

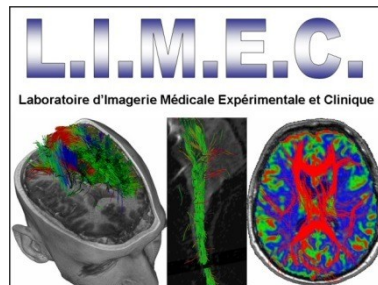


UNIVERSITÉ
PARIS-SUD 11

Tractographie Médullaire

Pr Denis Ducreux
Neuroradiologie, CHU Bicetre
CNRS IR4M (UMR 8081),
Université Paris 11

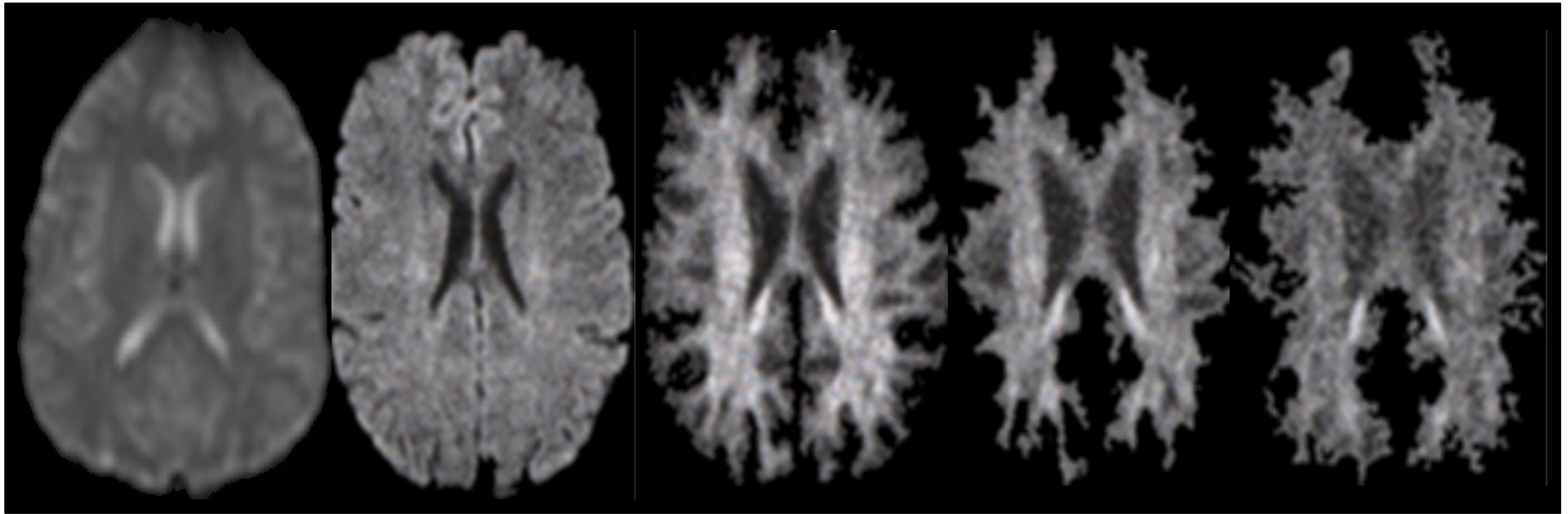
Hôpitaux
universitaires
Paris-Sud
Antoine-Béclère Bicêtre Paul-Brousse



Principes

IRM de DIFFUSION

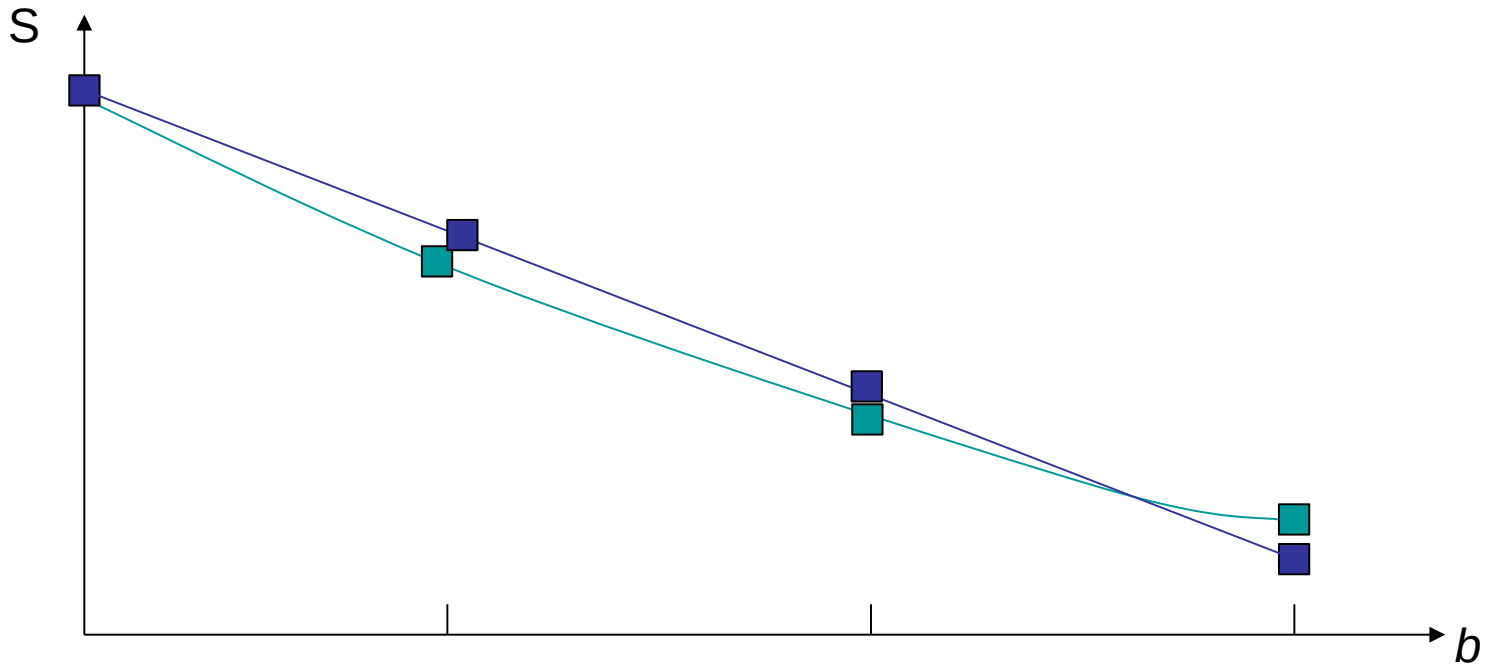
Séquence de Diffusion



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

Modèles mono et bi-compartmentaux

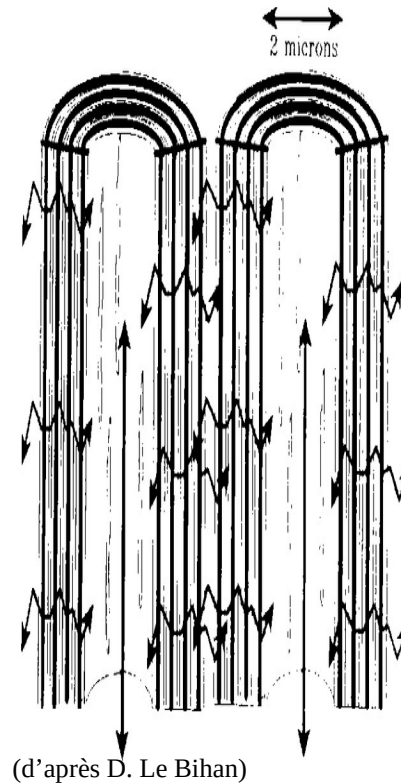
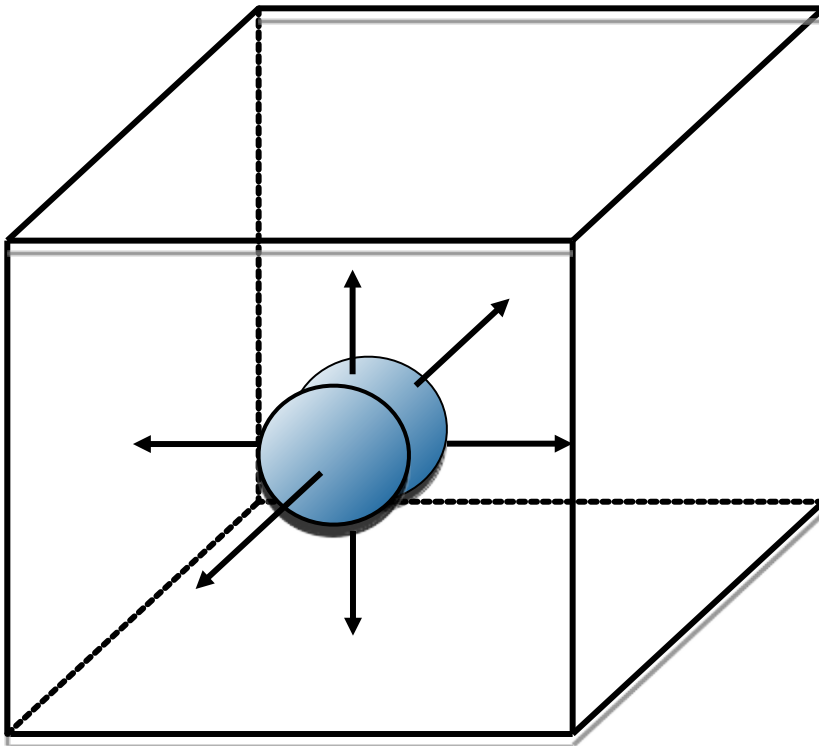


$$S_b = S_0 \cdot e^{-b \cdot D} \text{ versus } S_i(te, b) = [S_a \cdot e^{-te/T2a} \cdot e^{-b \cdot Da}] + [S_b \cdot e^{-(te/T2b)} \cdot e^{-b \cdot Db}]$$

IRM de Tenseur de

Méthode de Diffusion Oeuvre

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



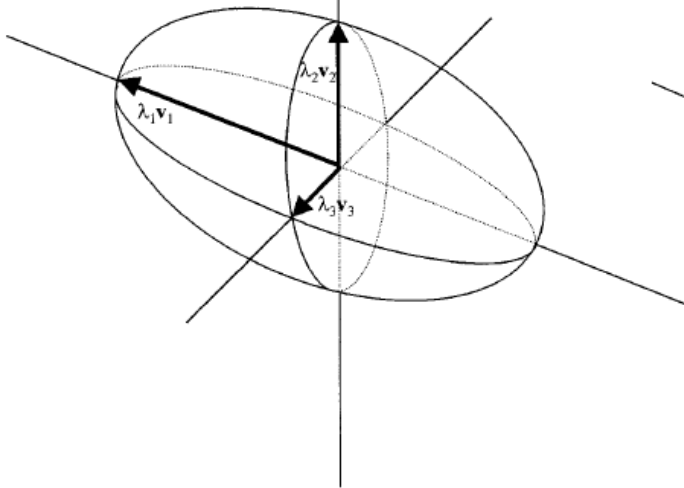
IRM de Tenseur de

Méthode de Diffusion

Oeuvre

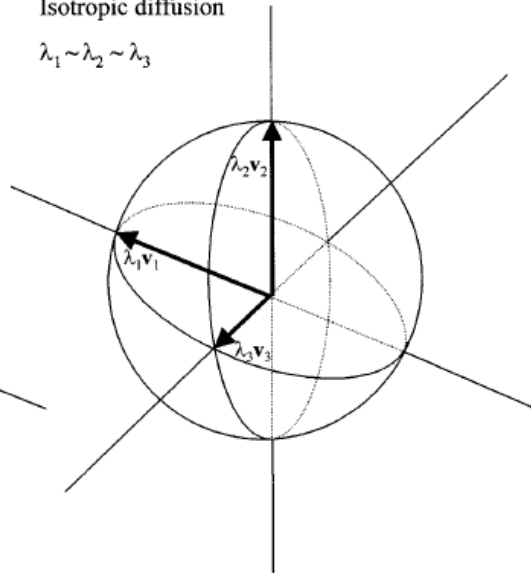
Anisotropic diffusion

$$\lambda_1 \geq \lambda_2 \geq \lambda_3$$



Isotropic diffusion

$$\lambda_1 \sim \lambda_2 \sim \lambda_3$$



v_1, v_2 et v_3
directions

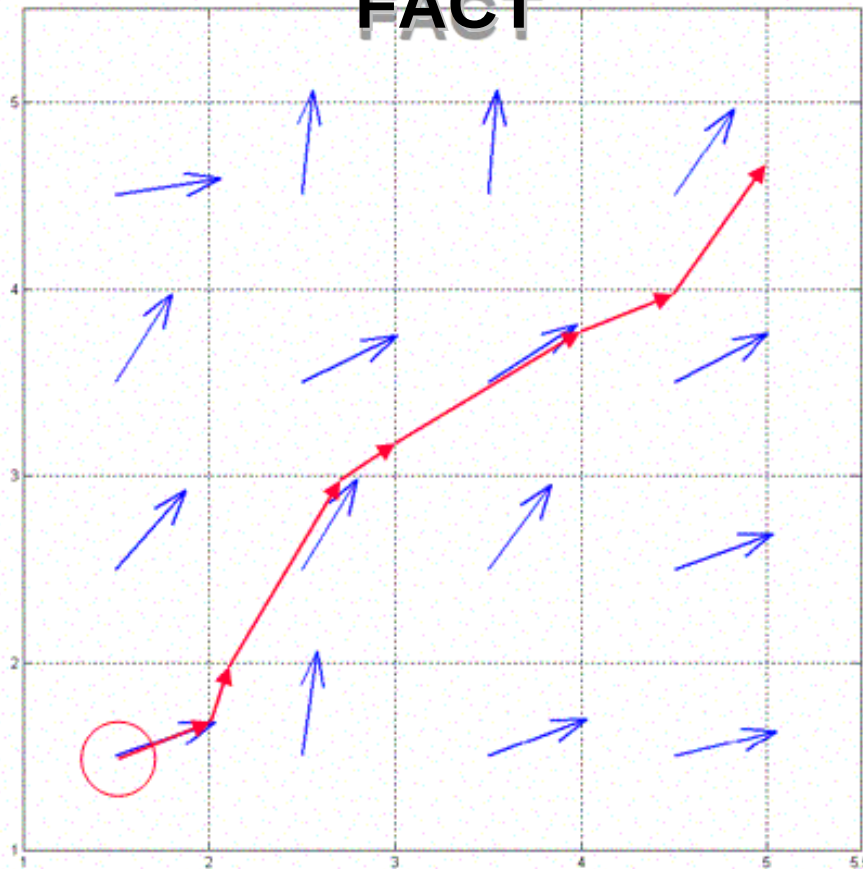
λ_1, λ_2 et λ_3
valeurs propres
(longueurs)

- 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

Tractographie par Modèles de Diffusion

FACT



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

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

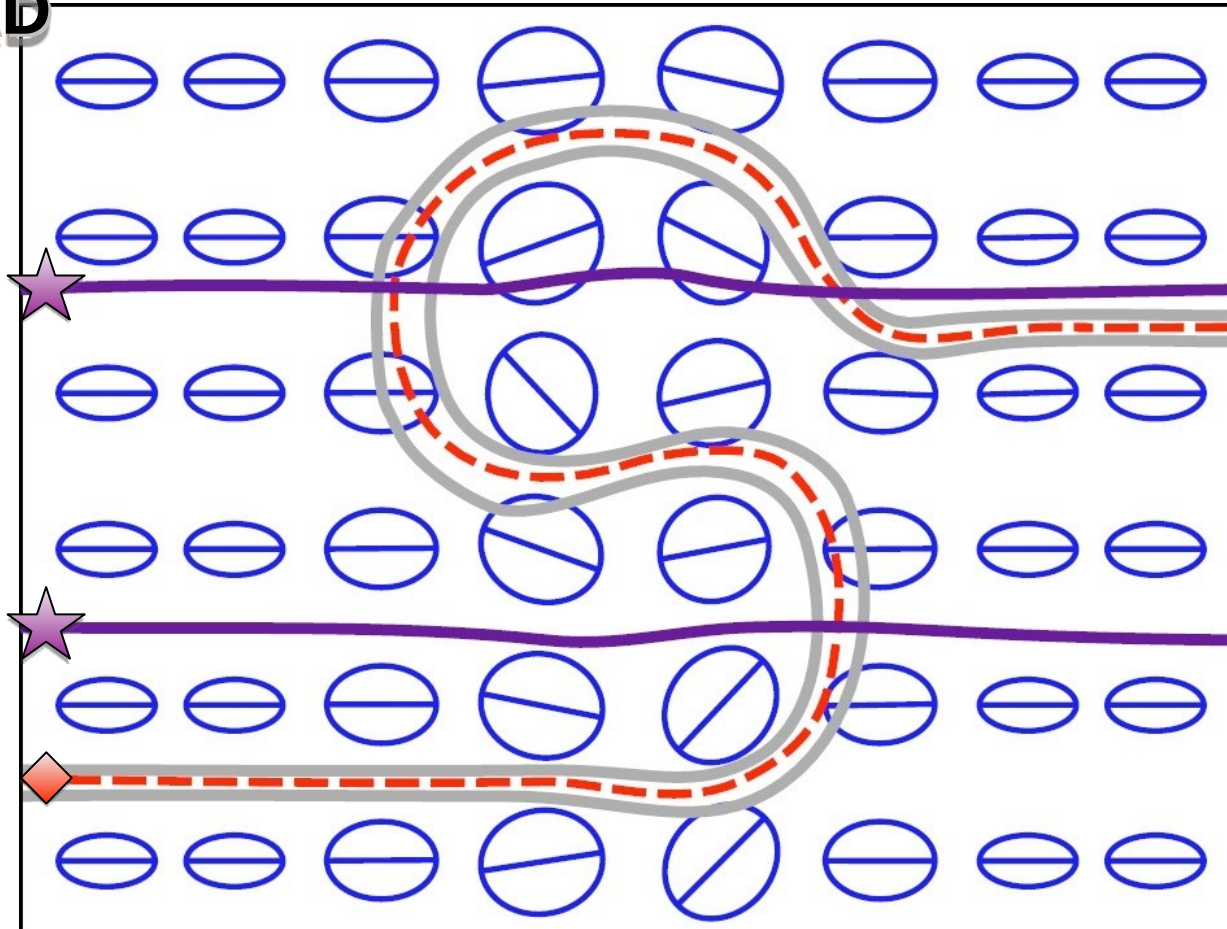
Avec :

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

IRM de Tenseur de

Tractographie Diffusion /

AD



Streamline vs Advection - Diffusion

IRM de Tenseur de

Méthodologie et Mise en Oeuvre

- Acquisitions Sagittales ou Axiales, EPI, jointives (voxel isotrope, ex: 2x2x2 mm)
- Bandes de saturation en avant et en arrière
- Gating cardiaque (si moelle thoracique), et/ou co-registation
- ≥ 15 directions à 1.5 T (SNR +++), b entre 500 et 900 s/mm², 2 NEX

