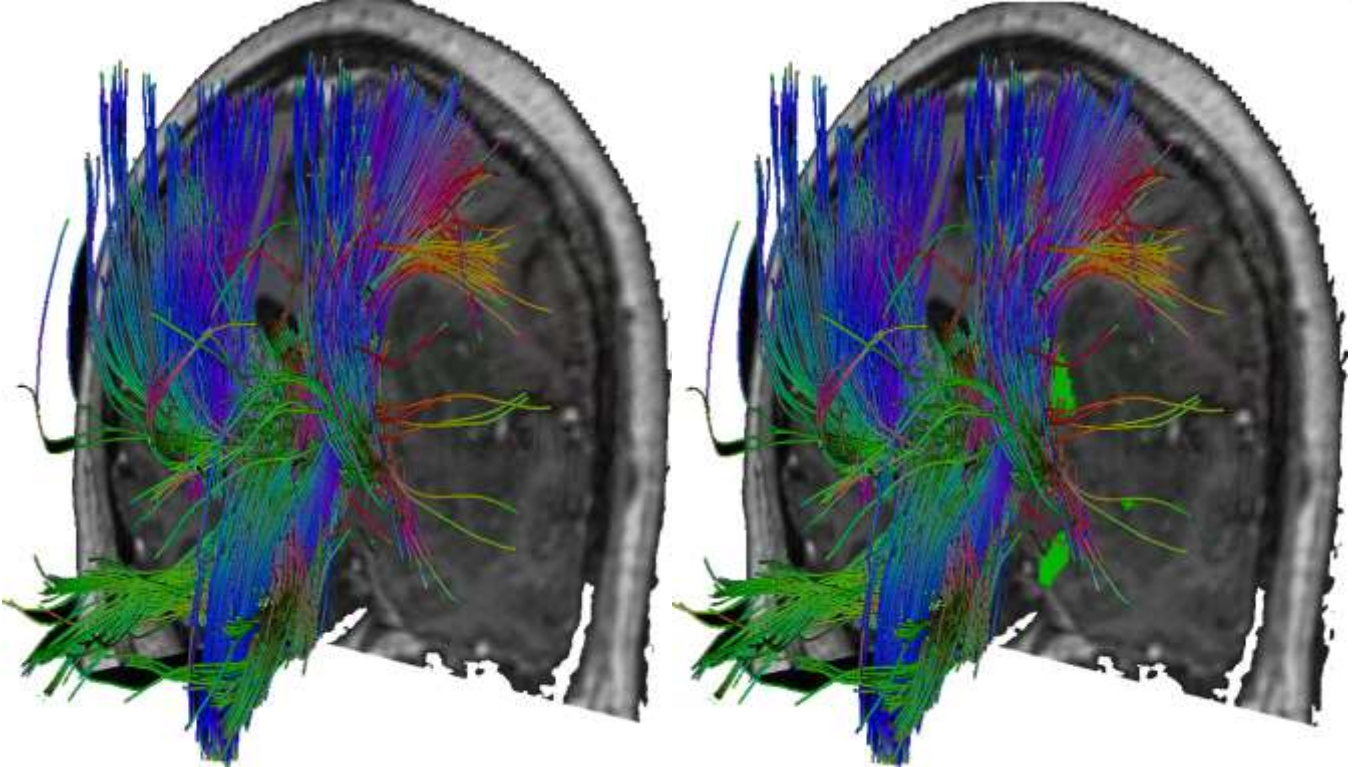
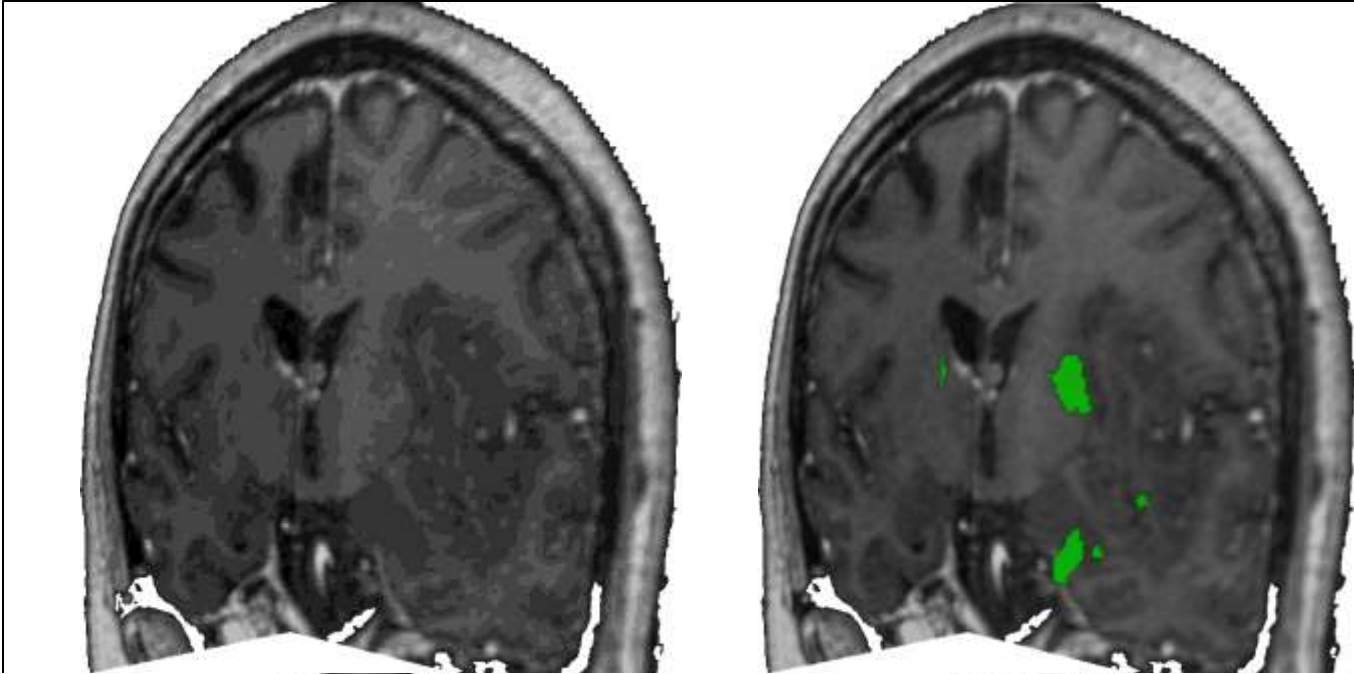
CBV

