Comparing Isotropic and Anisotropic Brain Conductivity Modeling: Planning Optimal Depth-Electrode Placement in White Matter for Direct Stimulation Therapy in an Epileptic Circuit

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TECNOLÓGICO DE MONTERREY®

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Introduction and objectives

Patients with pharmacologically resistant epilepsy

Responsive Direct Neurostimulation Therapy (NeuroPace)

FDA-Approval Pending

Patient-Specific Brain Conductivity

Isotropic model

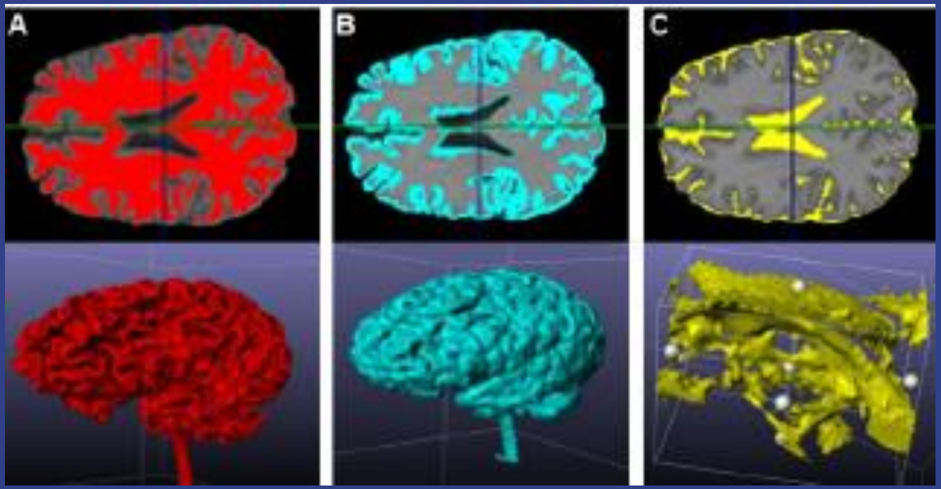
Predict the current propagation extent in pathological white matter

Anisotropic model

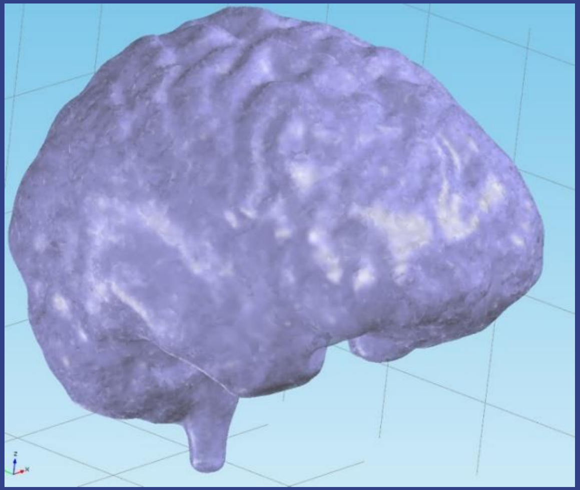
Proposed Workflow

FEM model → Determine ROI using E field → Calculate VOCA from ROI and create tractography → Post implant validation

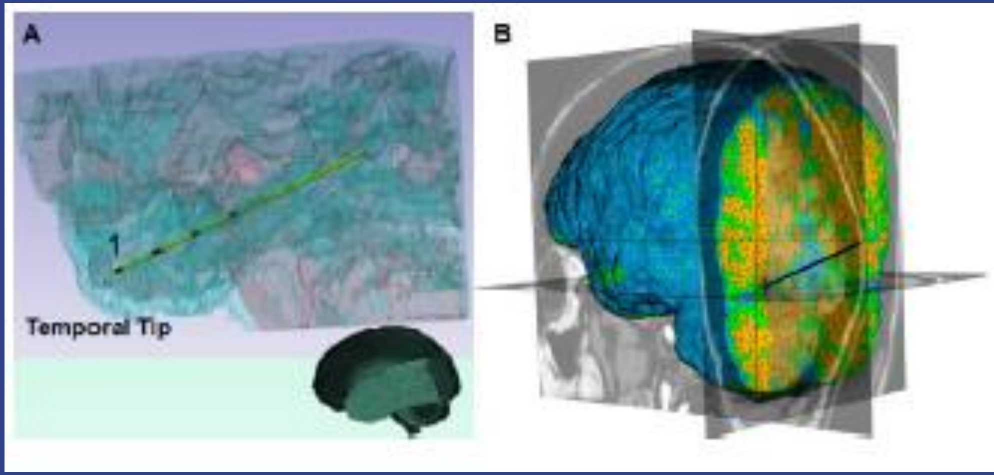
Isotropic model



Brain segmentation SPGR MRI (Scan IP)



Physical conductivities assigned.
Potential difference application.