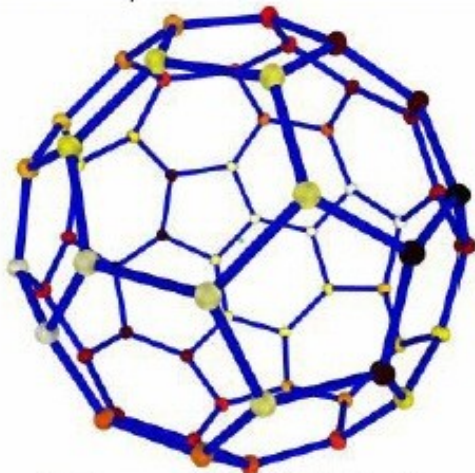
IRM de Tenseur de

Méthodes Diffusion

Oeuvre



Vector representation for 30 directions

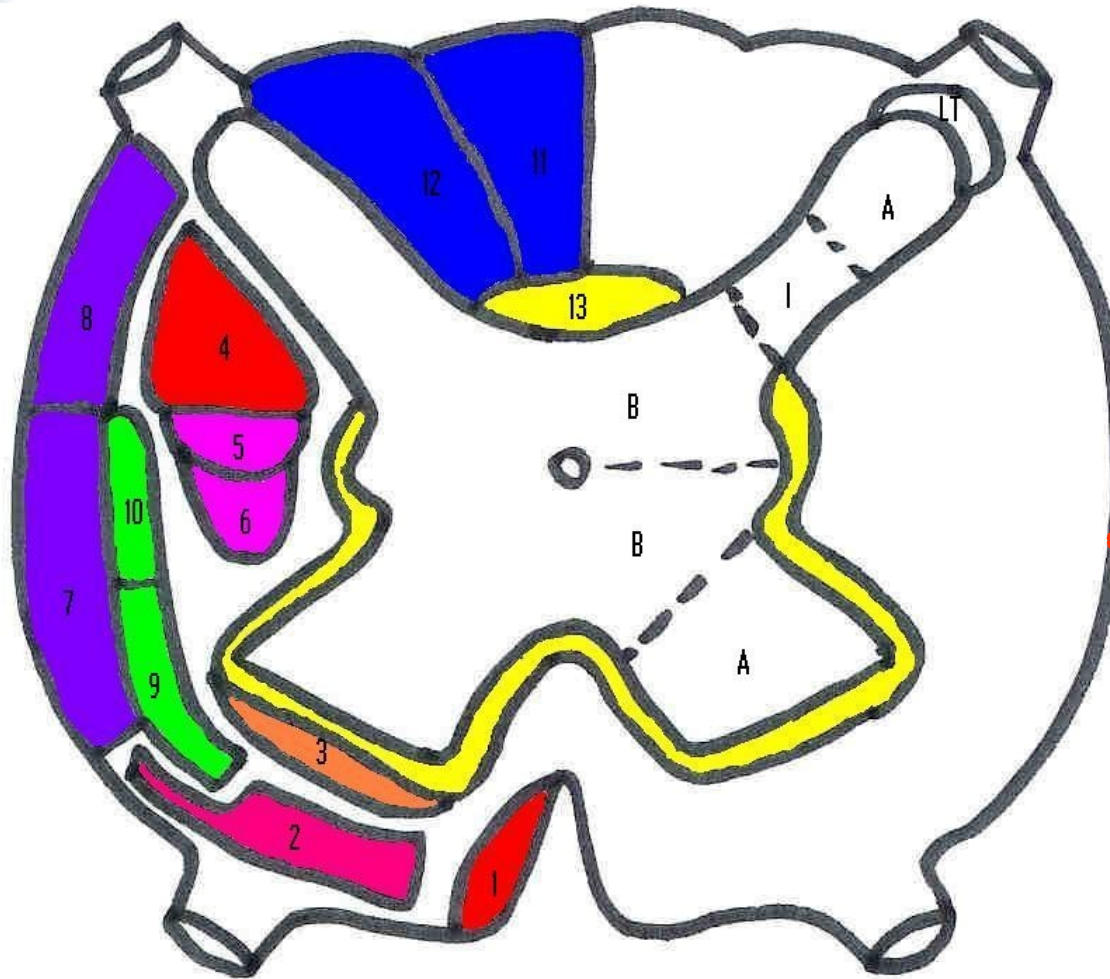


Point representation for 30 directions

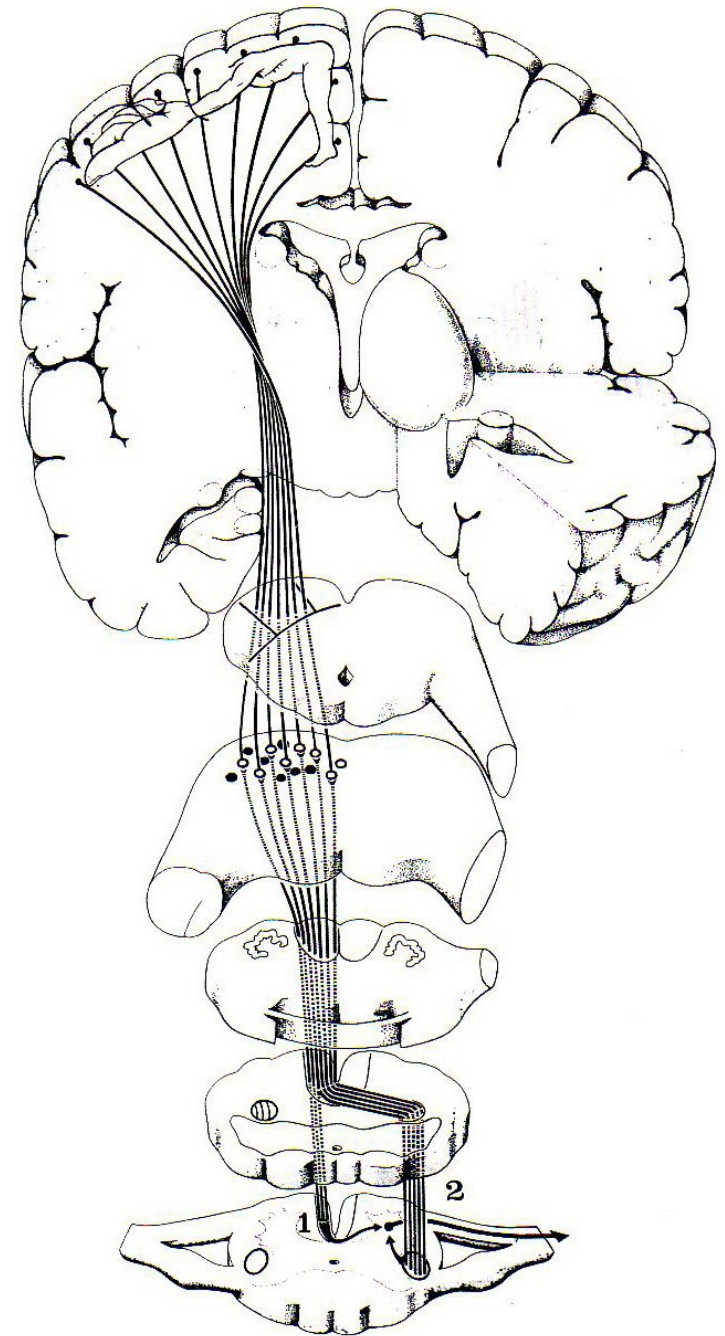
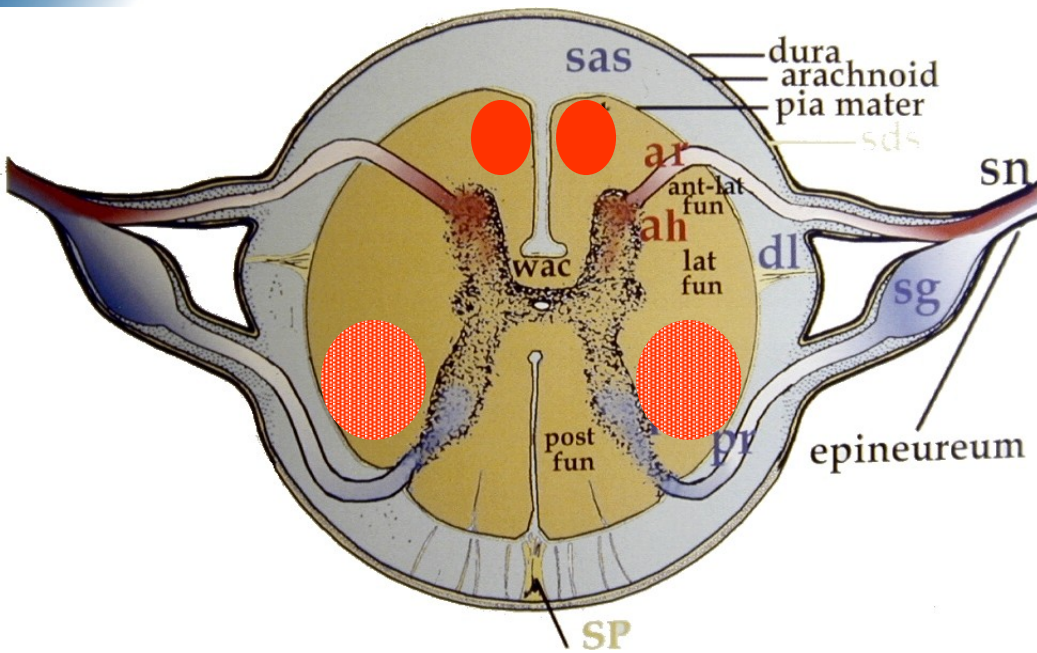
Choix du nombre de directions :

- 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 < 60)
- Corrections des macro-mouvements liée au nb de directions

Anatomie Médullaire Normale

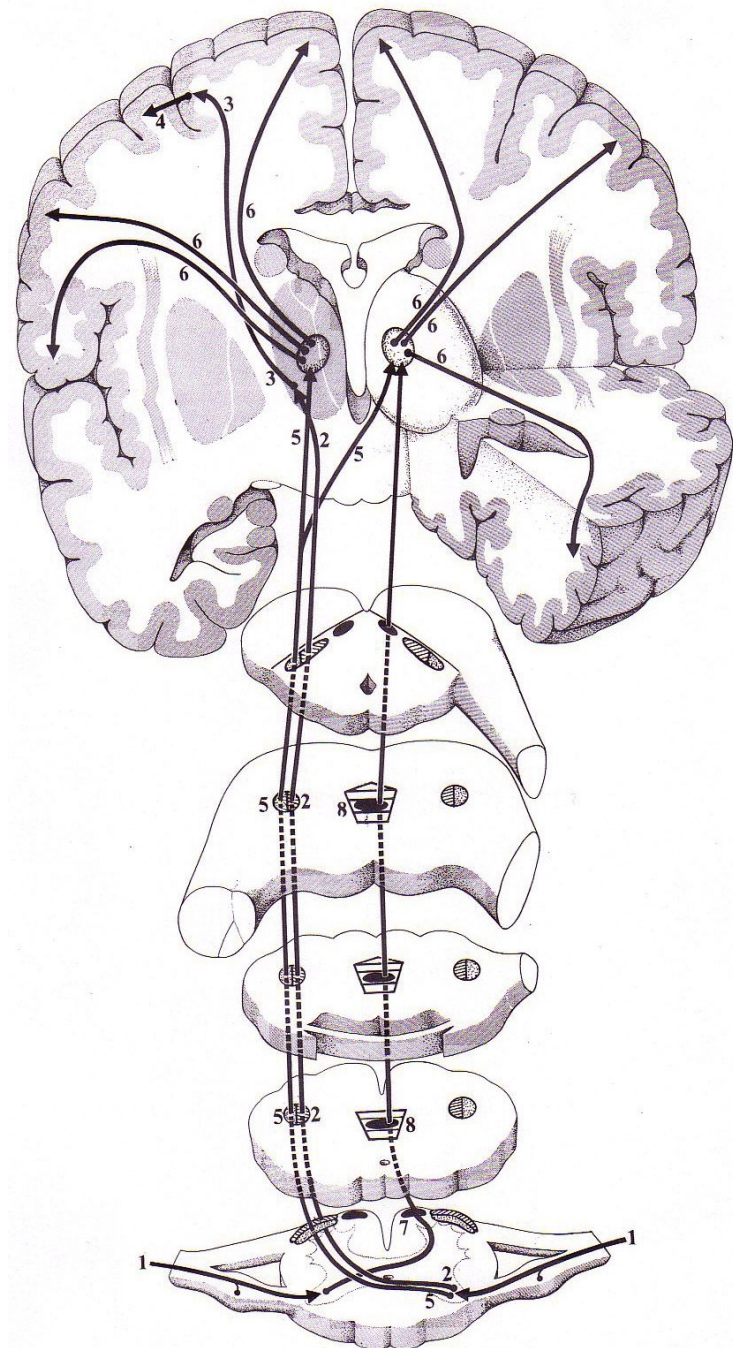
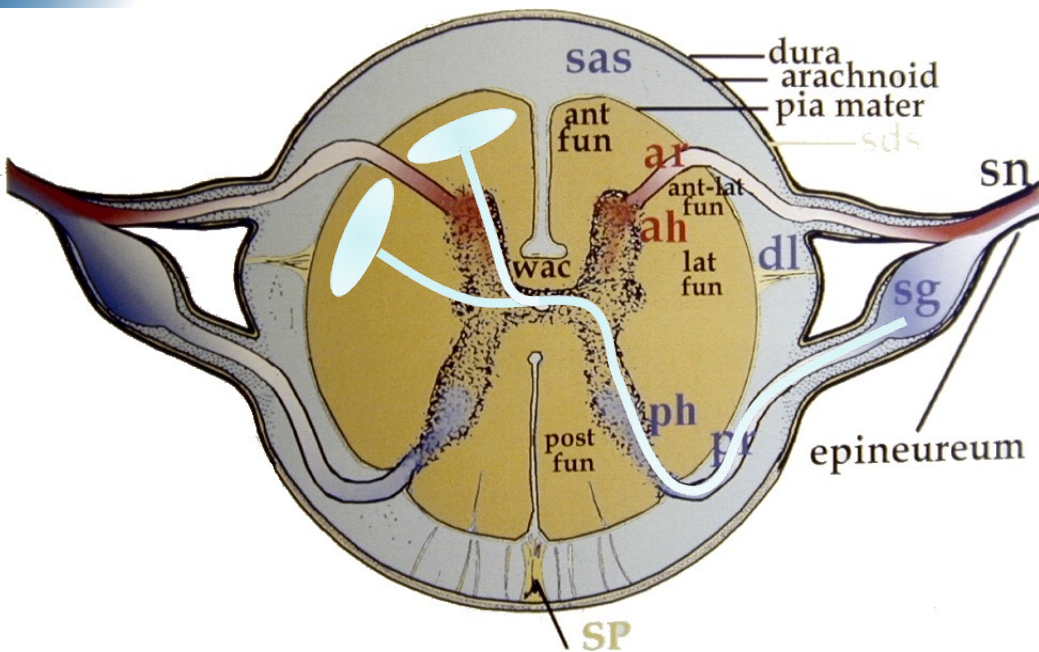


- 1-Faisceau cortico –spinal ventral
- 2-Champ de faisceaux extrapyramidaux
- 3-Faisceau tecto-spinal
- 4-Faisceau cortico-spinal dorsal
- 5-Faisceau rubro-spinal
- 6-Faisceau réticulo spinal latéral
- 7-Faisceau spino-cérébelleux ventral
- 8-Faisceau spino-cérébelleux dorsal
- 9-Faisceau spino-thalamique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



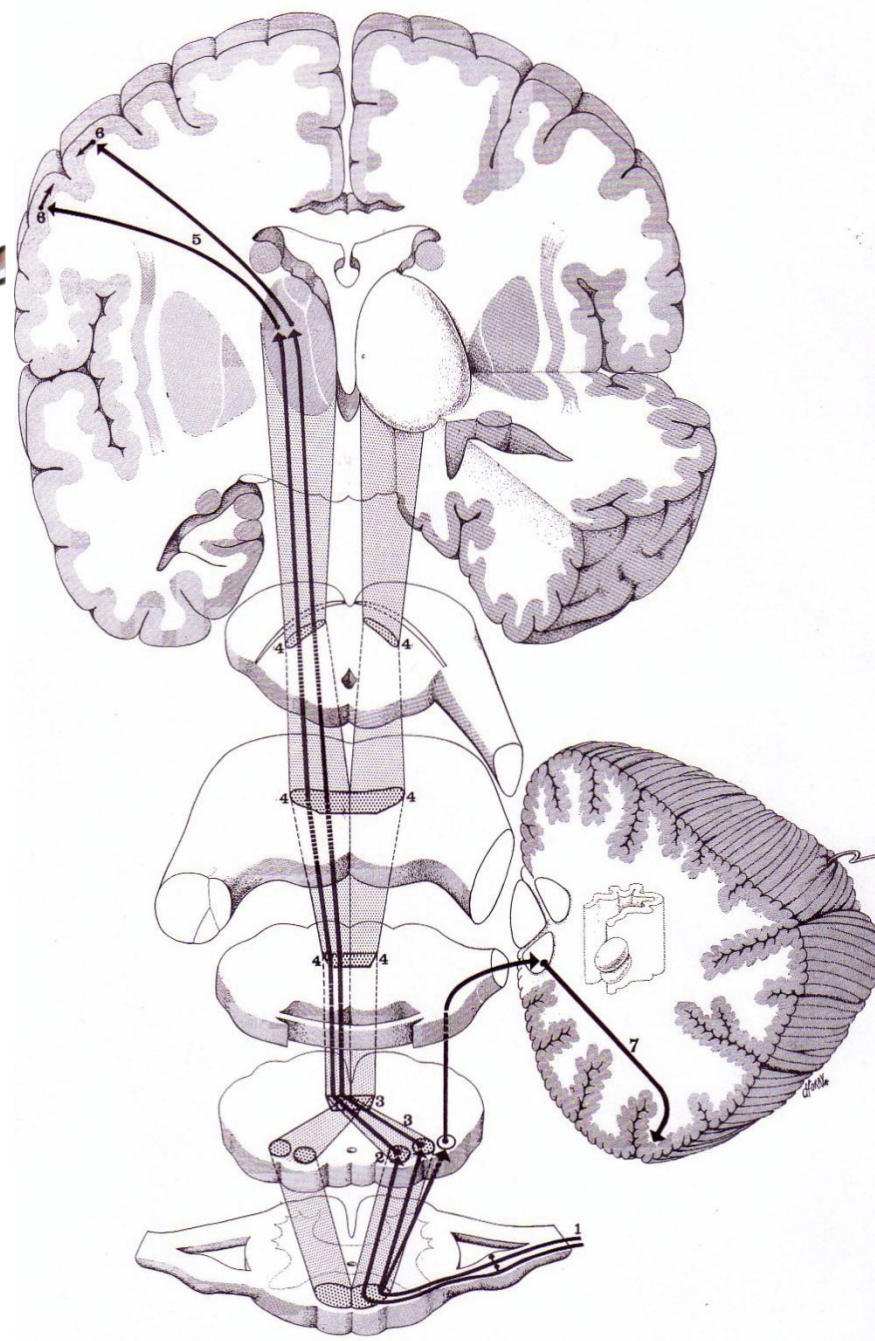
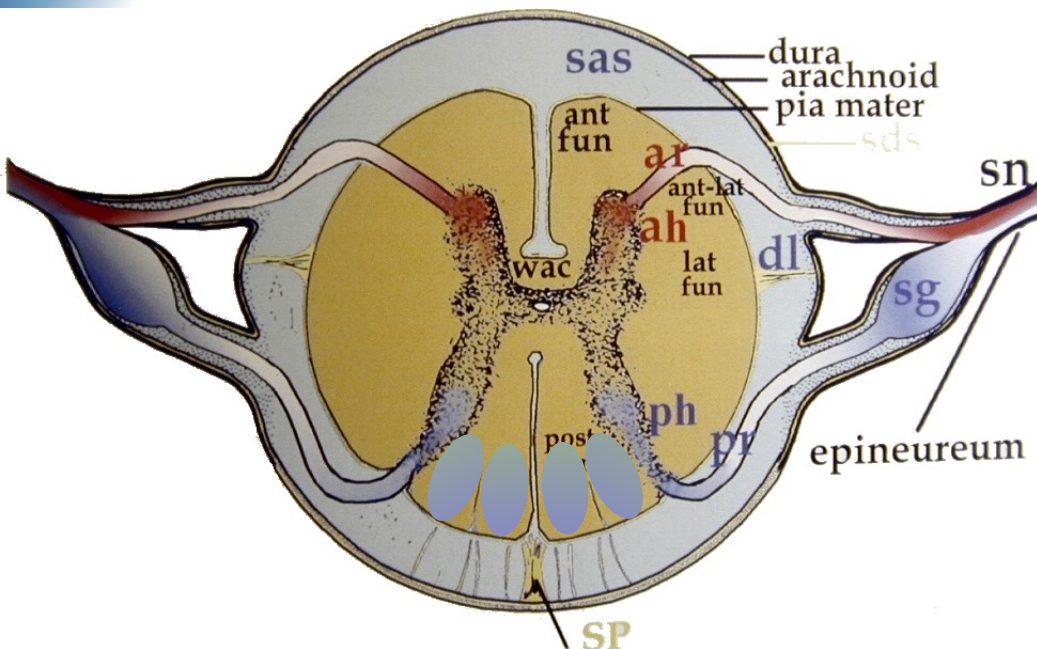
Voies motrices cortico-spinales

- *Faisceau latéral (décussation bulbaire : 80%)*
- *Faisceau ventral direct (20% des fibres)*



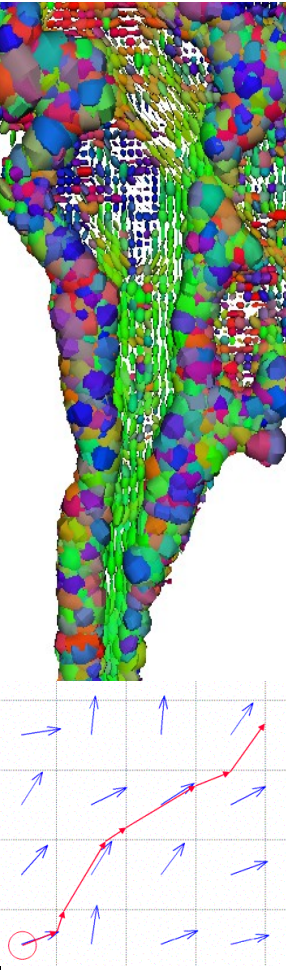
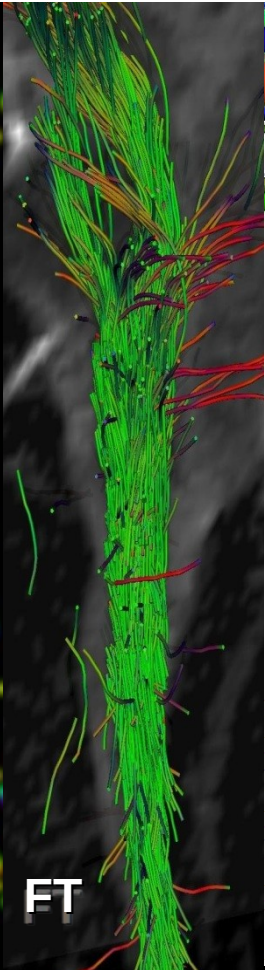
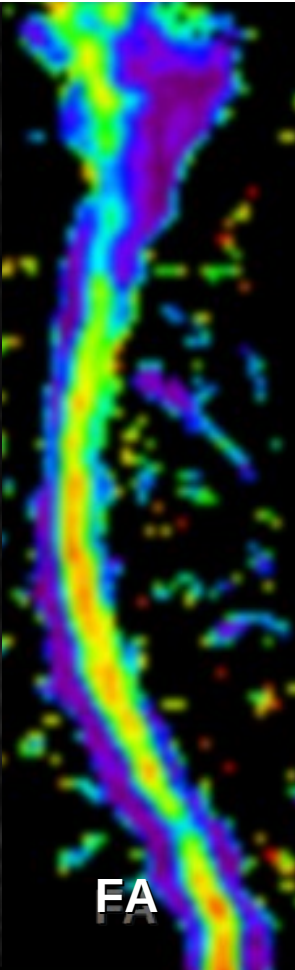
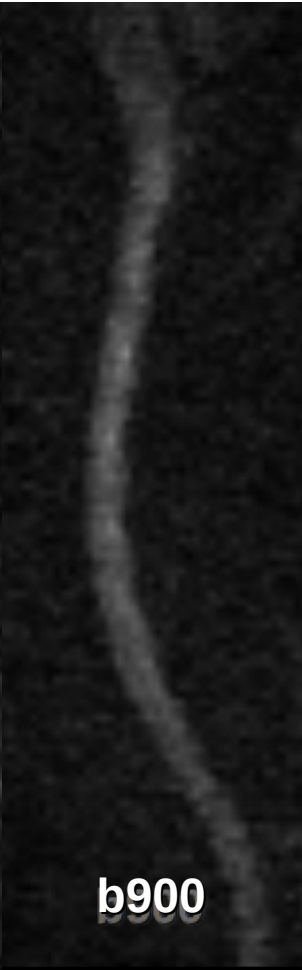
Voies sensibles extra lemniscales

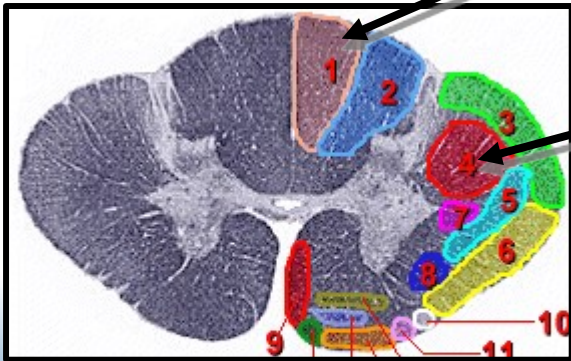
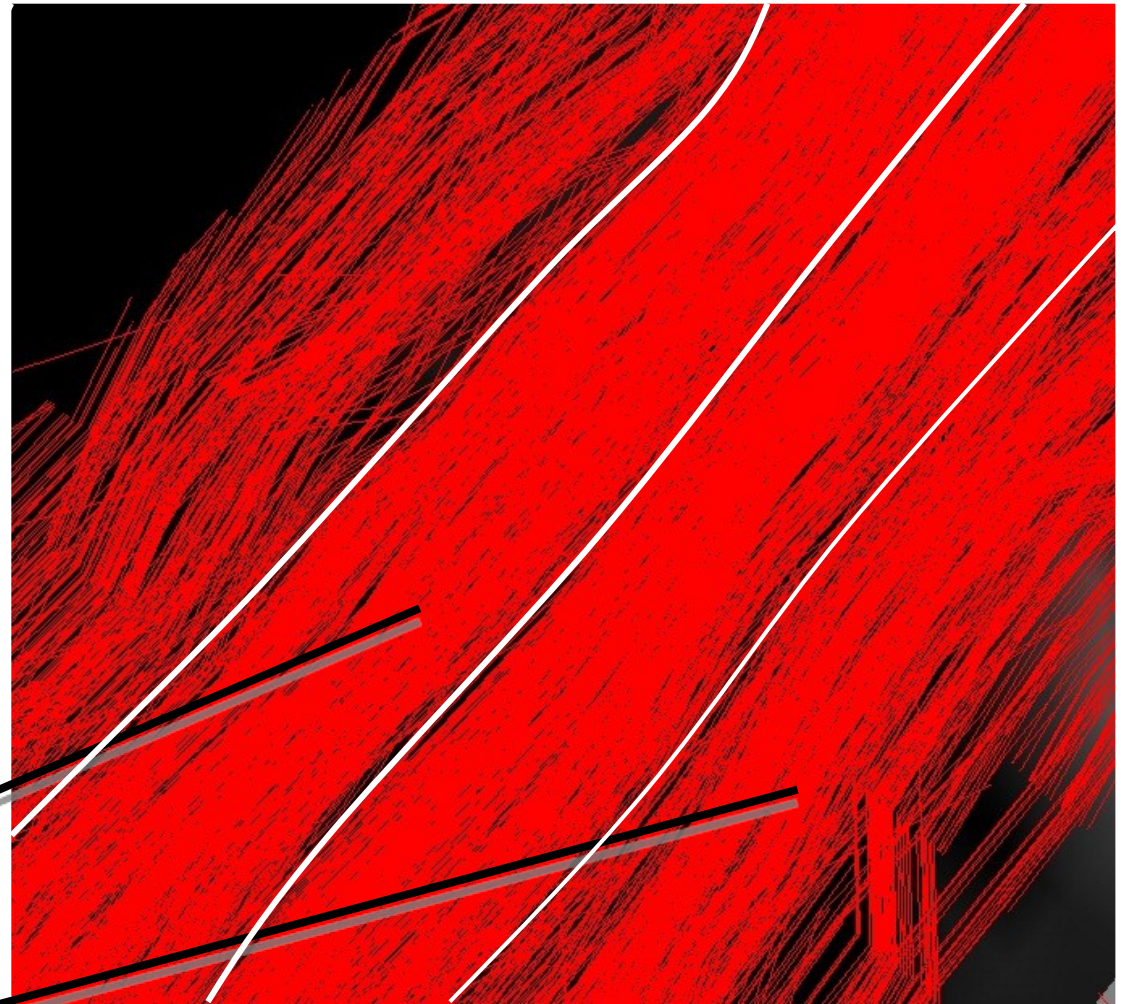
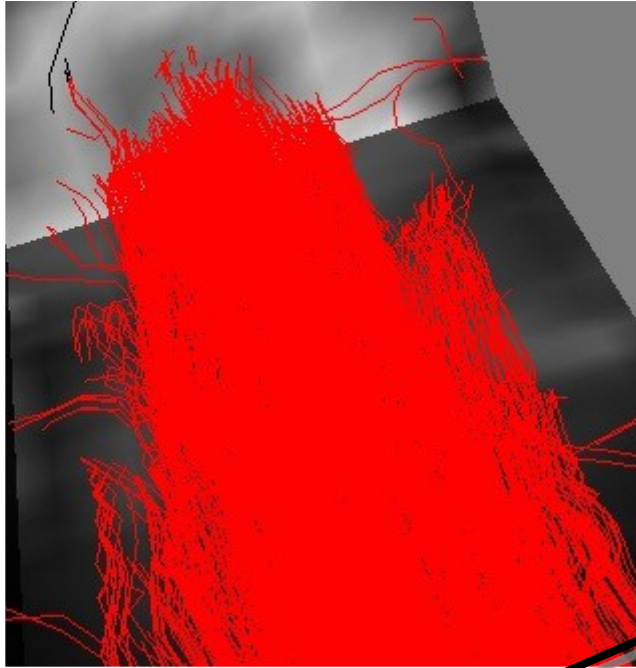
- **Faisceau spino-thalamique latéral**
 - Sensibilité thermique et douloureuse
- **Faisceau spino-thalamique antérieur**
 - Sensibilité tactile protopathique

