

L'utilité de la tractographie pour le traitement chirurgical de l'épilepsie



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Cours d'imagerie IMN530
Université Sherbrooke
26 novembre 2024



Conflits d'intérêt

- Neuralink (consultant)

Plan

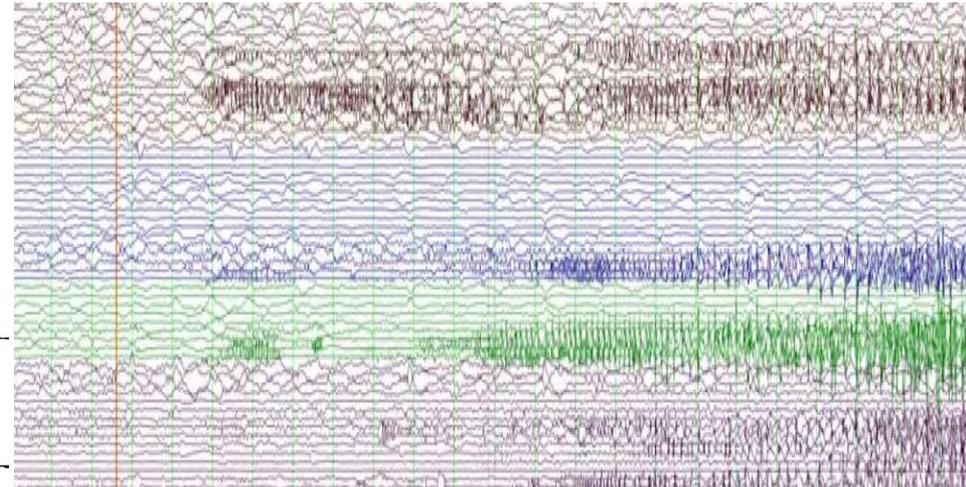
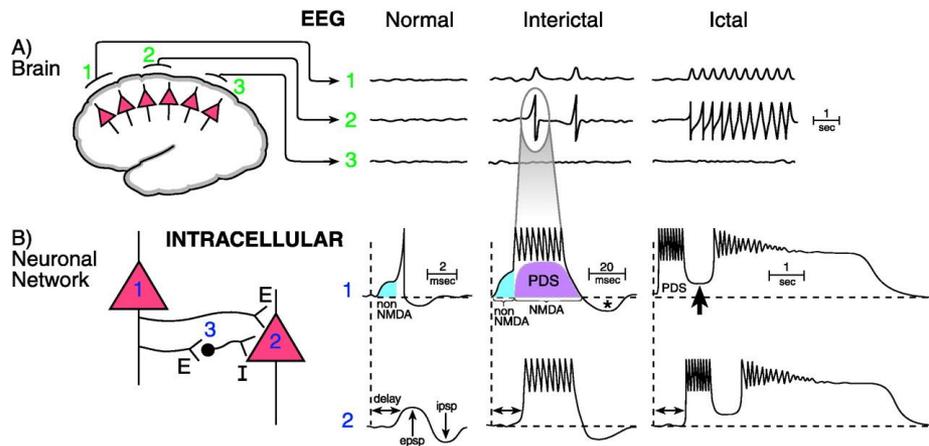
1. L'épilepsie
2. Principes de base de la tractographie
3. Applications en neurochirurgie d'épilepsie
4. Conclusion

Épilepsie

Crise épileptique

- Décharges neuronales anormales résultant en un changement comportemental

Abnormal Neuronal Firing



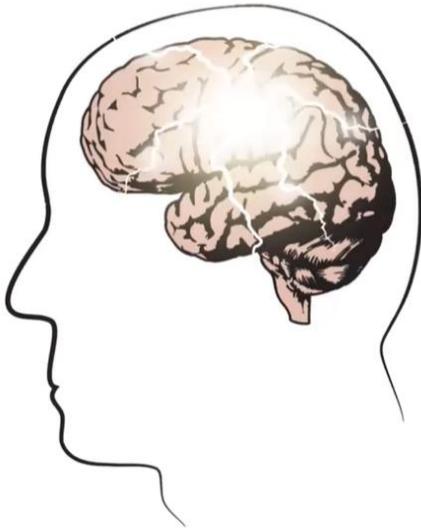
Stafstorm et al. 1998

Meneses et al. 2009

Vidéo 26



Épidémiologie de l'épilepsie



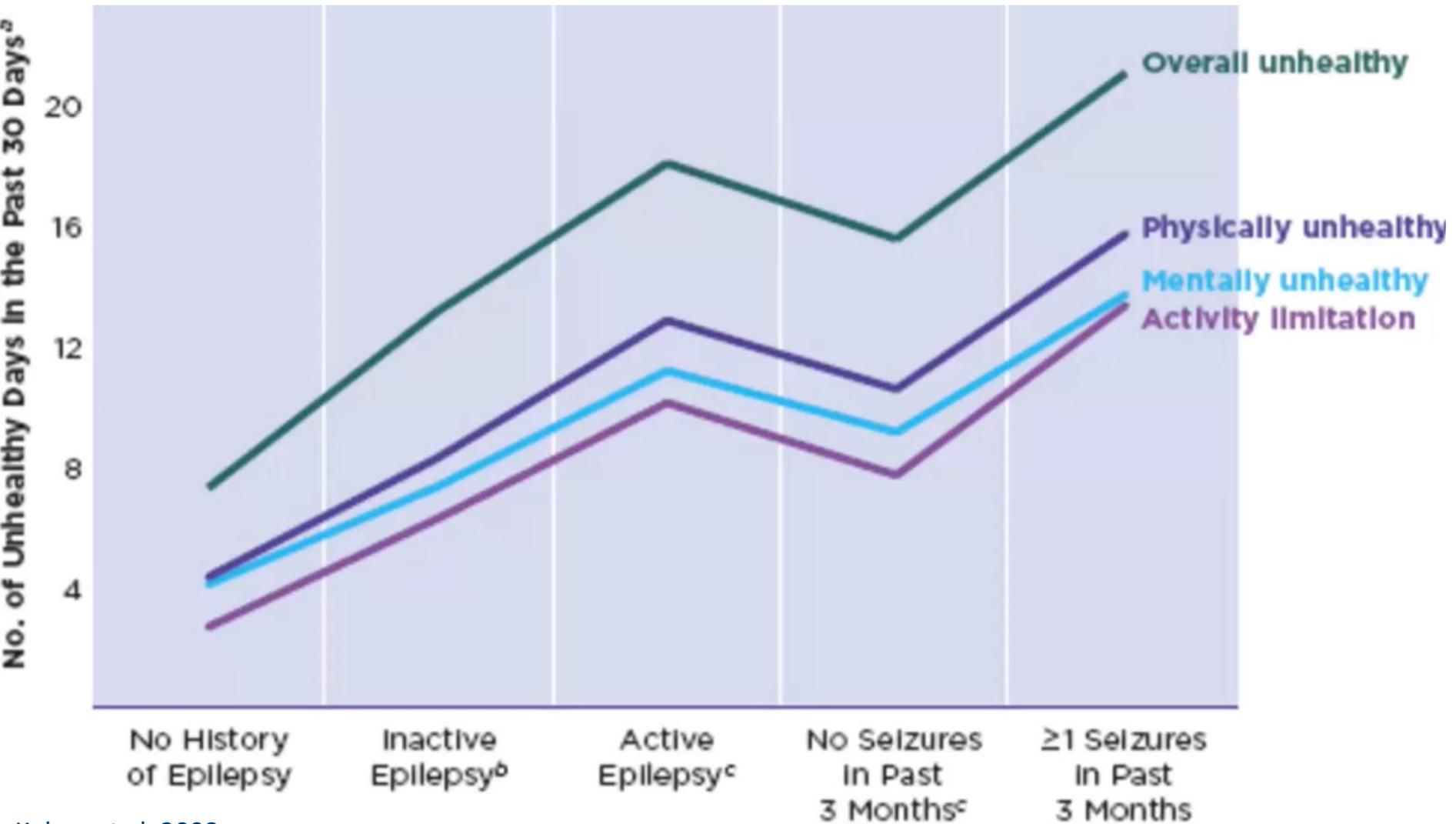
1% de la population en Amérique du Nord

50 millions à travers le monde

5 millions diagnostiqués par année

1% de la charge médicale mondiale

Impact sur la santé physique et mentale



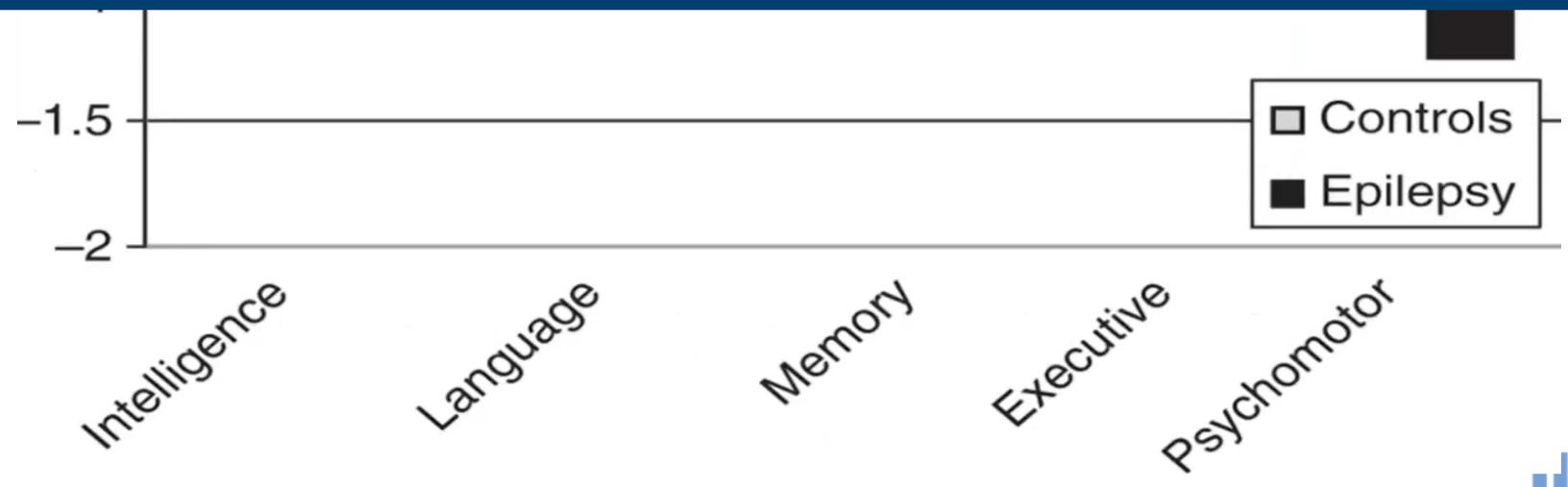
Kobau et al. 2008



Impact sur la santé cognitive



Impact sur la qualité de vie

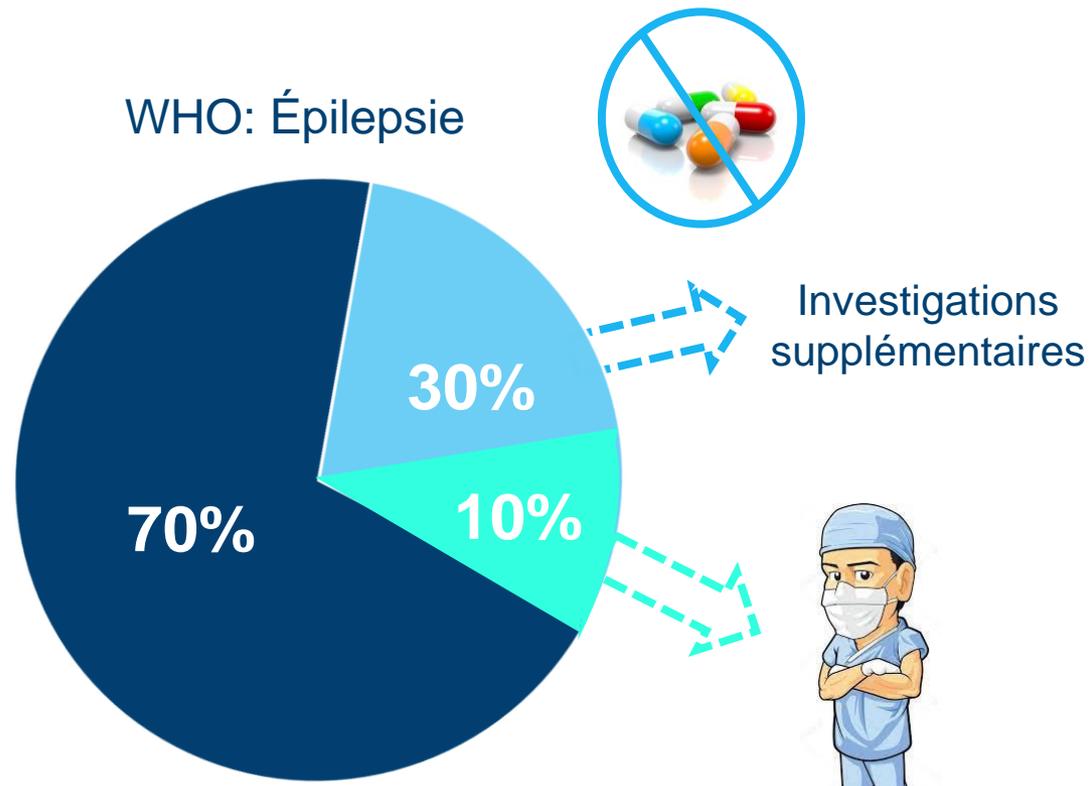
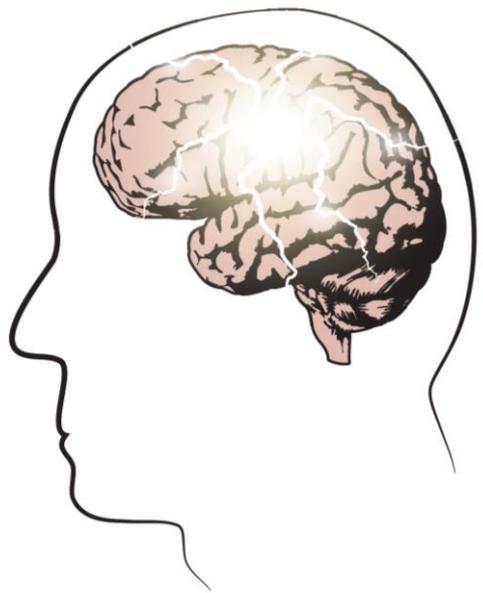


Hermann et al. 2007
Jobst et al. 2015



L'épilepsie

Impact significatif sur la QDV
1% de la population en Amérique du Nord



50-70% de succès

Amélioration de la QDV

5 millions de cas

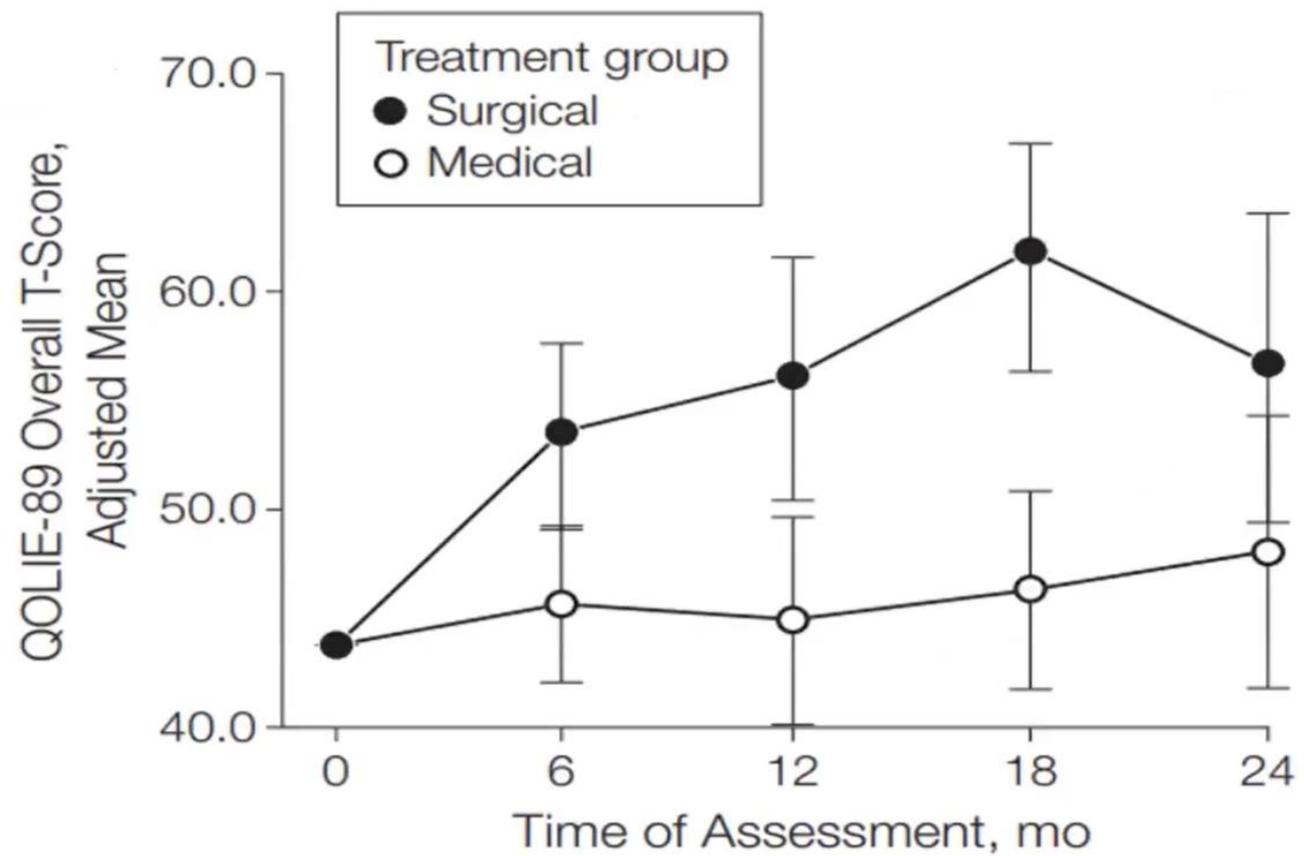


WHO: Épilepsie
Engel et al. 2016
Engel et al. 2019

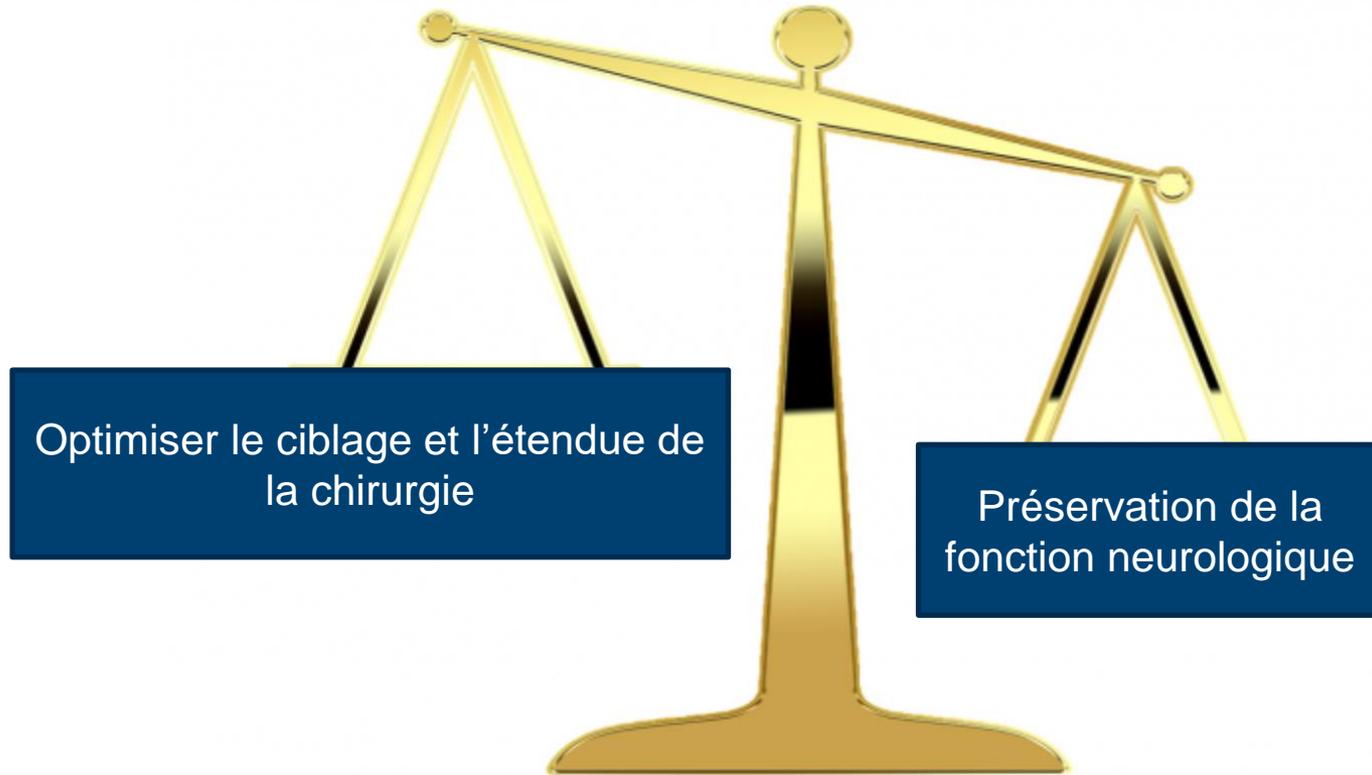


Traitement chirurgical

50-70% contrôle d'épilepsie



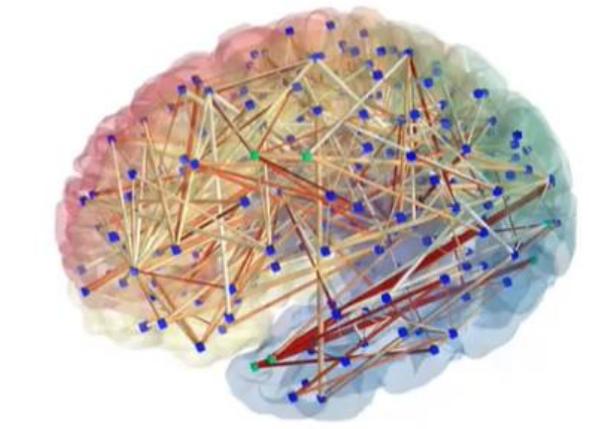
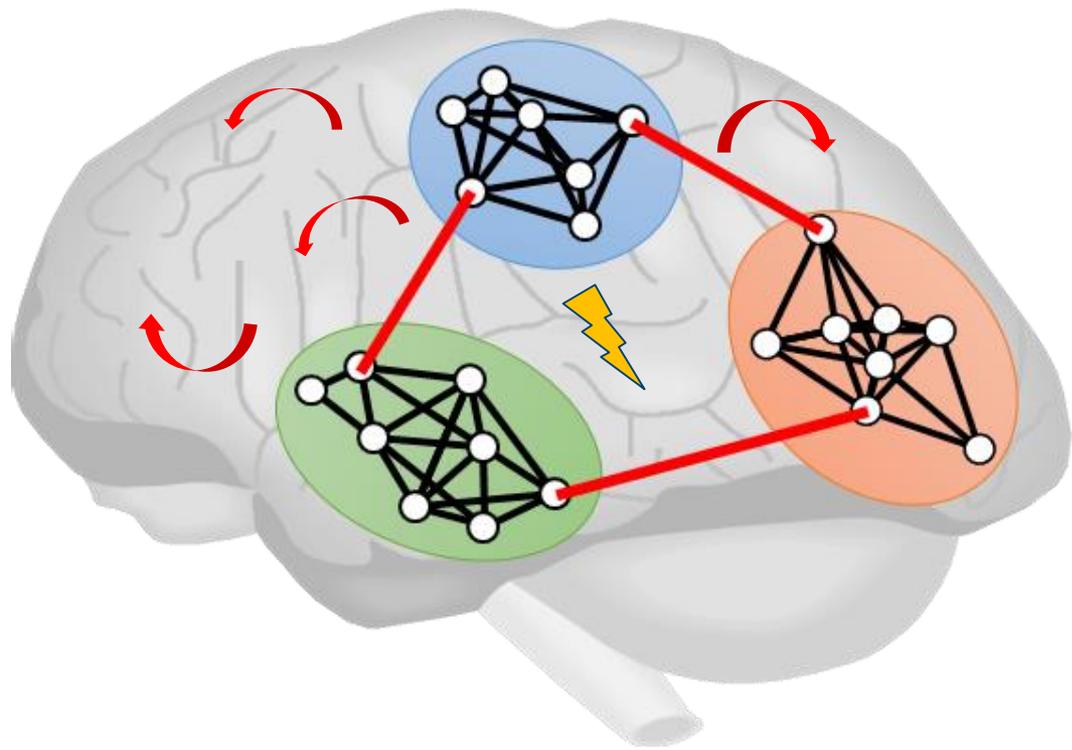
Défis en neurochirurgie d'épilepsie