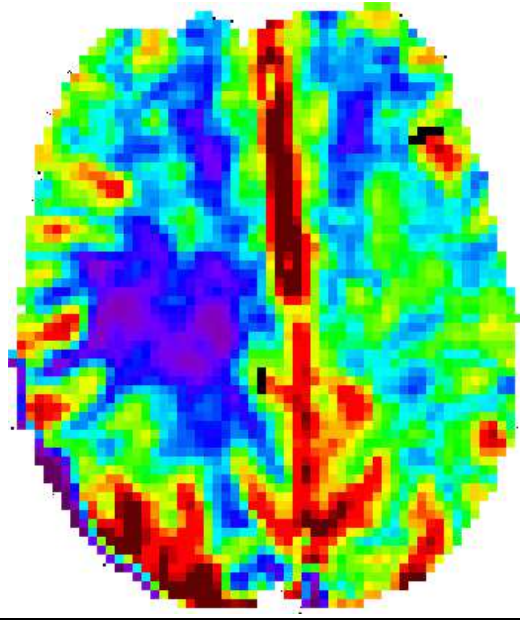
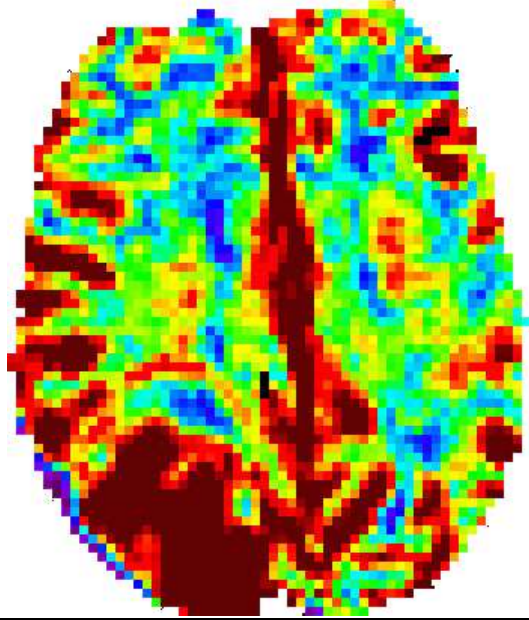