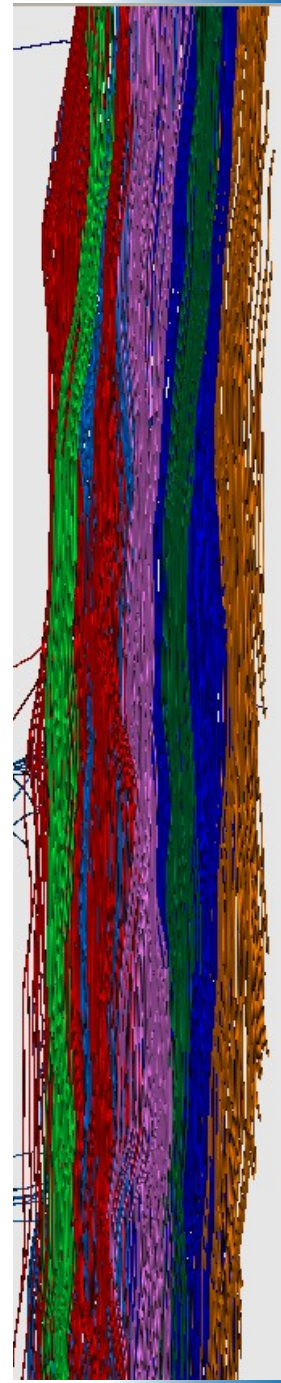
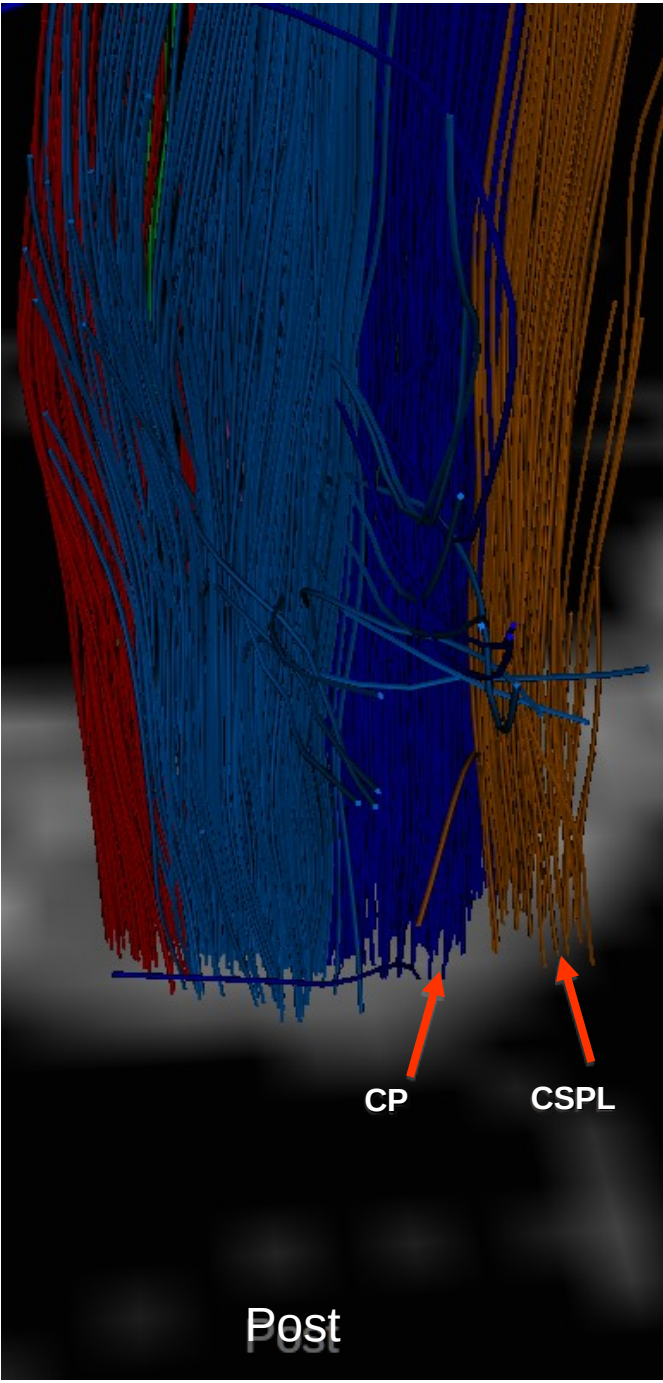
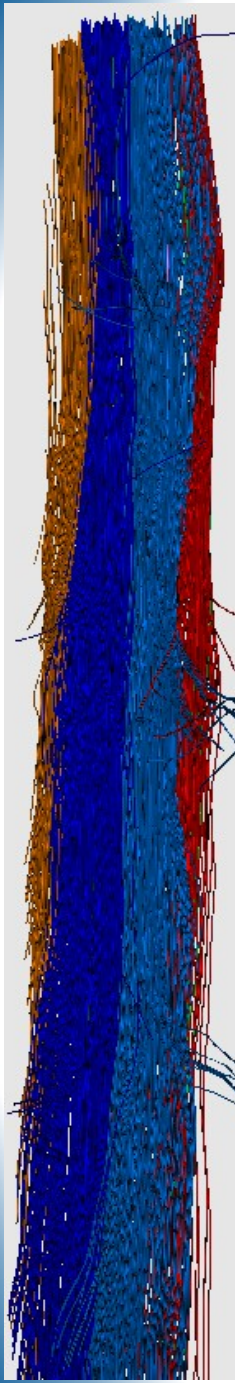


Voies sensibles lemniscales

- **Faisceau gracile médial**
- **Faisceau cunéiforme latéral**
- > **Sensibilité proprioceptive**







IRM de Tenseur de

Tractographie par Diffusion 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)

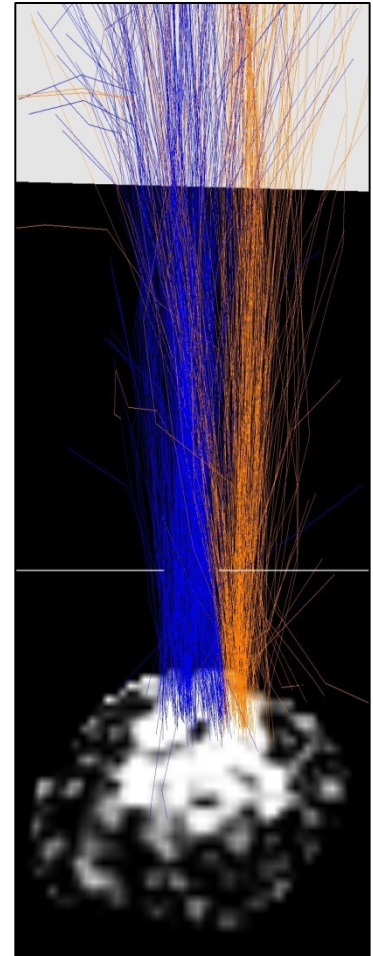
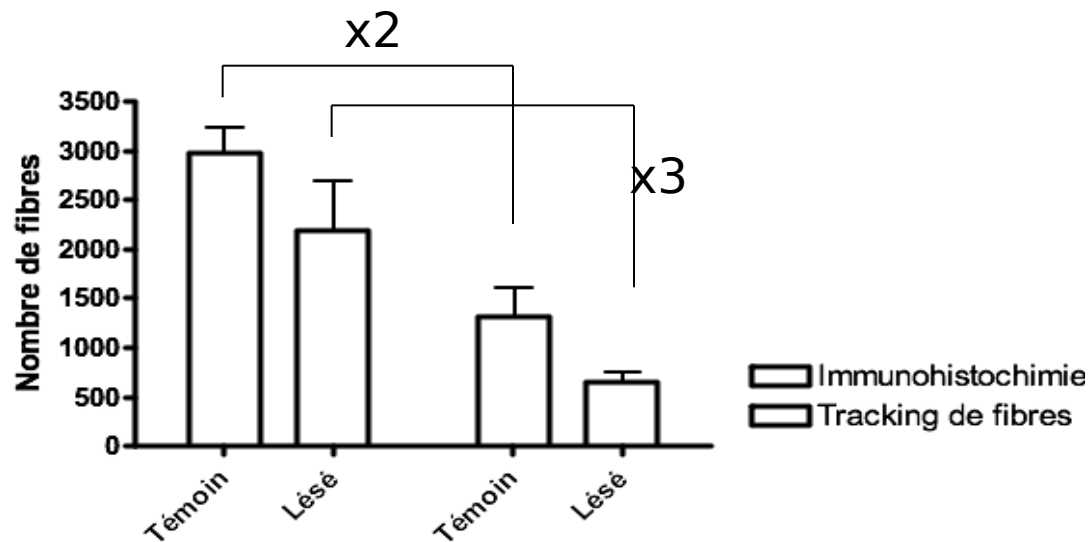
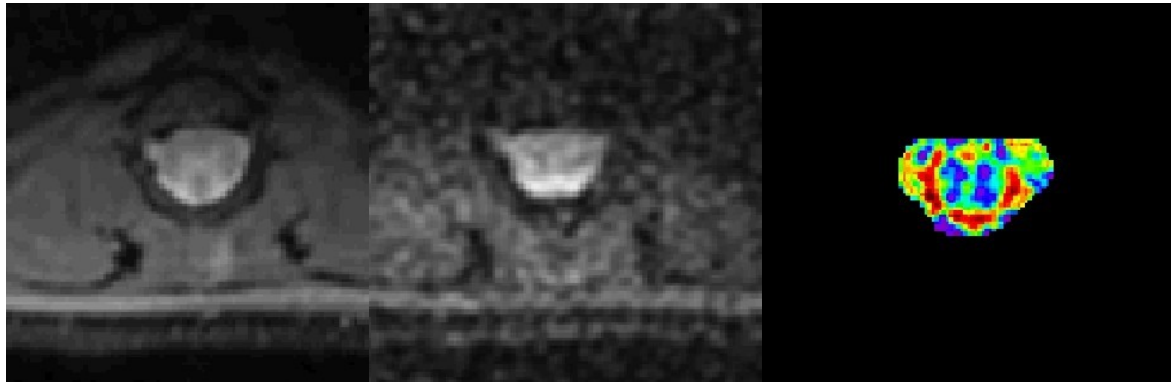
NB : Résultats obtenus en région cervicale moyenne (C4) avec un voxel de 6 mm³.

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.

Tractographie

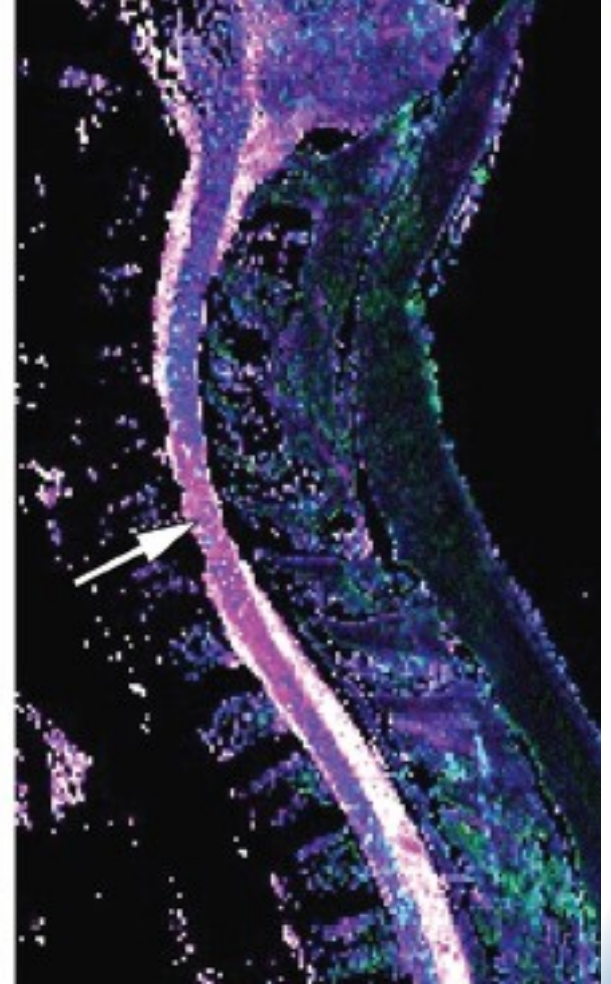
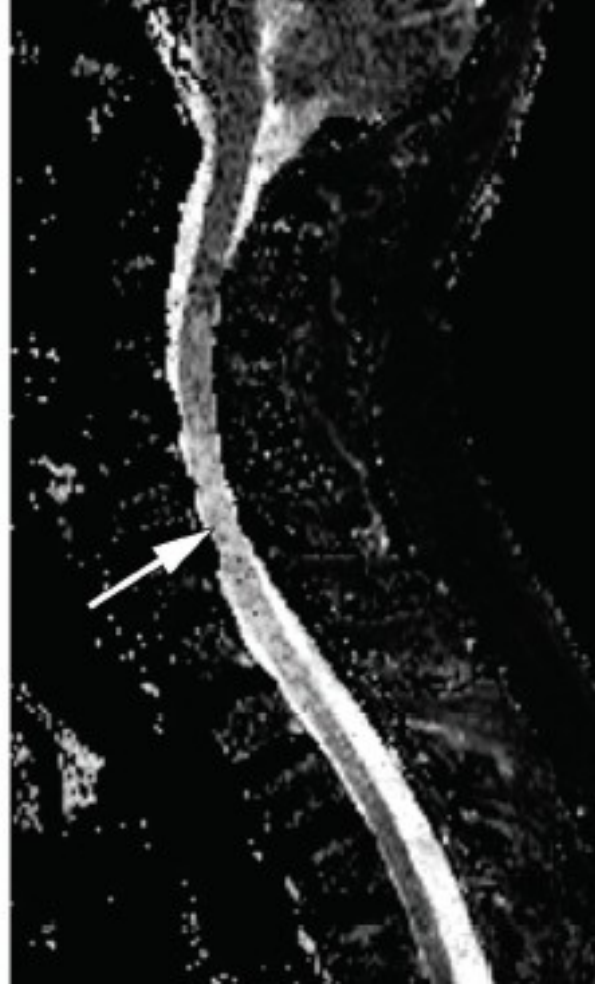
Vérification Expérimentales

Médullaire

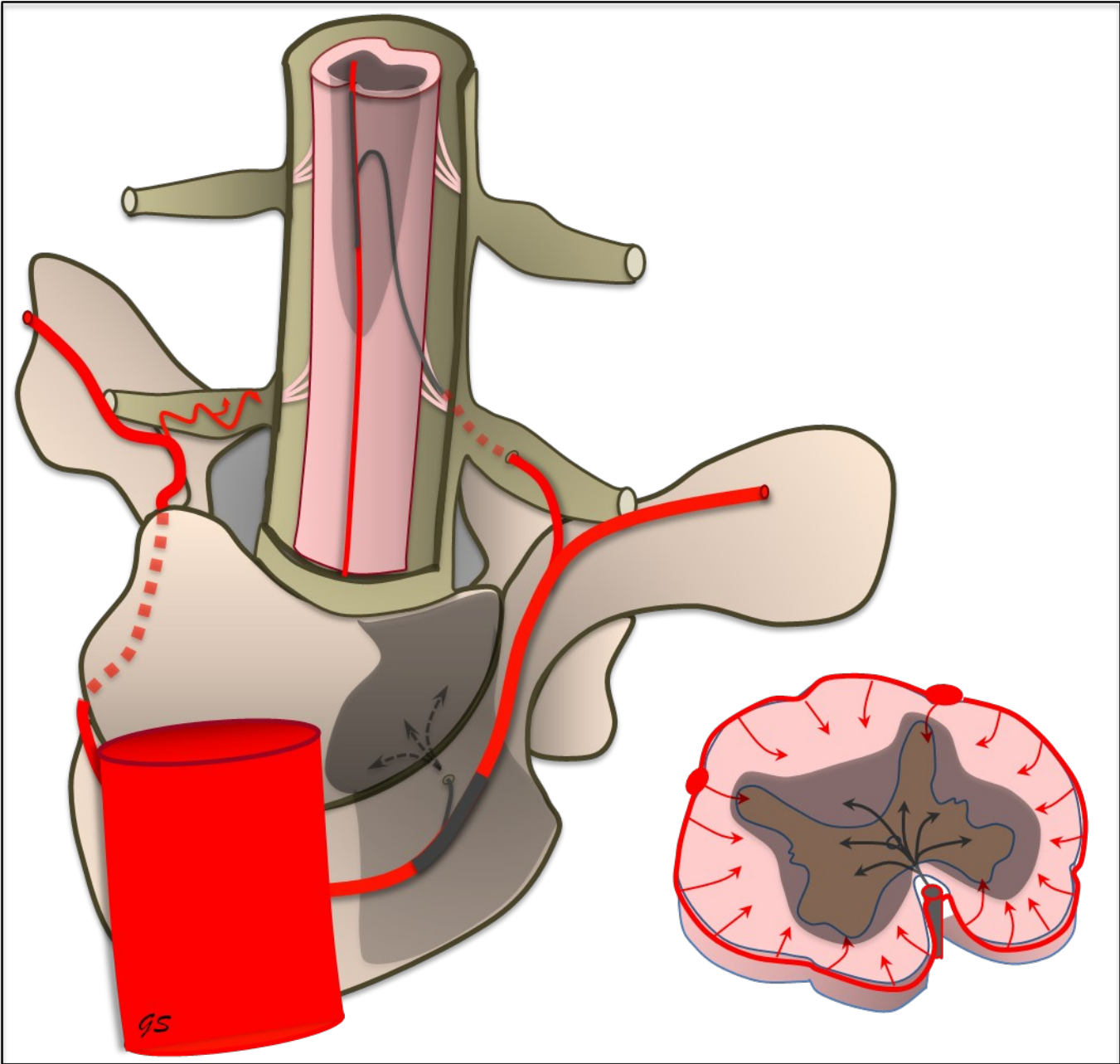


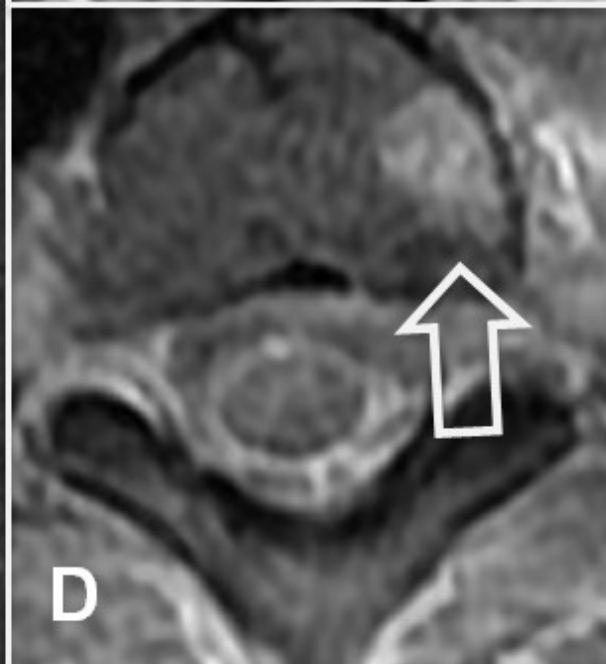
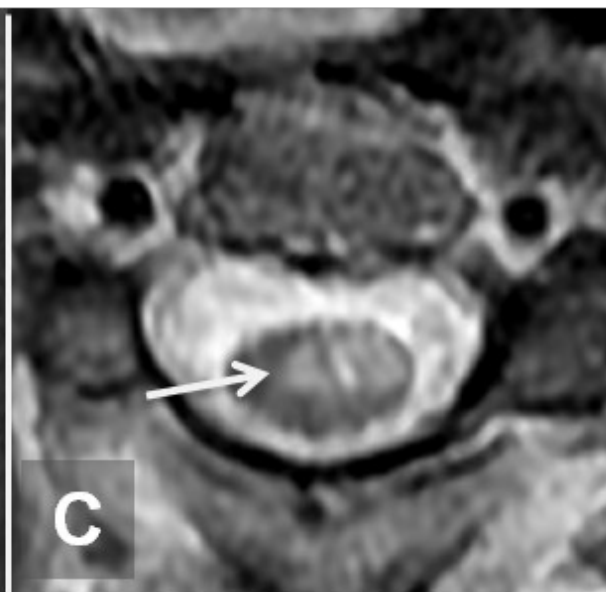
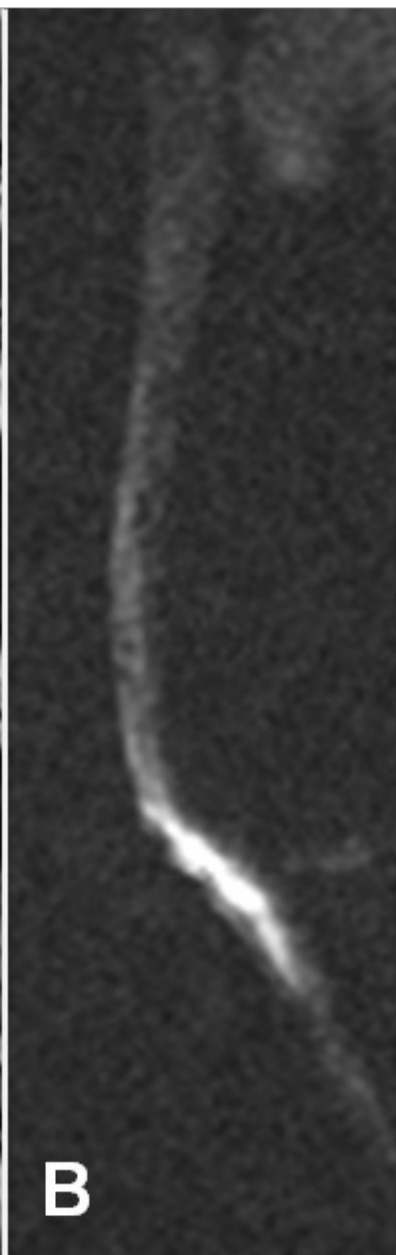
Applications Cliniques