Changement de paradigme

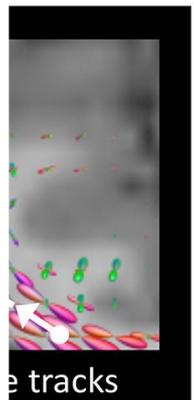
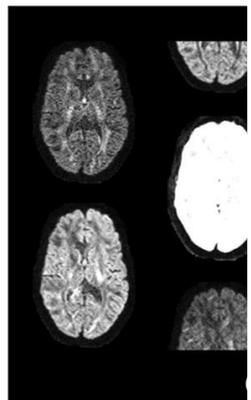
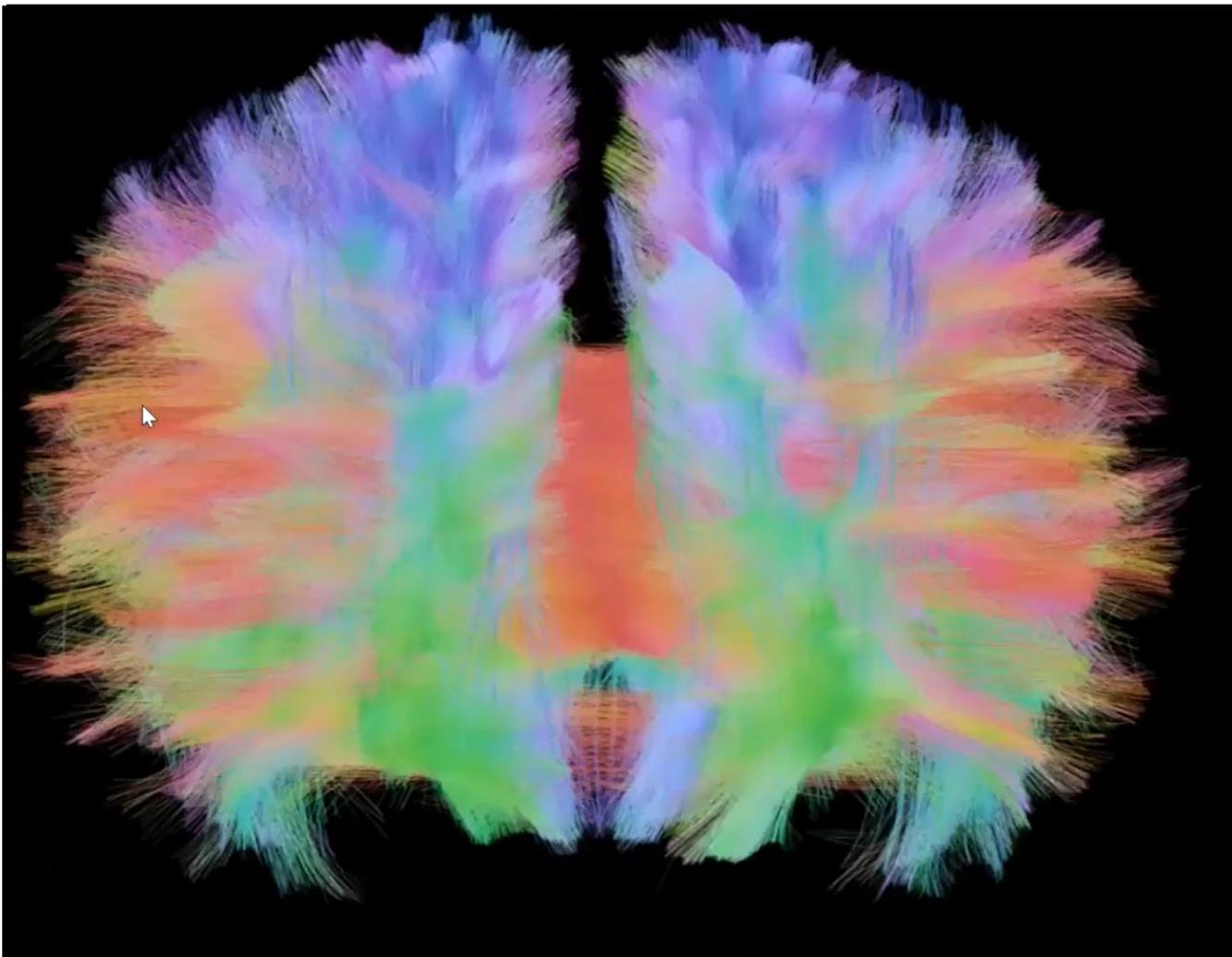
Le réseau épileptique

Réseau de régions corticales connectées par des faisceaux de matière blanche



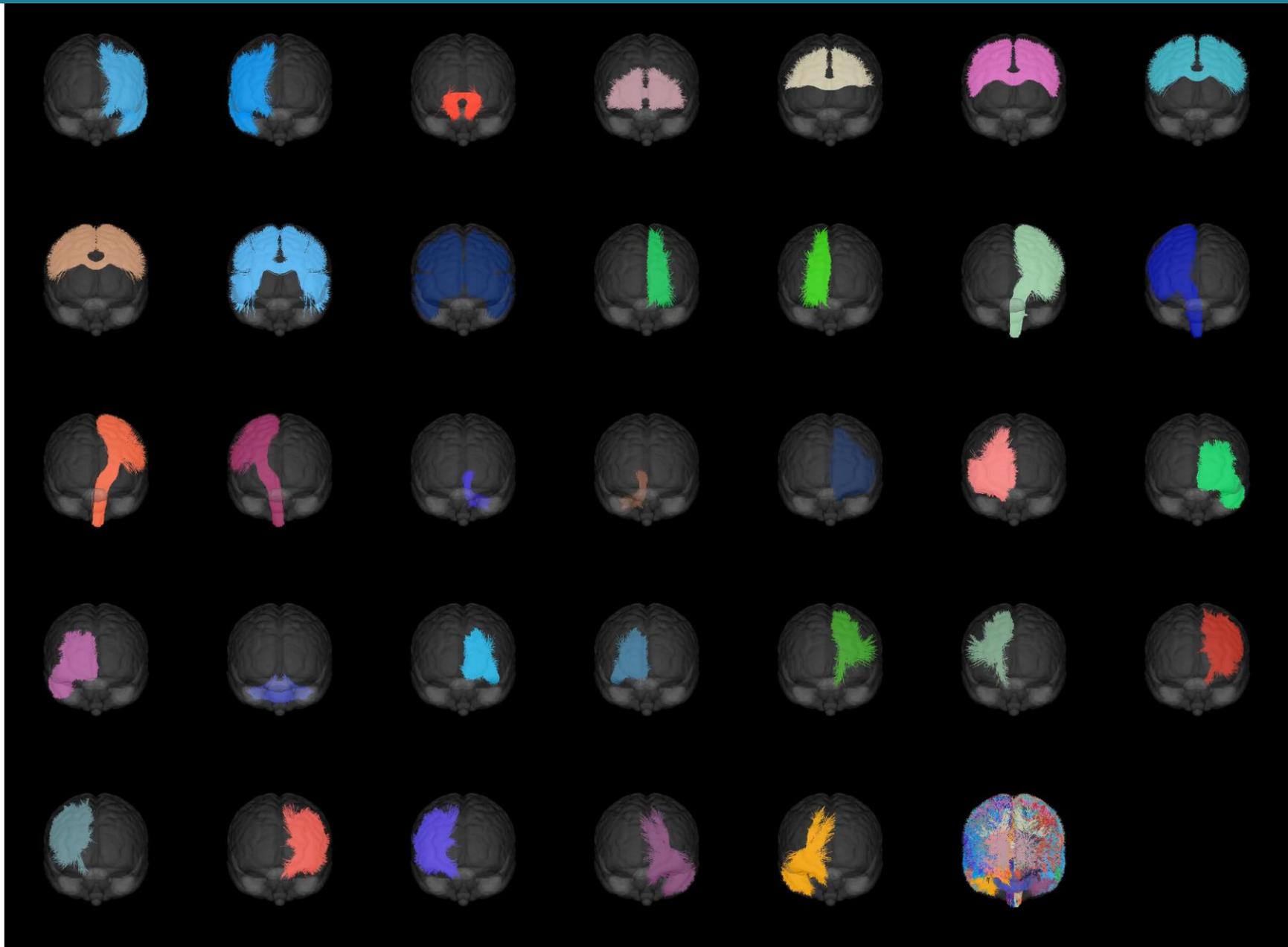
Tractographie
(diffusion des molécules d'eau)

IRM de diffusion et tractographie

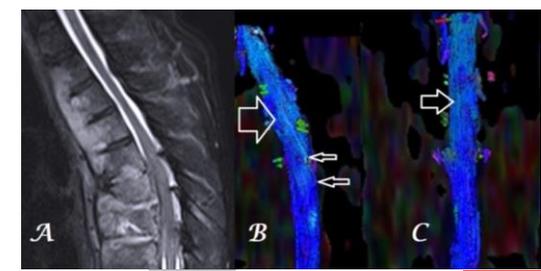
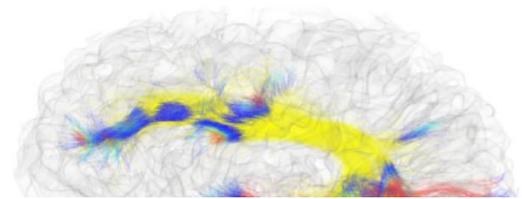
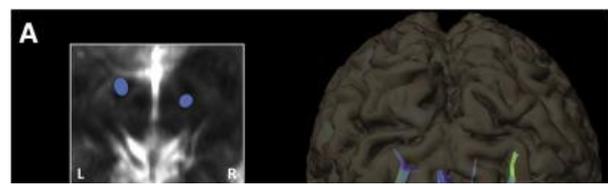


JEUSSIER et al., 2017

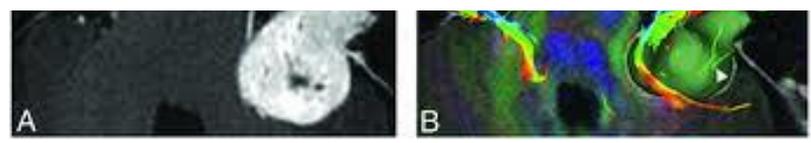
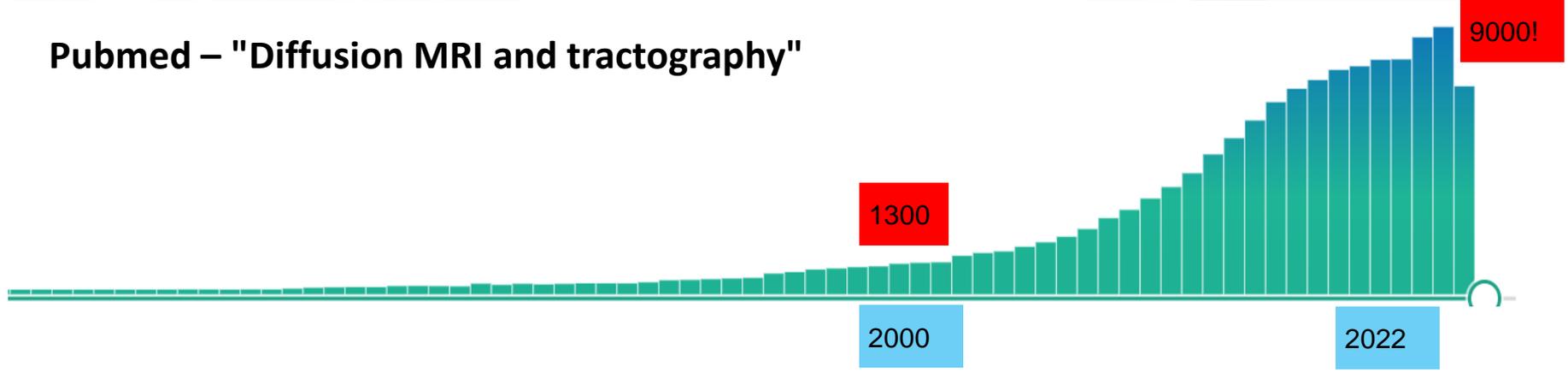




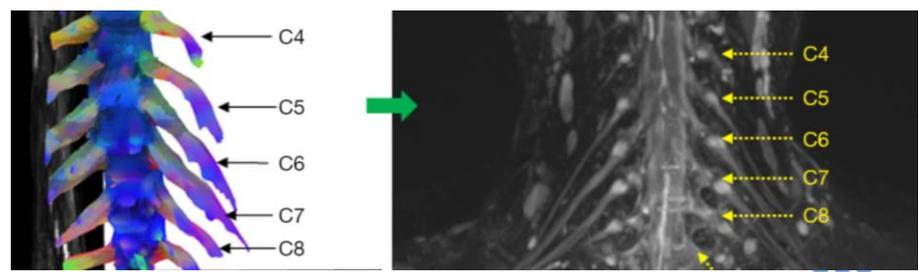
Multiples applications de la tractographie en neurochirurgie



Pubmed – "Diffusion MRI and tractography"



Base du crâne

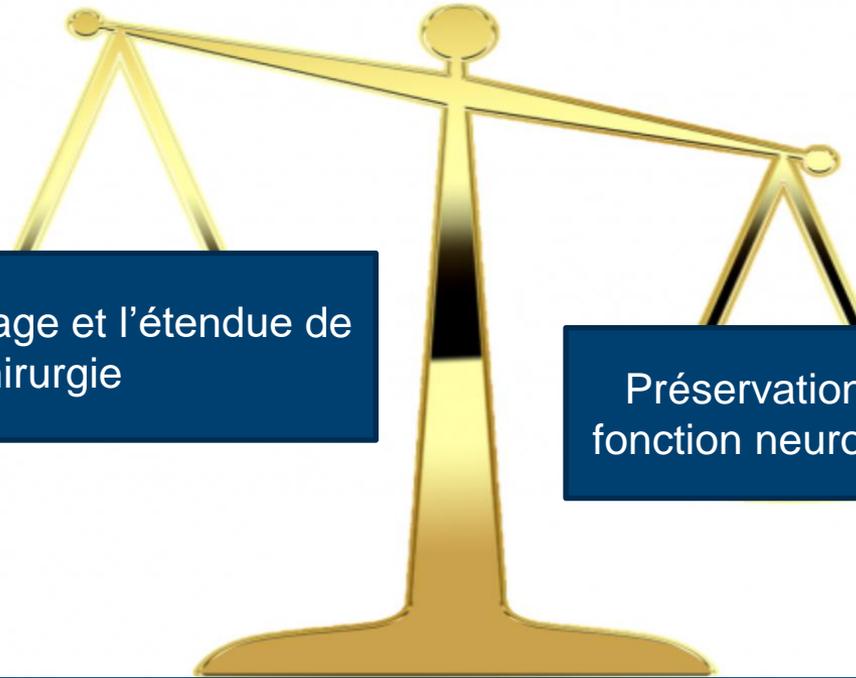


Nerfs périphériques



- Essayed et al. 2017
- Vanderweyen et al. 2020
- Rastogi et al. 2016
- Halawani et al. 2021
- Ibrahim et al. 2022

Utilité en neurochirurgie d'épilepsie?



Optimiser le ciblage et l'étendue de la chirurgie

Préservation de la fonction neurologique

1- IDENTIFICATION DE L'ORIGINE DES CRISES

2- PRÉDIRE L'ISSUE (CONTRÔLE ÉPILEPTIQUE)

3- PRÉVENIR LES COMPLICATIONS NEUROLOGIQUES

4- PRÉDIRE LA RÉCUPÉRATION FONCTIONNELLE POSTOPÉRATOIRE



Outils neurochirurgicaux

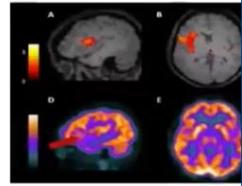
- IRM clinique
- IRM fonctionnelle
- PET scan
- MEG

IMPARFAITS

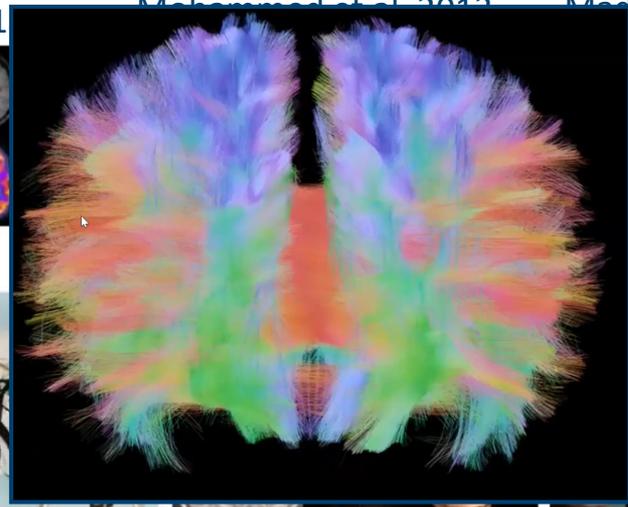
- Electrocorticographie
- EEG intracrânien
- Neuronavigation
- Stimulation intracortéale

Tractographie?