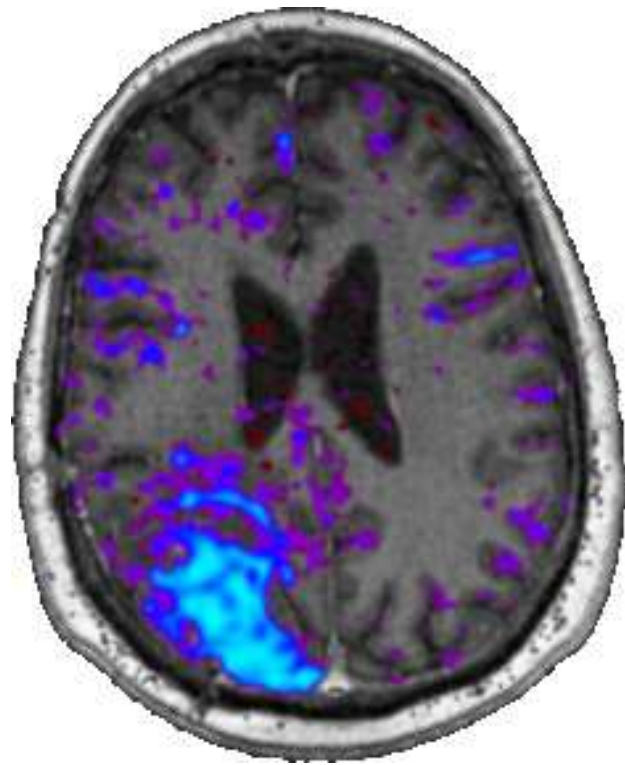
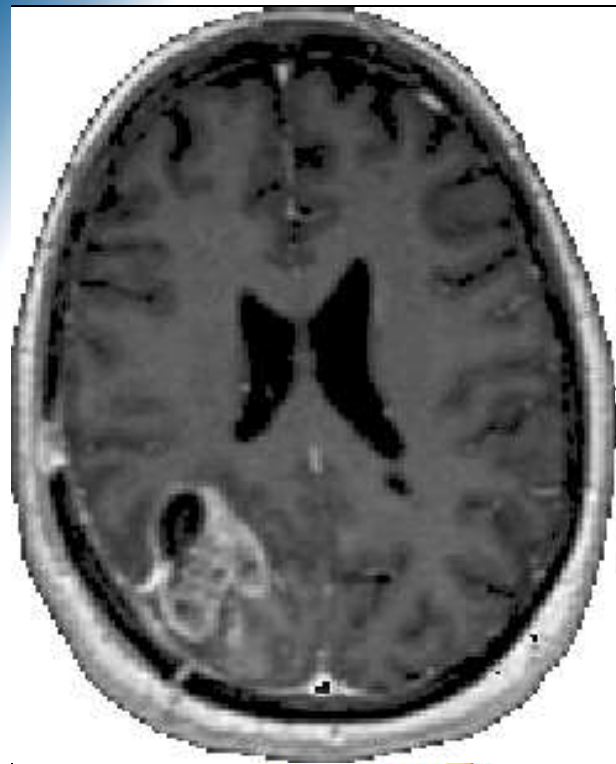


IRMf



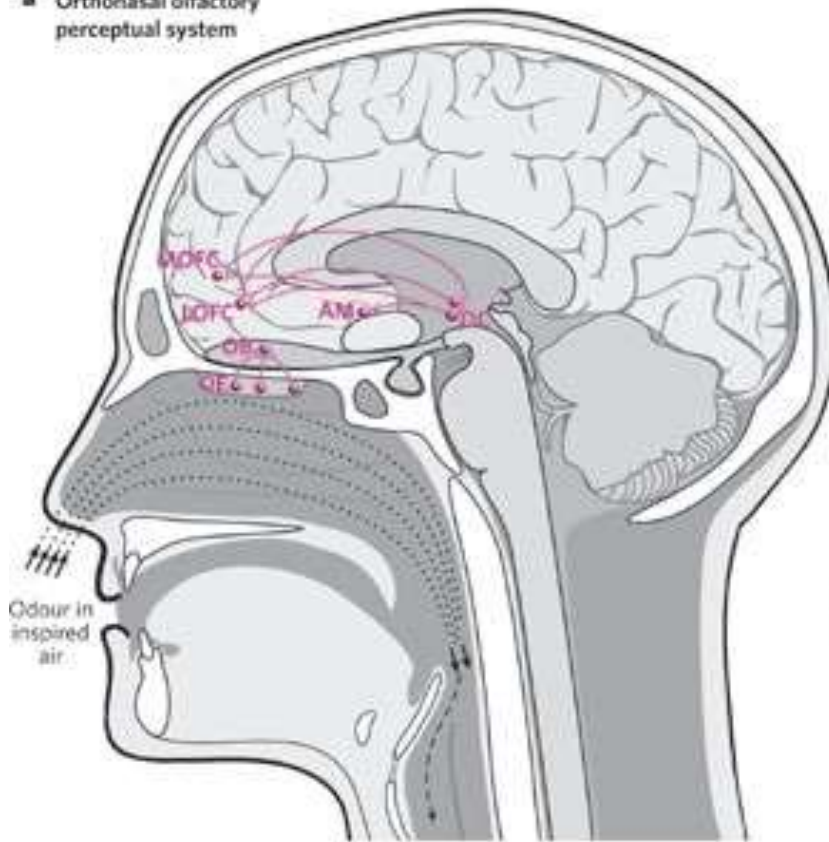