Depth Electrode Placement & Mesh Generation (CAD, +FE).

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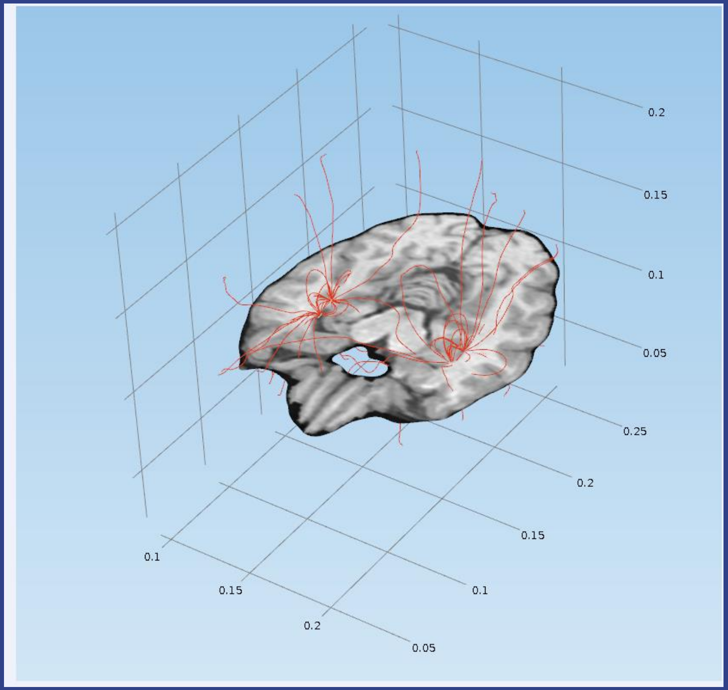
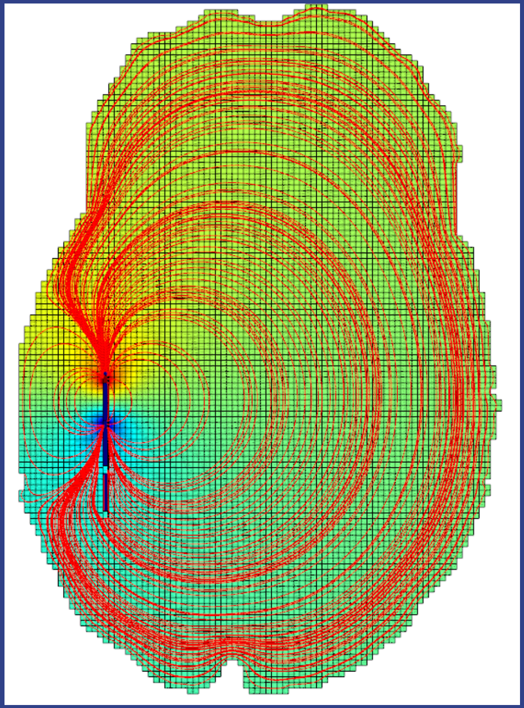
Isotropic model



3D model E-Field solution



Uniform E-field Distribution

Uniform Conductivities

- White matter = 0.15S/m
- Grey matter = 0.06S/m
- CSF = 1.79S/m
- $\Delta V = \pm 5V$