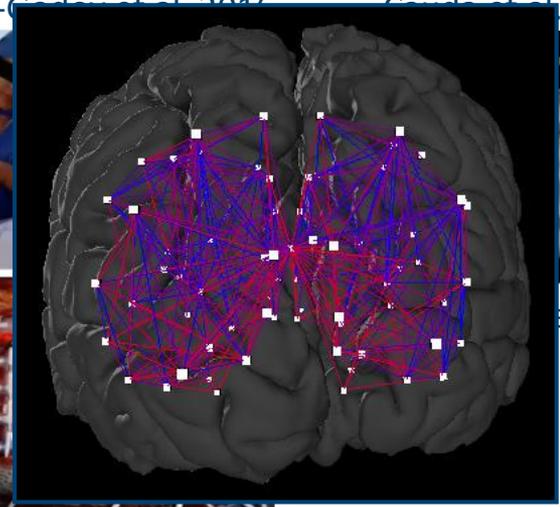
Fei et al. 2011



Mohammed et al. 2012



Medriz-Galvez et al. 2016



Galvez et al. 2011



et al. 2019

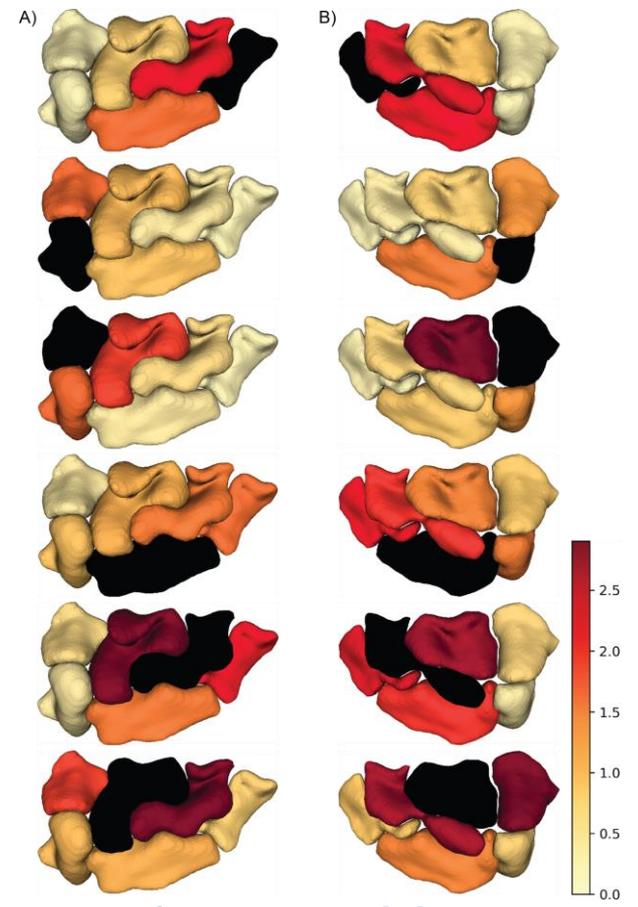
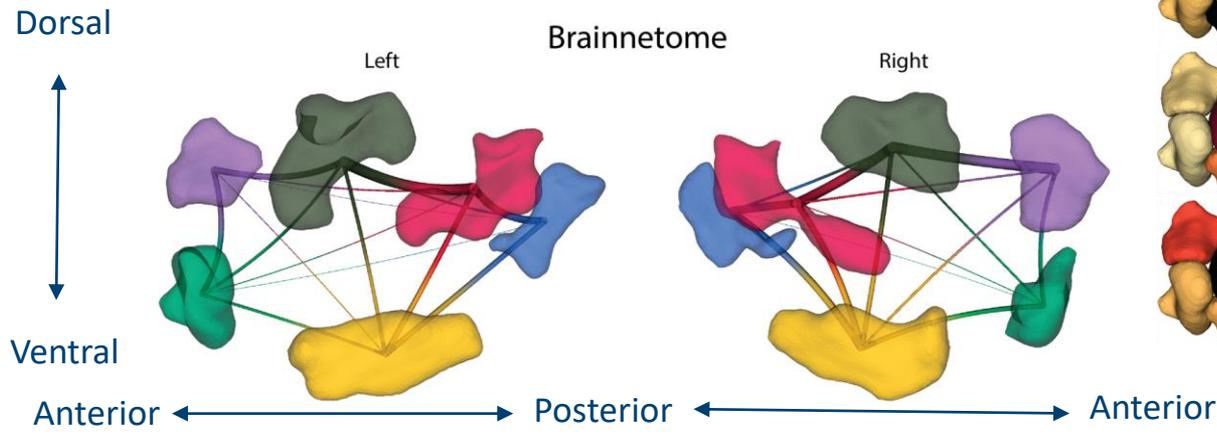
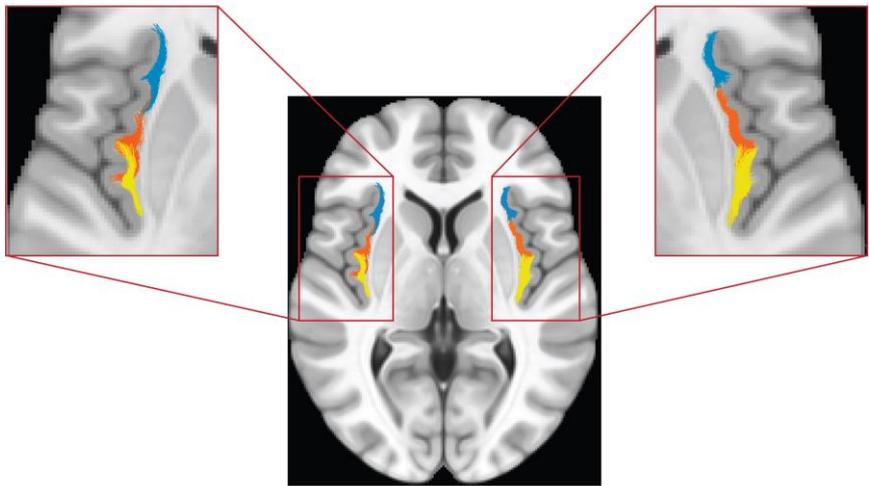


Identification de la source des crises

Épilepsie insulaire



Farbod Niazi
MD, MSc (c)



Connectivité à une
parcelle de référence
(noir)

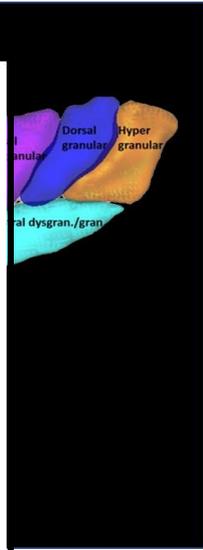
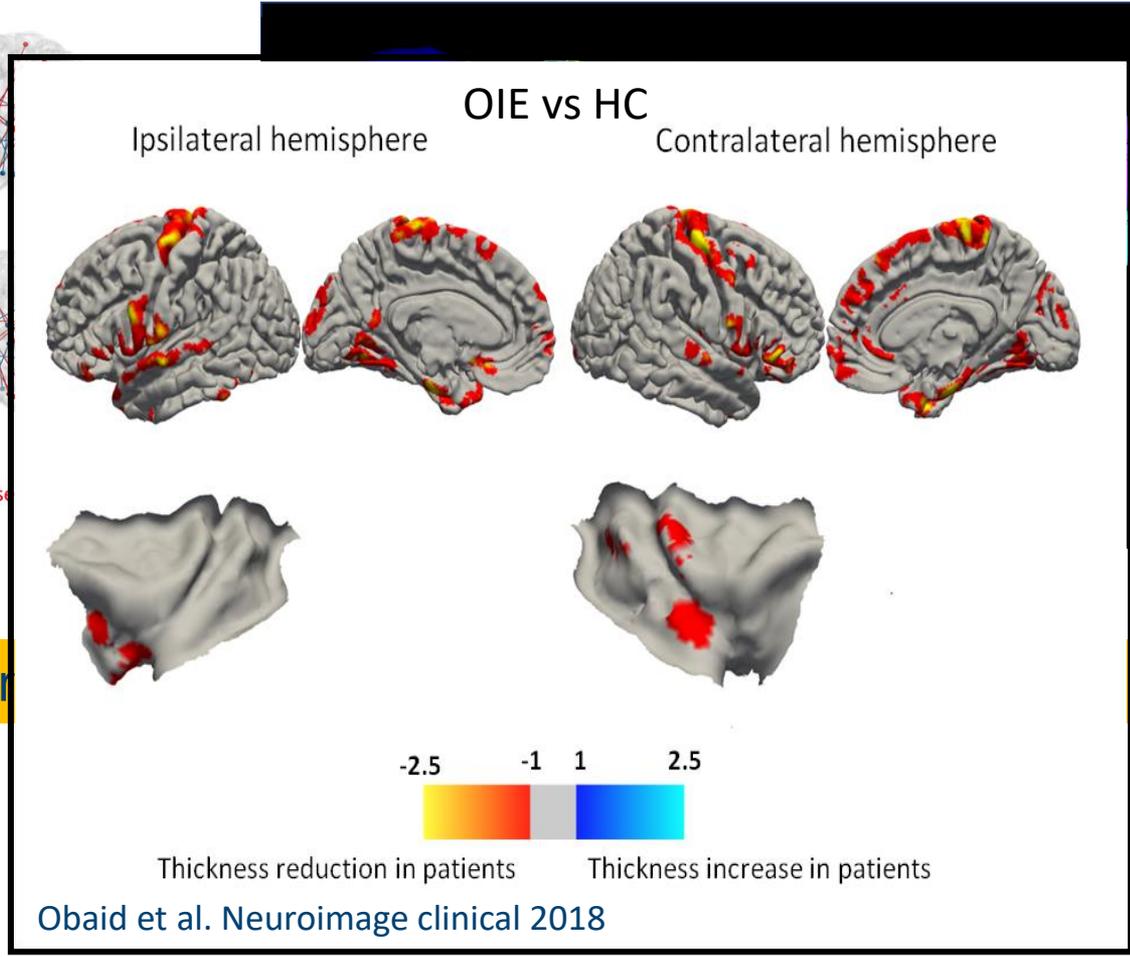
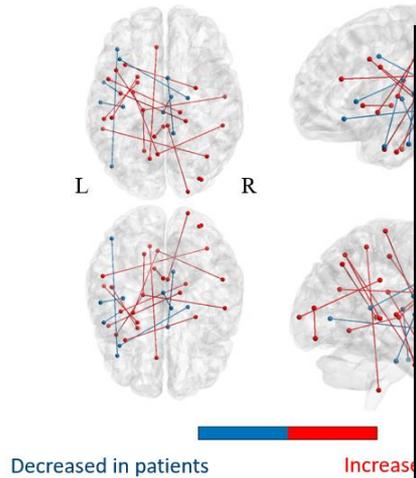
1. Tous les gyris sont interconnectés
2. Connectivité forte de l'insula moyenne
3. Connexions faibles entre l'insula antérieure et postérieure

En préparation



Identification de la source des crises

Épilepsie insulaire



Hyper

aire

Contribution de l'UdeM à la caractérisation de l'épilepsie insulaire

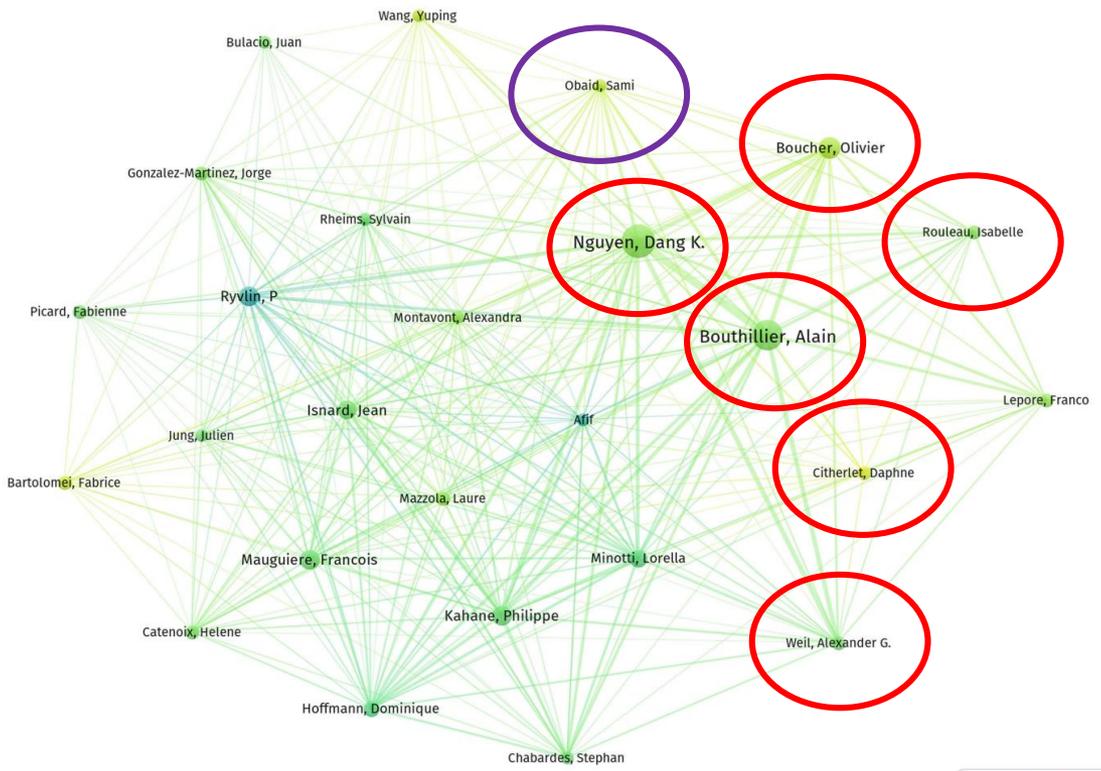
Open Access Full Text Article

ORIGINAL RESEARCH

Knowledge Atlas of Insular Epilepsy: A Bibliometric Analysis

2022

Manli Li¹, Xiaoli Ma¹, Chendi Mai¹, Zhiru Fan¹, Yangyang Wang², Yankai Ren¹

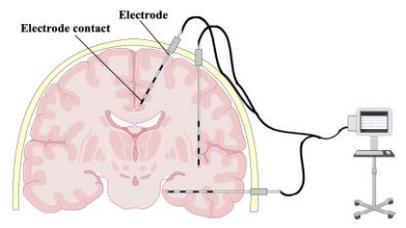


'Most influential authors in the field of insular epilepsy'



Dépeindre le réseau épileptique

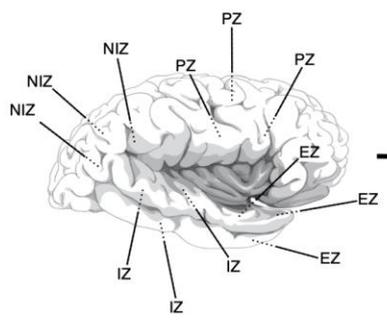
Tractographie tridimensionnelle



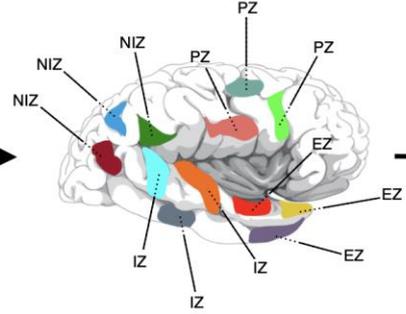
Arash Sarshoghi, MSc (c)



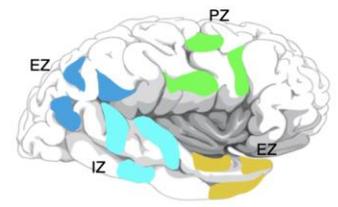
Classification of icEEG contacts



Identification of pertinent atlas-based parcels

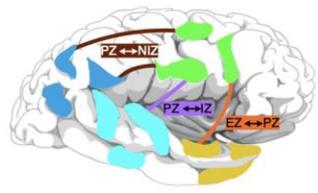
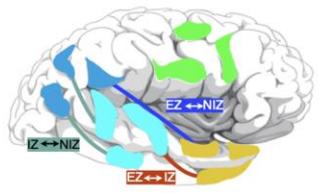


Classification of atlas-based parcels

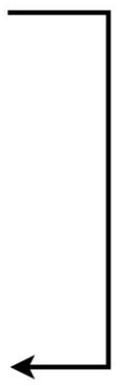
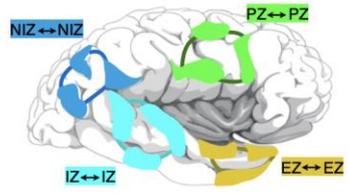


Creation of zone-based networks

Interzonal networks

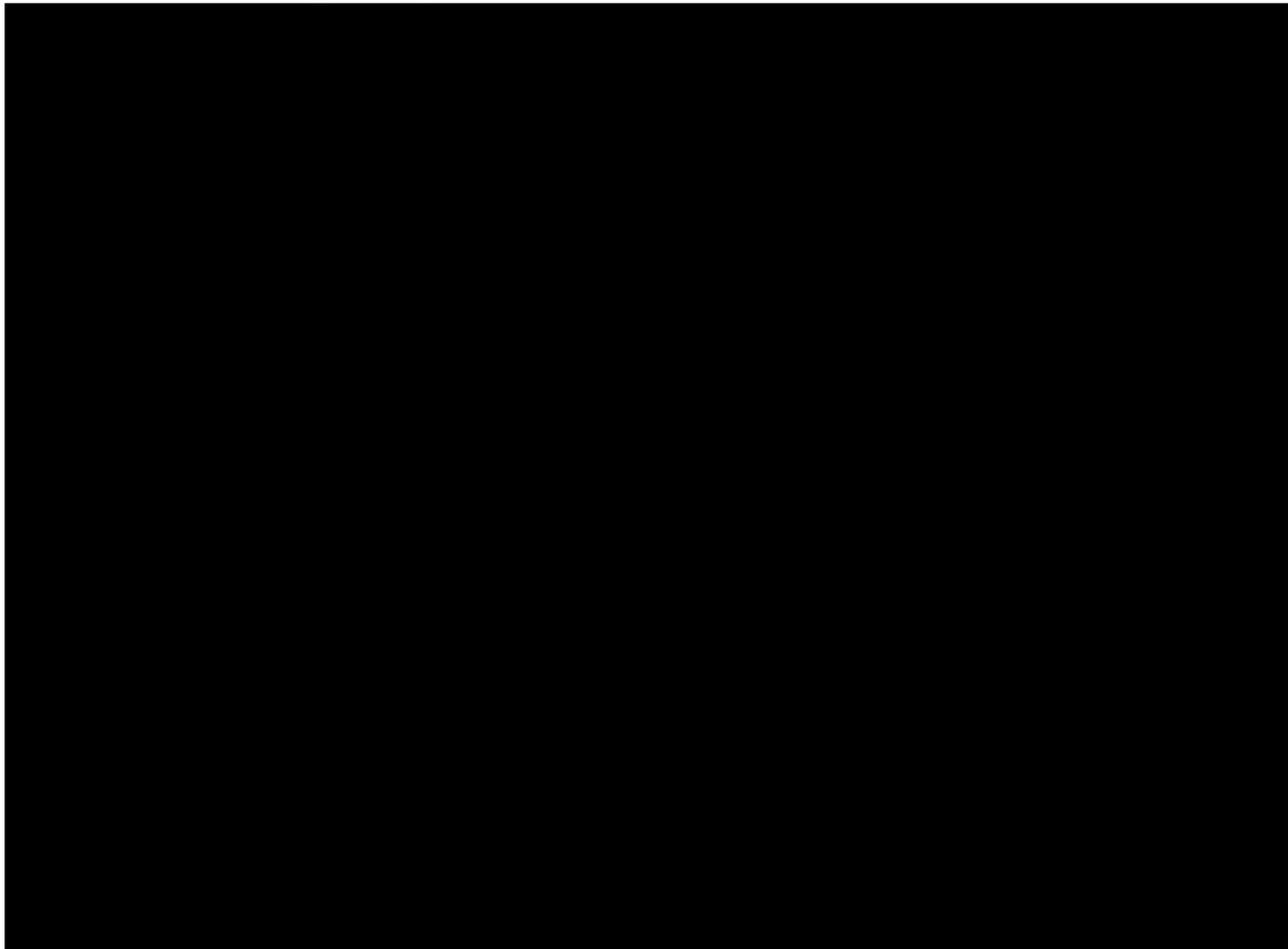


Intrazonal networks



Dépeindre le réseau épileptique

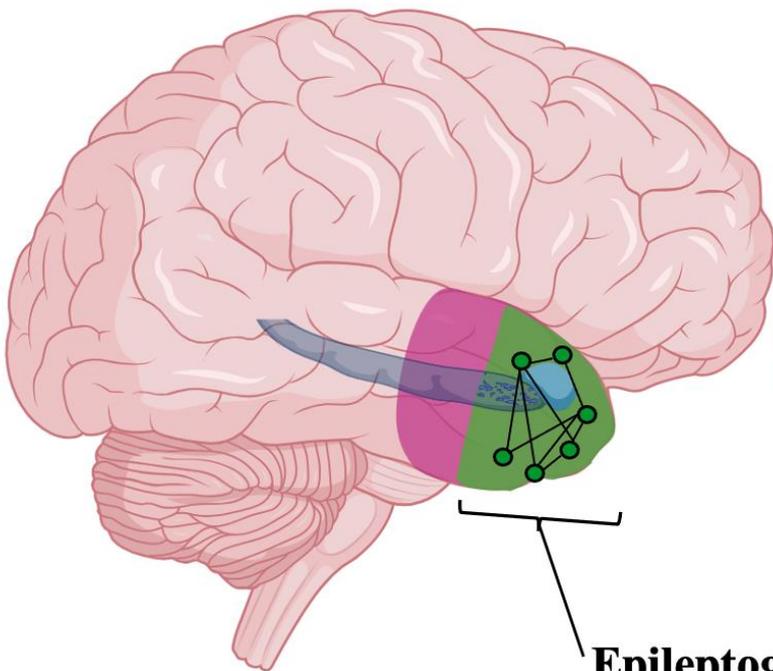
Tractographie tridimensionnelle



Prédire le contrôle épileptique postopératoire

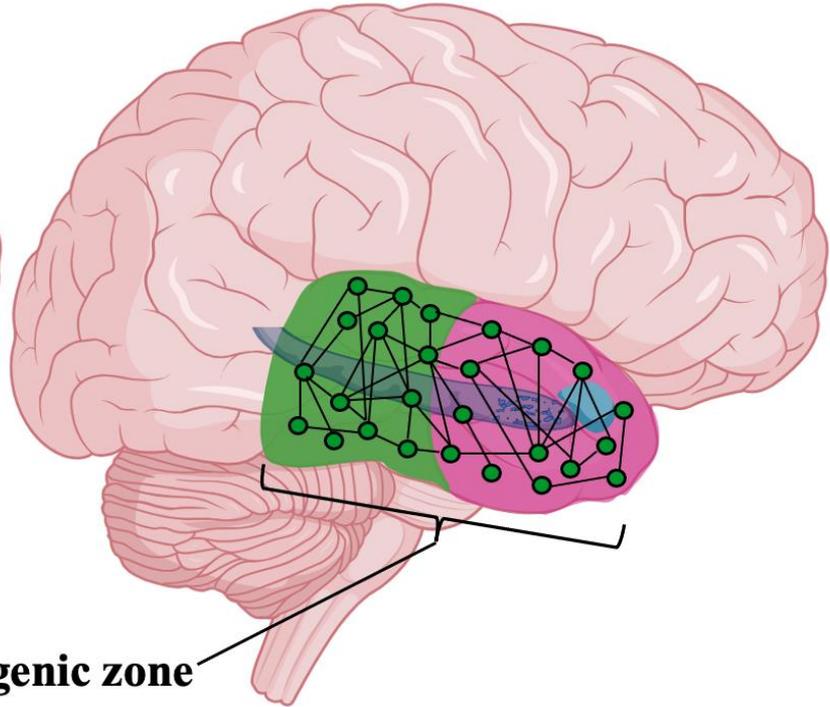
Épilepsie du lobe temporal

A



Bon contrôle

B



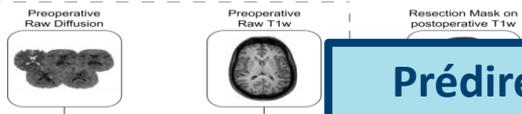
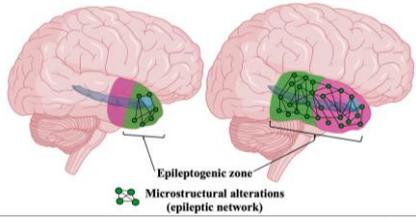
Mauvais contrôle