Z Score



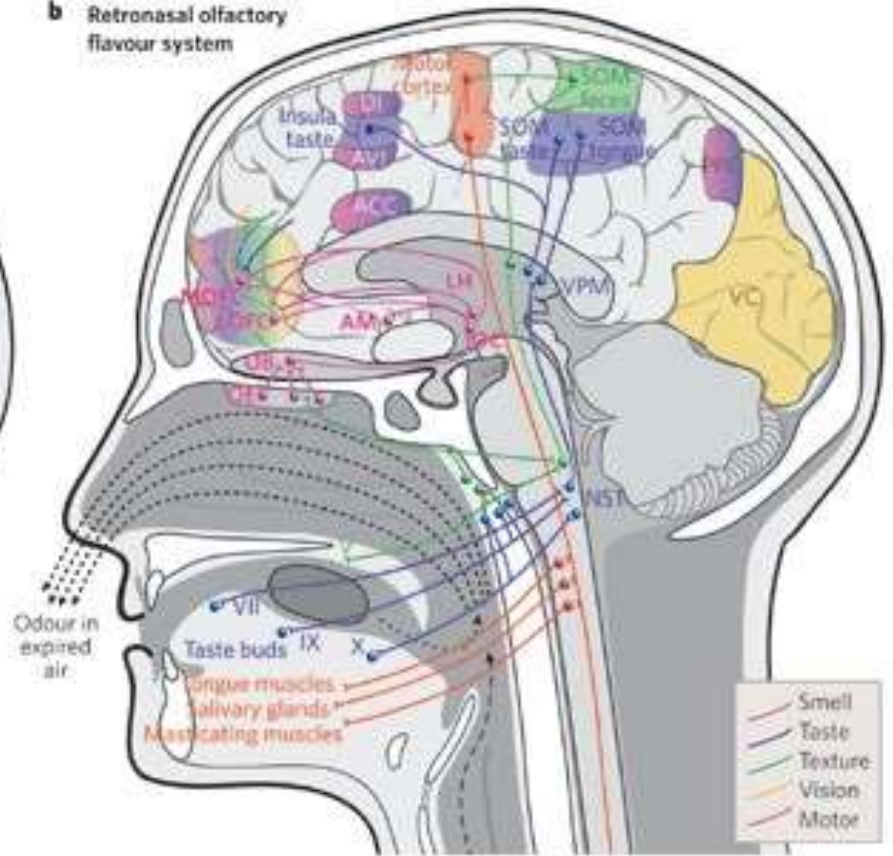


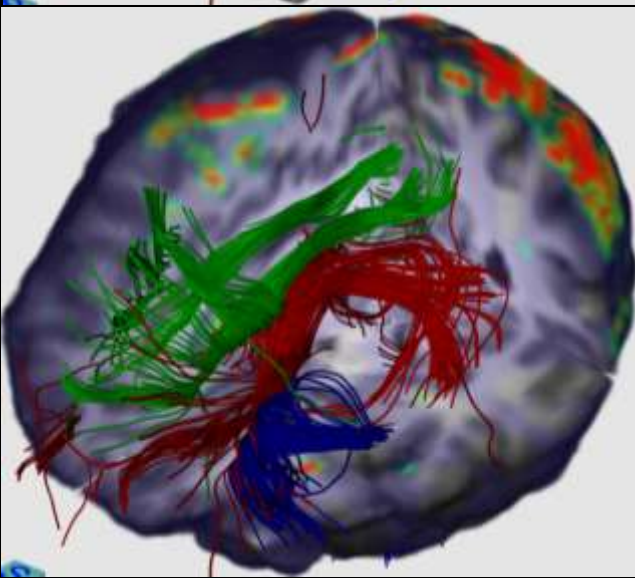