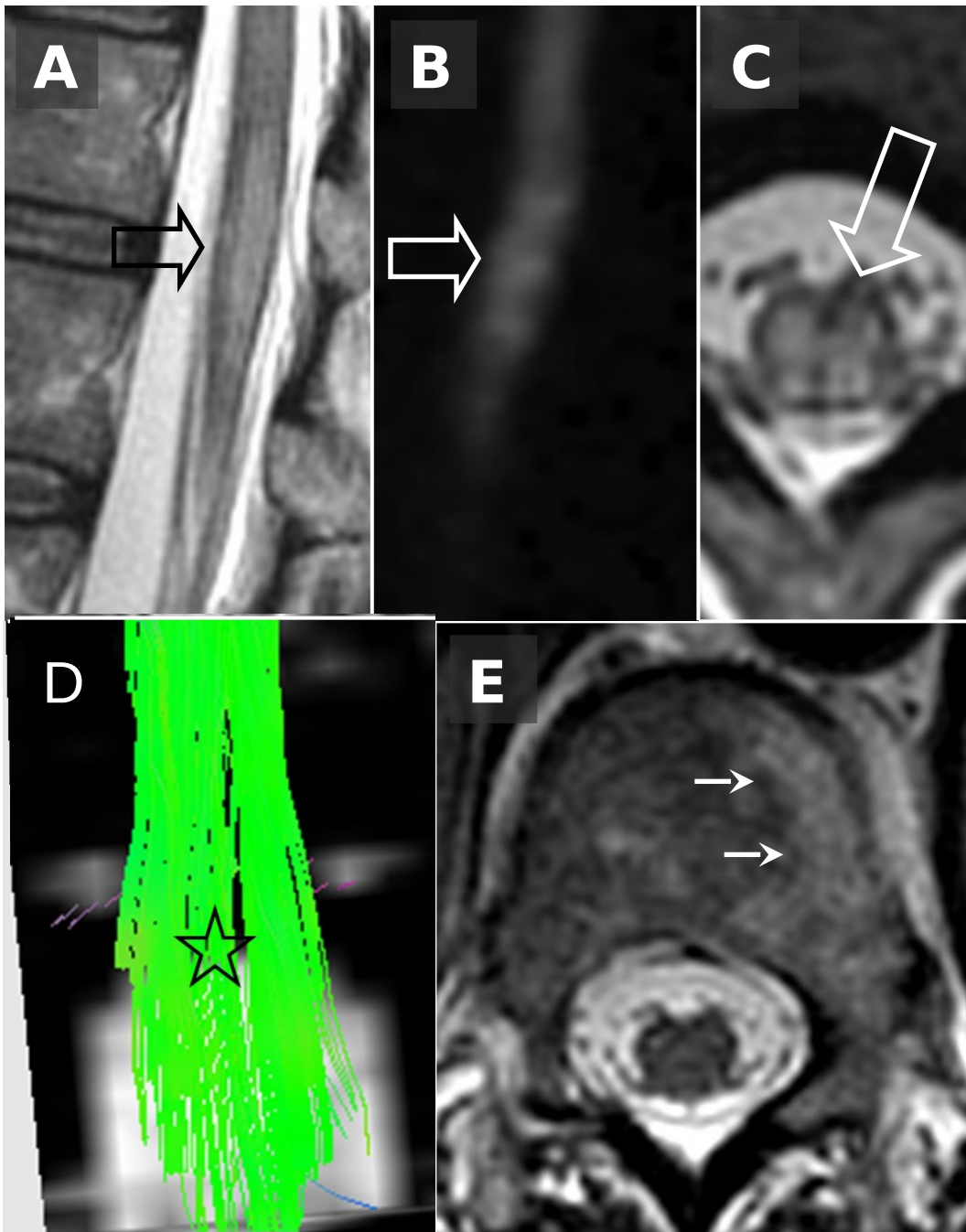
Myelopathie Cervicarthrosique



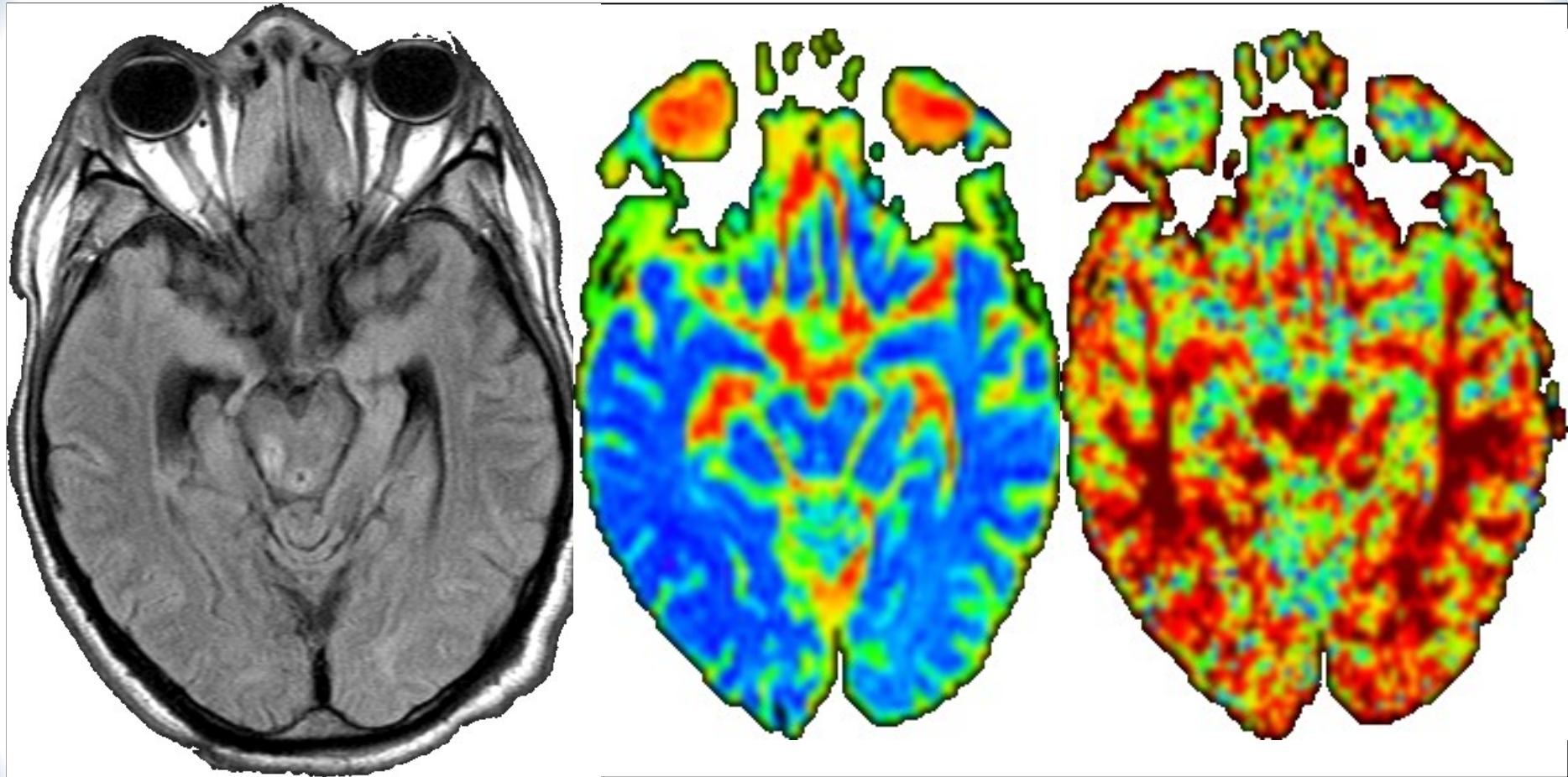
Ischémie Médullaire

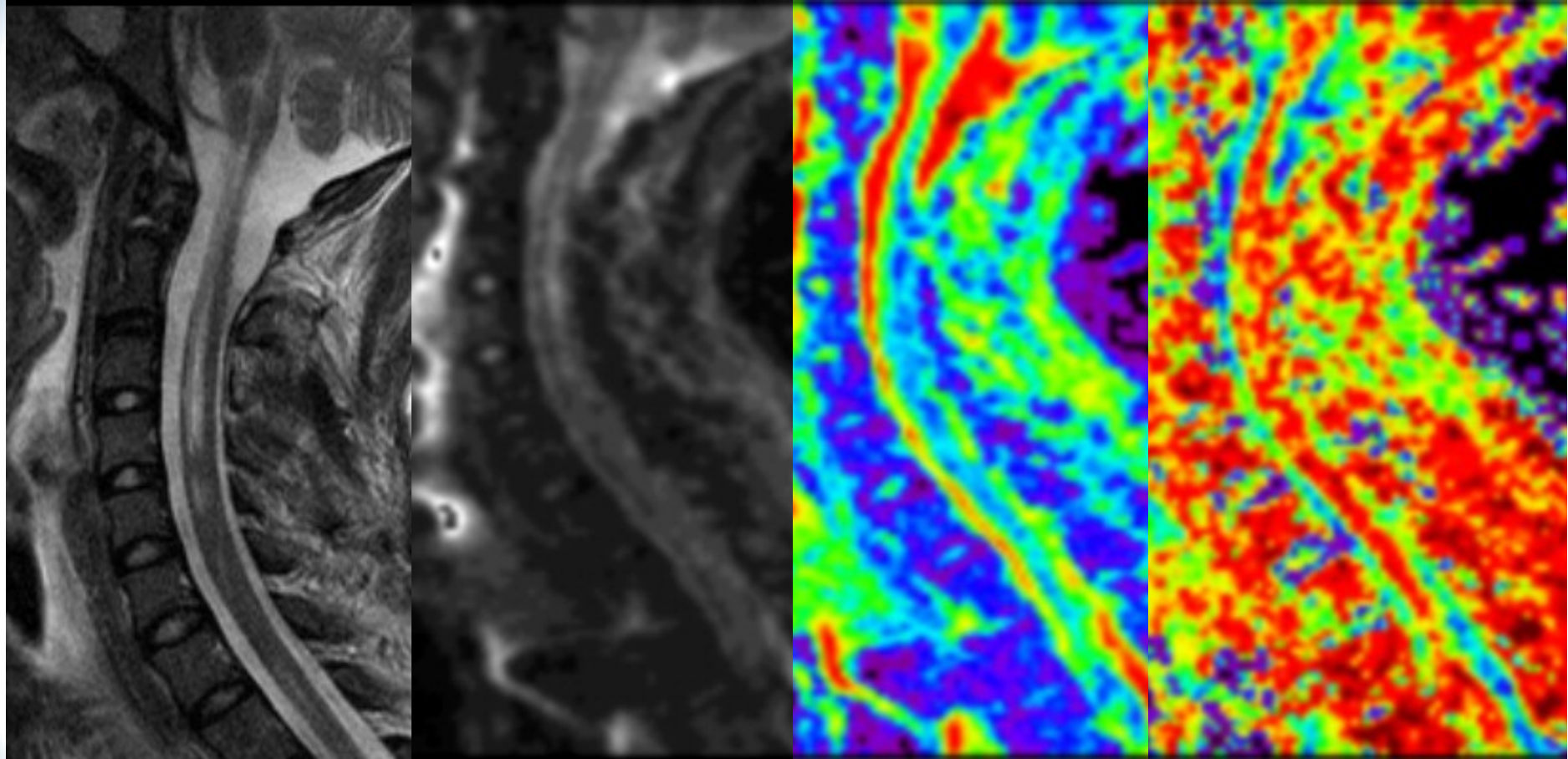


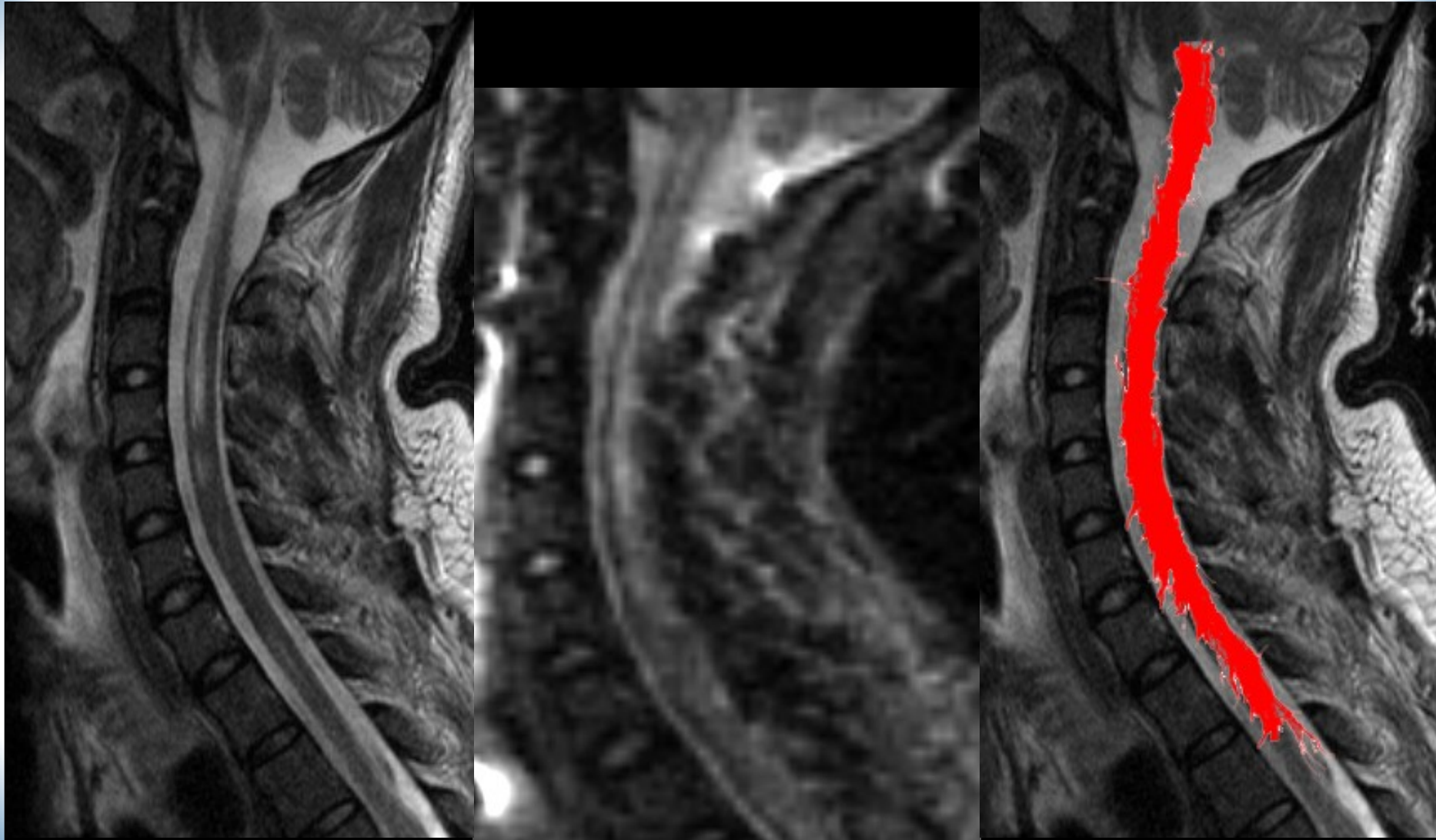




MELAS





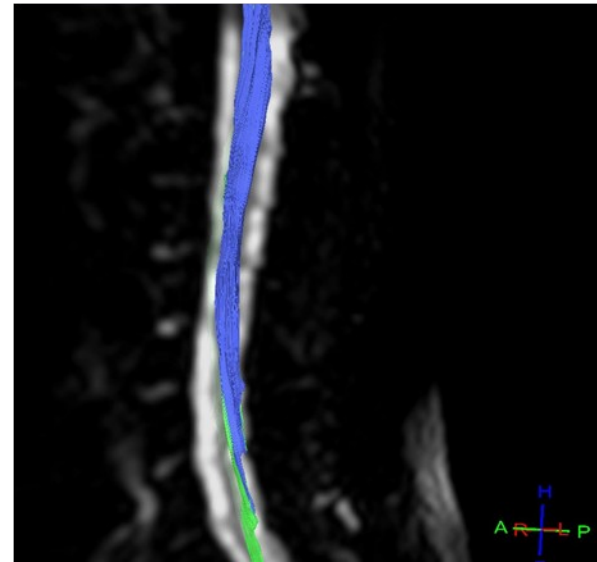
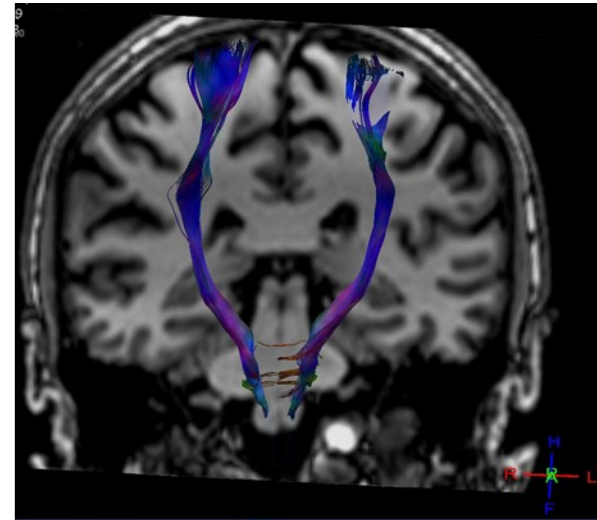


AMN

Brain and cervical spinal cord DTI in AMN

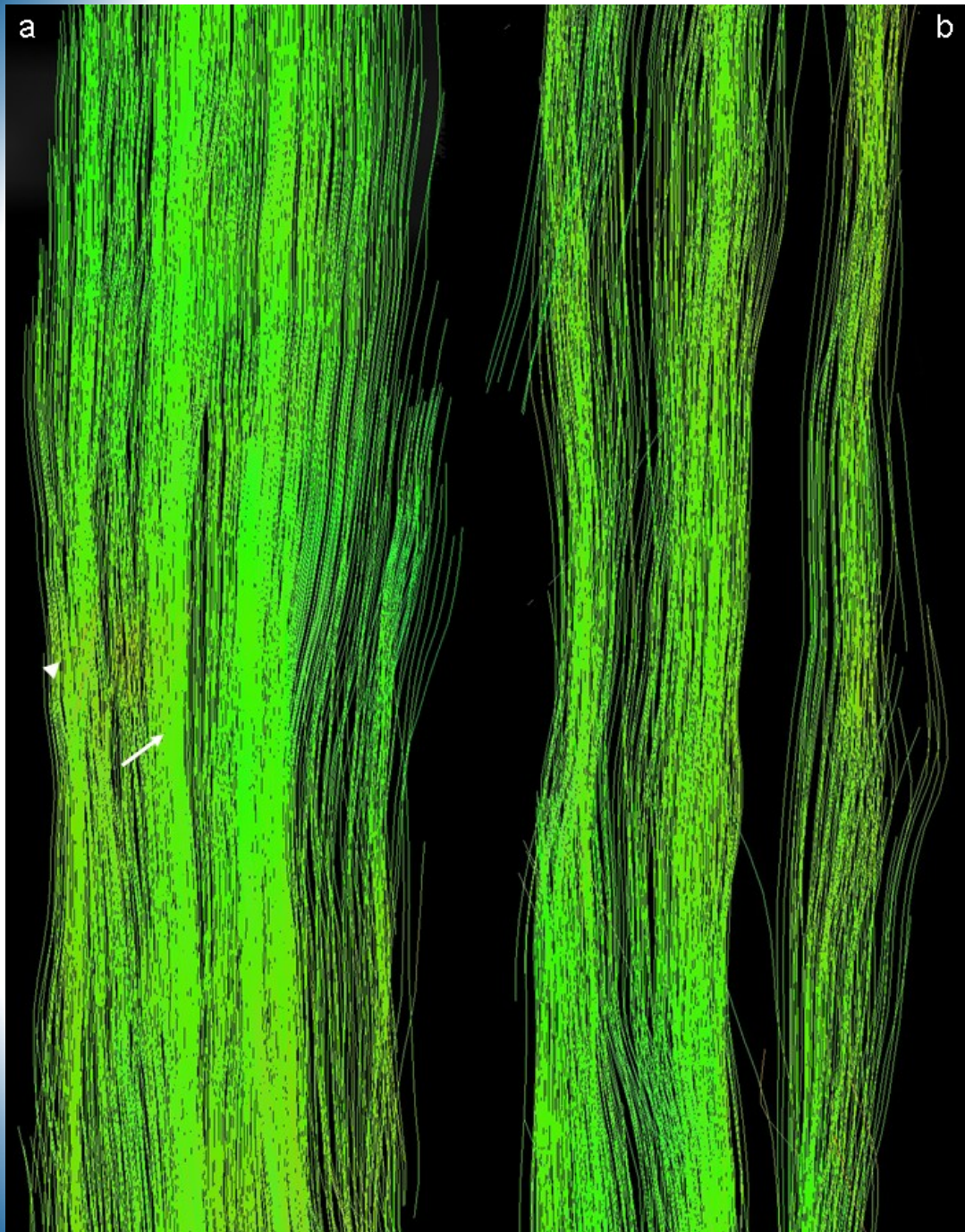


Severe atrophy of the dorsal spinal cord

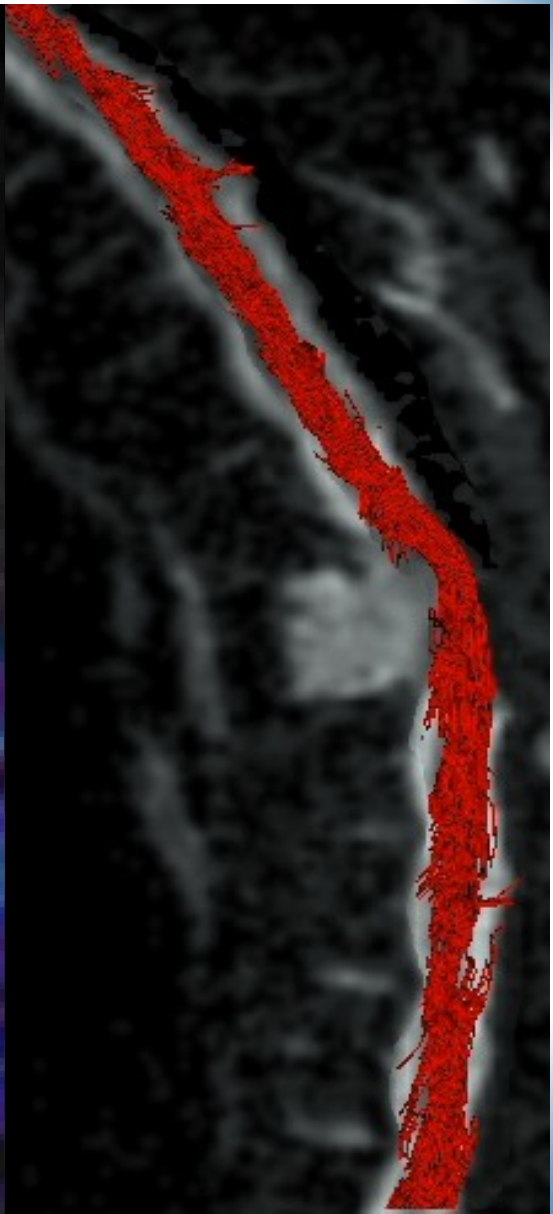
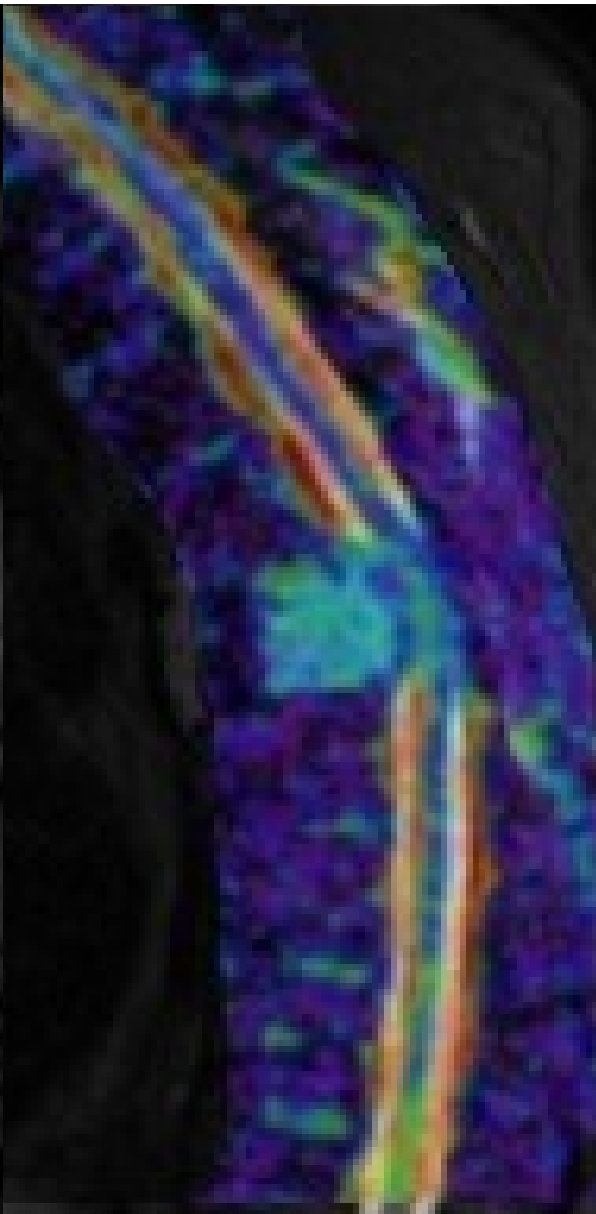
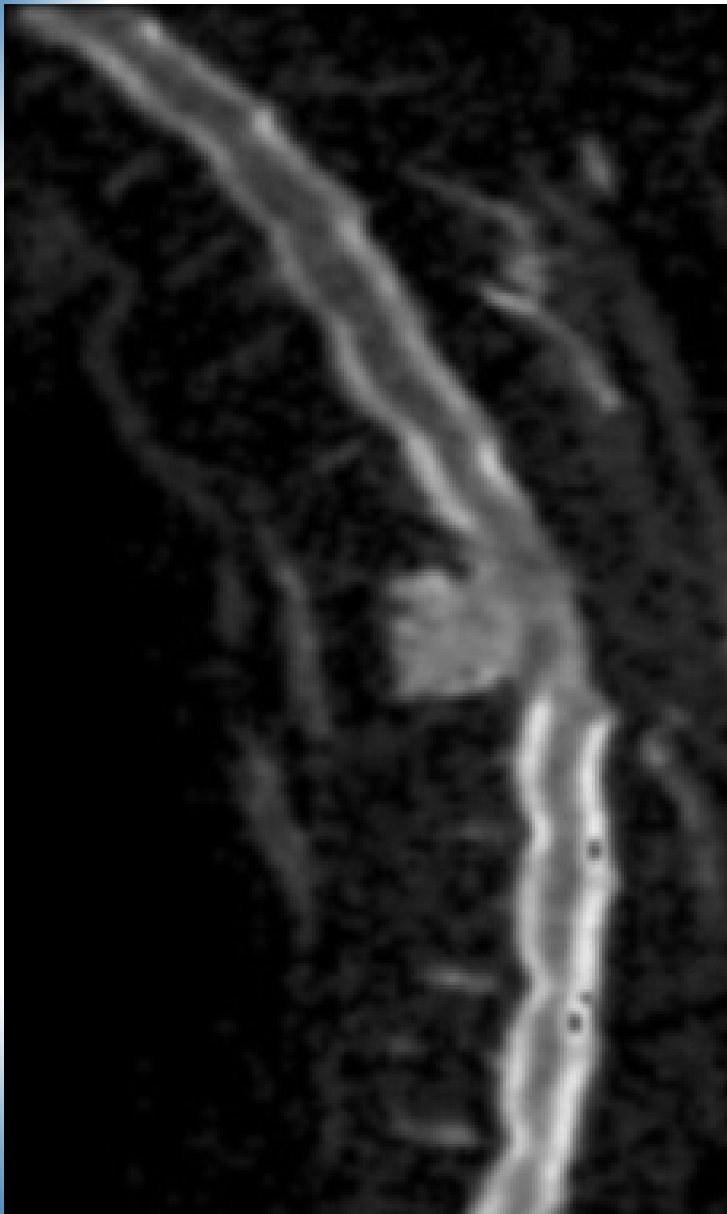