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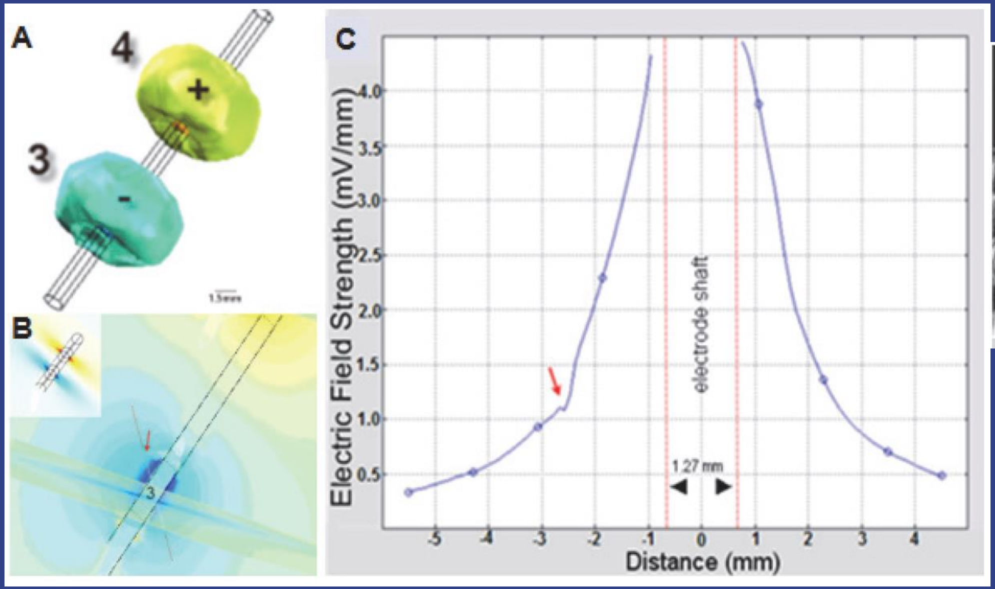
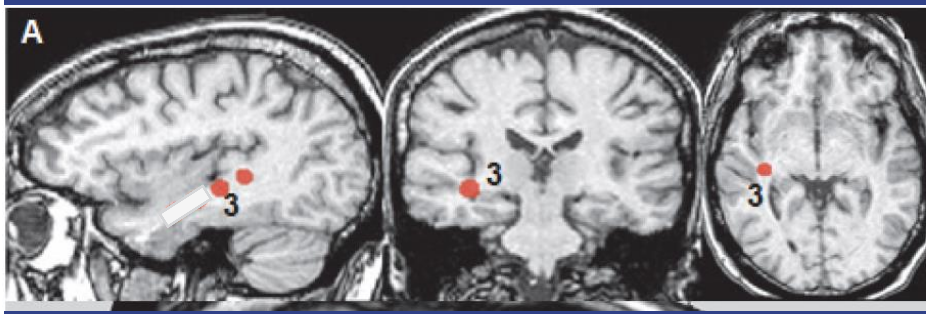
Determining ROI

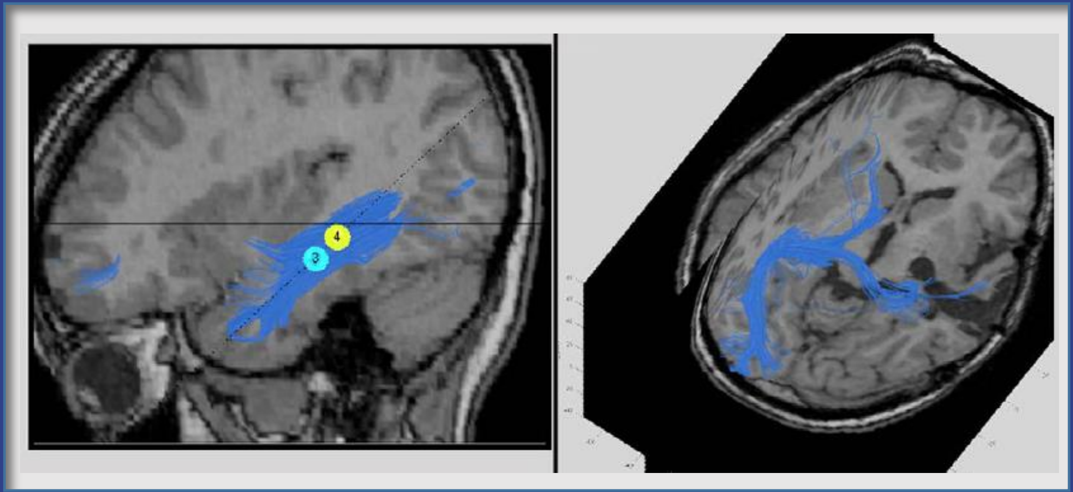




A radius of 3.75 mm from shaft center (midline between parallel red dotted lines) was assumed to influence axons encompassed by the magnitude of the electric field