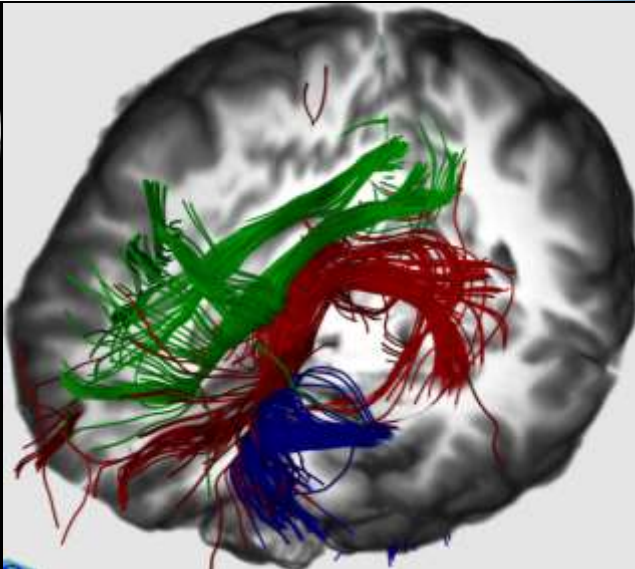
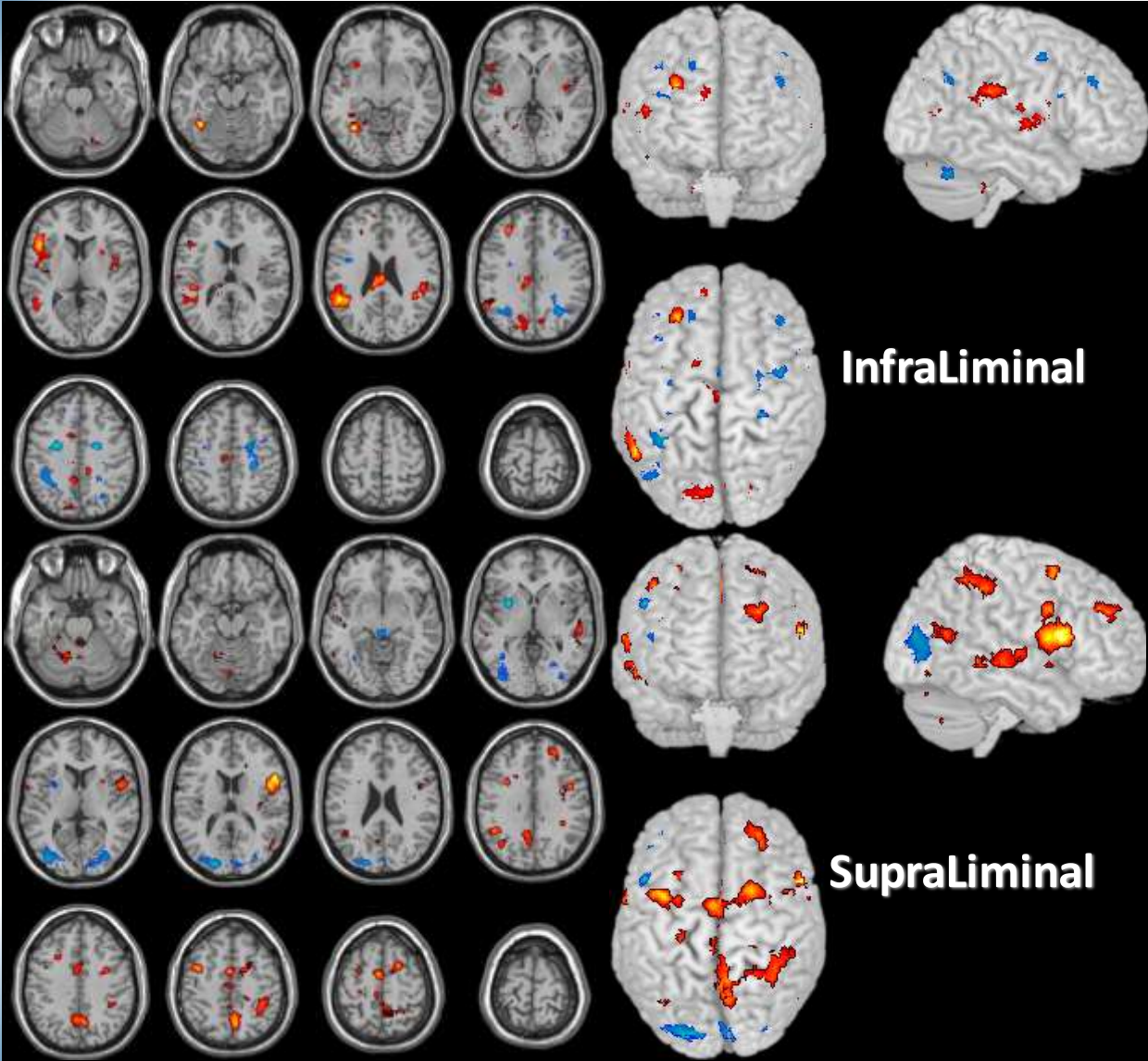