Myoclonies Propriospinales

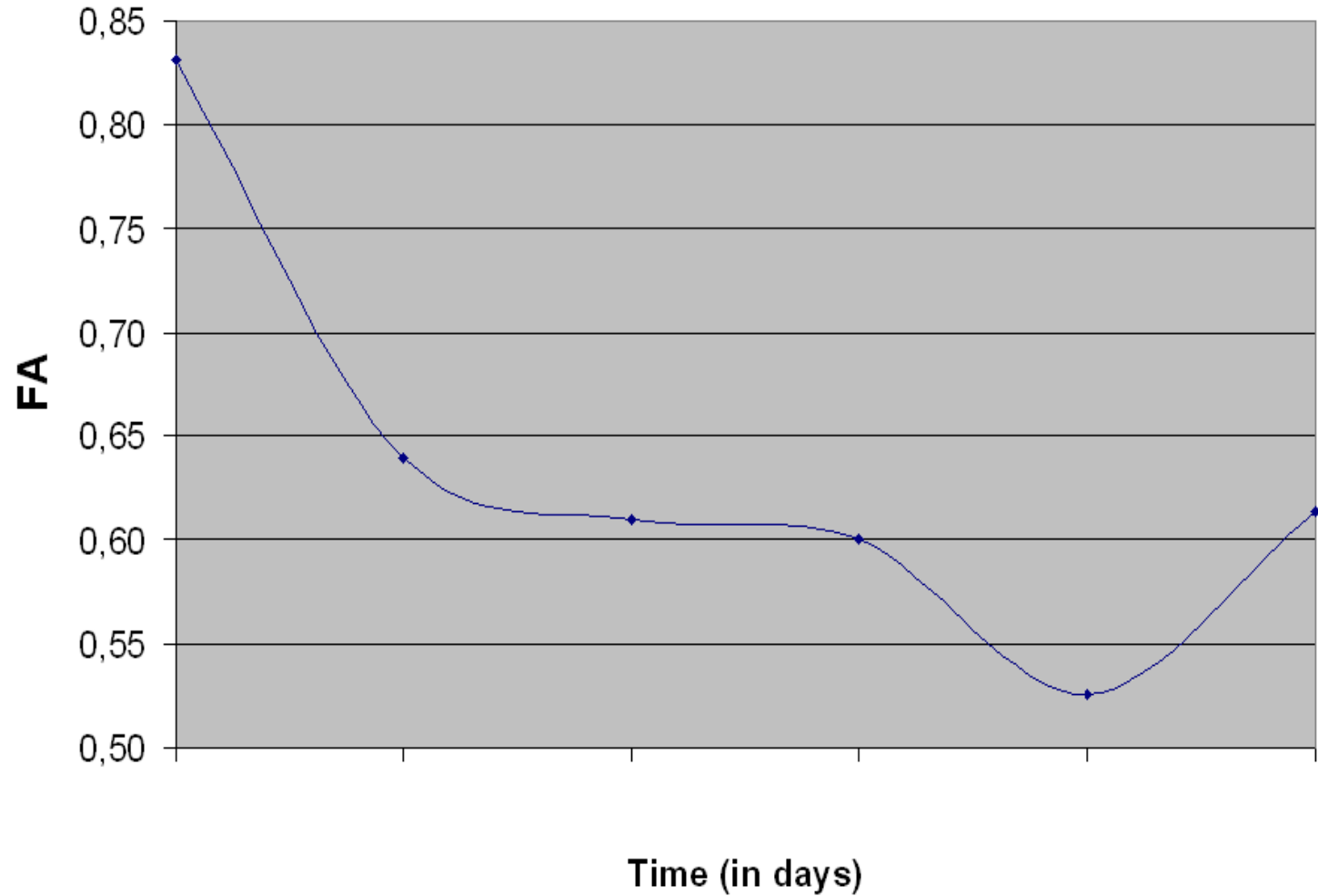
Myoclonies Propriospinales

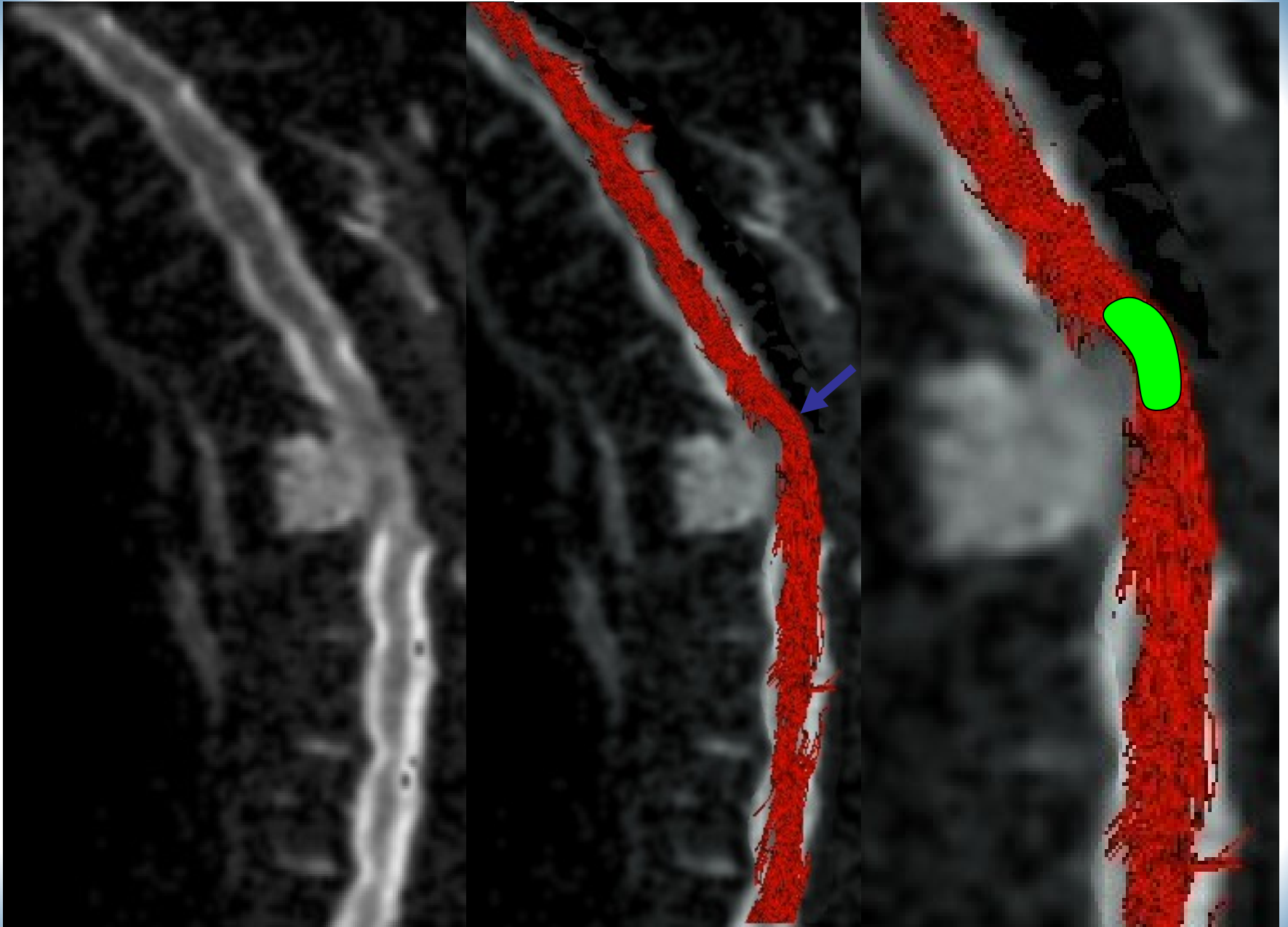


Compressions Médullaires



FA versus Time

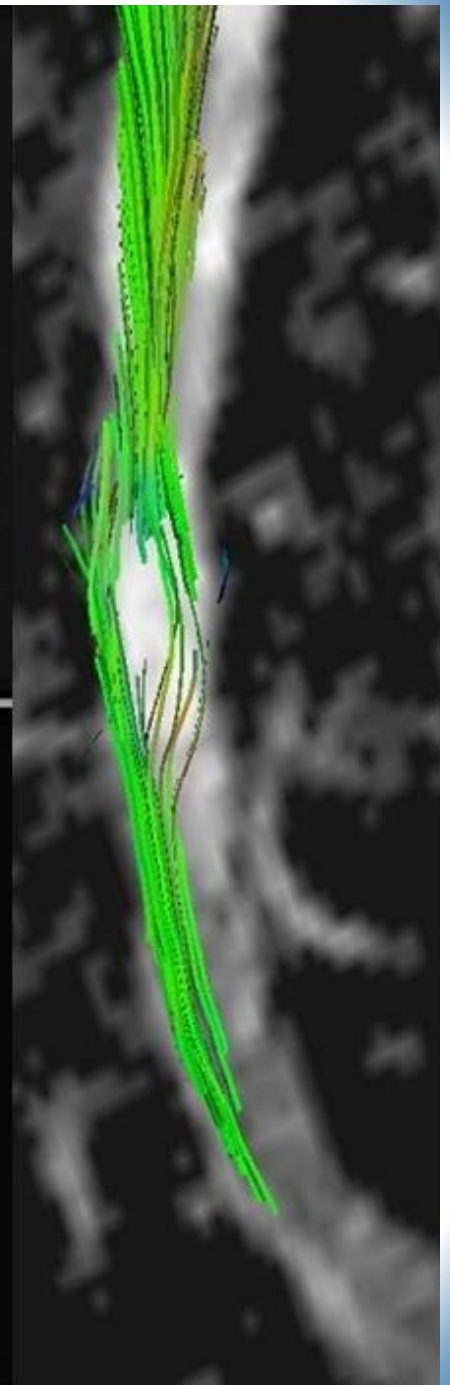
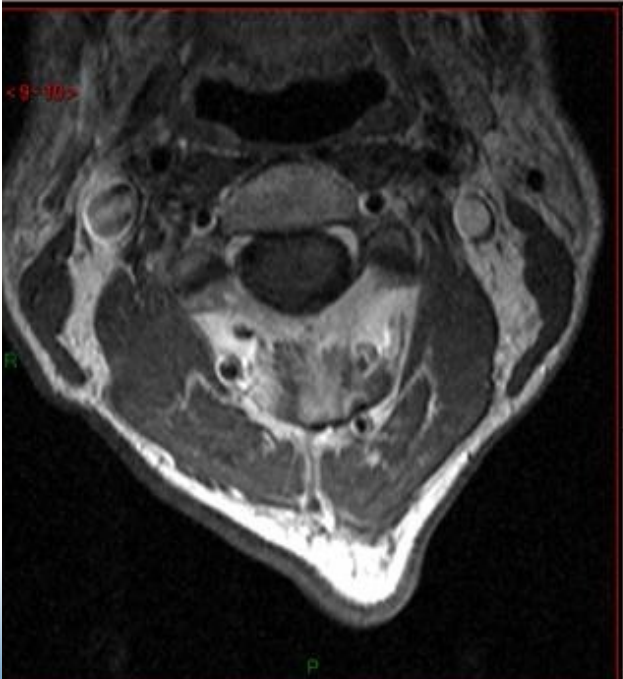