Epileptogenic zone

 **Microstructural alterations (epileptic network)**

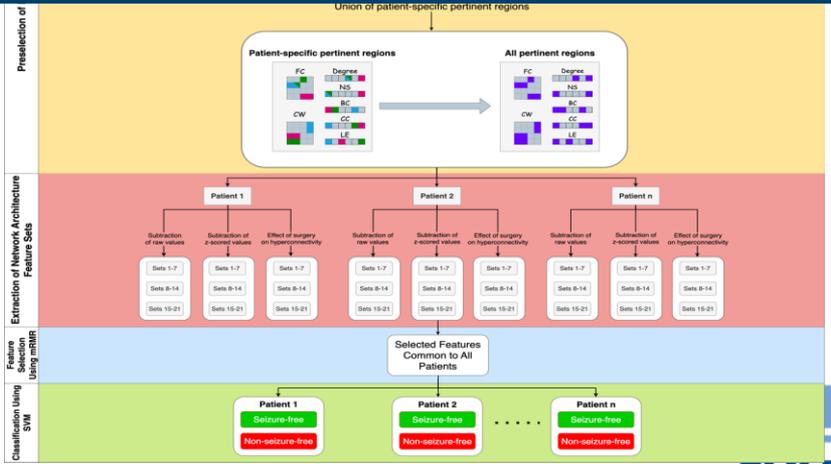
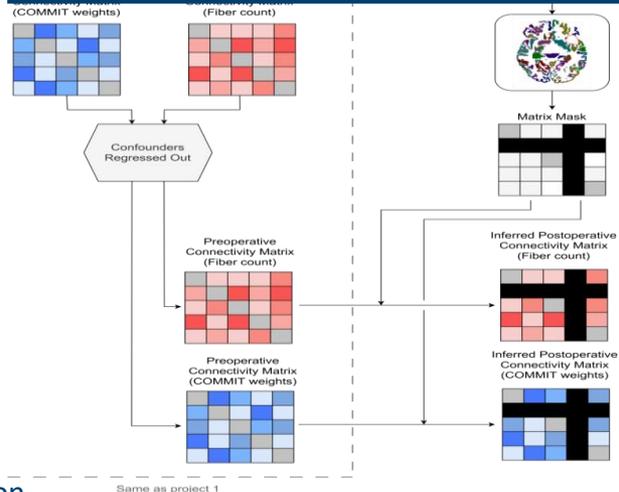
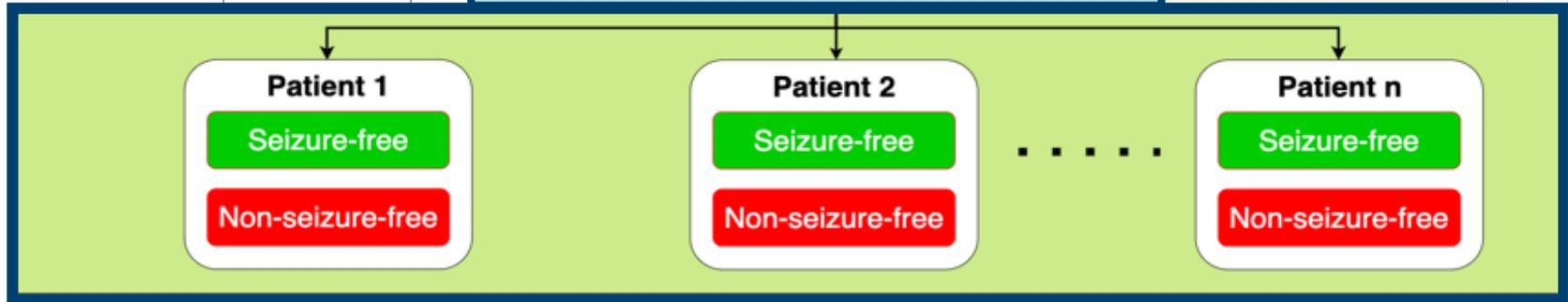
Prédire le contrôle épileptique postopératoire

Épilepsie du lobe temporal



Prédire le contrôle épileptique

Machine Learning Pipeline



In preparation



Éviter les complications neurologiques

Chirurgie de la région insulaire

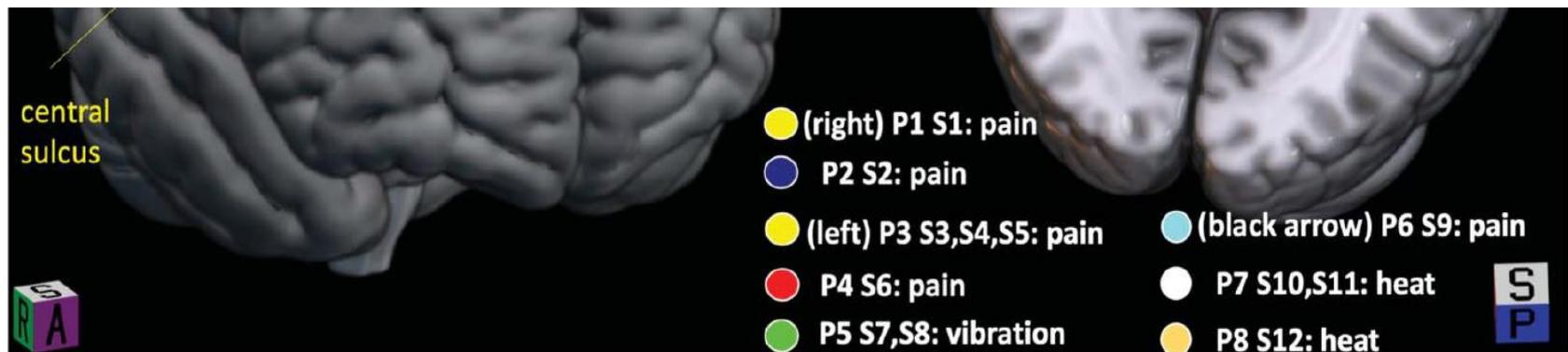
- Fibres de nociception

Commentary

PAIN[®]

**Under the insula: a commentary on
“electrostimulation of the white matter of the
posterior insula and medial operculum: perception
of vibrations, heat, and pain”**

Luis Garcia-Larrea



Mandonnet*, Obaid* et al. Pain 2023. *co-premiers auteurs

CHUM

Éviter les complications neurologiques

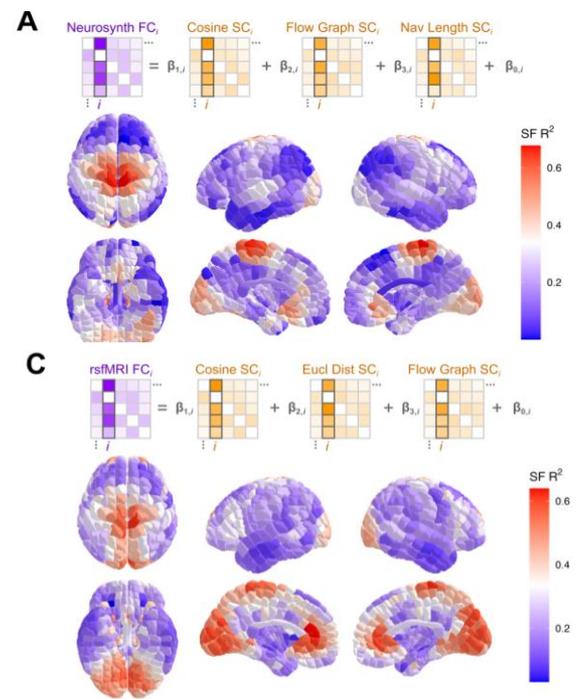
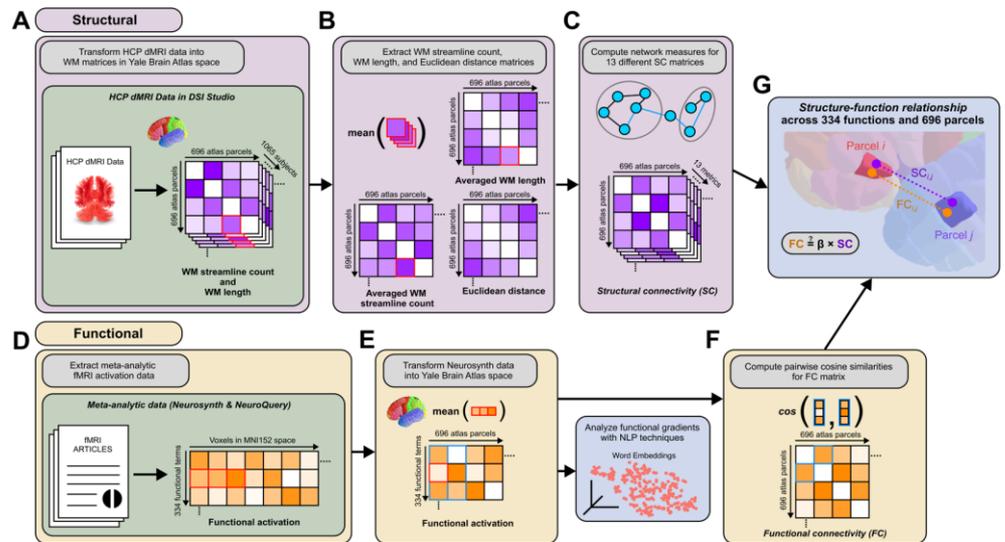
Relation structure-fonction

Mapping the structure-function relationship along macroscale gradients in the human brain

nature communications
2023

Received: 3 November 2023 Accepted: 5 August 2024
 Evan Collins^{1,2,3,4}, Omar Chishti^{1,2,5}, Sami Obaid^{1,6,7}, Hari McGrath^{1,8}, Alex King^{1,9}, Xilin Shen¹⁰, Jagriti Arora¹⁰, Xenophon Papademetris^{2,10,11}, R. Todd Constable^{1,2,10,12}, Dennis D. Spencer¹ & Hitten P. Zaveri¹³

Évaluer les regions où la structure prédit la fonction



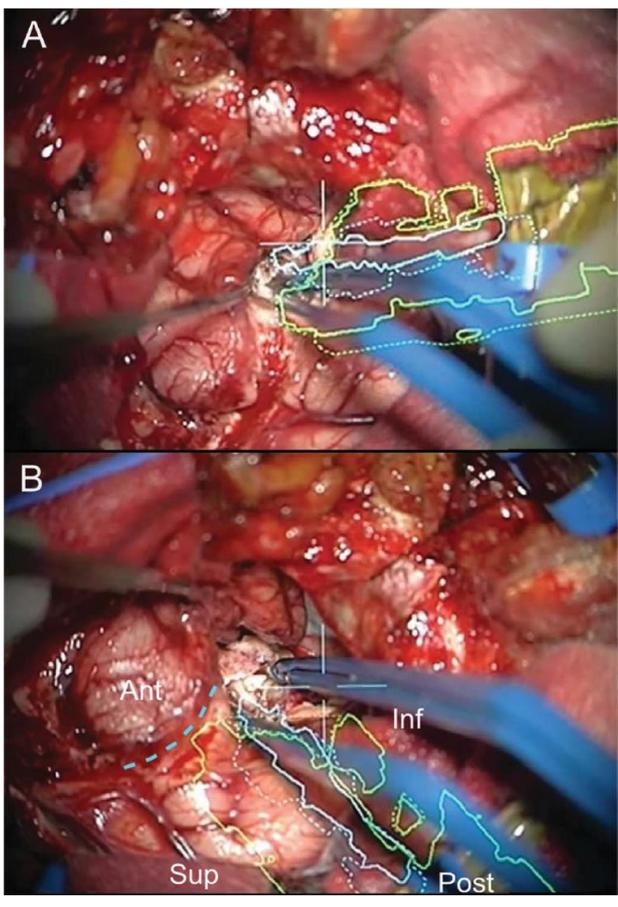
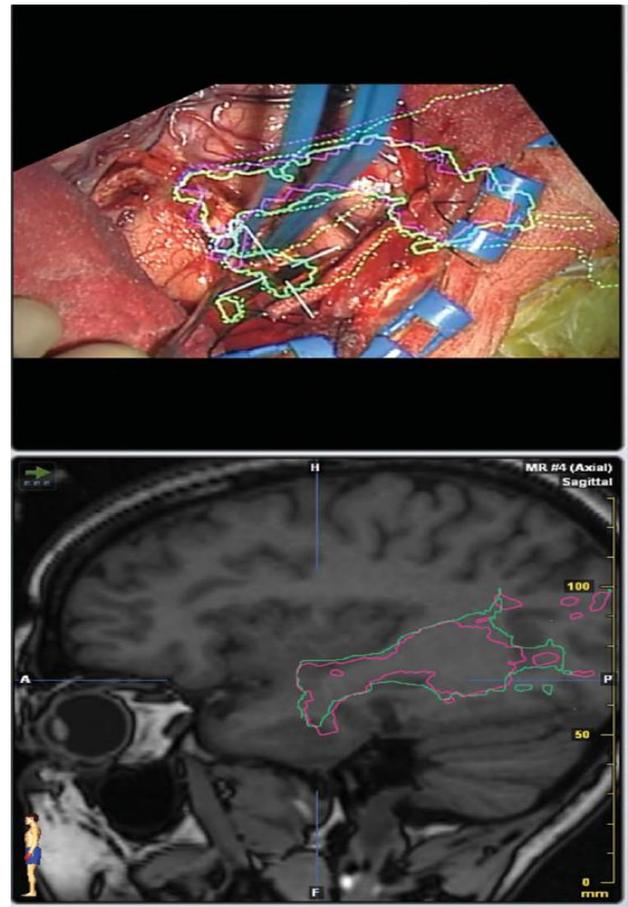
Structure-function correlation in primary cortical areas



Éviter les complications neurologiques

Chirurgie pour épilepsie du lobe temporal

- Radiations optiques – champs visuels



21 patients

Tractographie:
14% déficit CV
Tous aptes à conduire

Sans tractographie:
24% déficit CV
13% inaptes à conduire



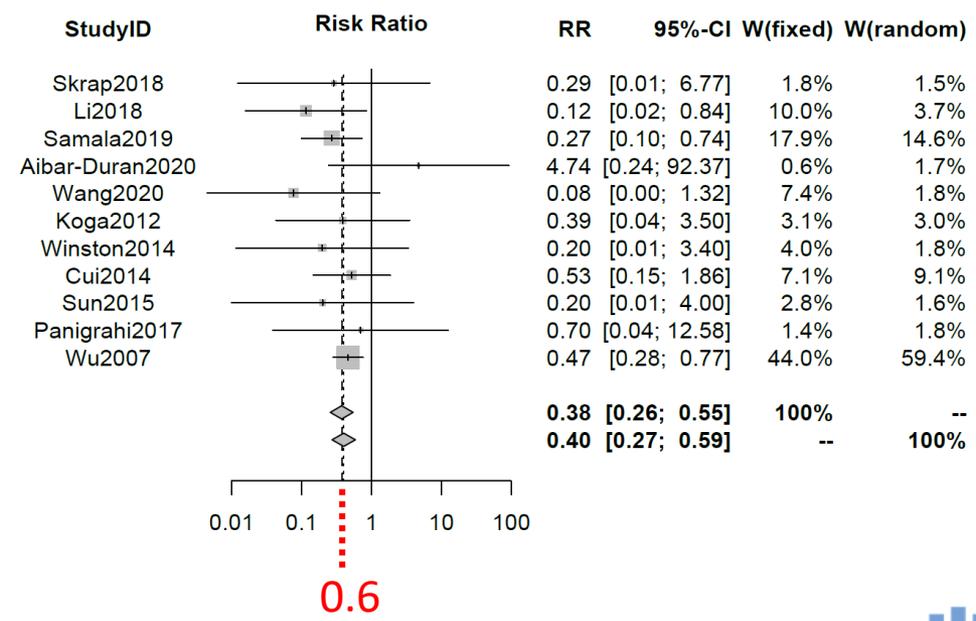
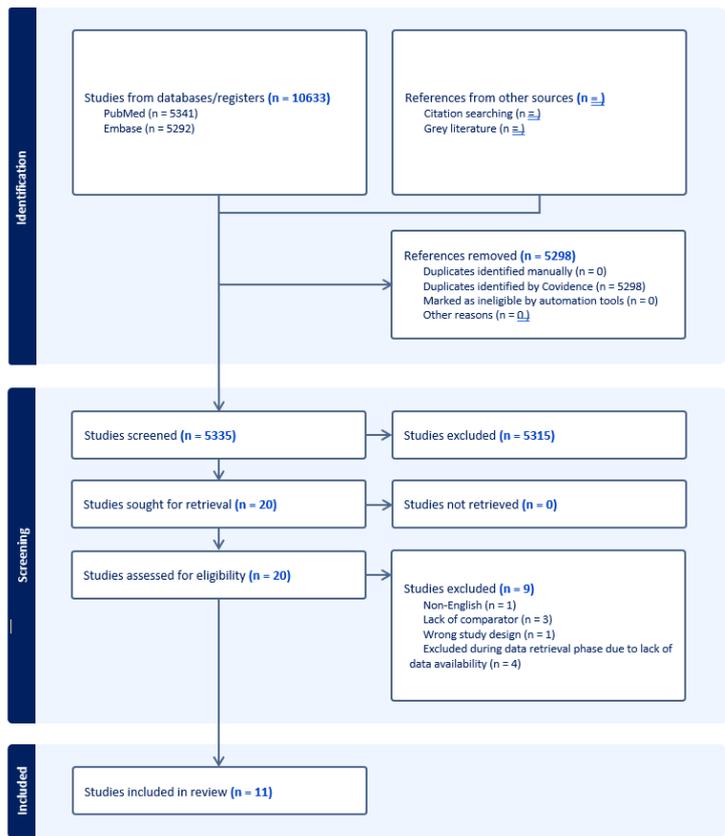
Éviter les complications neurologiques Tractographie des faisceaux fonctionnels

Méta-analyse: tractographie vs chirurgie standard



Guido Guberman, MD, PhD

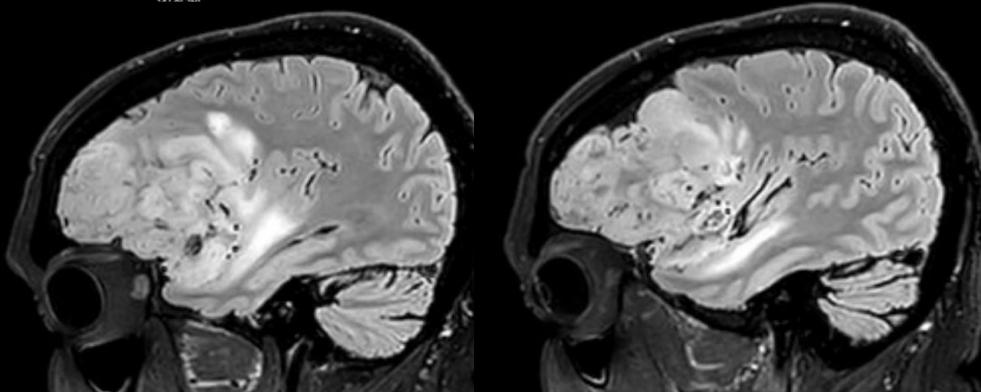
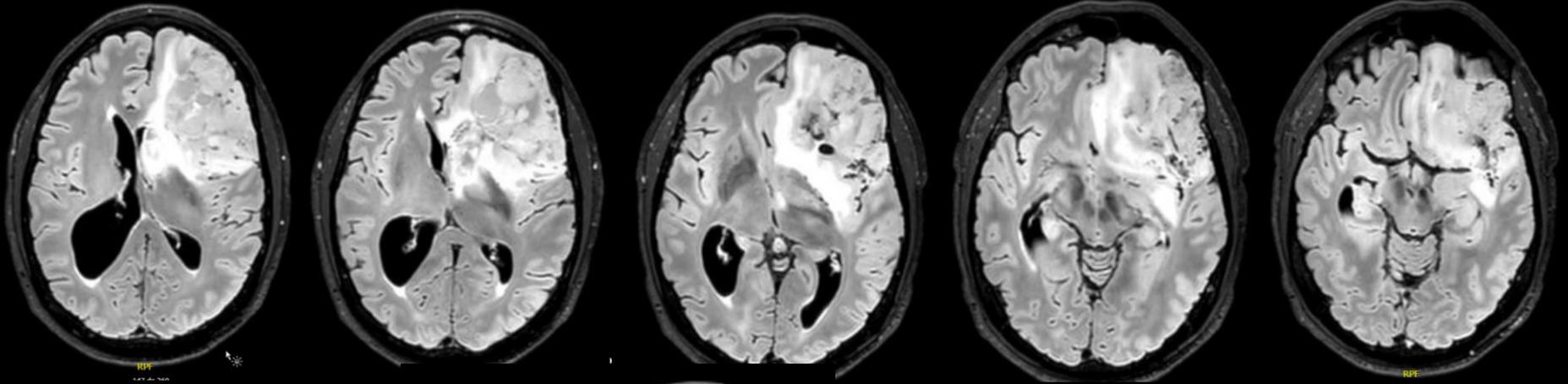
11 articles
755 patients