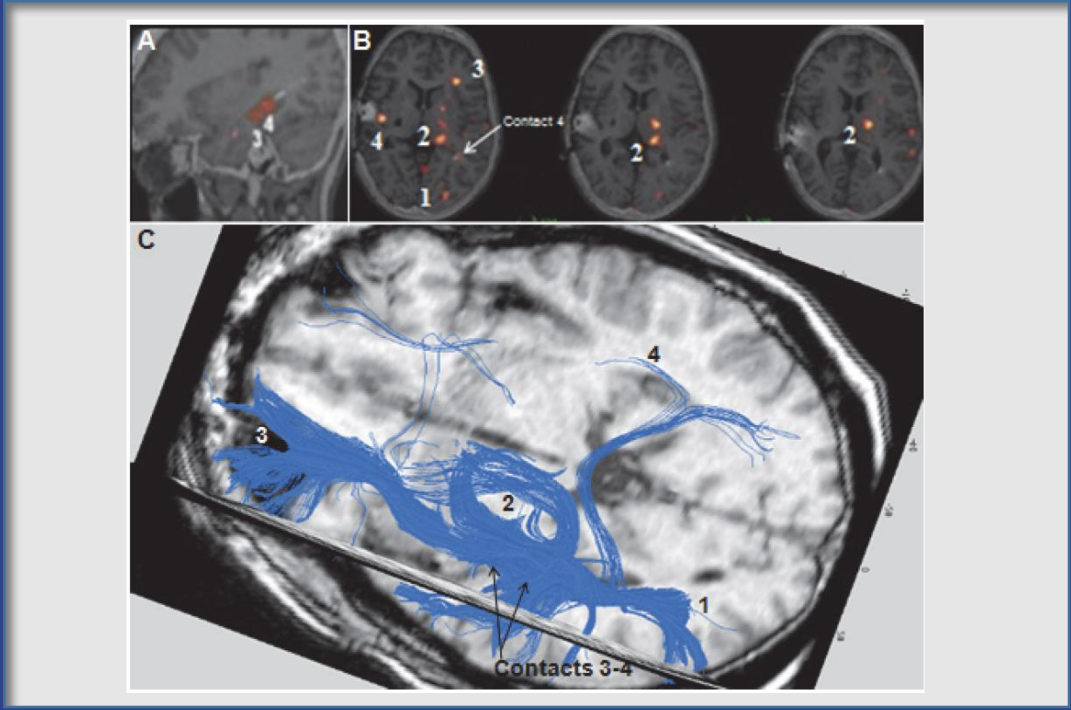
Using DTI to Predict Stimulated Neural Circuit

Pre-implantation
Tractography Model
Using deterministic
tracking algorithm
from DTI scan



Post-implantation
validation

SAS = Subtraction Activated
SPECT=Single-photon emission
computed tomography



Anisotropic model

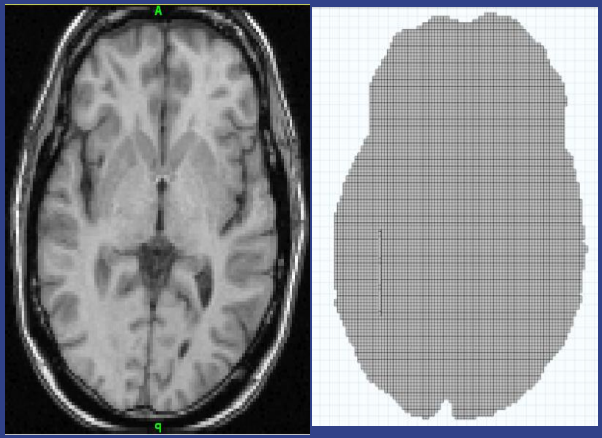
$$\boldsymbol{D} = \begin{bmatrix} Dxx & Dxy & Dxz \\ Dxy & Dyy & Dyz \\ Dxz & Dyz & Dzz \end{bmatrix}$$

Extract Diffusion Tensor from DTI: One tensor per voxel (Matlab)