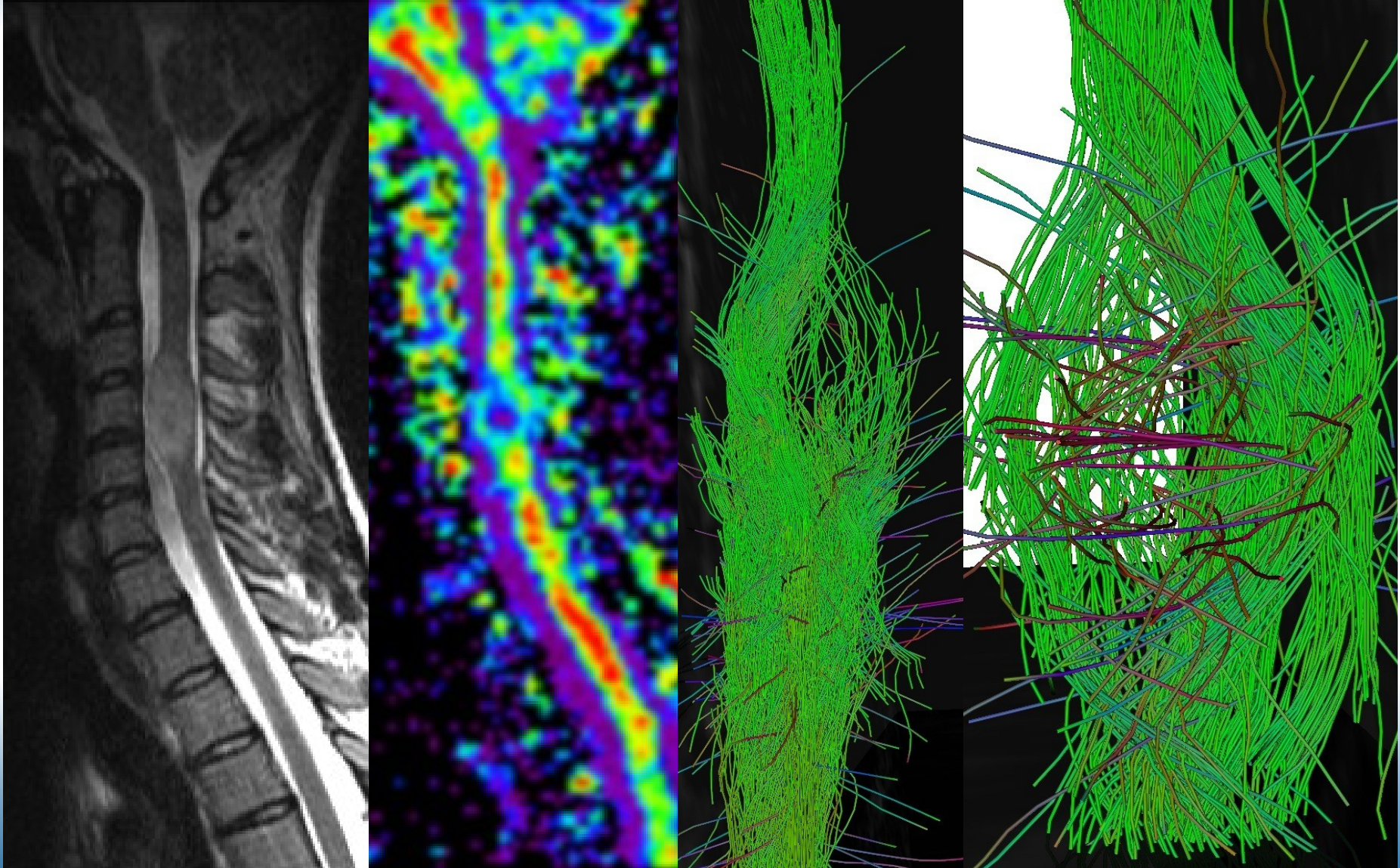
Tumeurs Médullaires

Ependymome

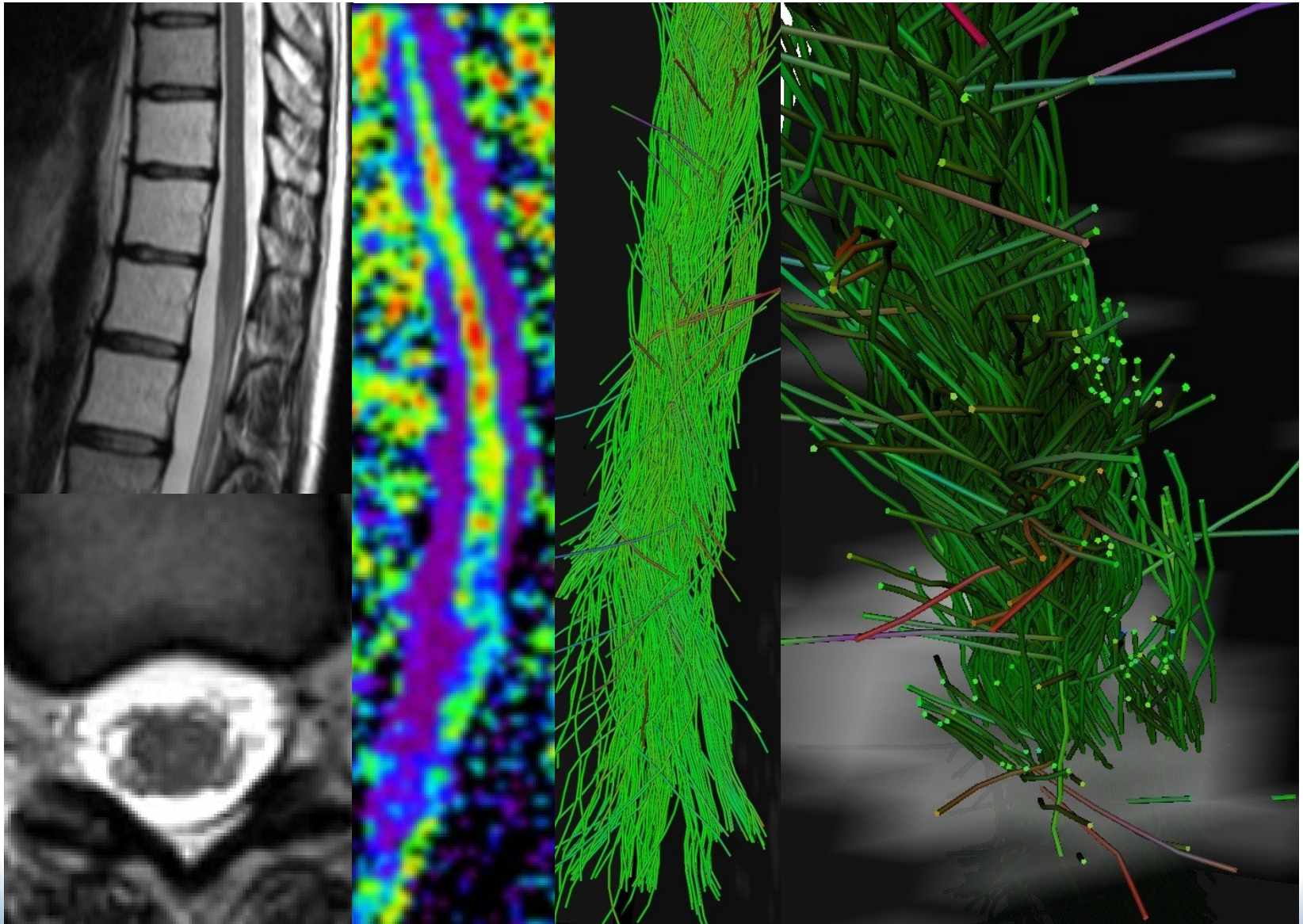




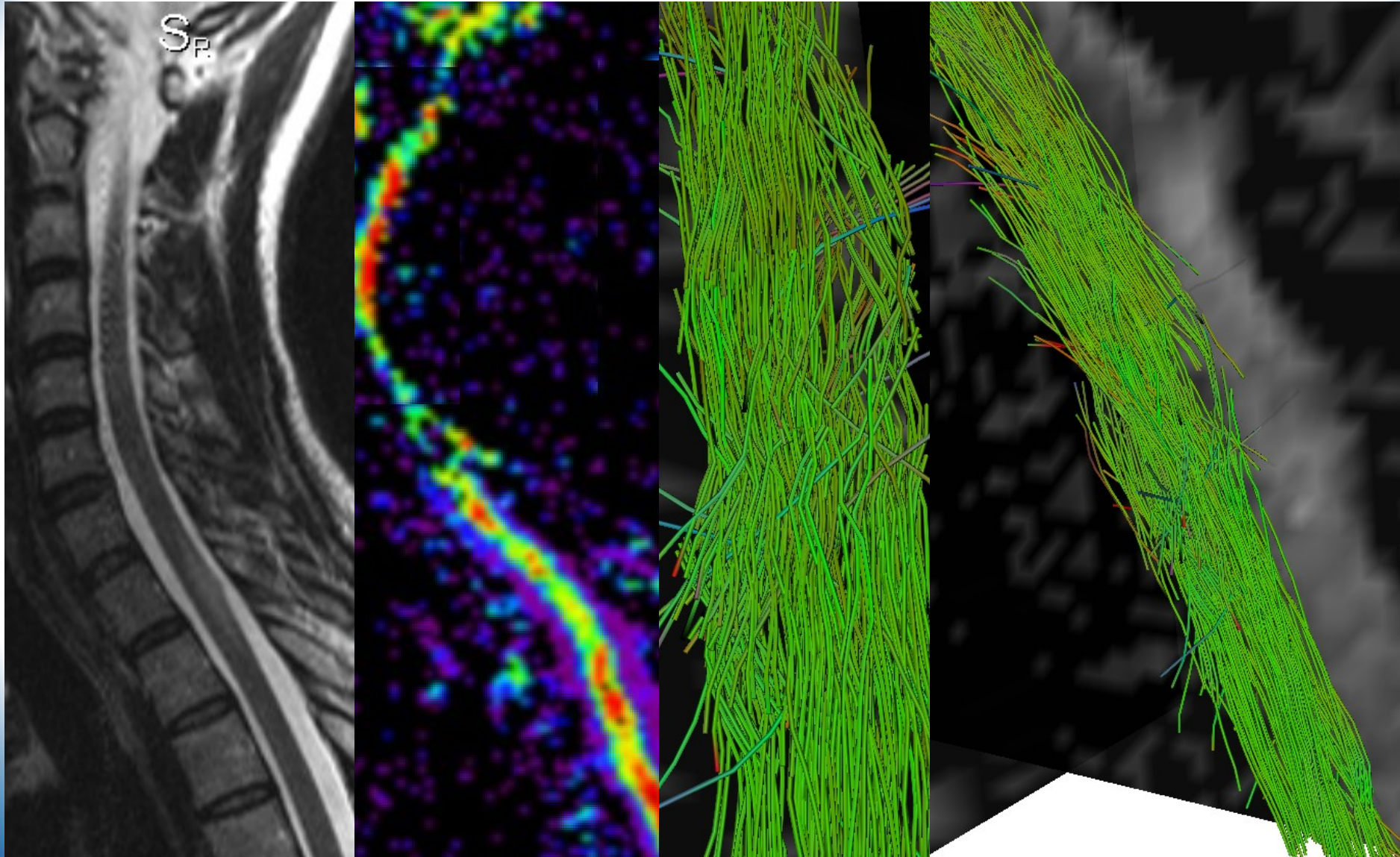
Astrocytome



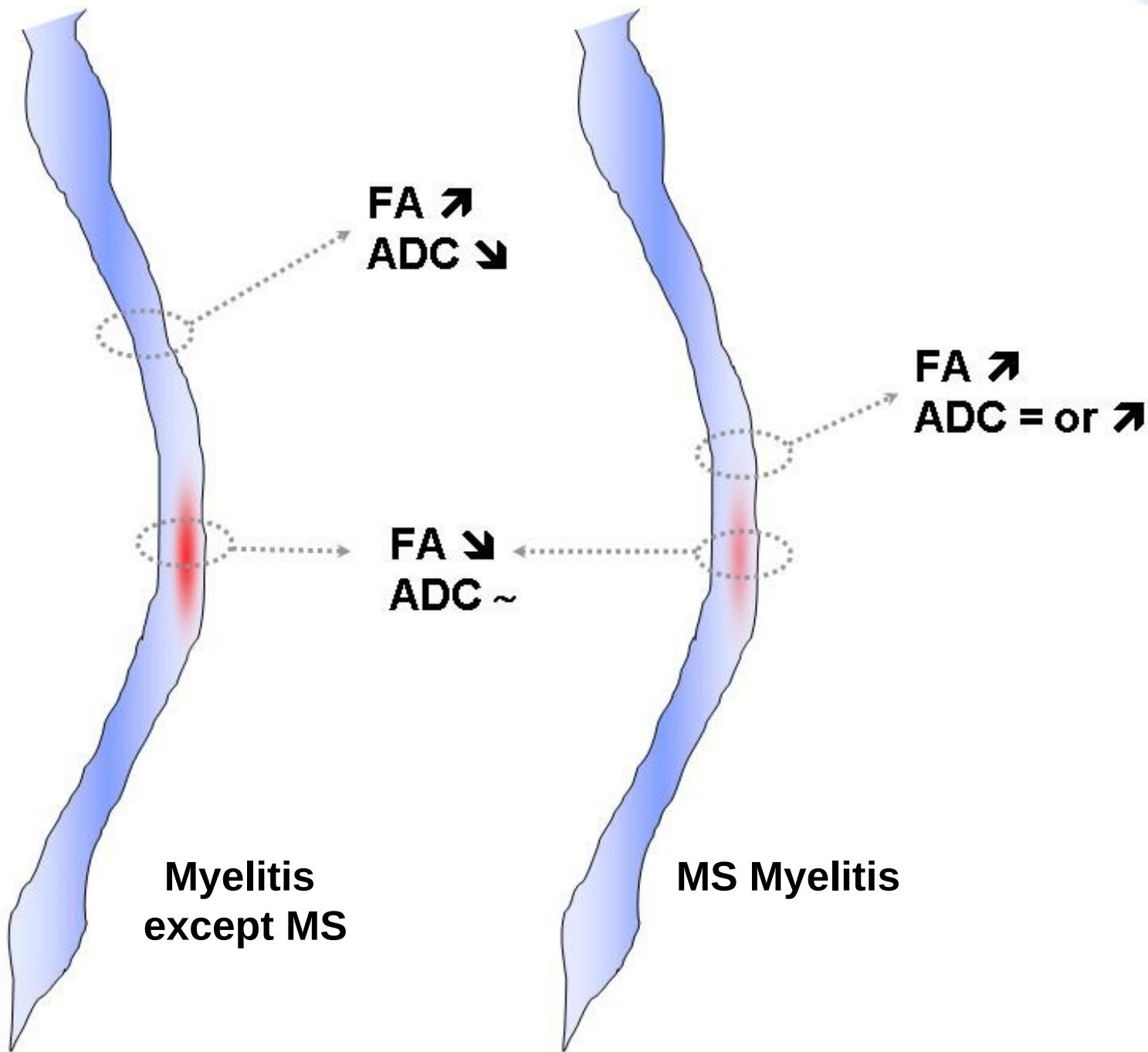
Métastases

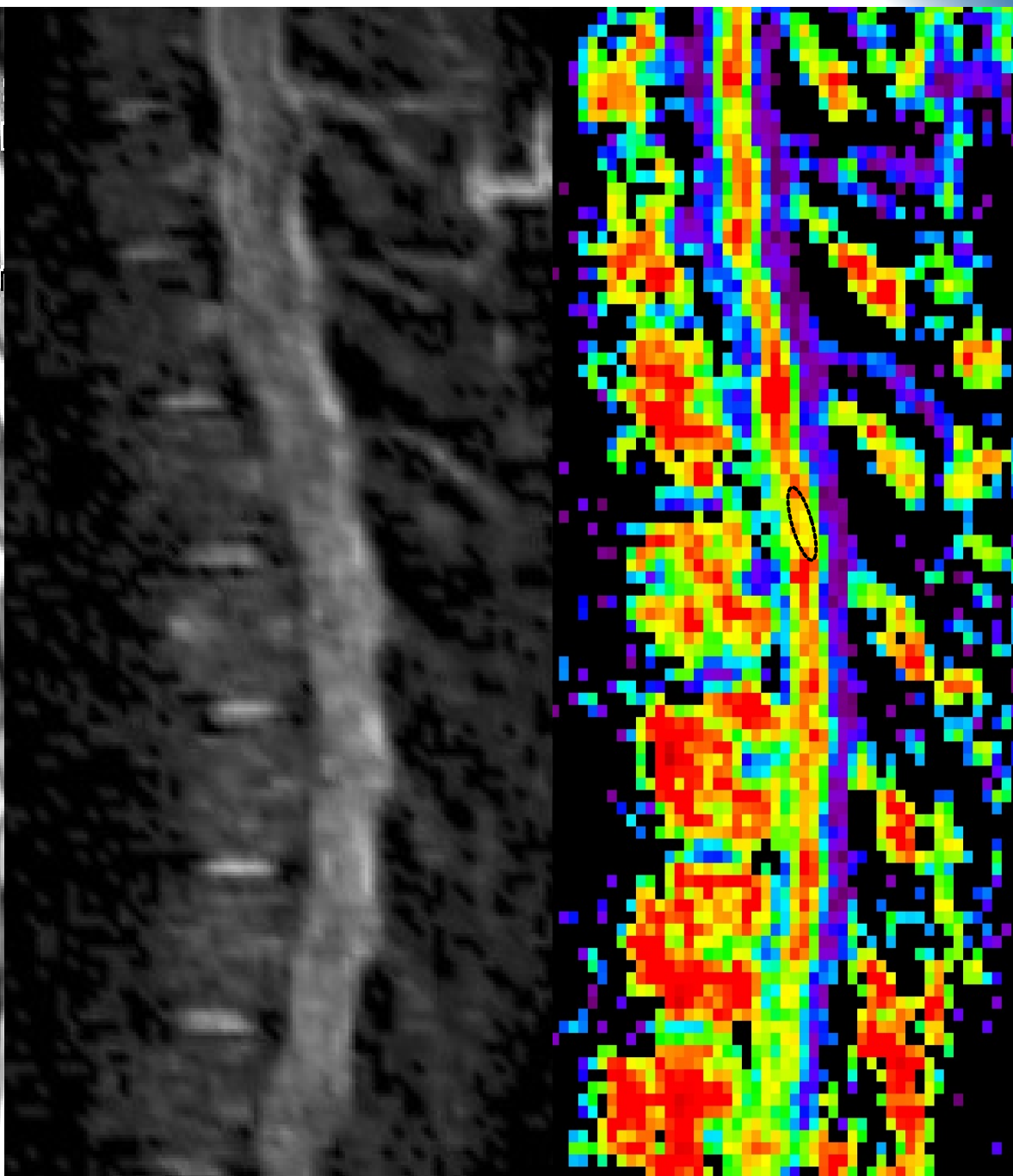
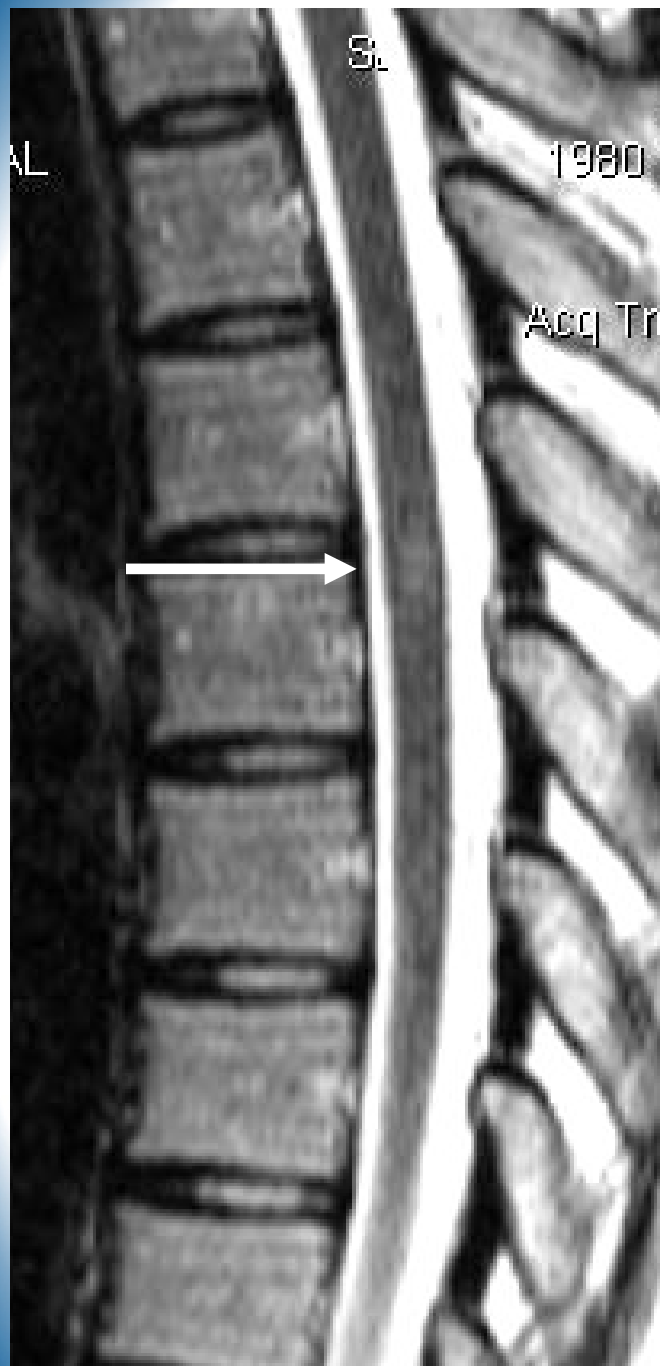


Hémangioblastome

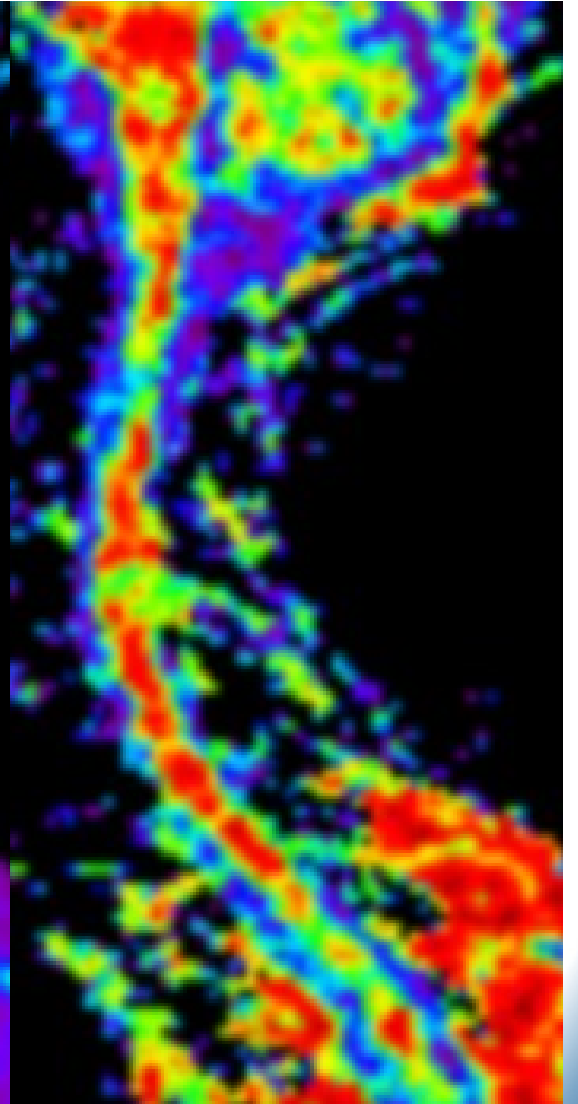
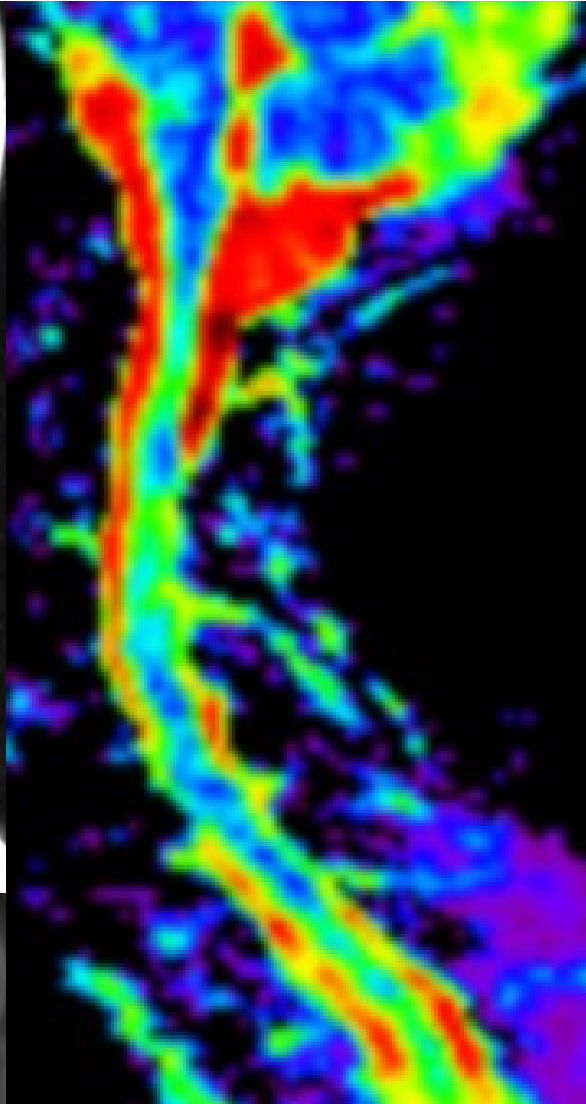
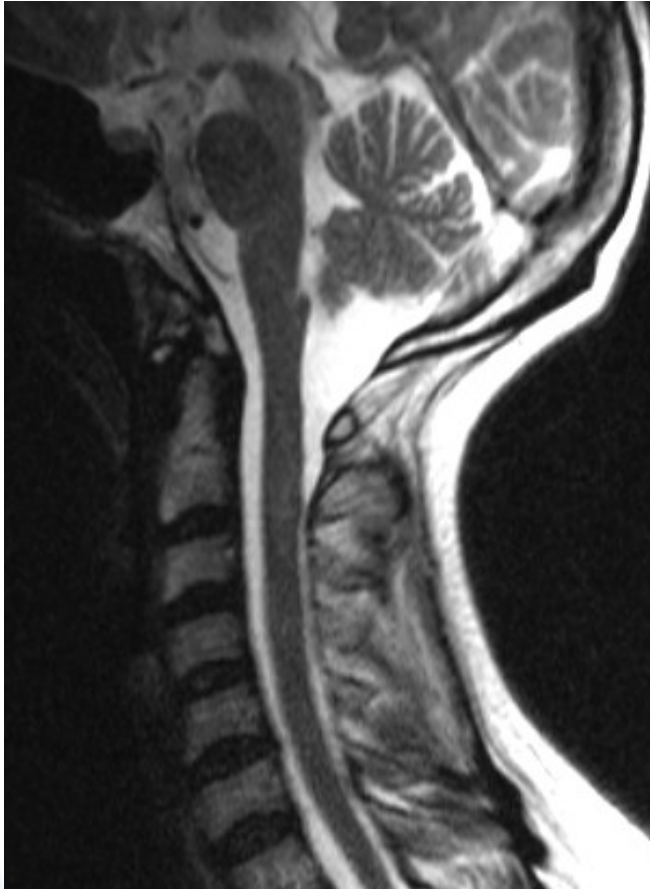


**Processus
Inflammatoires
Médullaires et
Régénération Axonale**

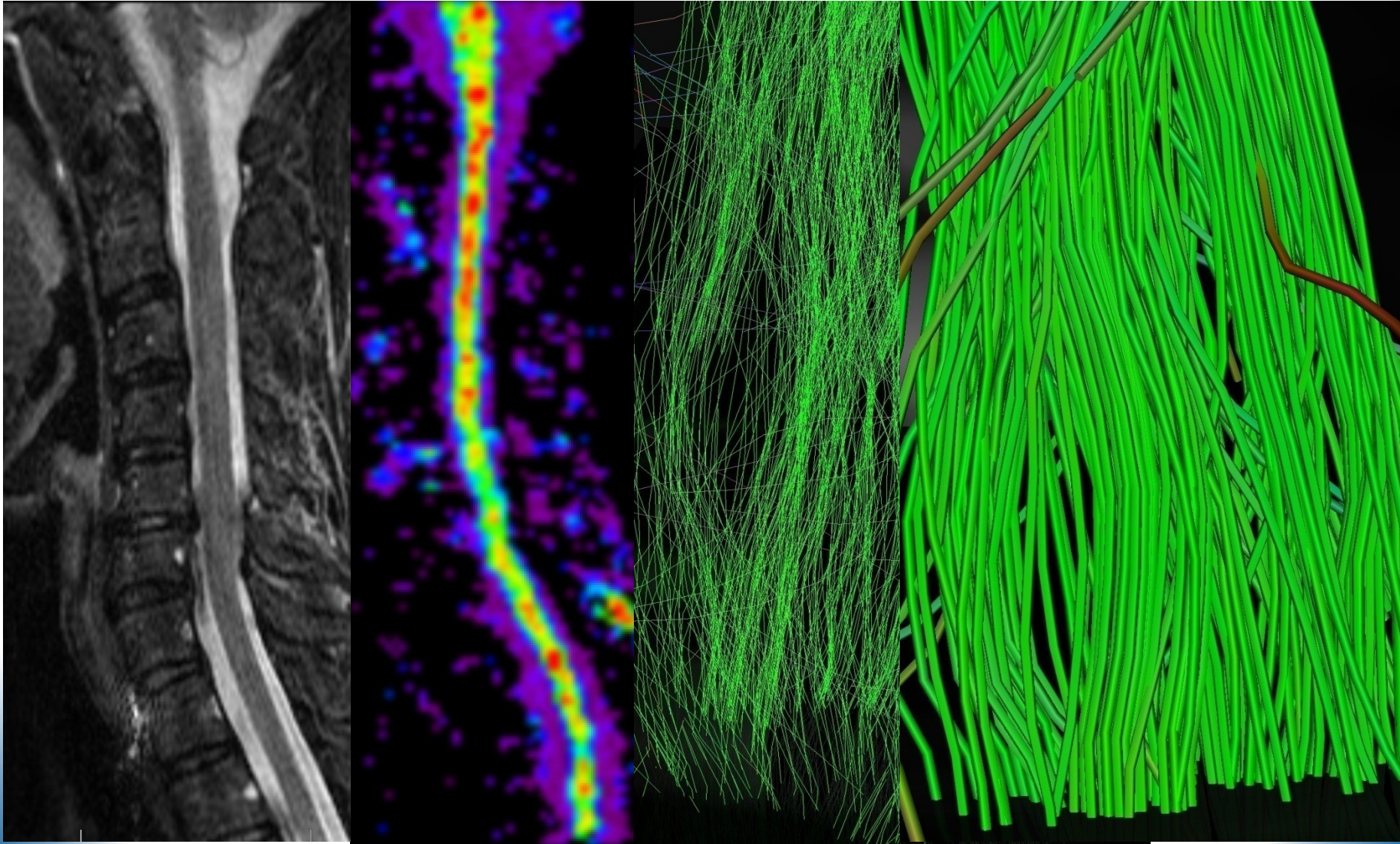




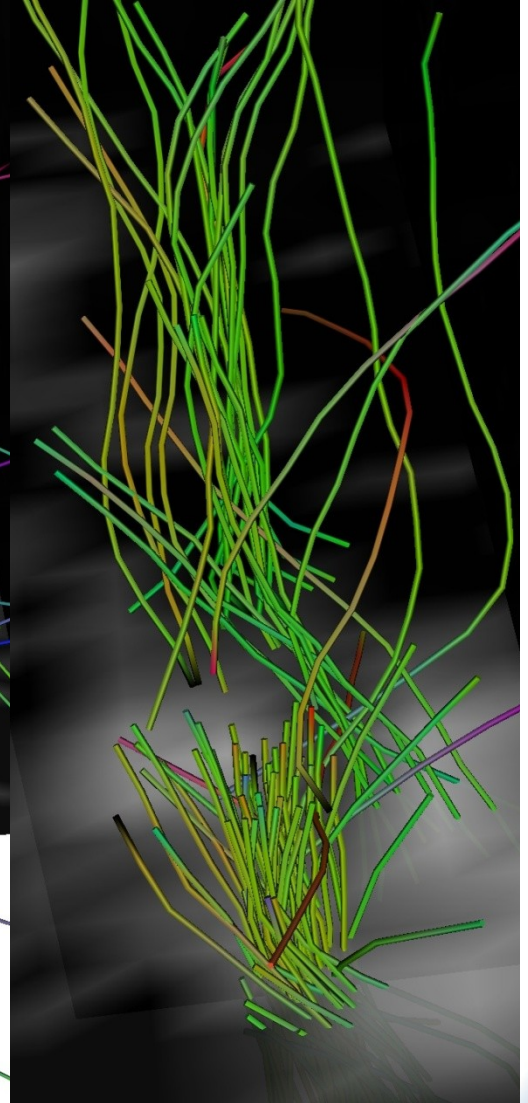
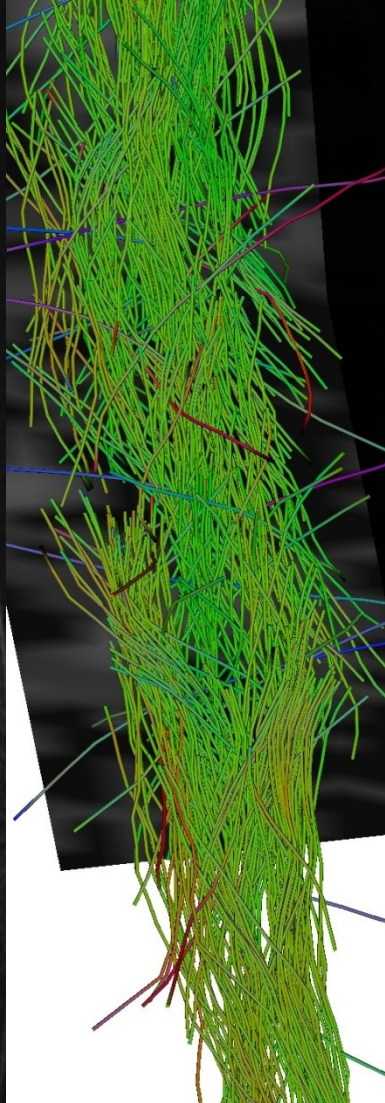
Myélites