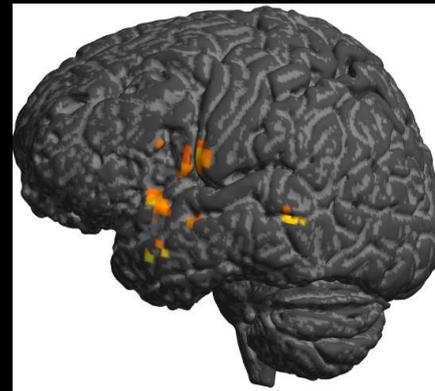
Cas illustratif

- Homme de 56 ans
- Crises inconscientes multiples

IRM structurelle



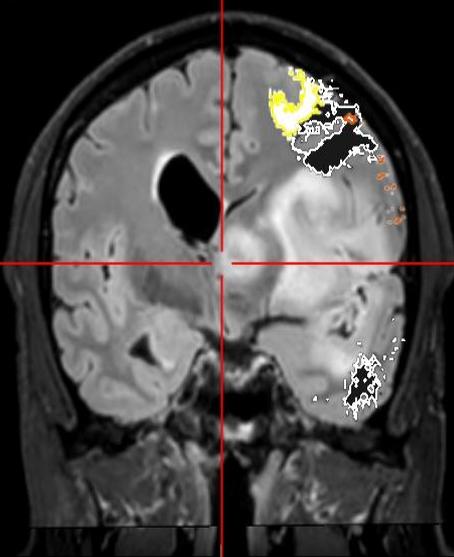
IRMf



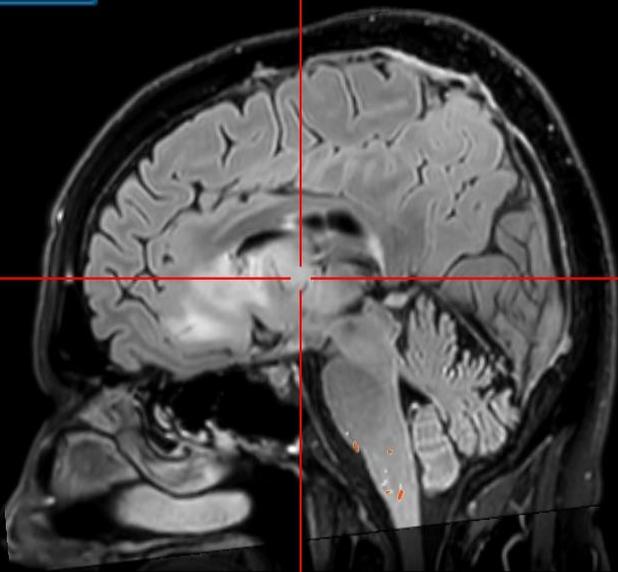
Register

Navigate

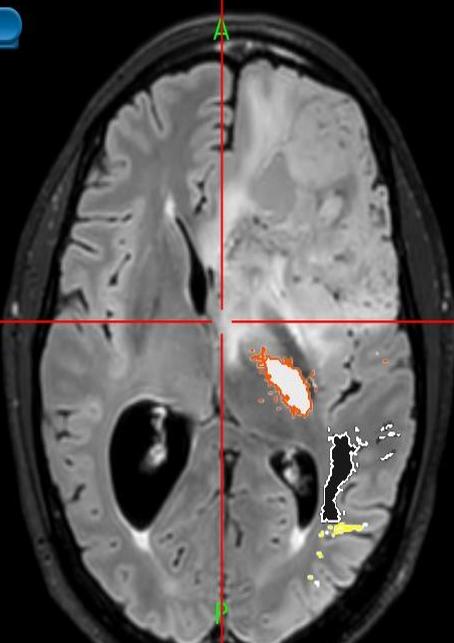
Coronal



Sagittal



Axial



3D



- Exams
- Models
- Adjust
- Blend
- Browse
- Zoom
- Move
- Rotate
- Recenter
- Annotate
- Measure

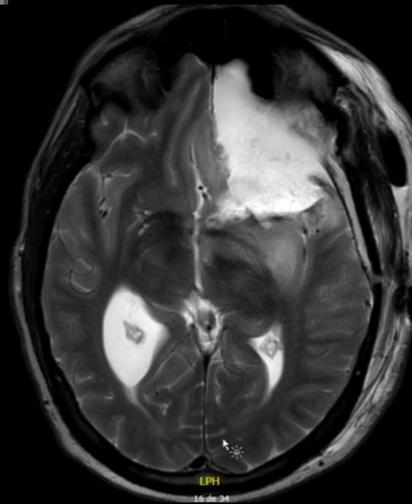
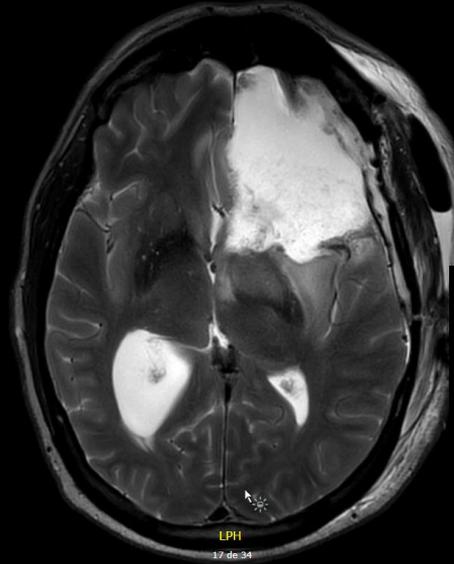
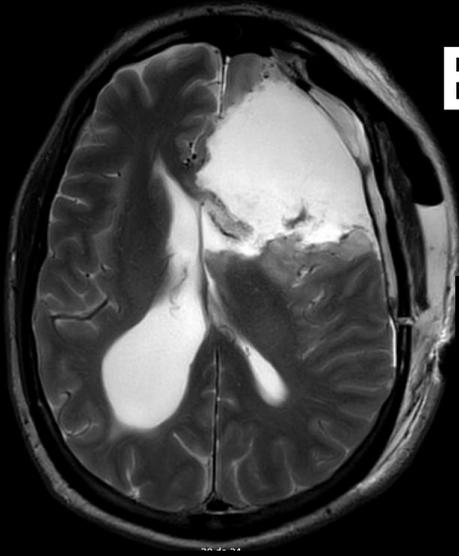
MODIFY IMAGES

- Cycle Views
- Select Projection
- Snapshot
- Foot Switch
- STEALTH
- Camera
- Help
- Admin
- Exit

CONTROL PANEL

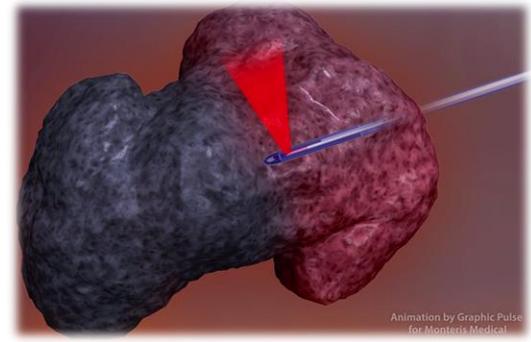
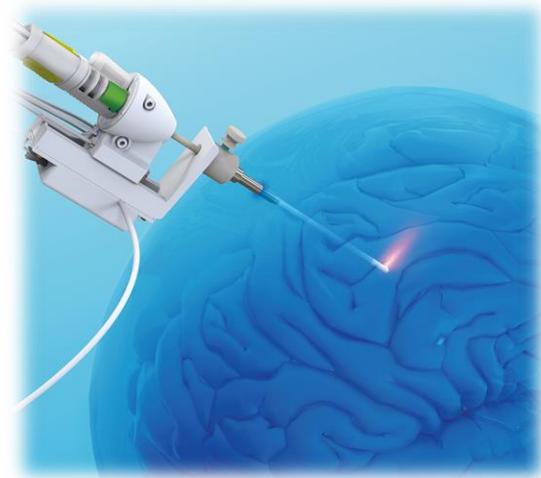
Passive Planar, Blunt
 Small Passive Cranial Frame

Évolution postopératoire



Pas de déficit neurologique postopératoire

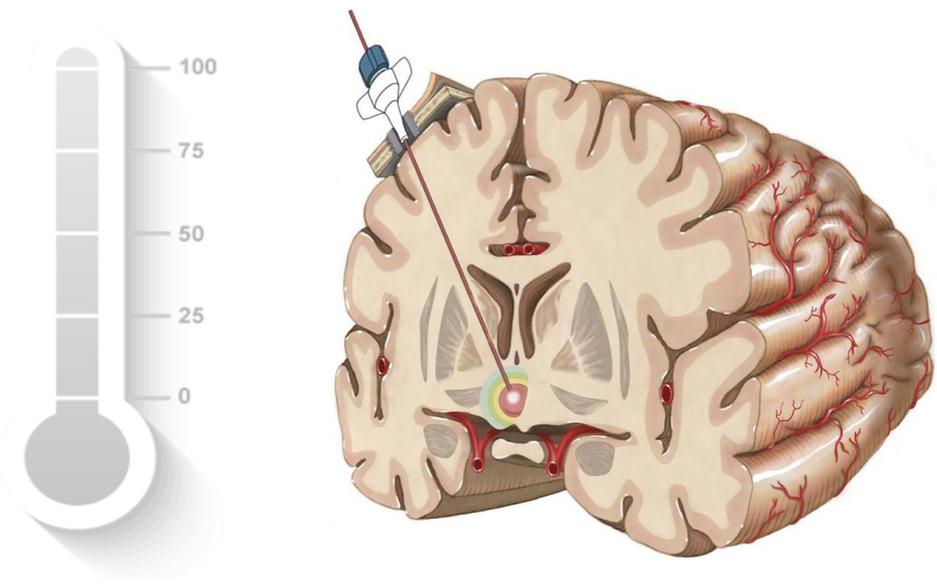
Ablation au laser guidée par IRM



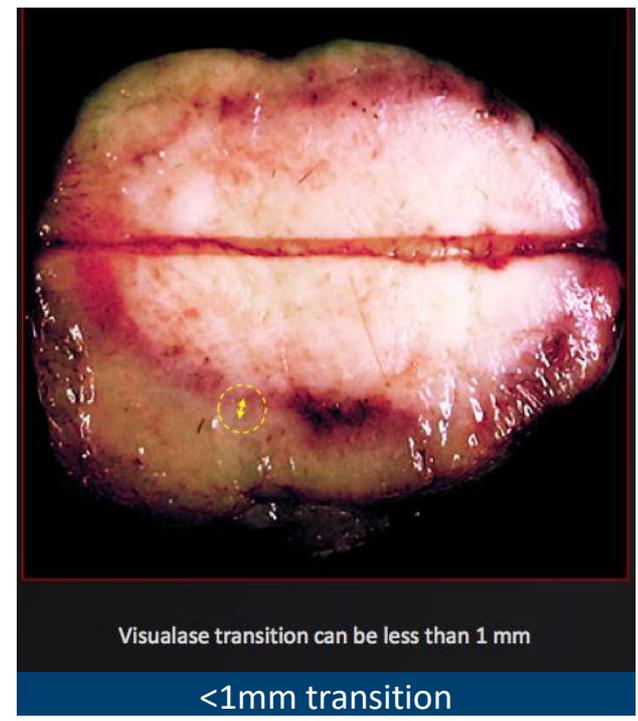
Alternative minimalement invasive!

Ablation au laser guidée par IRM

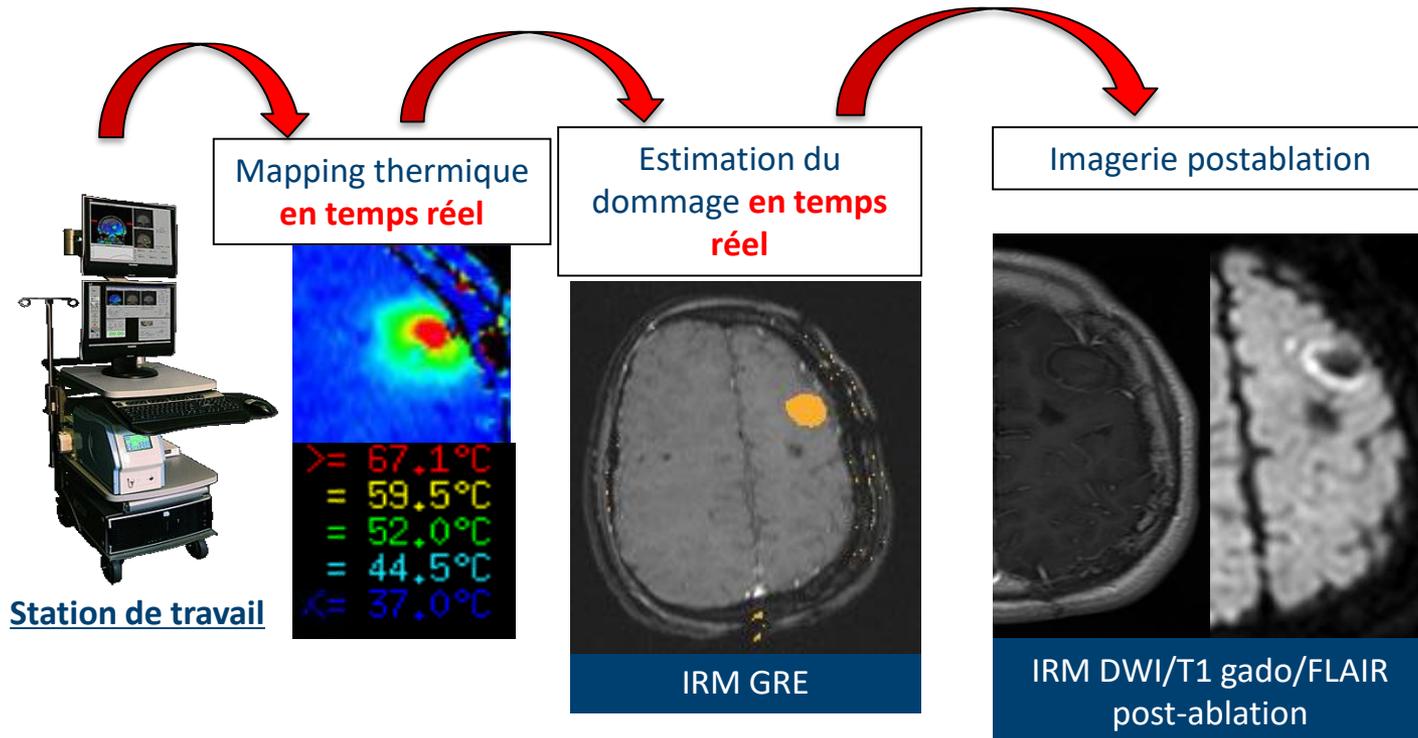
Placement stéréotaxique

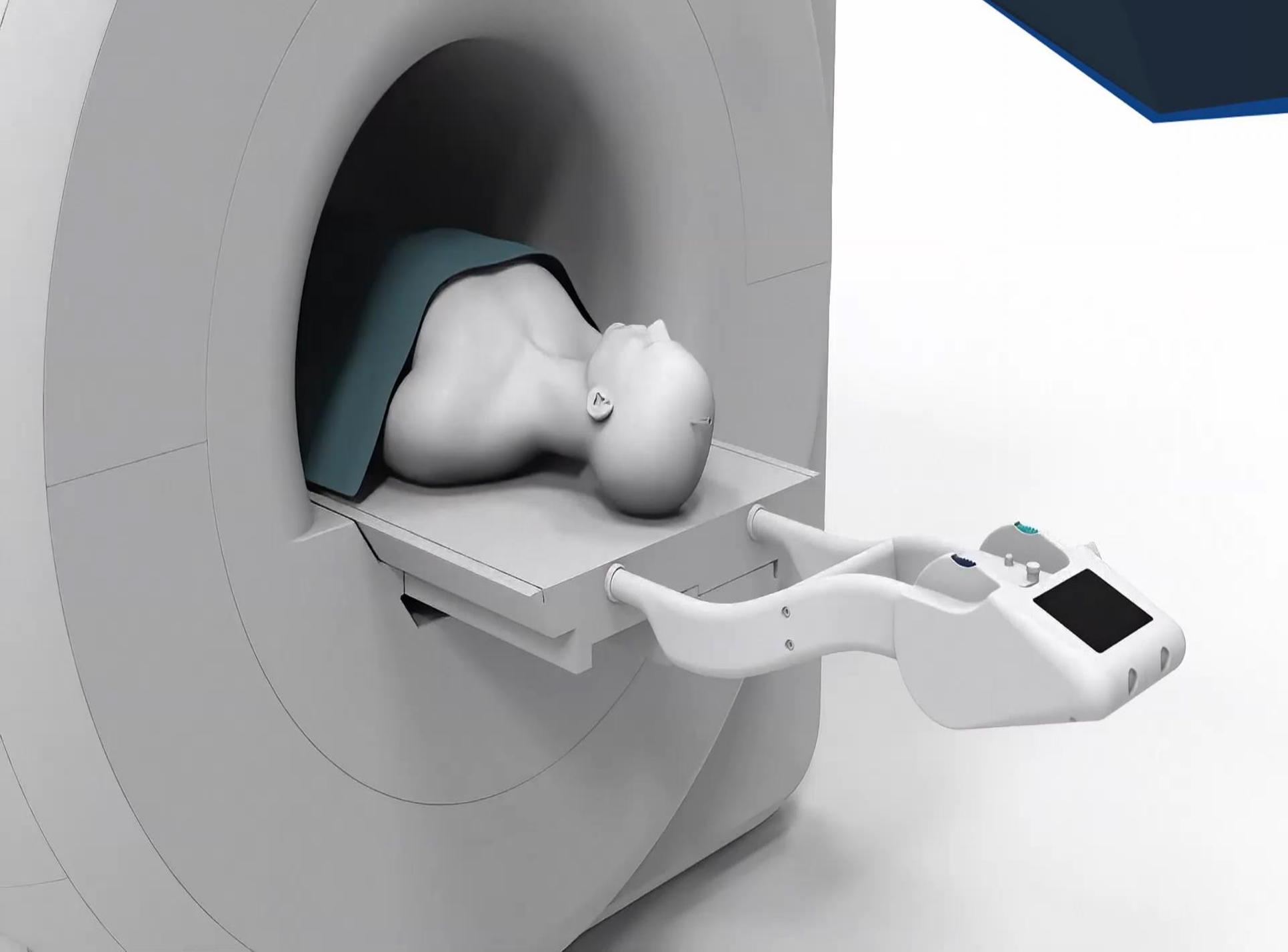


44 - 59° C – Dommage thermique 'time dependent'

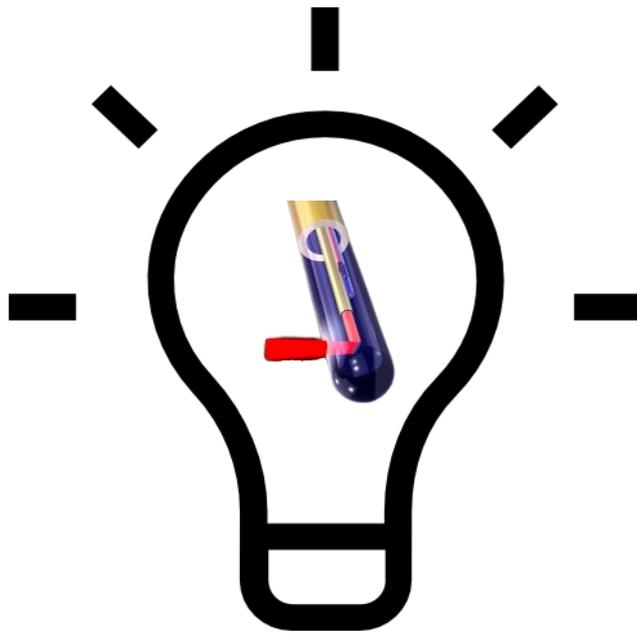


Ablation au laser guidée par IRM



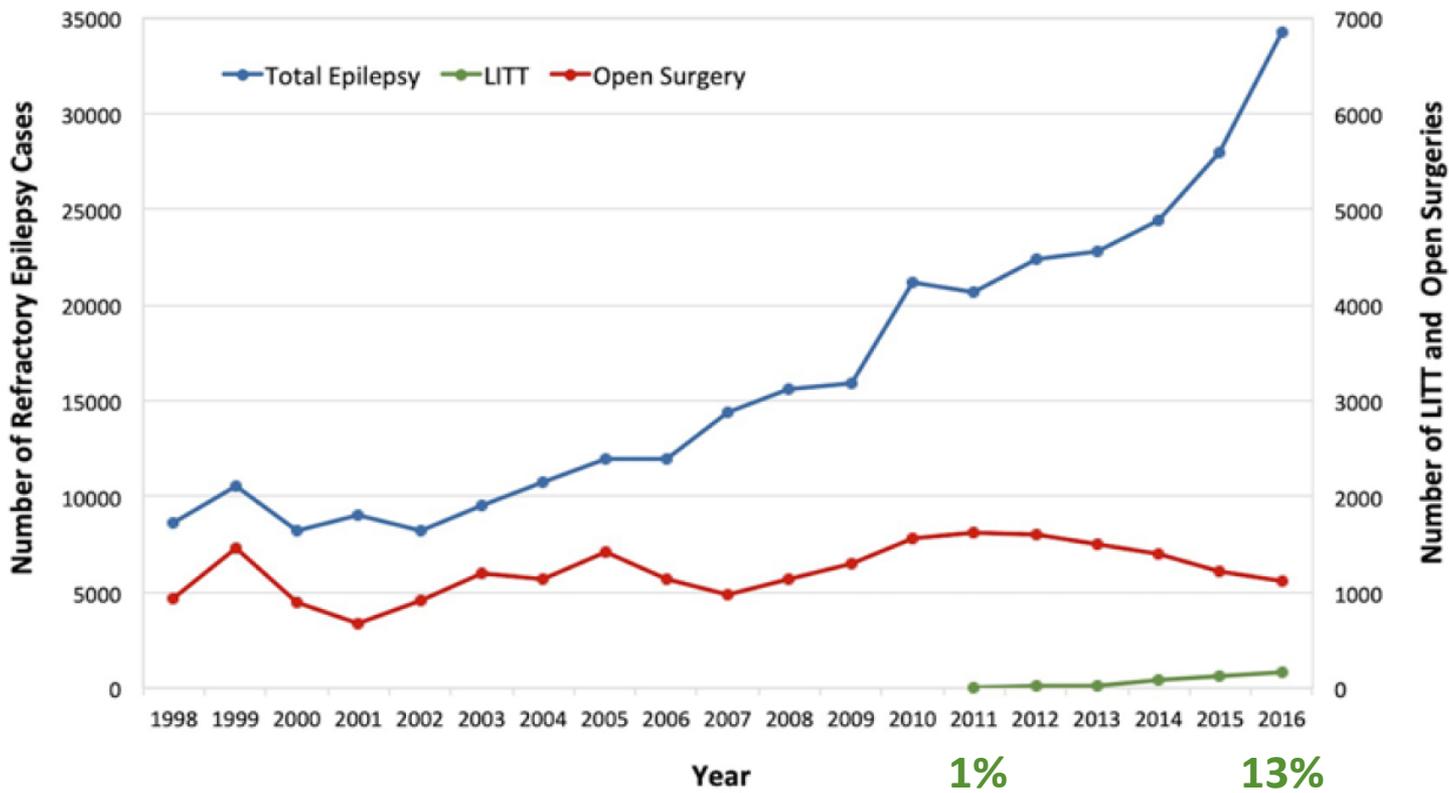


Avantages du laser



- ✓ **Minimalement invasif**
- ✓ **Incision millimétrique**
- ✓ **Peu de douleur**
- ✓ **Pas de USI**
- ✓ **Durée d'hospitalisation de 1-2 jours**
- ✓ **Feedback en temps réel**
- ✓ **Risque d'infection quasi nul**
- ✓ **Morbidité neurologique moindre**
- ✓ **Réopération facile**
- ✓ **Avantage cosmétique**