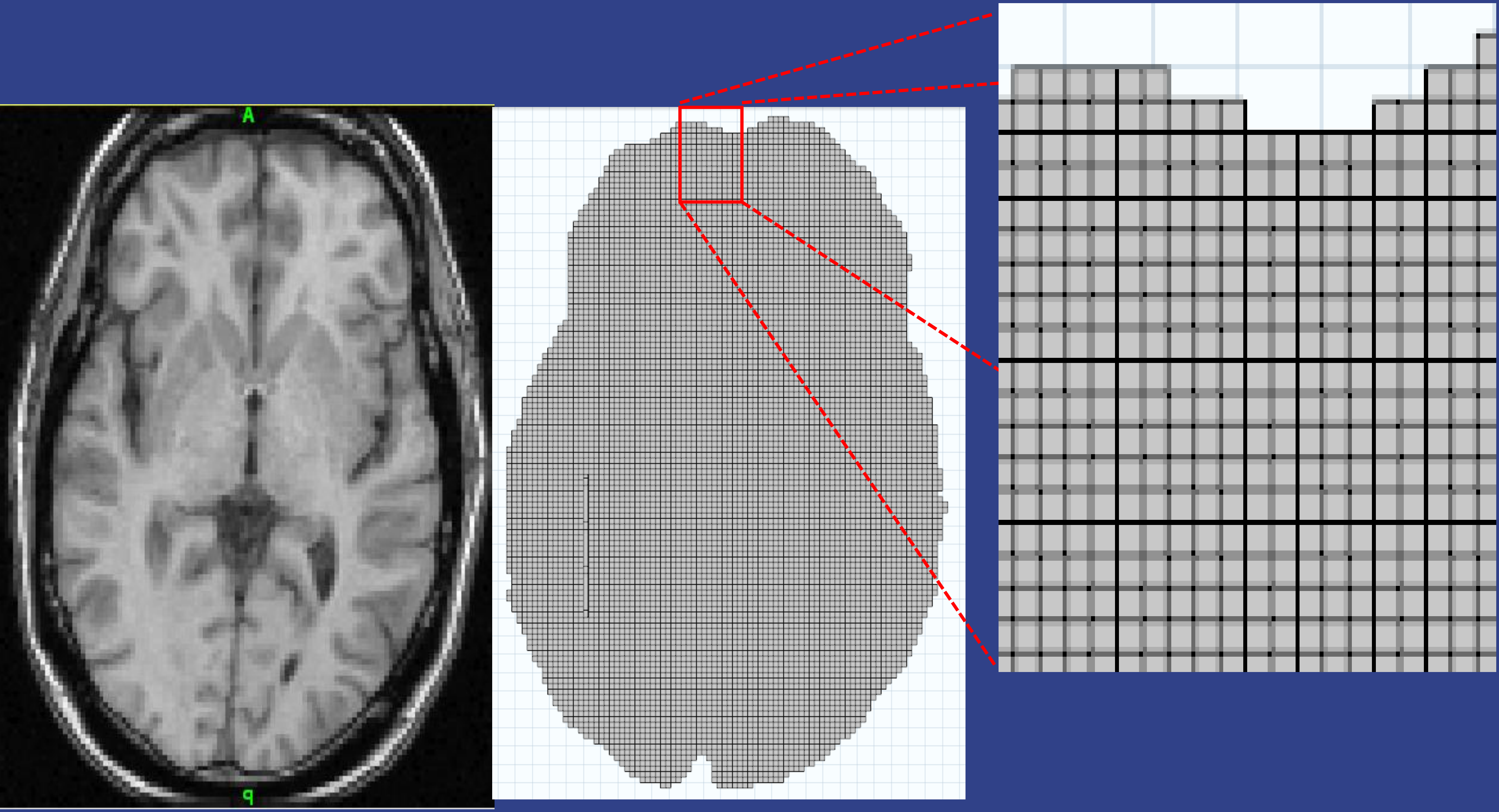
Relate each Diffusion Tensor to a Conductivity Tensor (Matlab)

$$\boldsymbol{\sigma} = \left(\frac{\sigma_e}{d_e}\right)\boldsymbol{D}$$

Create a rectangular geometric entity for each voxel (LiveLink)



Anisotropic model (creating geometry)



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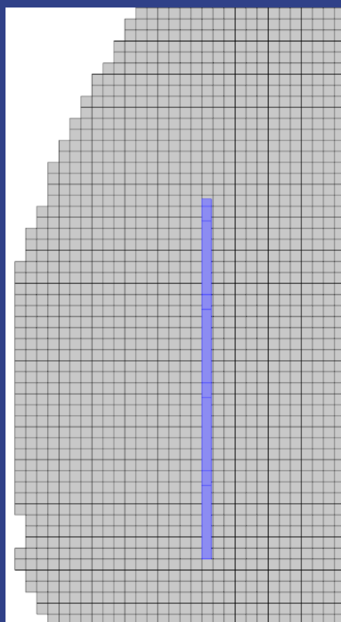
Anisotropic model



4 conductors separated by insulators.