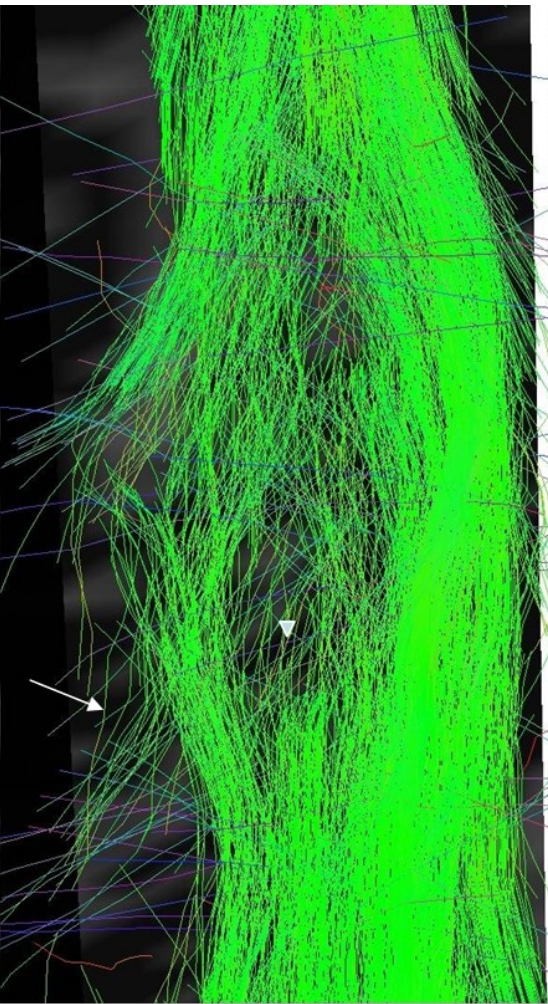
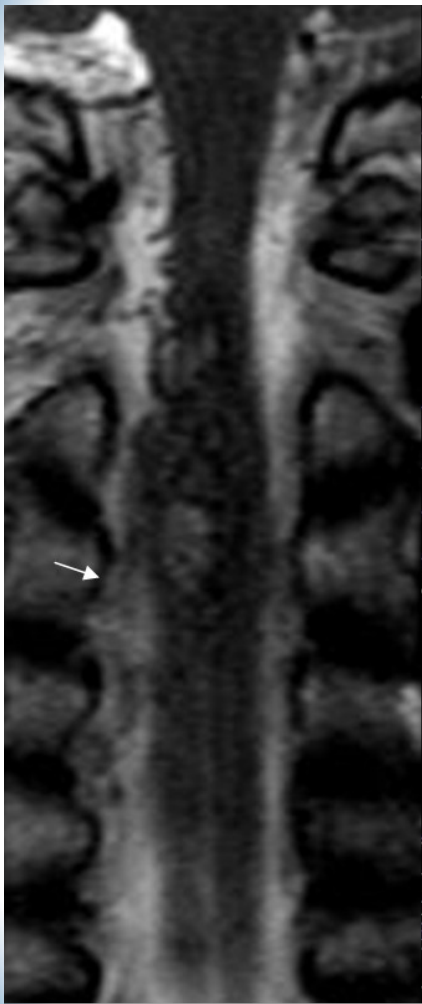
Sclérose en Plaques



Sarcoidose

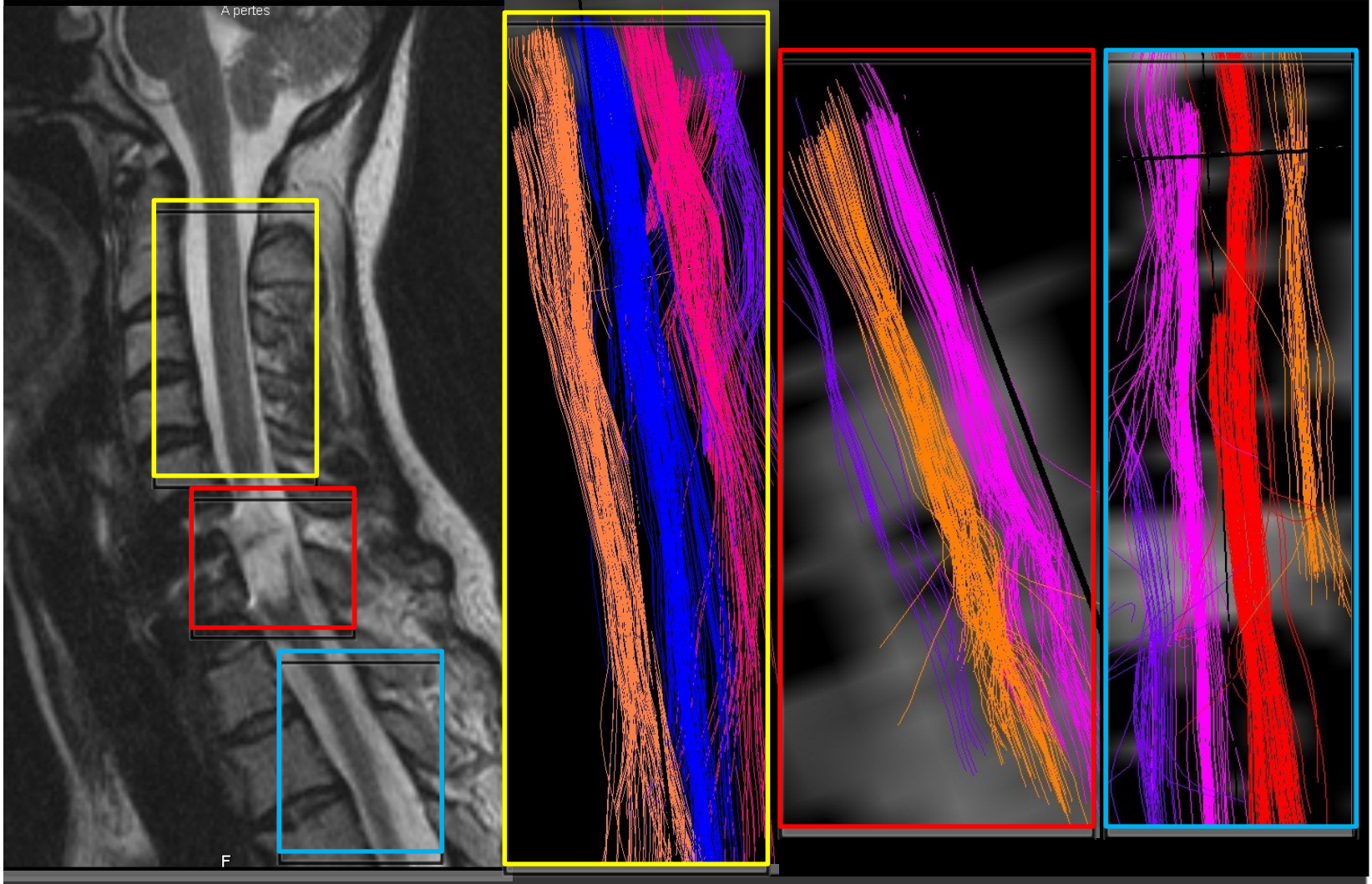


Processus Vasculaires Malformatifs

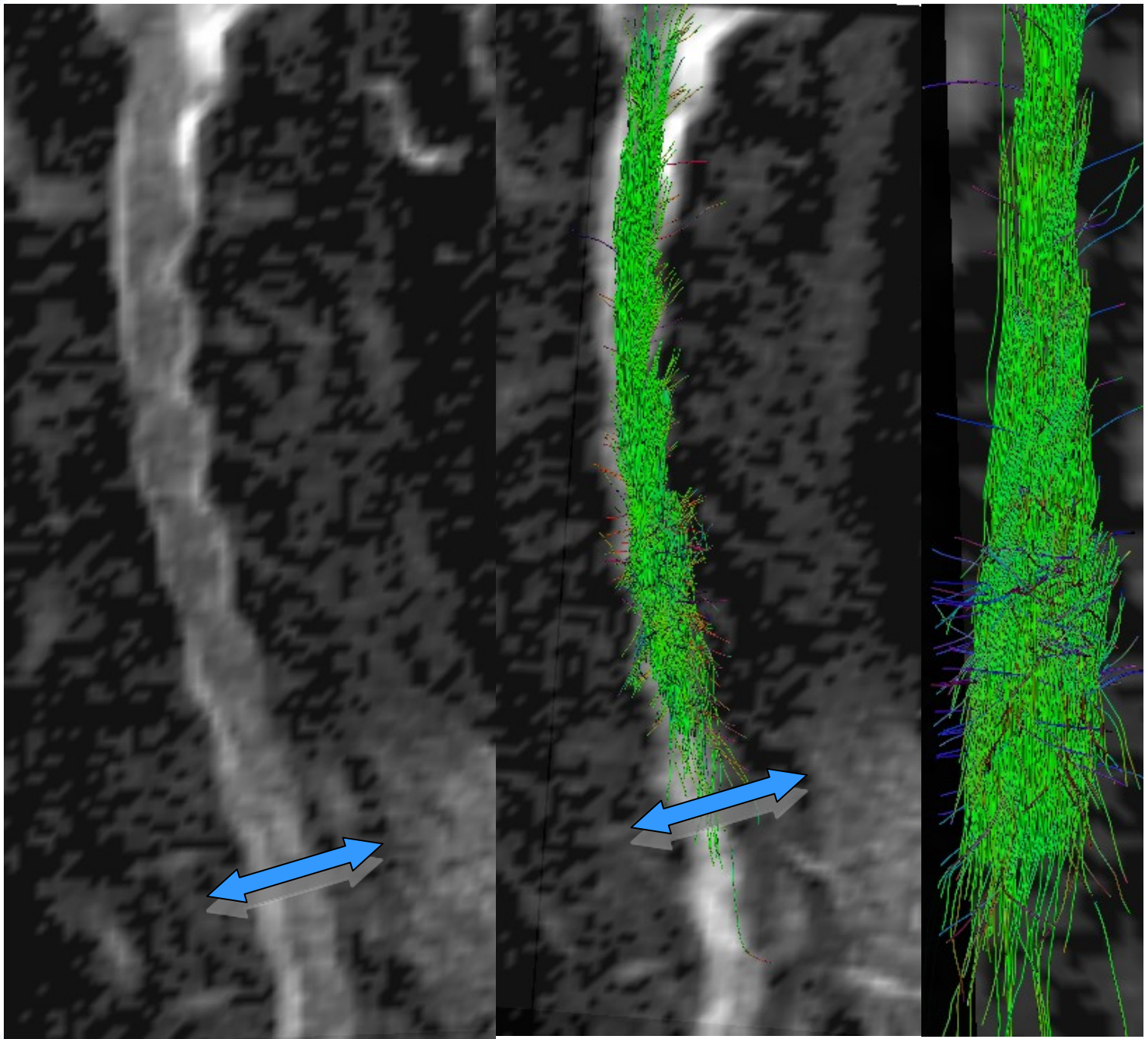


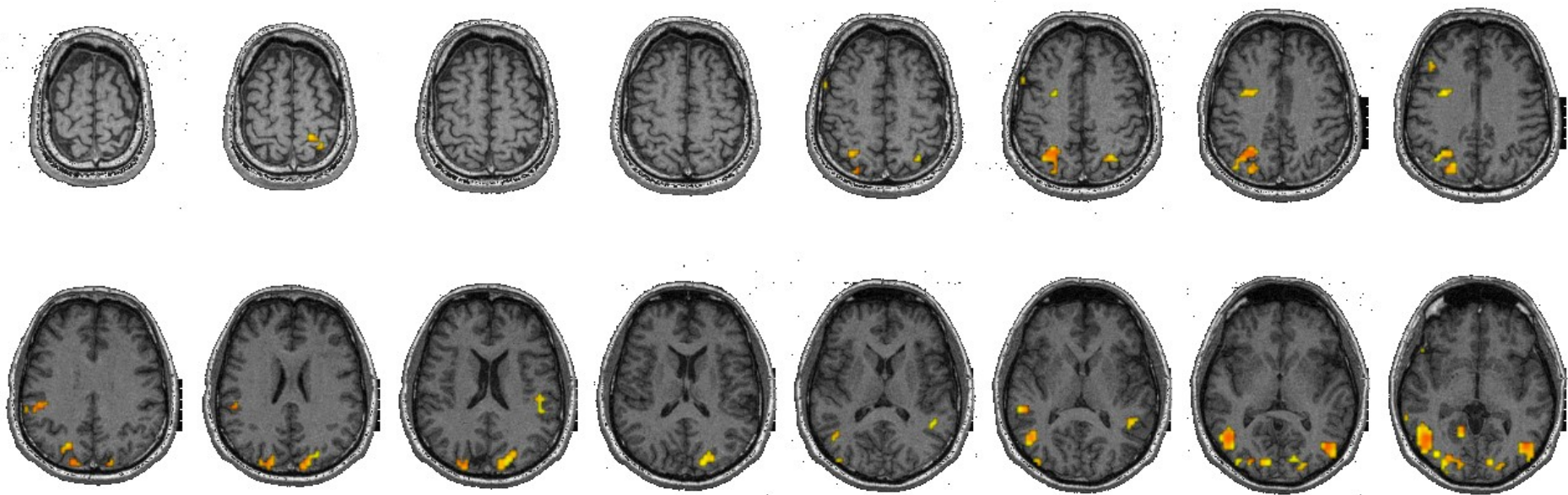
Sections Médullaires

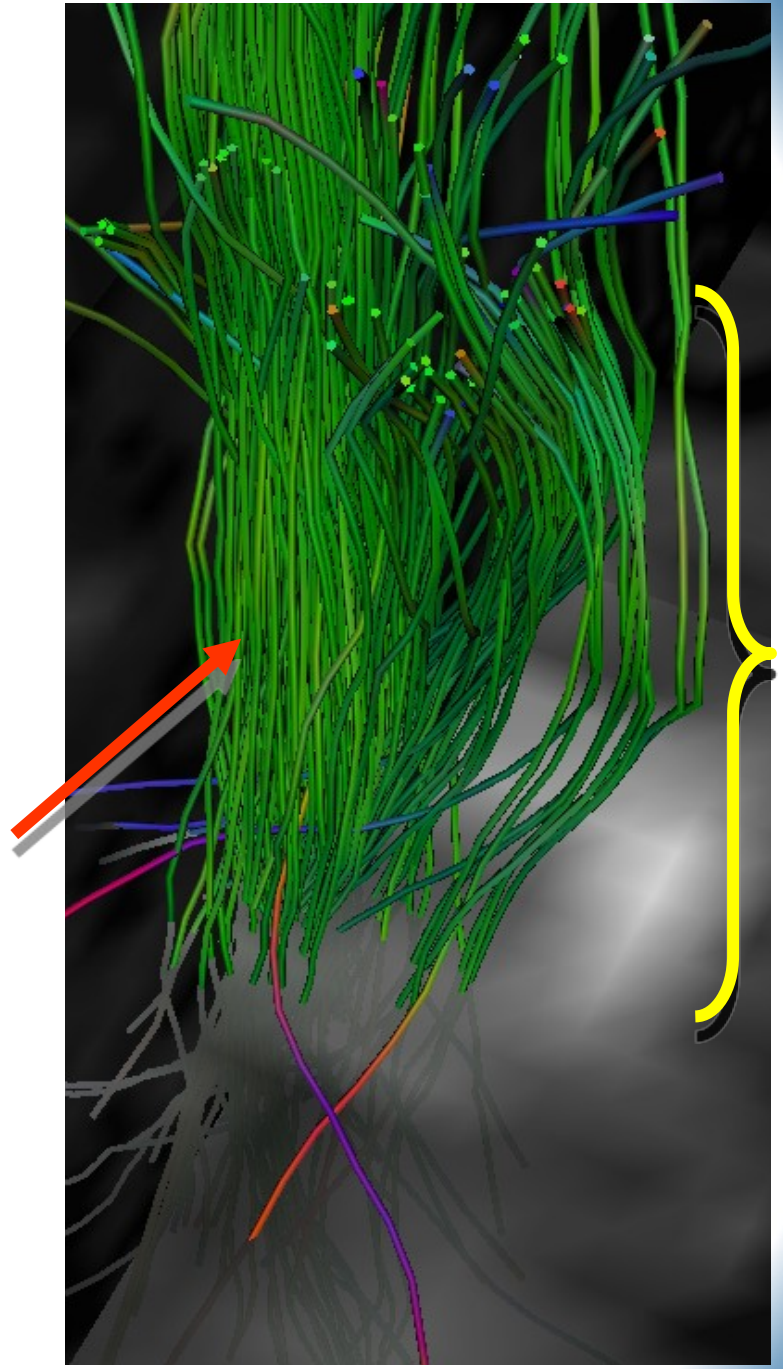
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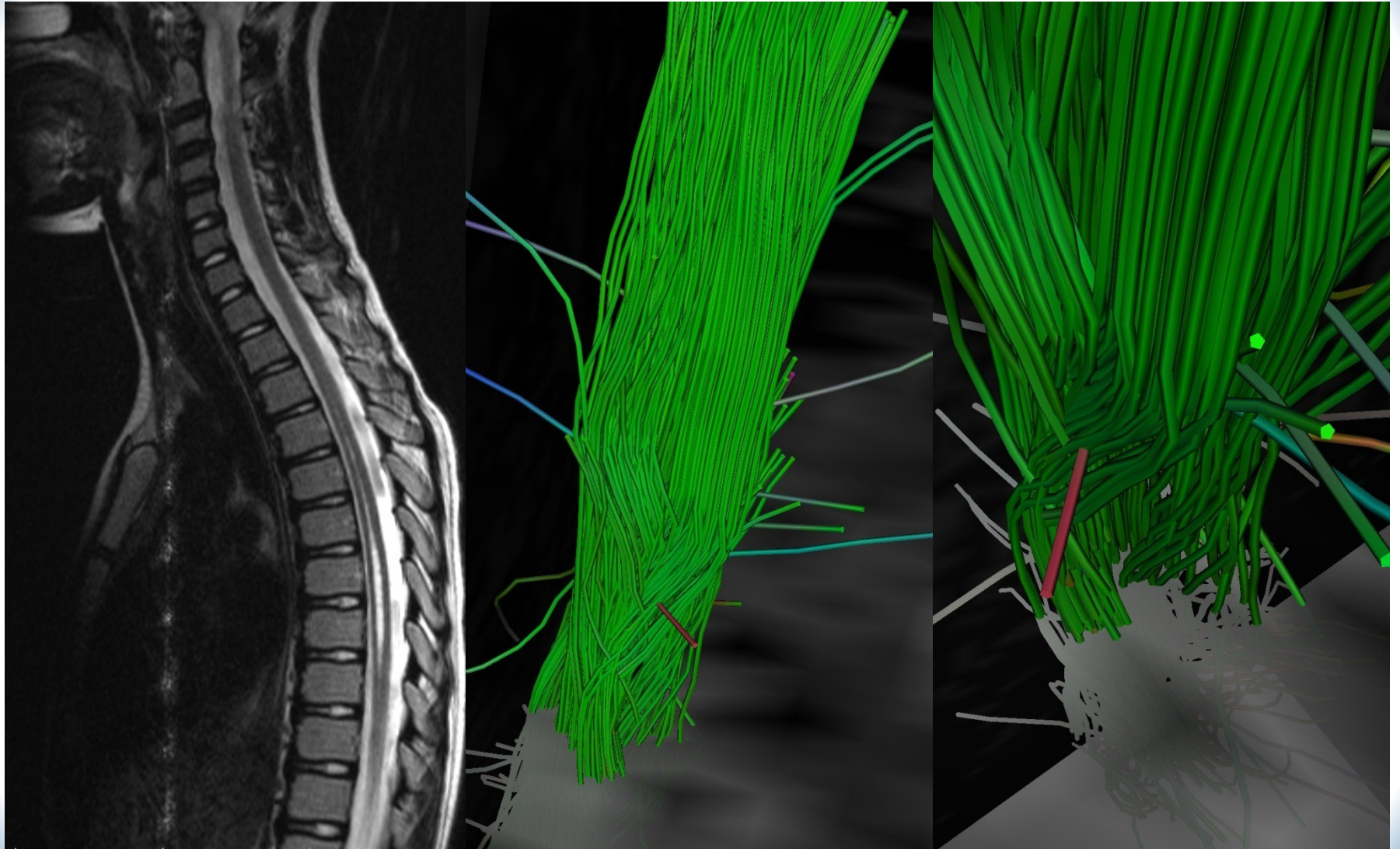
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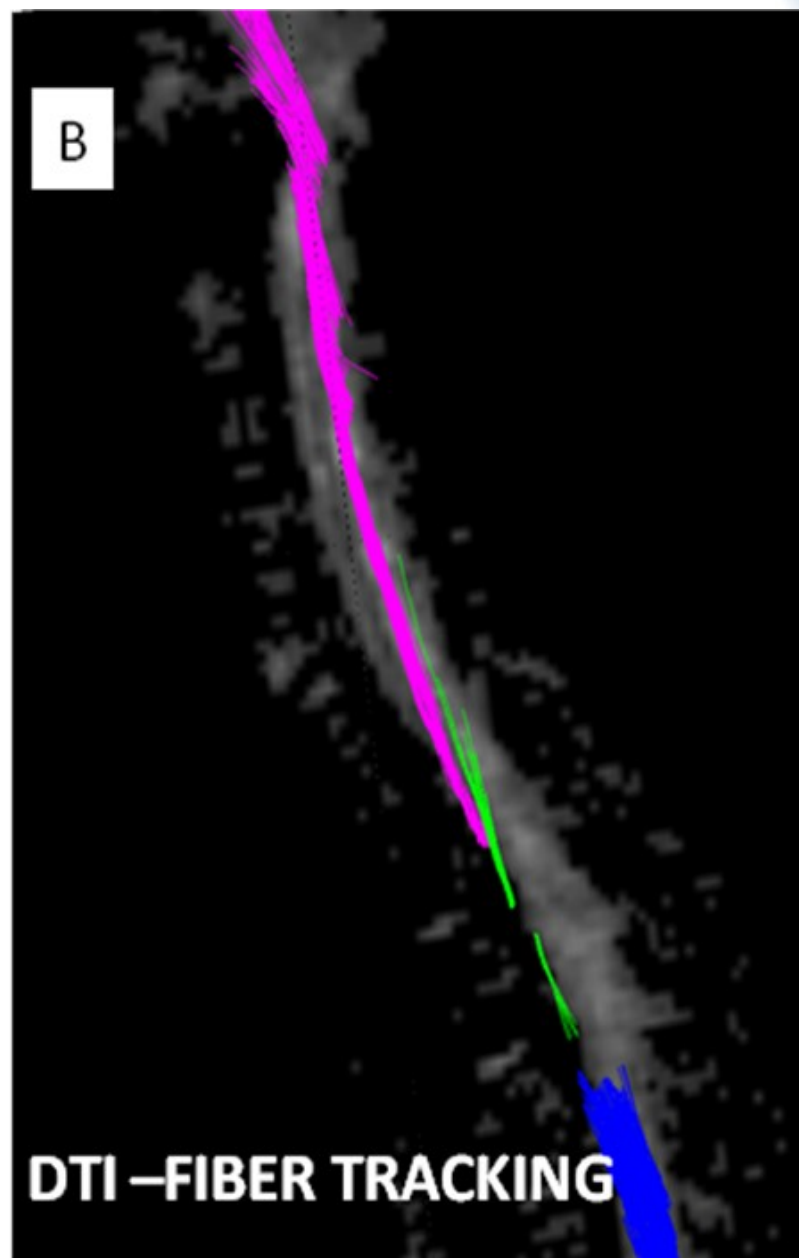