Gain en popularité

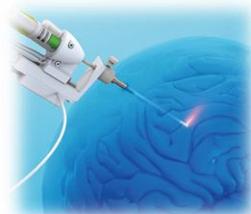


Sharma et al. Neurosur Focus. 2020

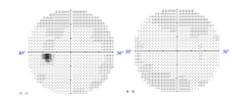


Éviter les complications neurologiques

Chirurgie au laser



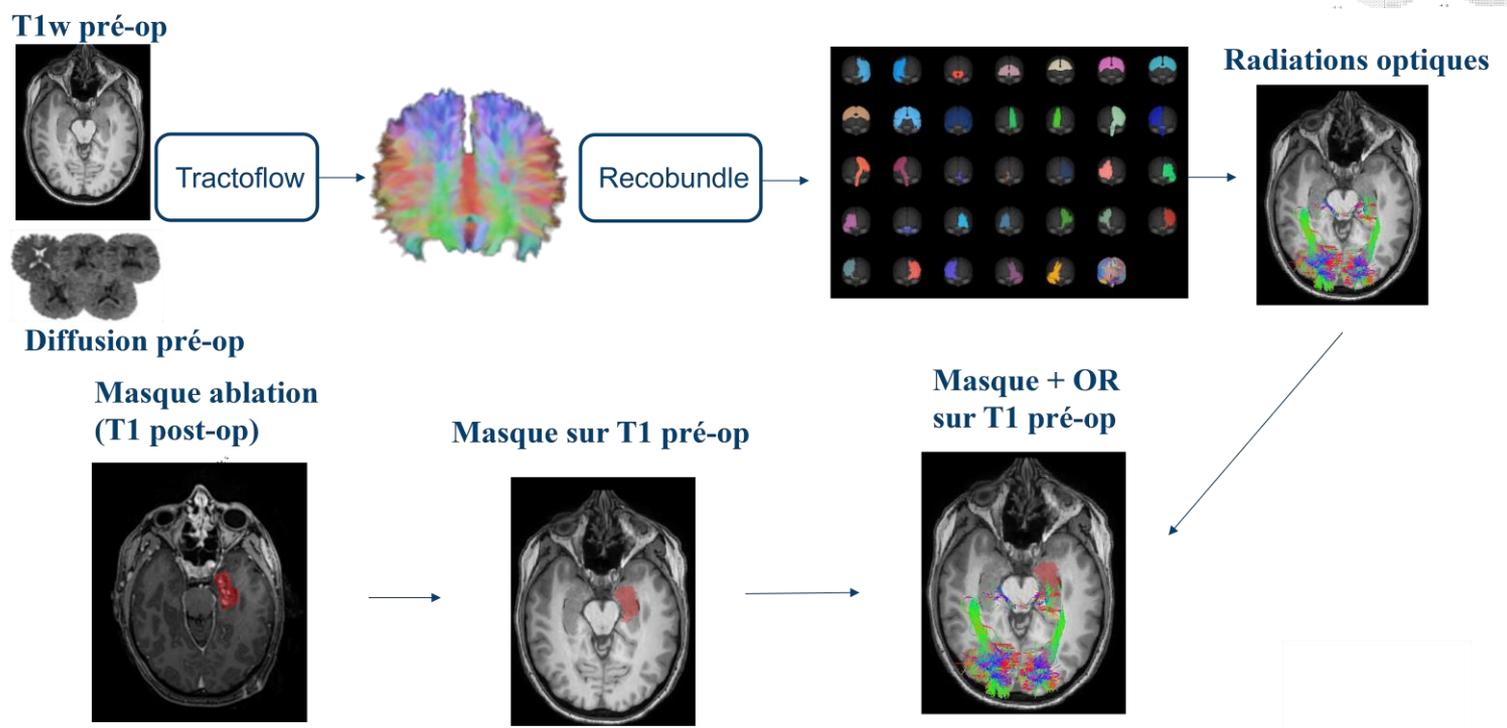
Tractographie des Ros pour éviter les déficits des CVs



Sandrine Ghali
MD (c)



Salma Kharriss
BSc



In preparation



Éviter les complications neurologiques

Chirurgie au laser



Tractographie des Ros pour éviter les déficits des CVs



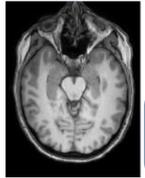
Sandrine Ghali
MD (c)



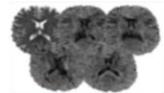
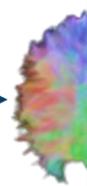
Salma Khriess
BSc



T1w pré-op

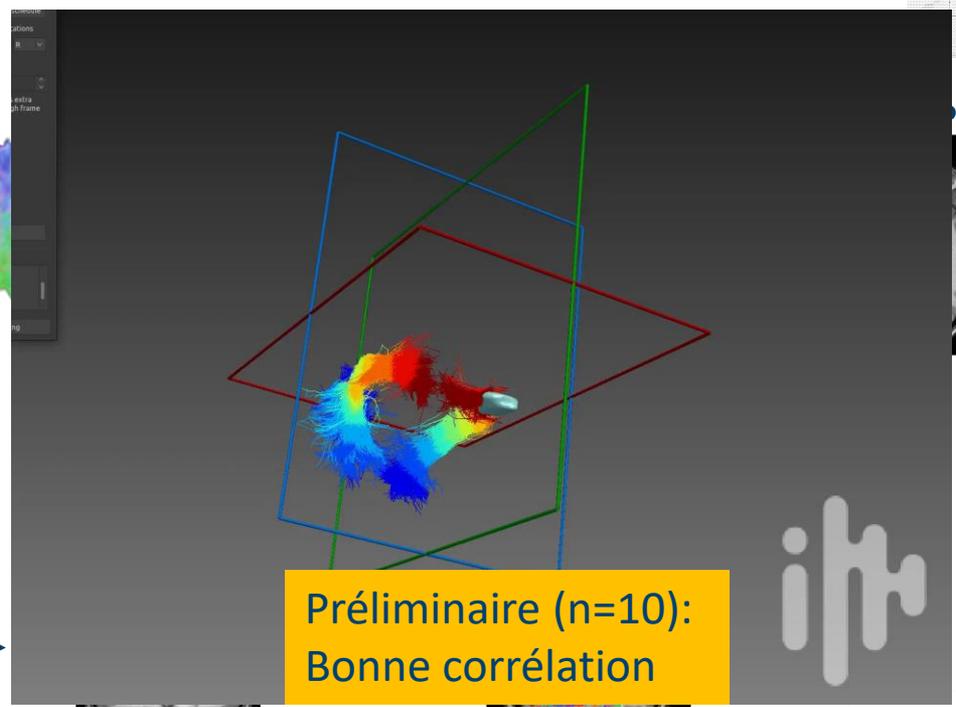
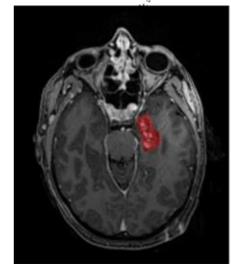


Tractoflow



Diffusion pré-op

Masque ablation
(T1 post-op)



Preliminary (n=10):
Bonne corrélation

Cas illustratif

- Homme de 30 ans
- Épilepsie depuis 6 ans

NEUROSURGICAL
FOCUS
VIDEO

Neurosurg Focus Video 11(1):V15, 2024

Laser interstitial thermal therapy of a single nodule in a complex epileptic network with multiple periventricular nodular heterotopias

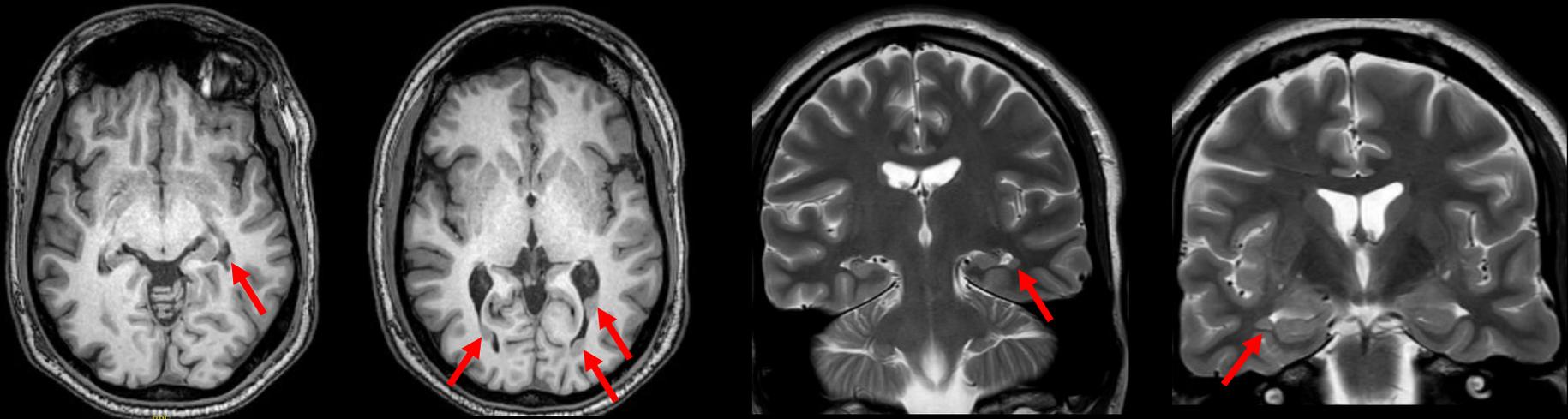
Sami Obaid, MD, CM, PhD,¹⁻³ Albert Guillemette, BSc,^{1,2} Samuel Lapalme-Remis, MD, CM, MA,^{4,5} Joseph Yuan-Mou Yang, MBChB, PhD,⁶ Alexander G. Weil, MD,^{2,7} and Alain Bouthillier, MD, MSc^{2,3}