7.6 IRM Fonctionnelle Olfactive

a Orthonasal olfactory perceptual system



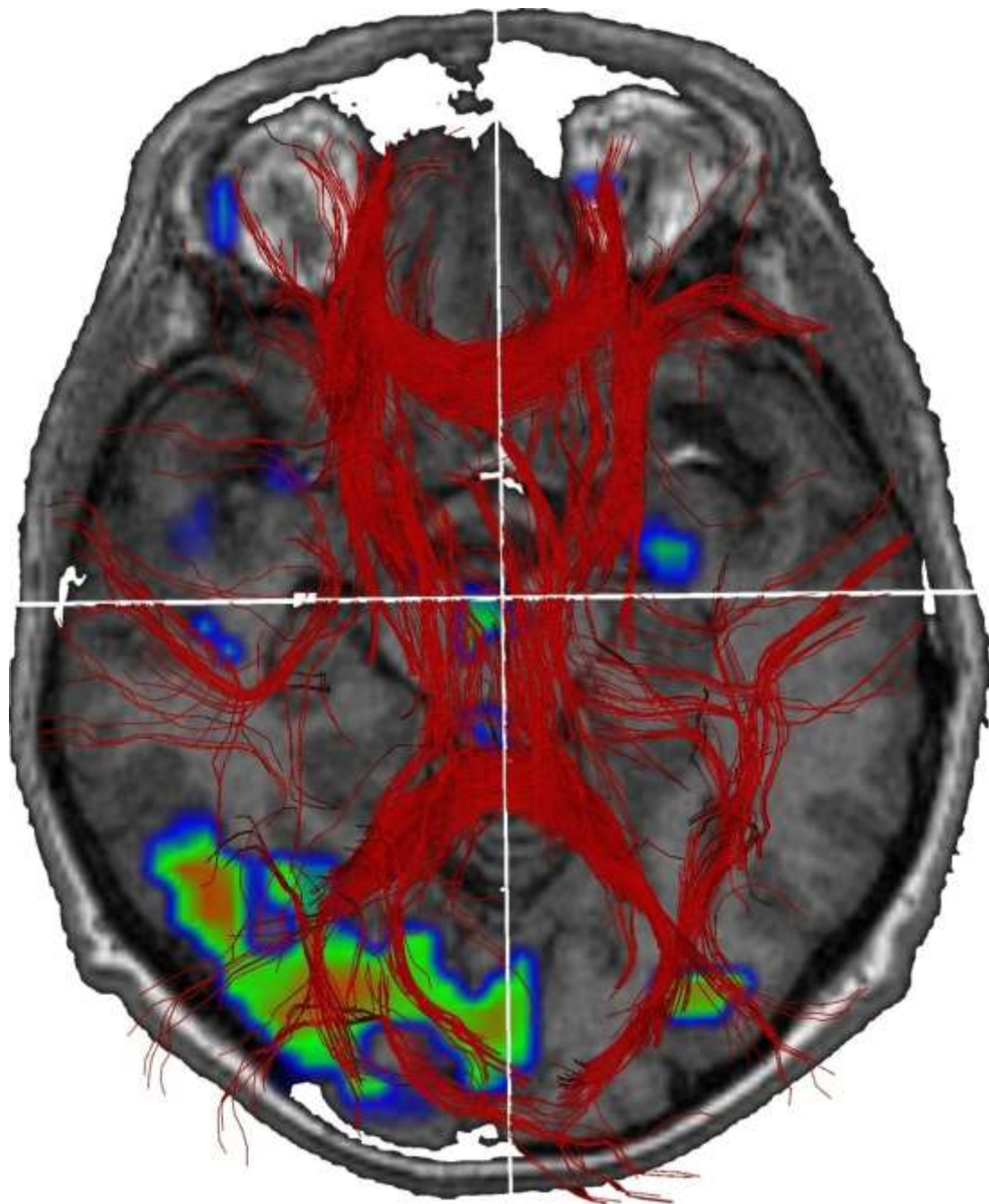
b Retronasal olfactory flavour system