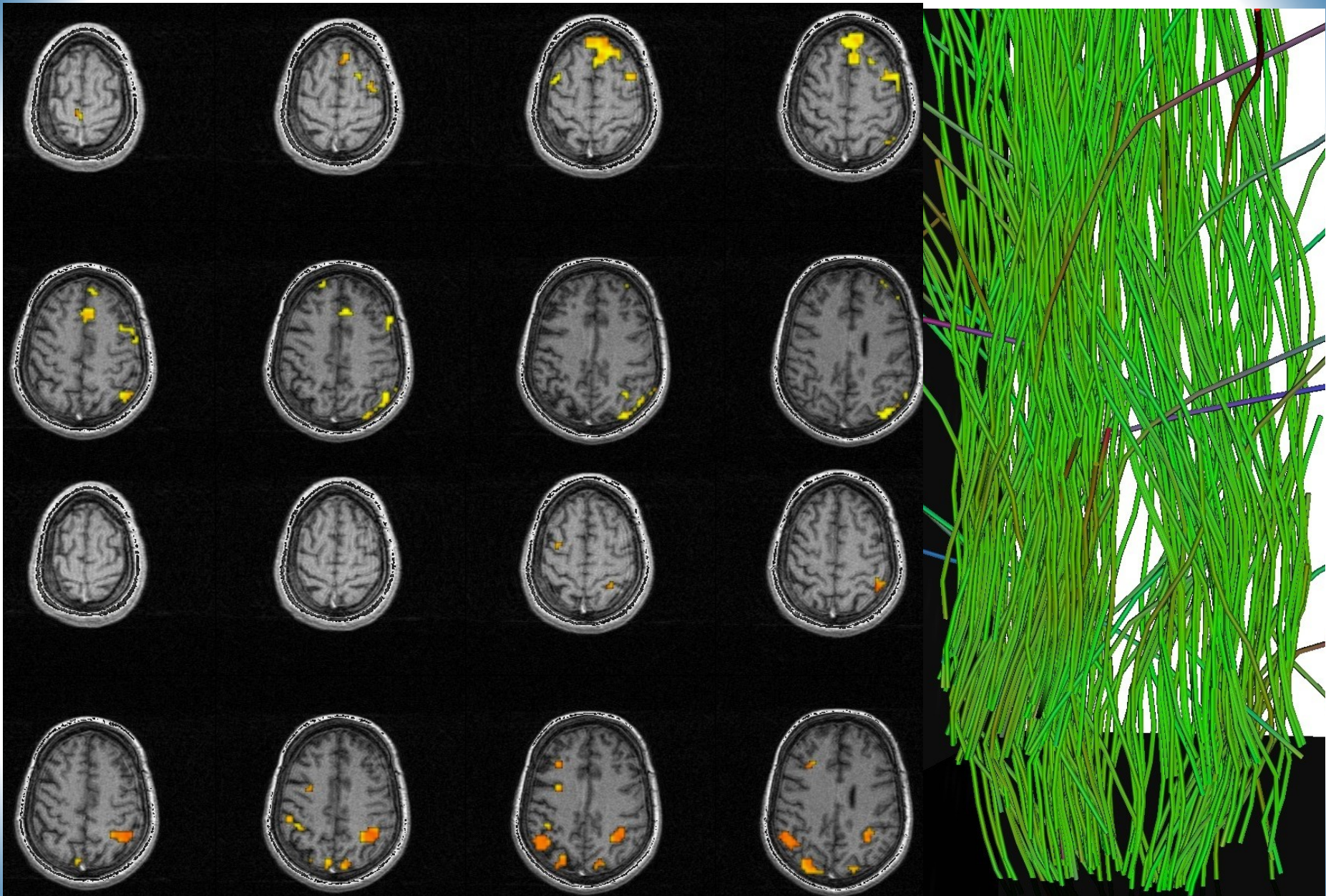




Syringomyélie

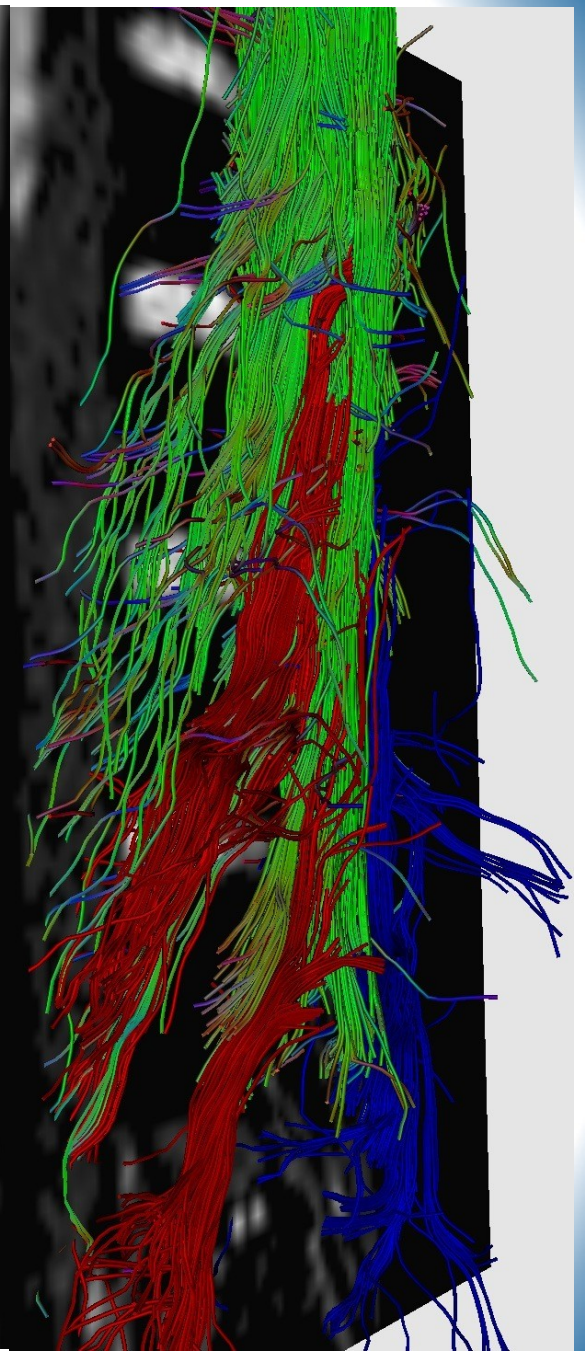
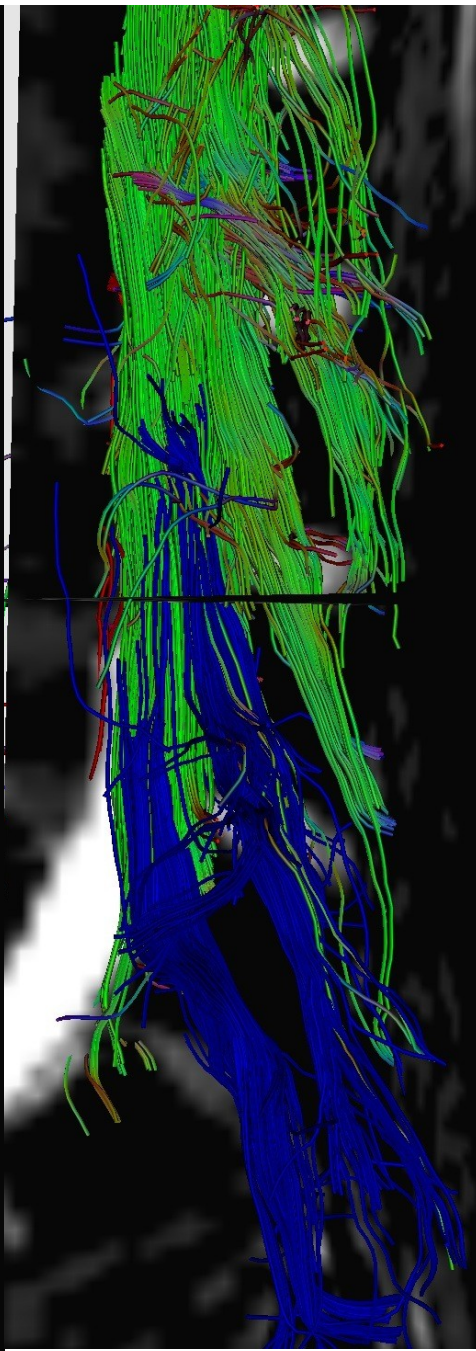
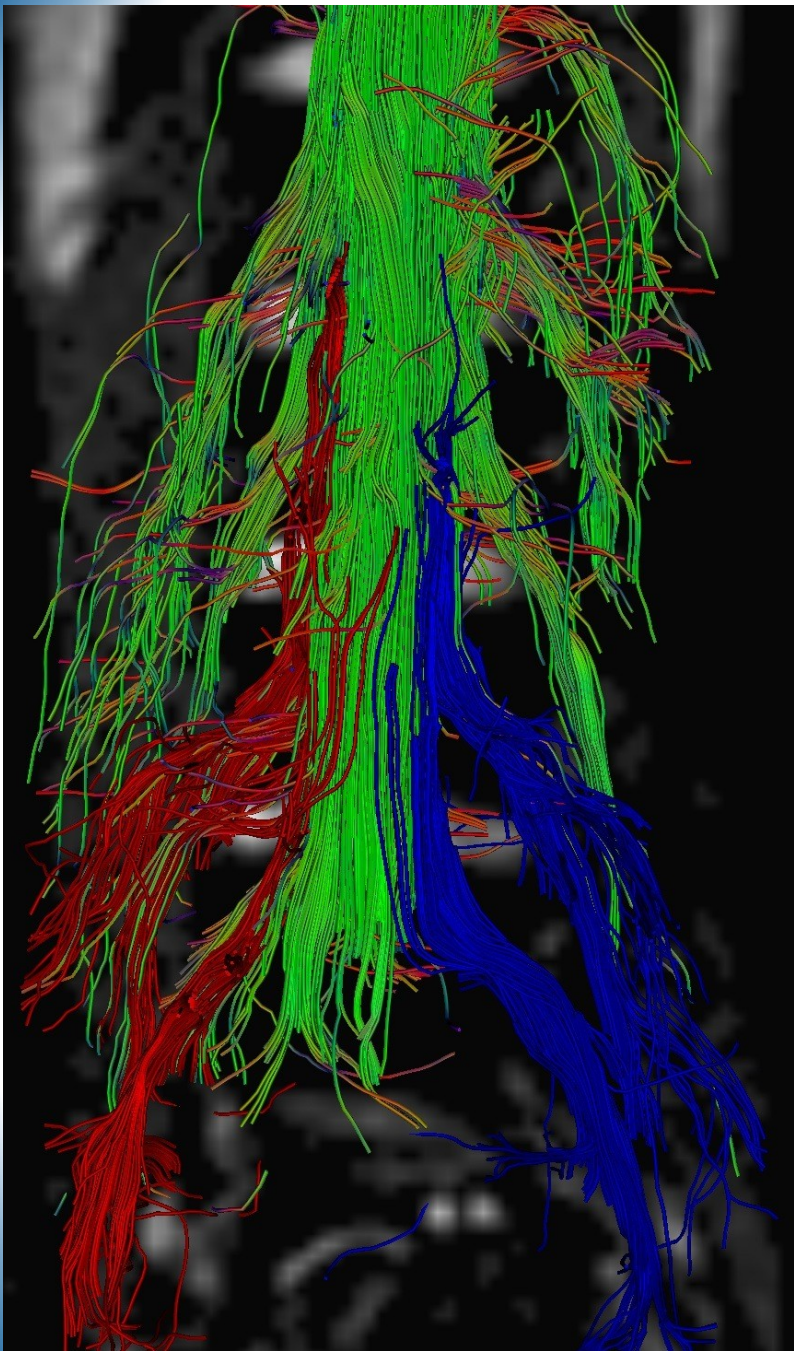




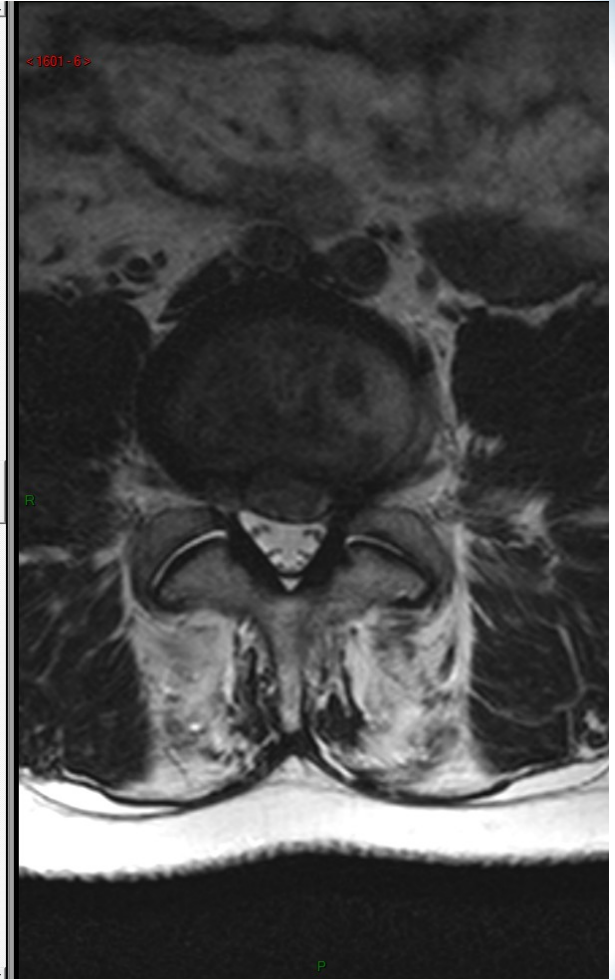


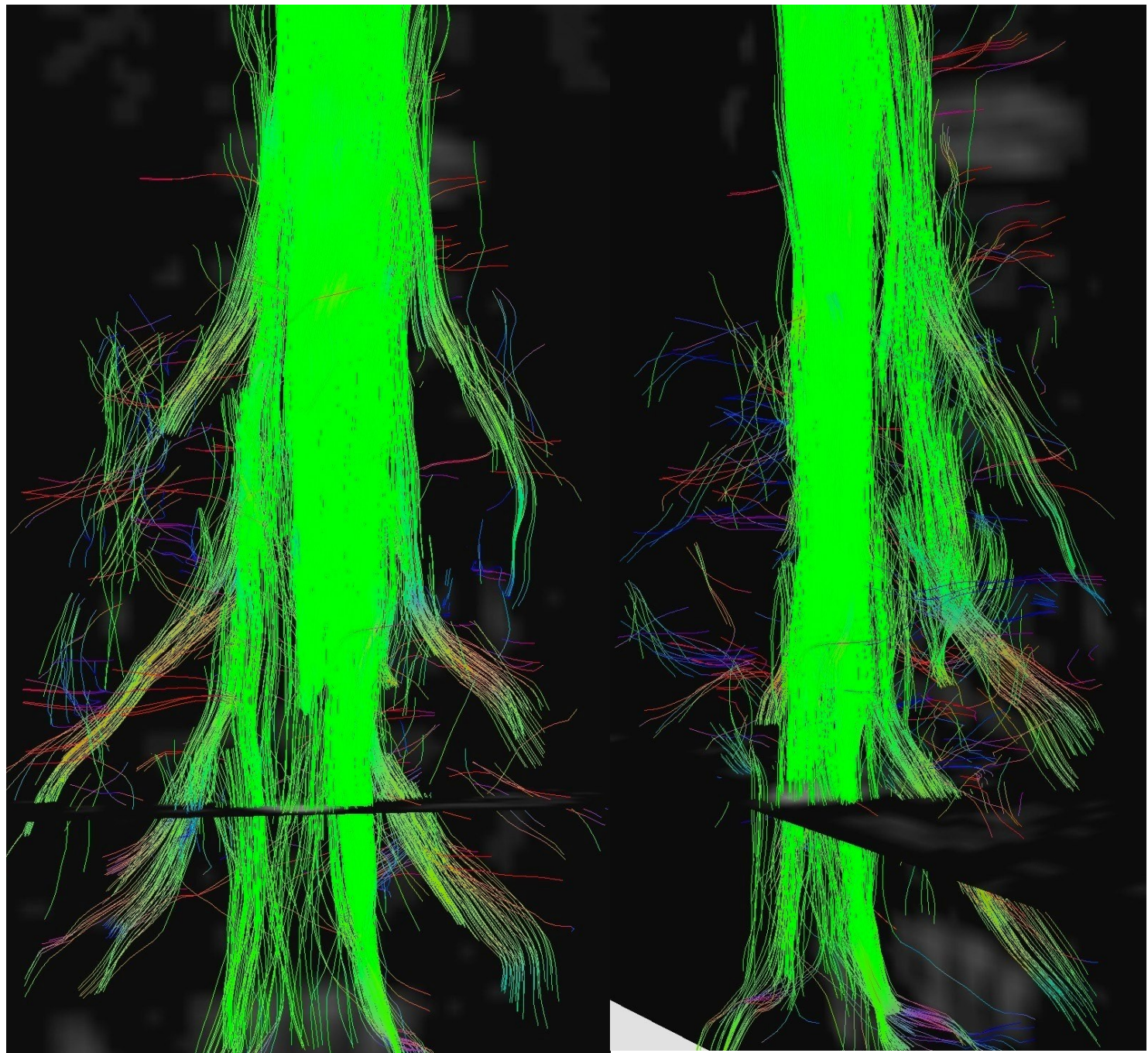
Radiculopathies





Hernies Discales

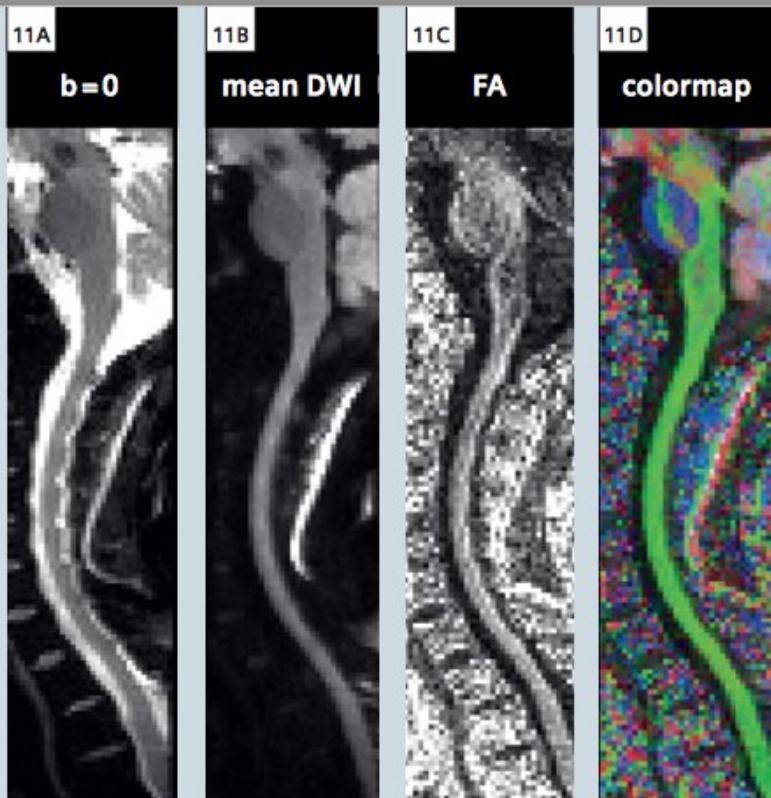




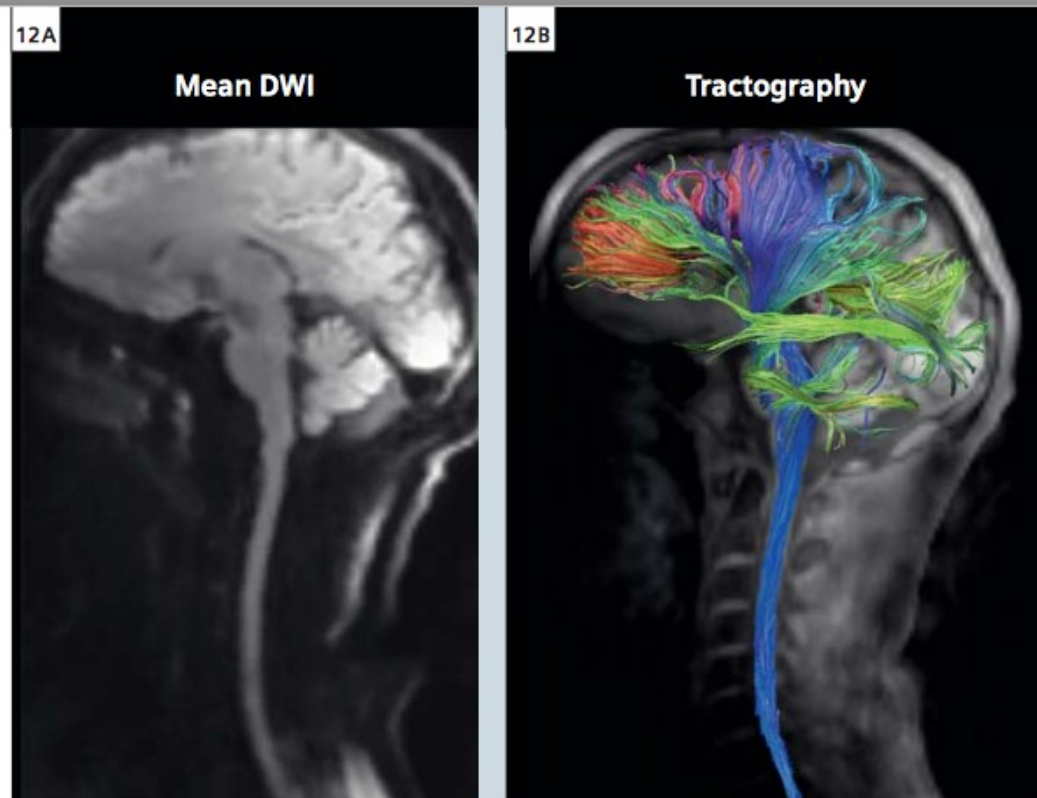
Conclusions

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- **Tractographie médullaire : diagnostique et pronostique ++**
- **Choix du nb de directions et du facteur b +++**
- **Qualité de la saturation graisse / gating cardiaque**
- **Qualité post-traitement (algorithmes +++)**
- **Ne se conçoit jamais sans analyse concomitante de la FA et de l'imagerie morphologique +++**



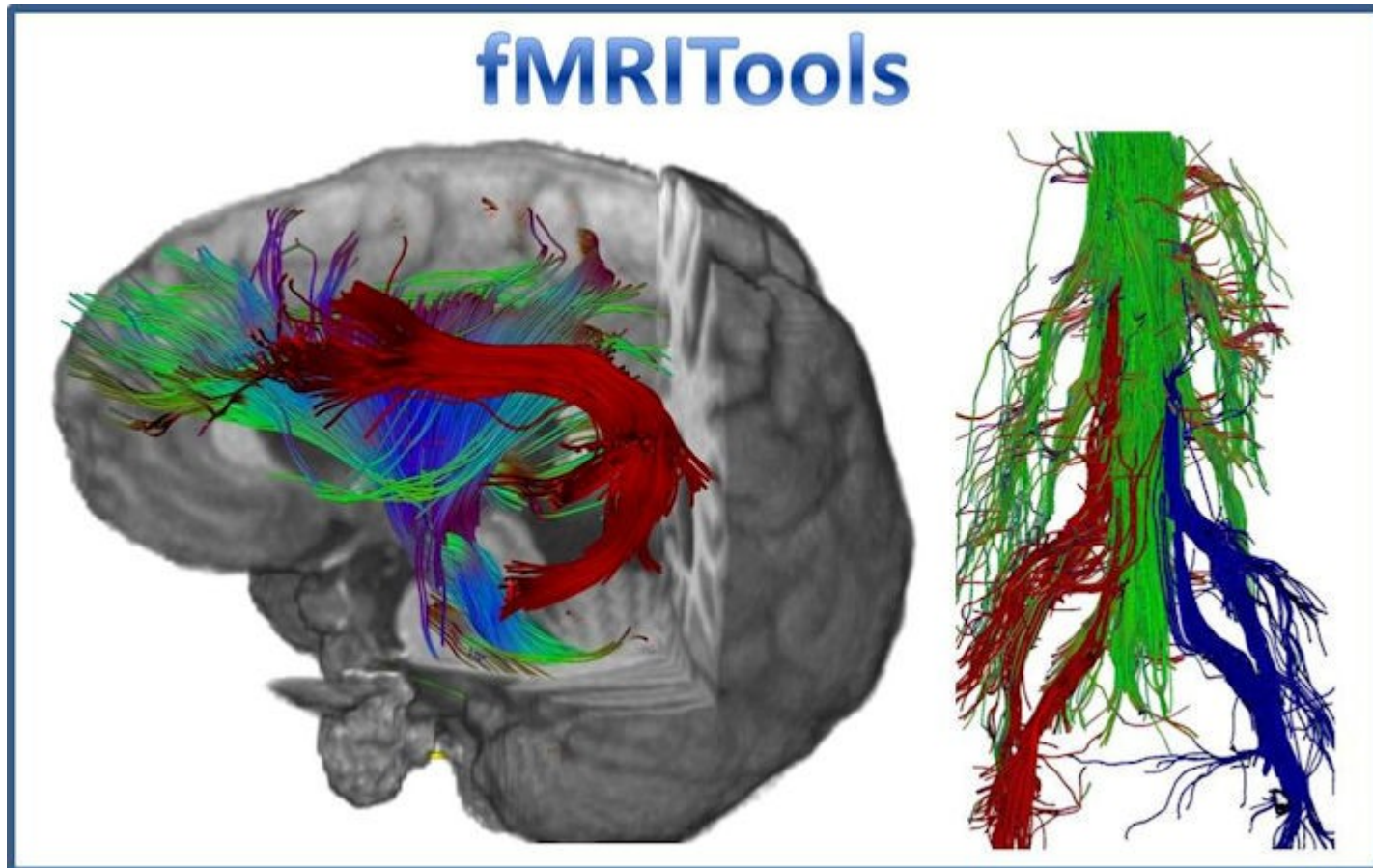
11 Human cervical spinal cord. 1.7 mm isotropic, 3 shots, R = 3, TE 74 ms, Cardiac gating, b 800 s/mm², 30 directions in 8 min.



12 Sagittal view of the mean diffusion-weighted images (12A) and fiber tractography overlaid on the anatomical image (12B). Almost no distortions are observed, which makes it possible to explore white matter connections from cortical areas down to the spinal cord without spurious interruptions.

L.I.M.E.C.

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