EEG

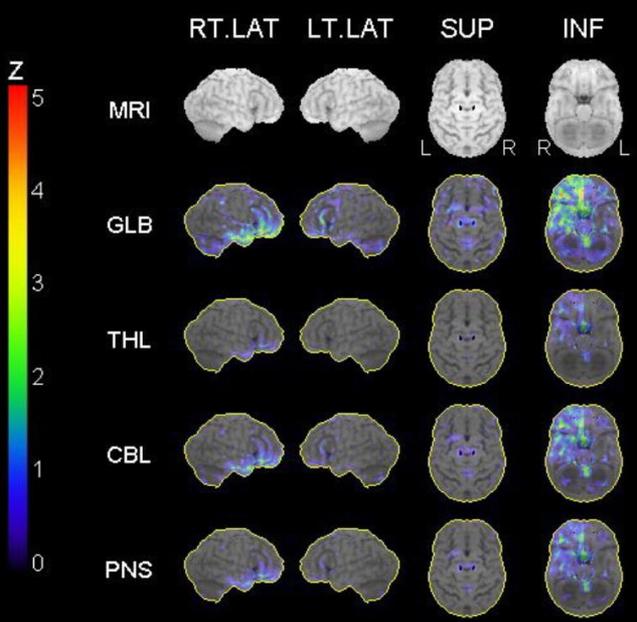
- Temporal droit

IRM

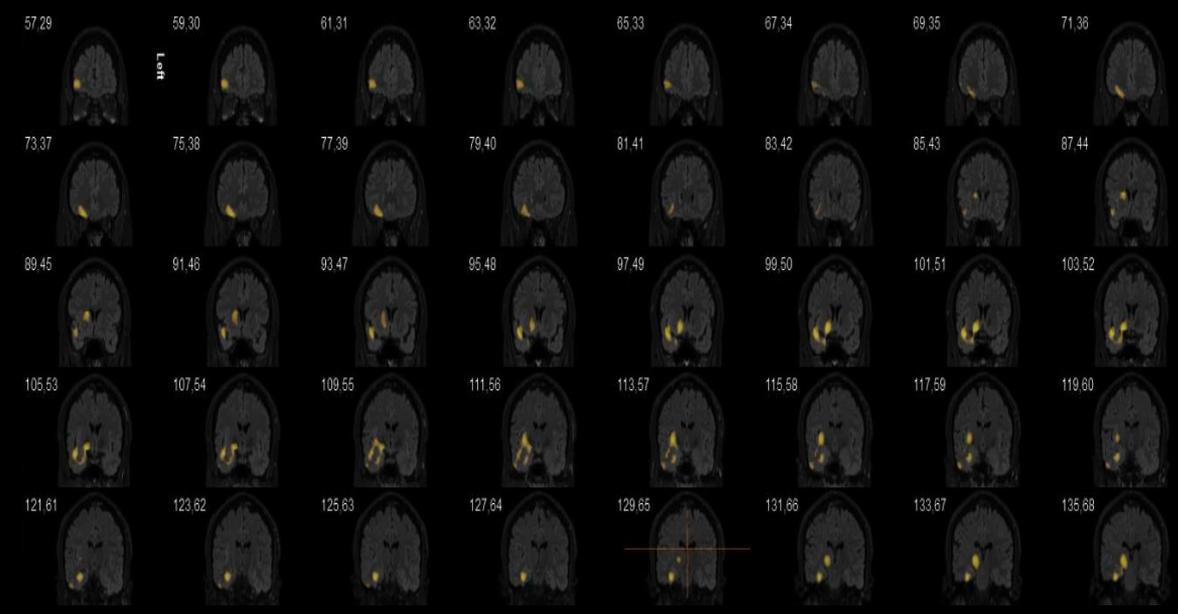
- Multiple nodules périventriculaires



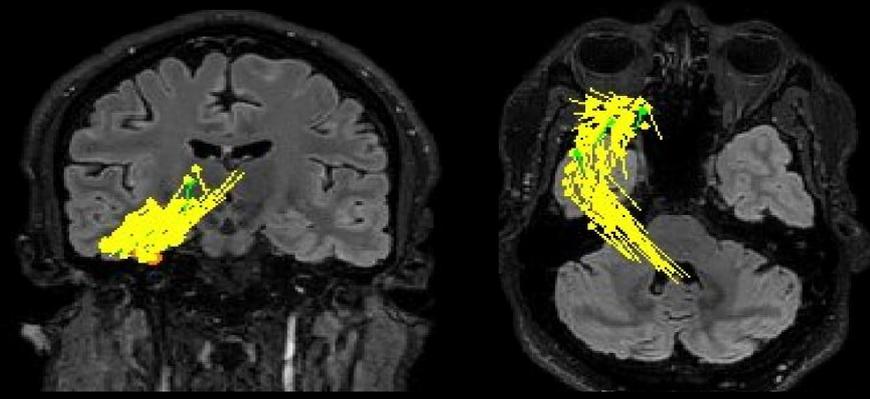
PET scan



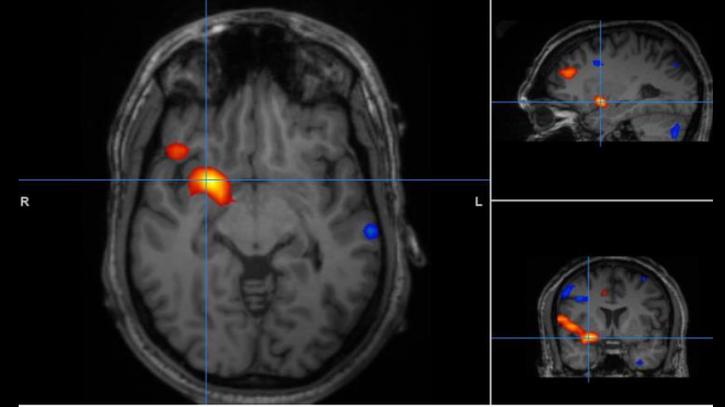
SPECT ictal



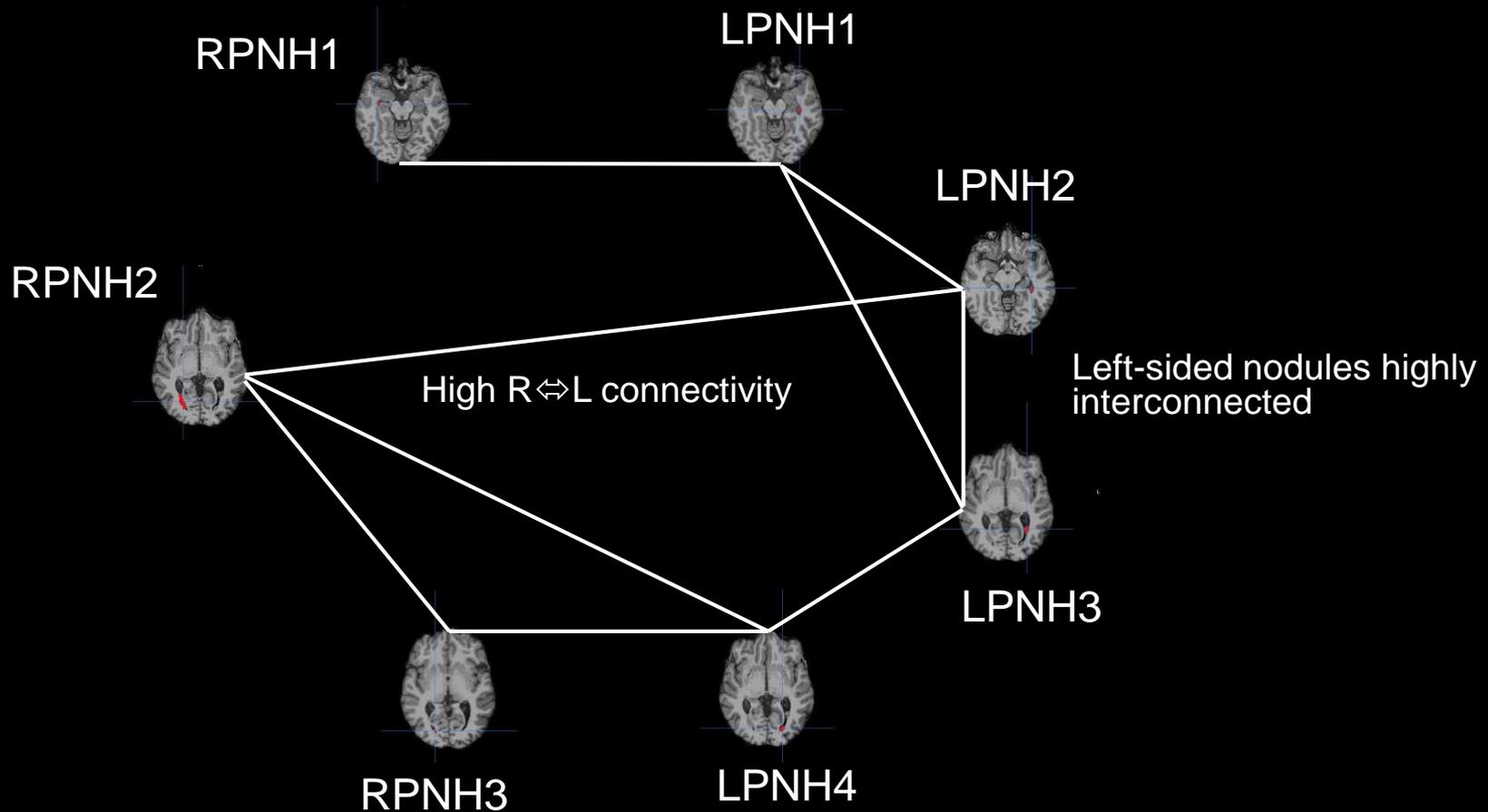
MEG



IRMf-EEG

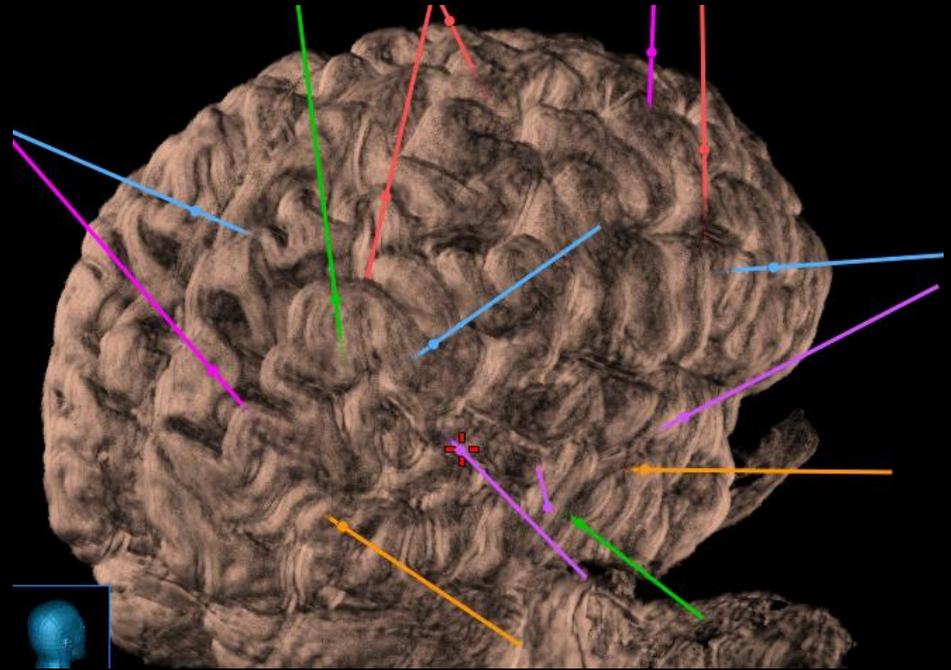


IRMf au repos: étude des réseaux



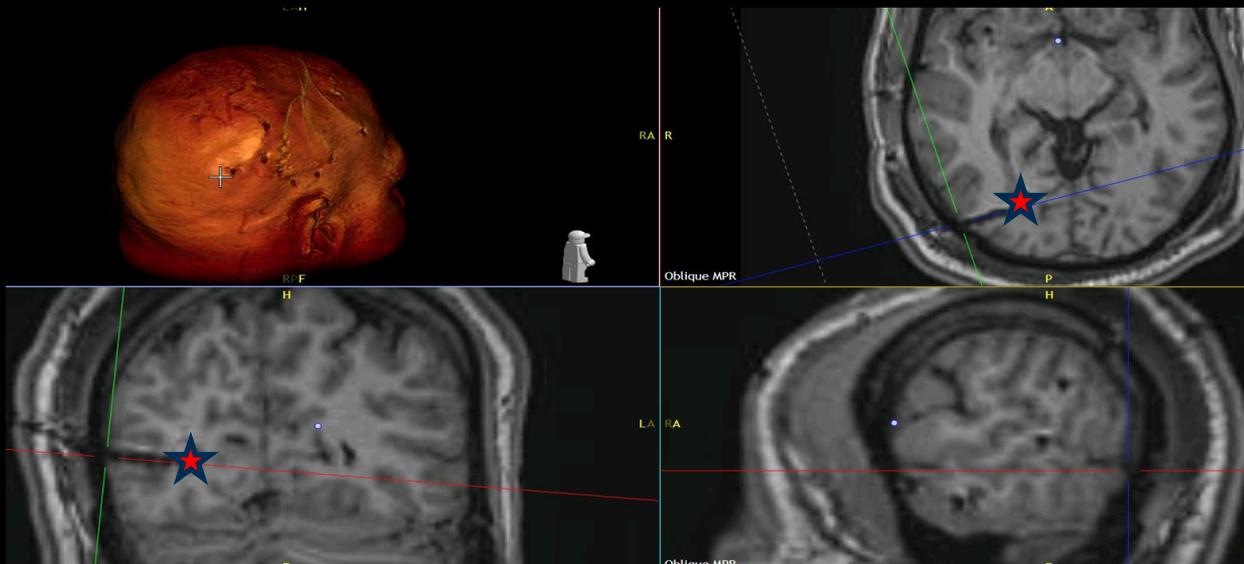
Étude EEG intracrânienne

- 15 électrodes
 - Orbitofrontal
 - Temporal médial & latéral
 - Insula
 - Nodules et cortex sus-jacent

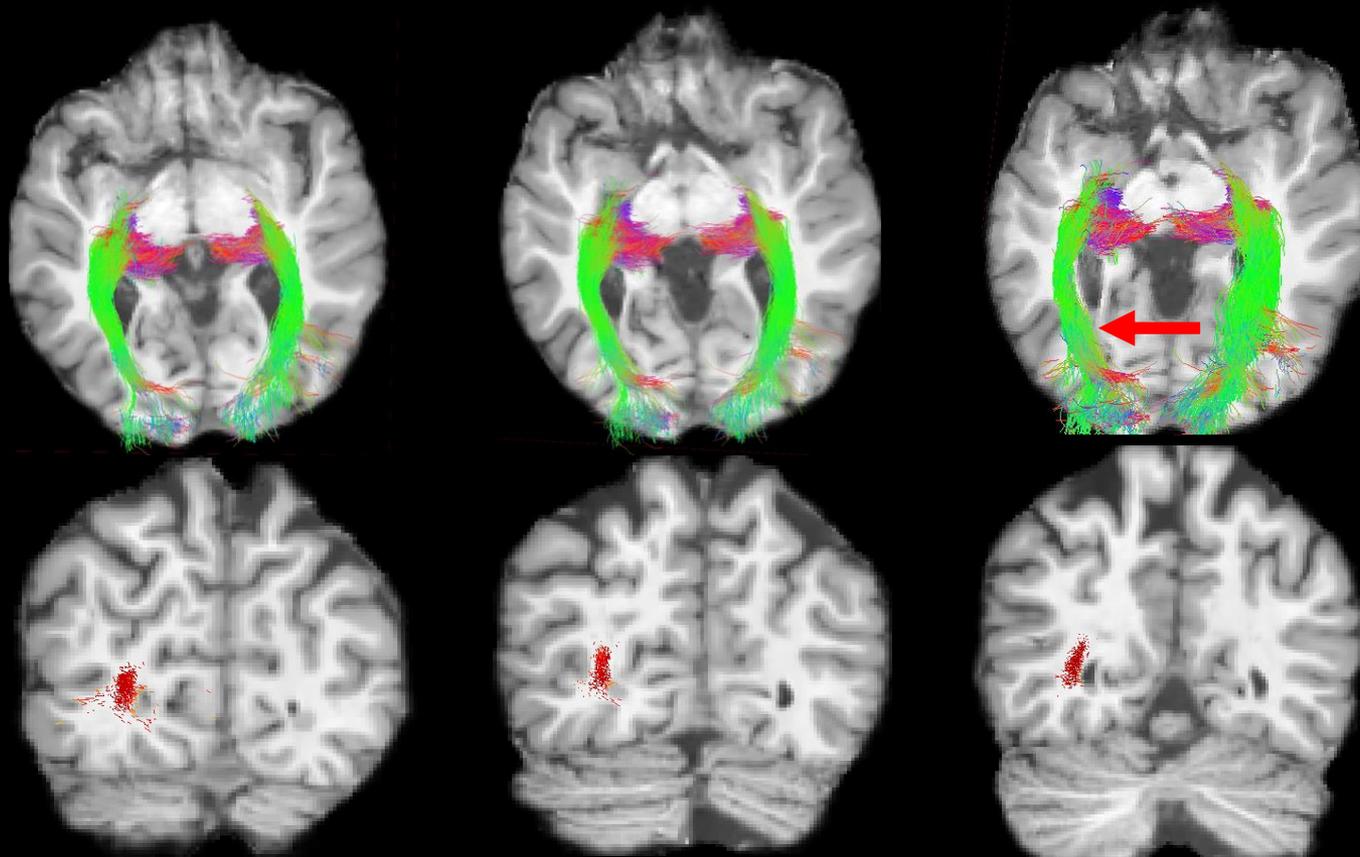


Résultats de l'EEG intracrânienne

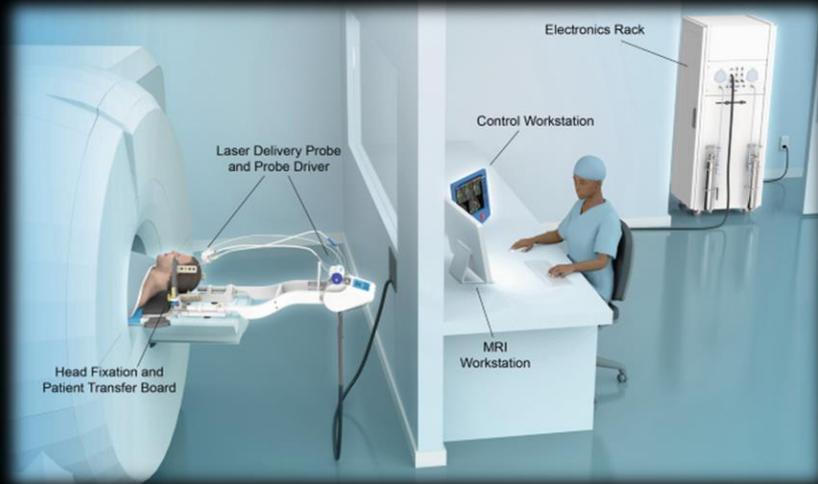
- Début des crises: nodule occipital droit
- Chirurgie au laser



Planification préopératoire



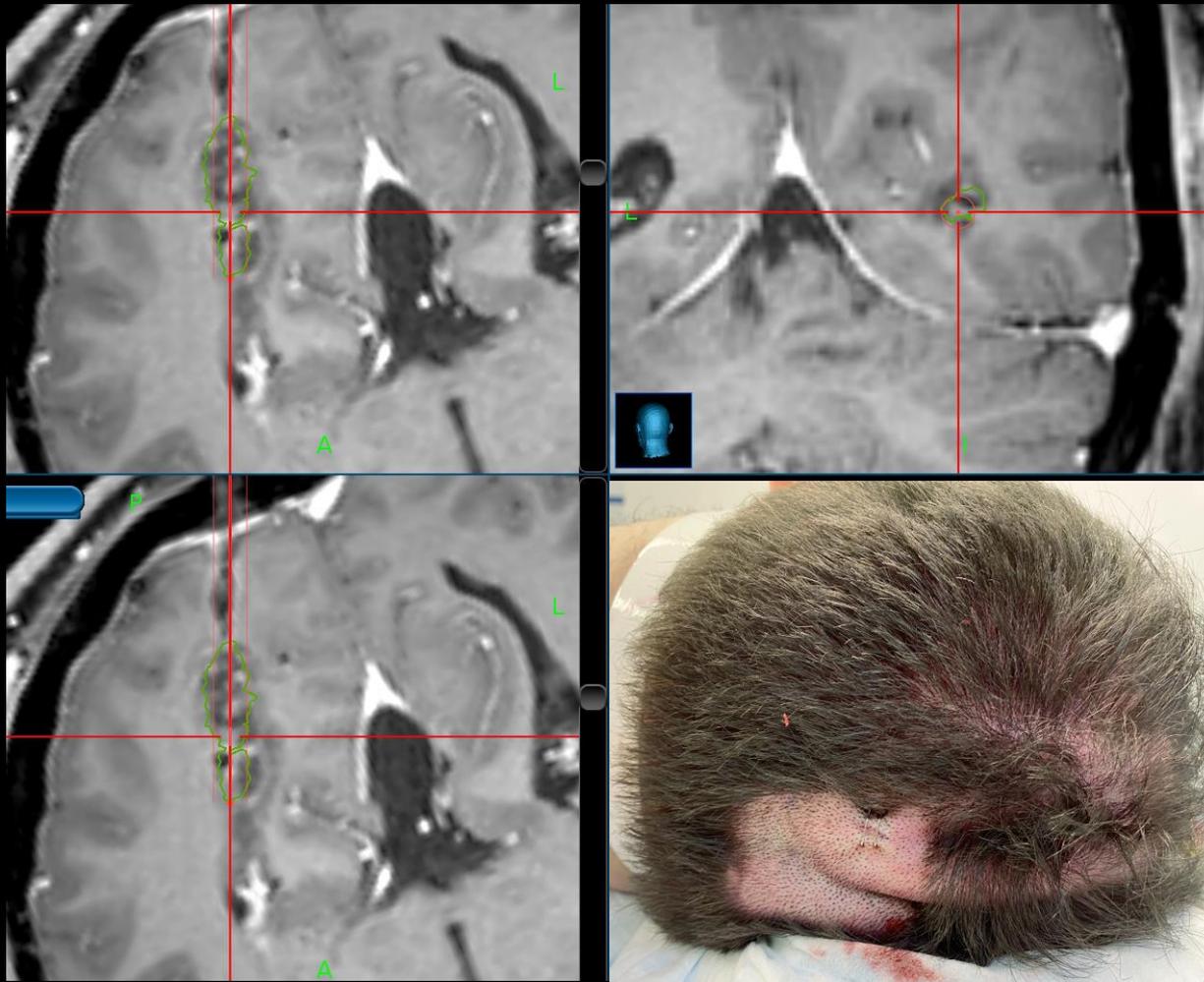
Position et insertion du boulon



Ablation

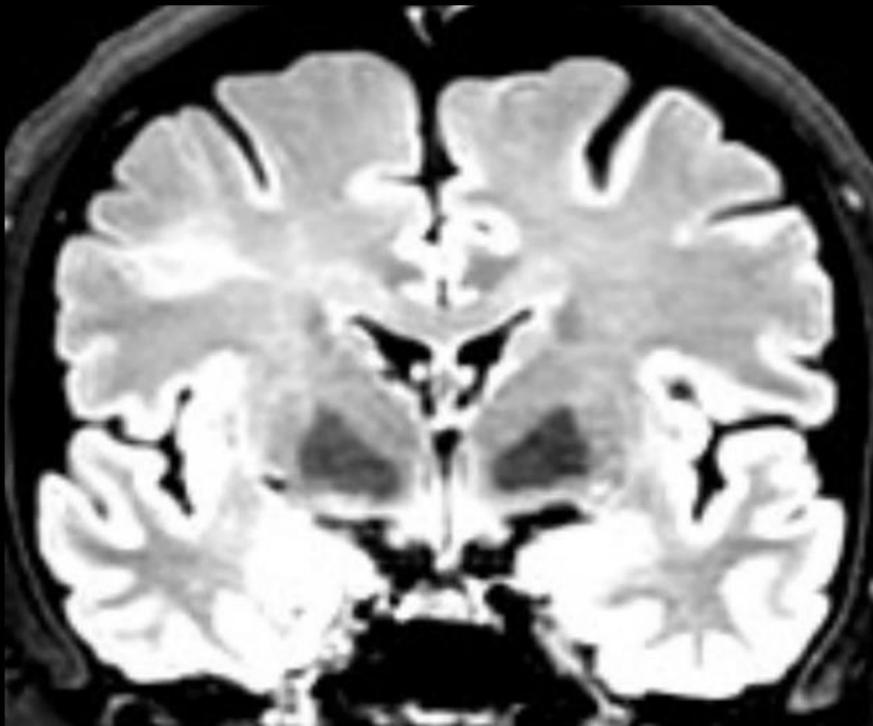
The interface displays a multi-view MRI scan of a brain slice. The top row shows three 'Probe's Eye' views (Slice 2, Slice 1, Slice D1) with temperature readings: 31.2°C, 35.7°C, 34.1°C, 32.0°C, 30.5°C, and 33.8°C. The bottom row shows 'Inline 1' and 'Inline 2' views with a temperature reading of 33.8°C. A color scale at the top indicates temperature from 20 to 80. The right sidebar contains controls for 'Treat', 'Acquisition', 'Noise Masking', 'Reference Point Selection', 'Temperature Monitoring', and 'Laser'. The 'Laser' section shows 'Cooldown Progress' with 'Status' as 'Ready' and 'Laser Output' at 80%. The bottom status bar shows 'System Status' as active, 'FullFire 2.2', and 'Temp 11.4°'.

IRM post traitement et fermeture

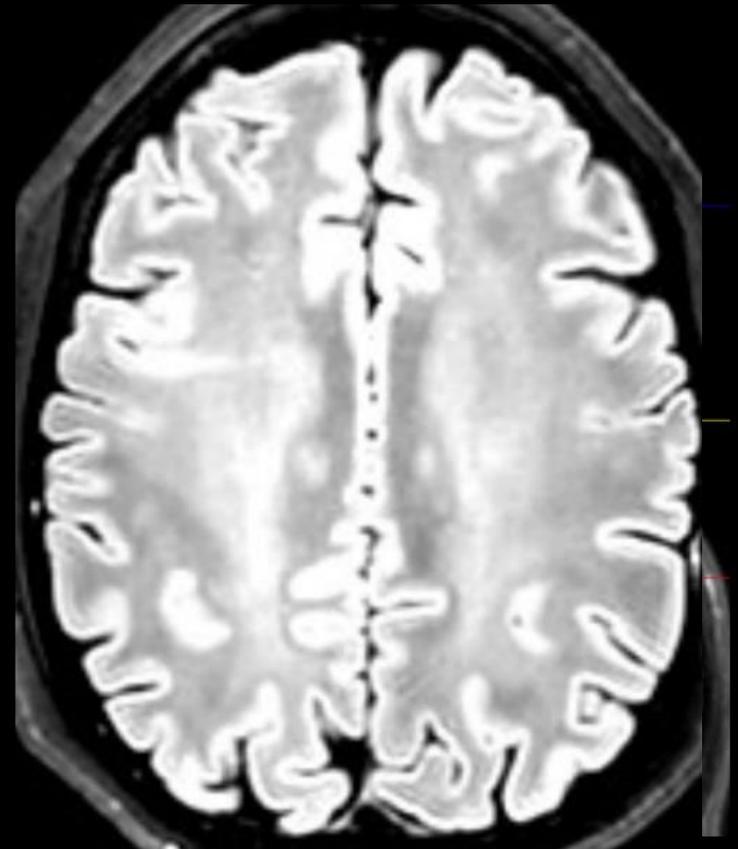


Cas illustratif

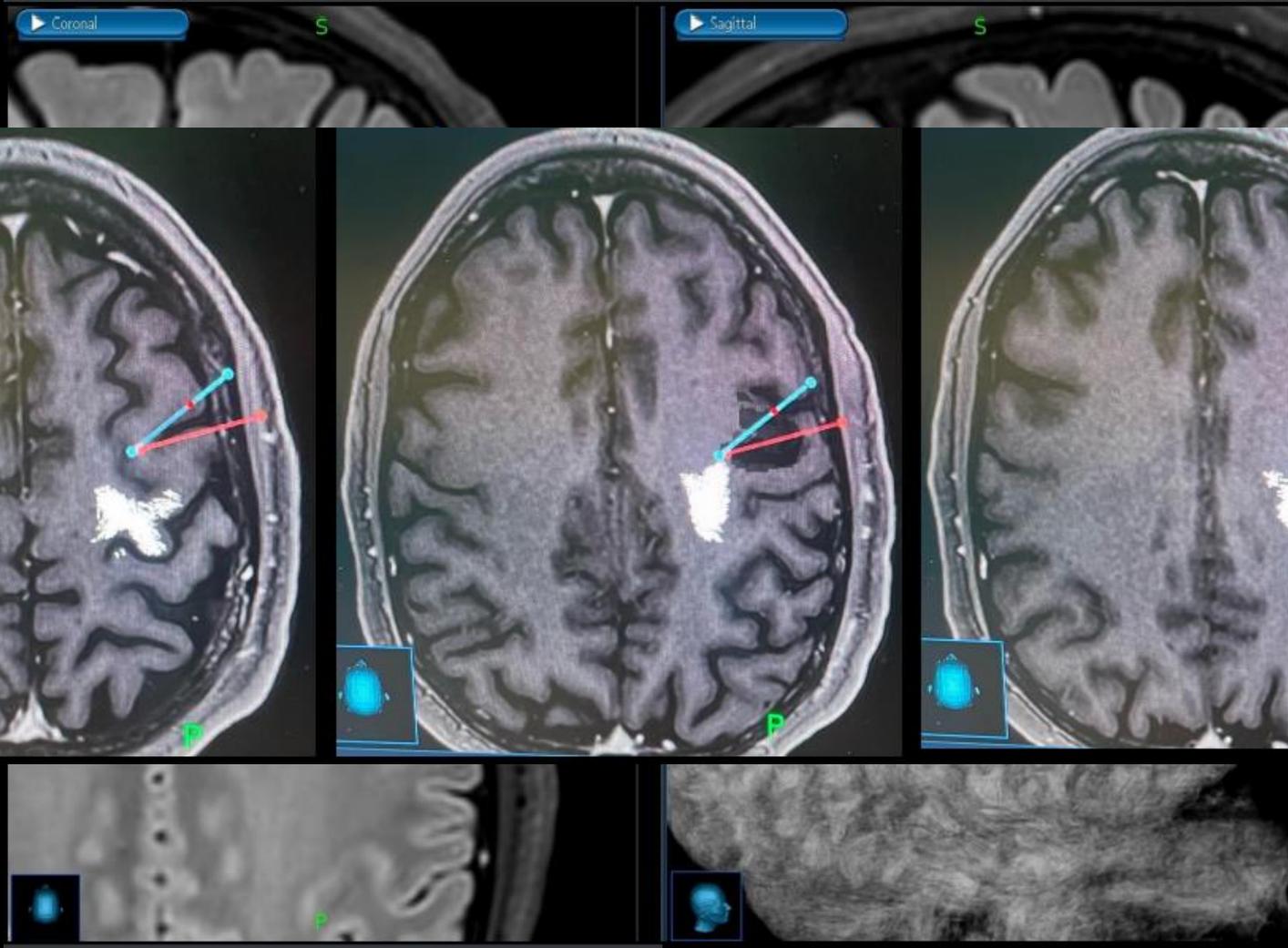
- Femme de 50 ans
- Épilepsie depuis 20 ans