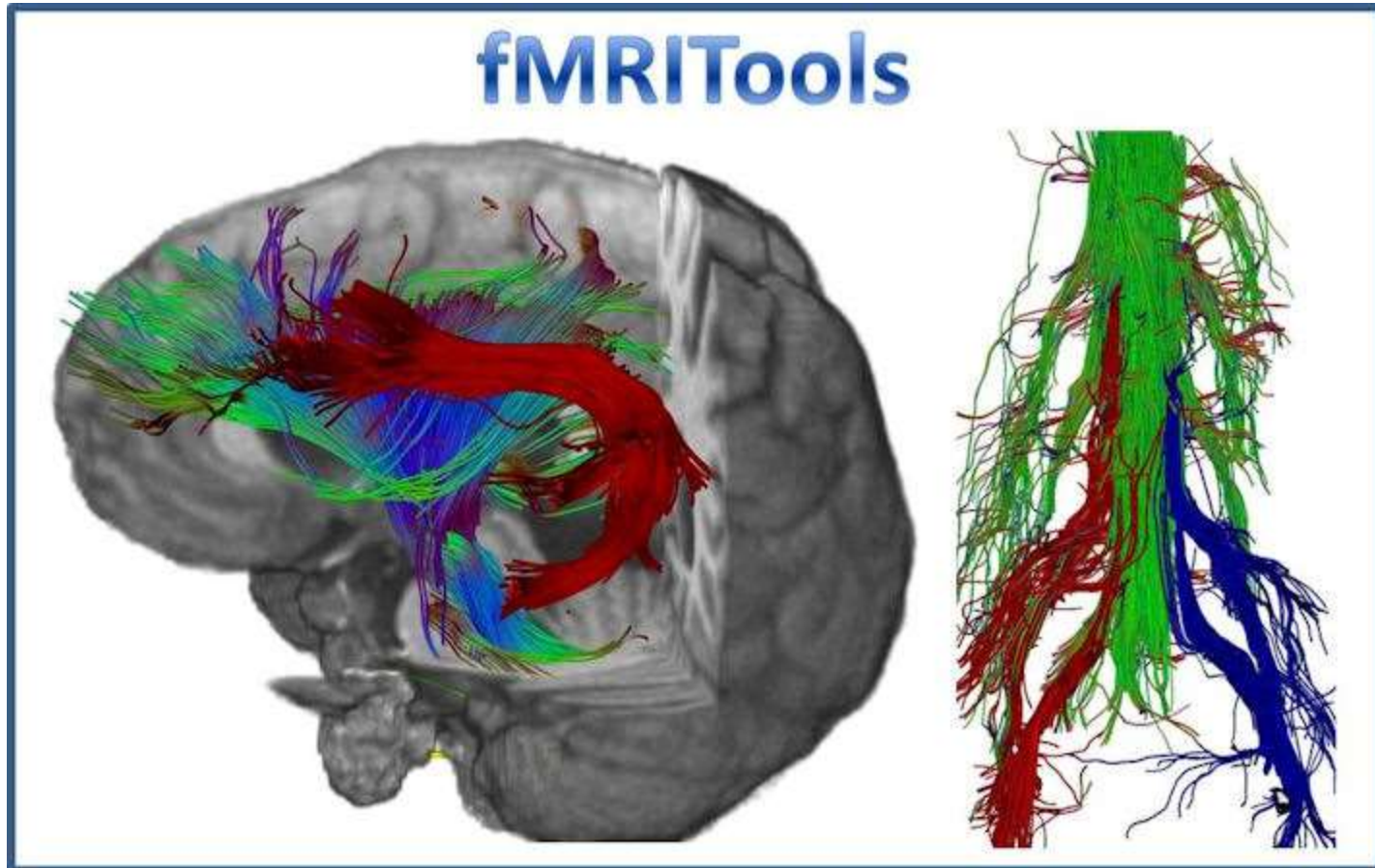


8. Conclusions



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