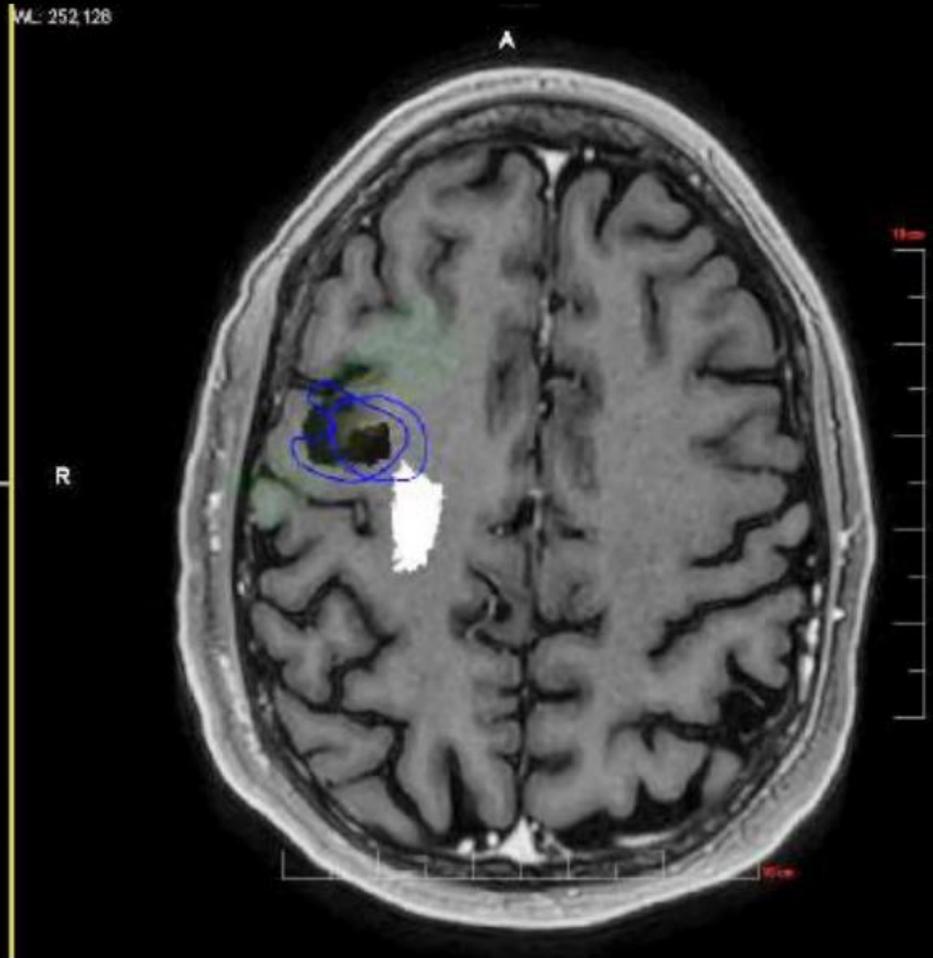
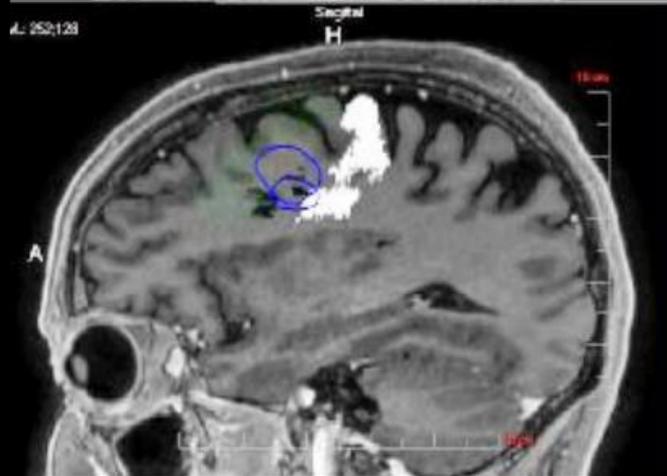
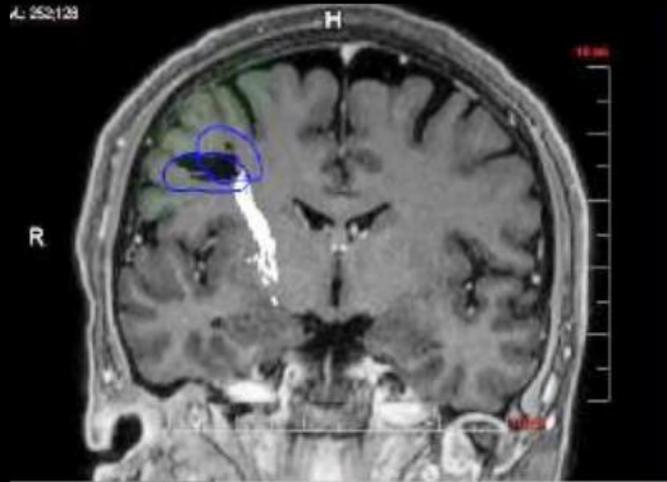
FLAIR hypercontrasté



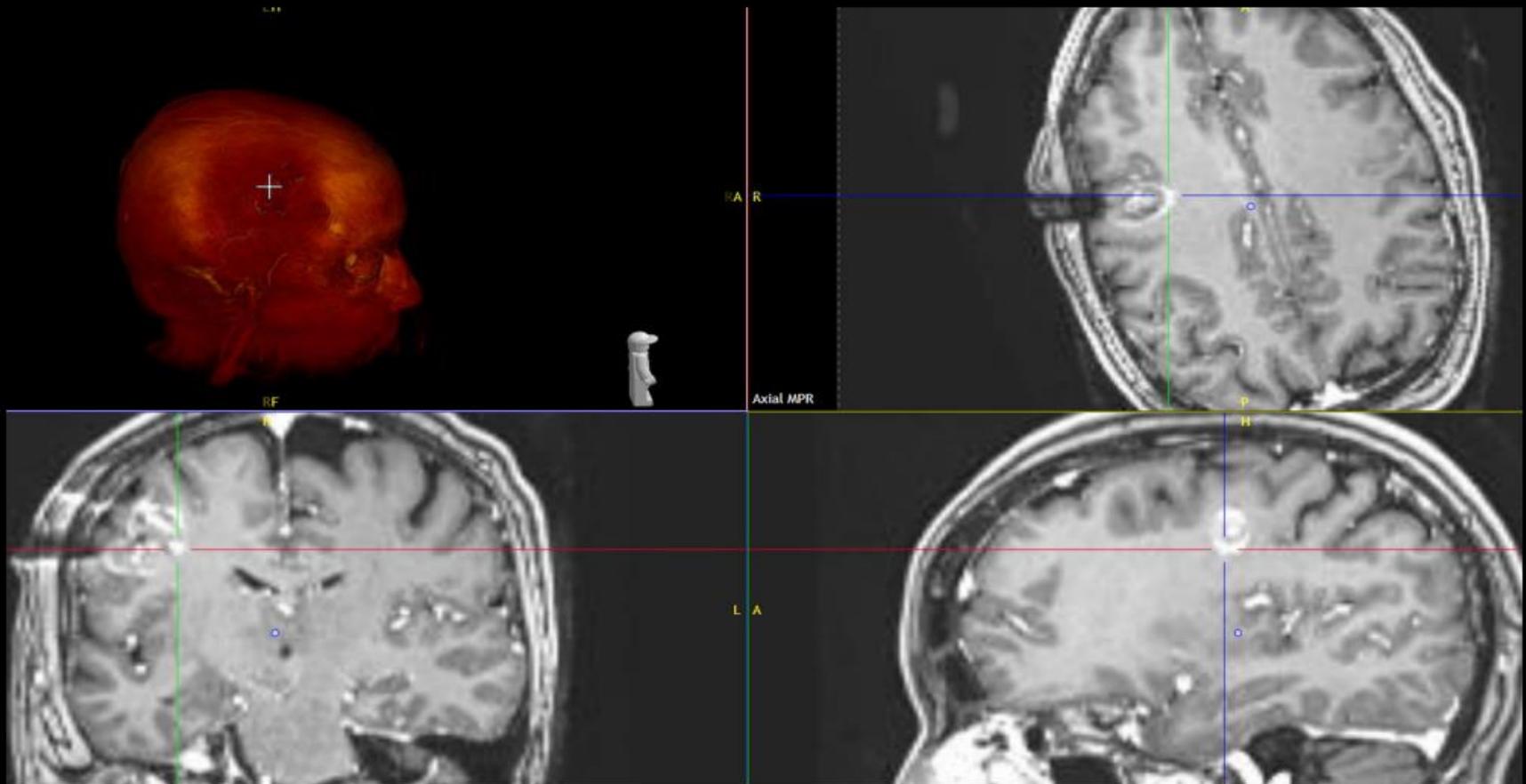
Planification



Ablation



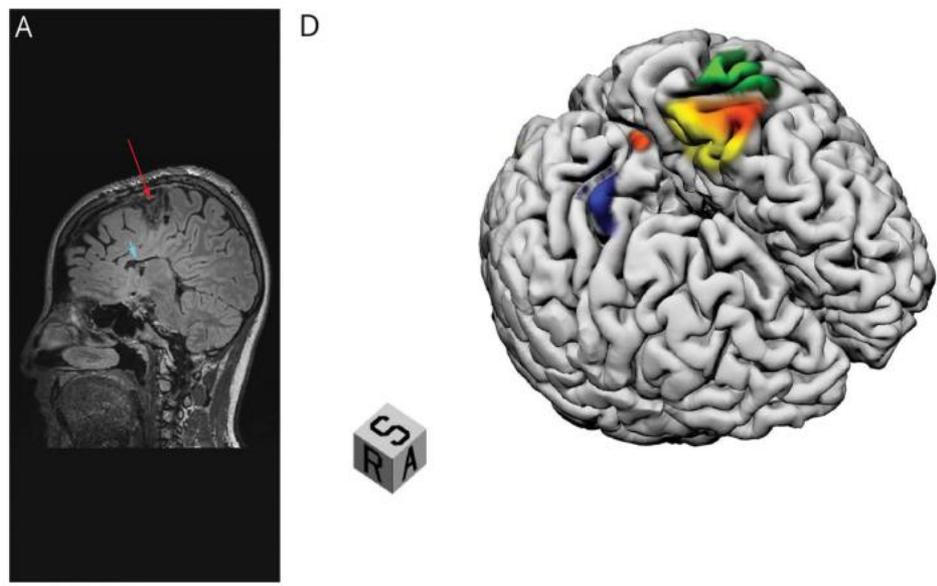
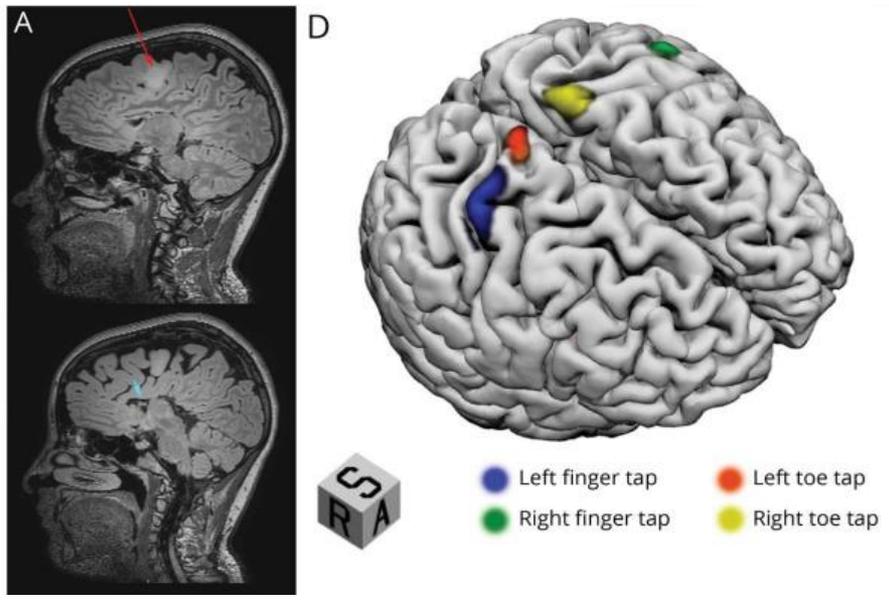
Évolution postopératoire



- Asymptomatique
- Congé le lendemain de la procédure
- Forces normales

Évaluation de la plasticité postopératoire

Chirurgie de l'aire motrice supplémentaire



3 mois postop

Récupération surprenante

Chirurgie pour épilepsie insulaire

Received: 4 April 2022 | Accepted: 28 September 2022
 DOI: 10.1002/epi4.12663

Epilepsia Open™ Open Access

CRITICAL REVIEW

Predictors of outcomes after surgery for medically intractable insular epilepsy: A systematic review and individual participant data meta-analysis

Sami Obaid^{1,2} | Jia-Shu Chen³ | George M. Ibrahim⁴ | Alain Bouthillier² |
 Evan Dimentberg^{1,5} | Werner Surbeck⁶ | Elena Guadagno⁷ |
 Tristan Brunette-Clément^{1,2} | Nathan A. Shlobin⁸ | Aidan Shulkin¹ |
 Andrew T. Hale⁹ | Luke D. Tomycz¹⁰ | Marec Von Lehe¹¹ |
 Michael Scott Perry¹² | Francine Chassoux¹³ | Viviane Bouilleret¹⁴ |
 Delphine Taussig^{14,15} | Martine Fohlen¹⁵ | Georg Dorfmueller¹⁵ |
 Koichi Hagiwara¹⁶ | Jean Isnard¹⁷ | Chima O. Oluigbo¹⁸ | Naoki Ikegaya¹⁹ |
 Dang K. Nguyen²⁰ | Aria Fallah²¹ | Alexander G. Weil^{1,2,22}



Bouthillier et al. 2019

Neurological Complication	Value	No. of patients*
Total No. of Patients with Complication Profile	221	
No. of Patients with Postoperative Complications	94 (42.5%)	221
Transient	74 (33.9%)	218
Permanent	17 (7.8%)	218
Transient Duration < 1 Week	5 (2.5%)	204
Transient Duration 1 week to 3 Months	46 (22.5%)	204
Transient Duration > 3 Months	9 (4.4%)	204

Récupération en moins de 6 mois



Récupération surprenante

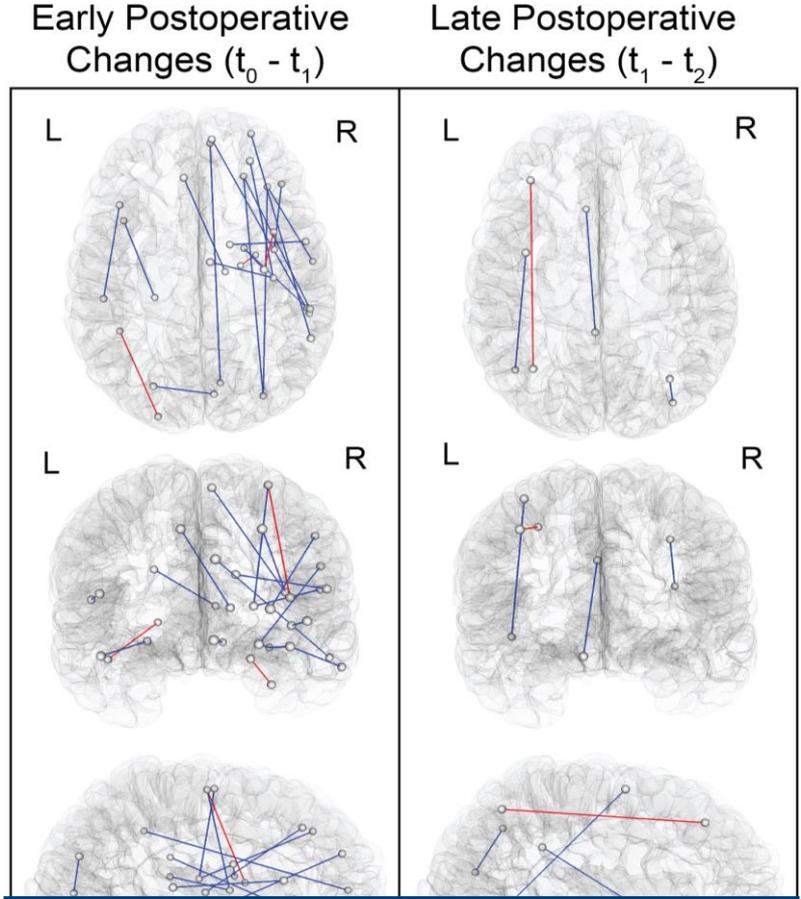
Chirurgie pour épilepsie insulaire

Progressive remodeling of structural networks following surgery for operculo-insular epilepsy

frontiers | Frontiers in Neurology 2024

Sami Obaid^{1,2,3,4*}, Guido I. Guberman⁵, Etienne St-Onge⁶, Emma Campbell⁷, Manon Edde⁴, Layton Lamsam⁸, Alain Bouthillier³, Alexander G. Weil^{1,9}, Alessandro Daducci¹⁰, François Rheault¹¹, Dang K. Nguyen^{1,2,12†} and Maxime Descoteaux^{4†}

- Patients avec épilepsie insulaire scannés multiples fois après la chirurgie
- Analyses longitudinales de connectivité structurelle

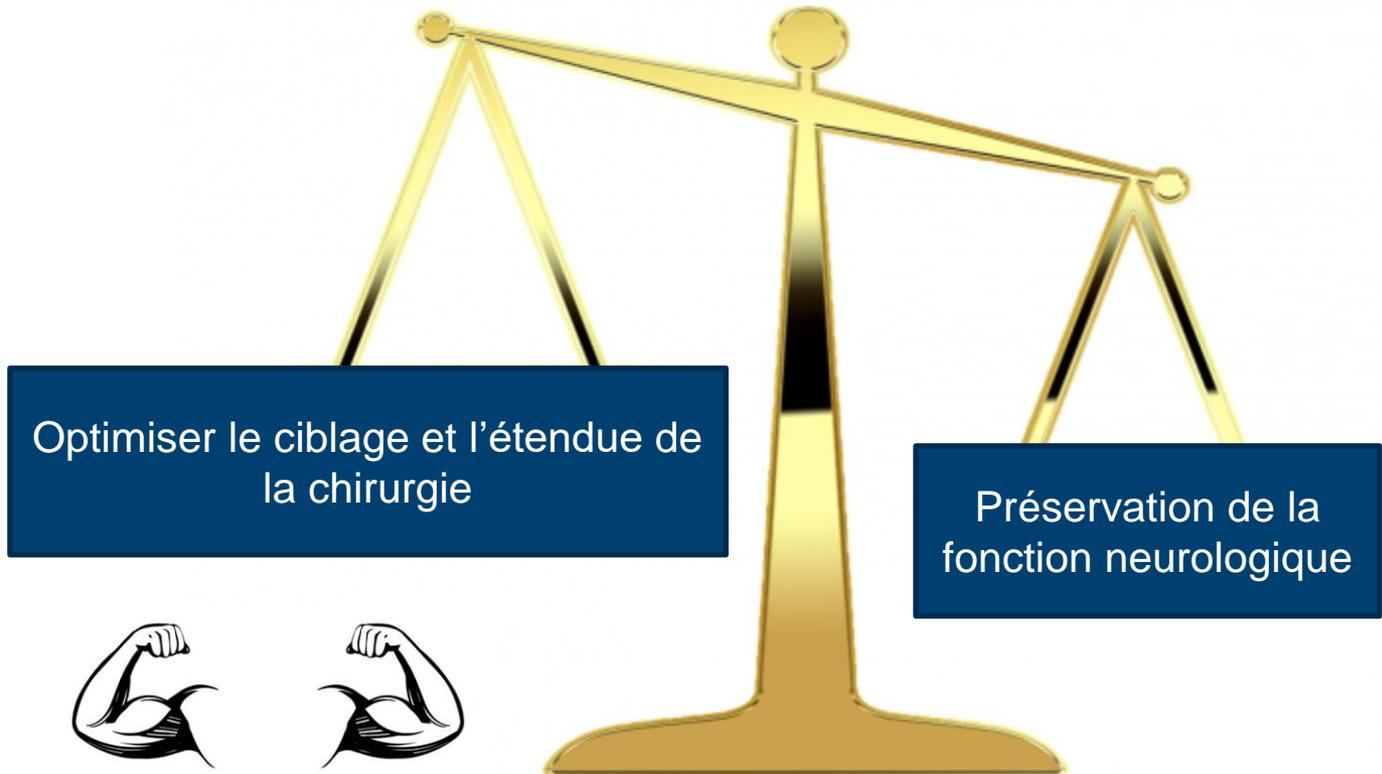


1. ↑ force de connexions autour de la résection et controlatéralement

2. Changements en ≤ 6 mois



La tractographie en neurochirurgie d'épilepsie



- 1- IDENTIFICATION DE L'ORIGINE DES CRISES
- 2- PRÉDIRE L'ISSUE (CONTRÔLE ÉPILEPTIQUE)
- 3- PRÉVENIR LES COMPLICATIONS NEUROLOGIQUES
- 4- PRÉDIRE LA RÉCUPÉRATION FONCTIONNELLE POSTOPÉRATOIRE



Conclusion

- La tractographie a le potentiel d'améliorer l'**efficacité** et la **sécurité** de la chirurgie d'épilepsie
- Utilité démontrée et son implémentation progresse
- **Multimodalité** pour favoriser une meilleure issue clinique
- **Thérapie personnalisée!**



Remerciements

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Équipe de recherche – ONSET lab



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Surgical **E**pilepsy **T**reatment



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QUALITÉ

INTÉGRITÉ

INNOVATION

COLLABORATION

PERFORMANCE