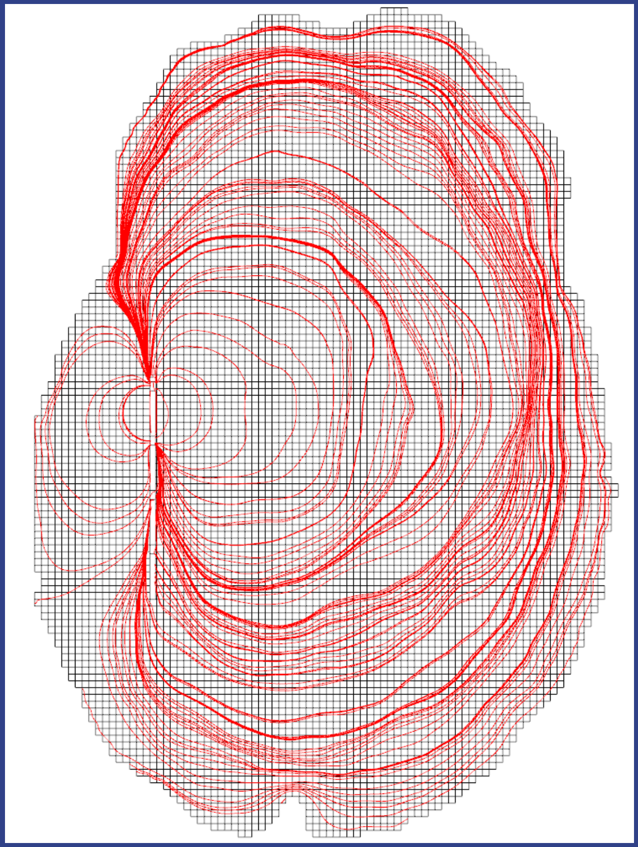
Placing electrode

Apply
$\Delta V=\pm5V$

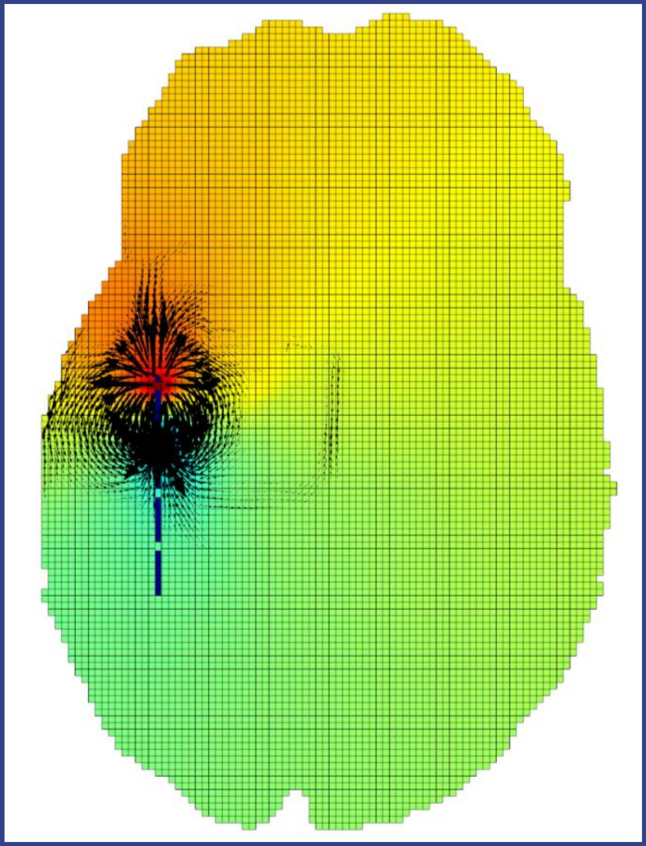
Placing electrode:

- 4 conductors (Platinium/Iridium) separated by insulators

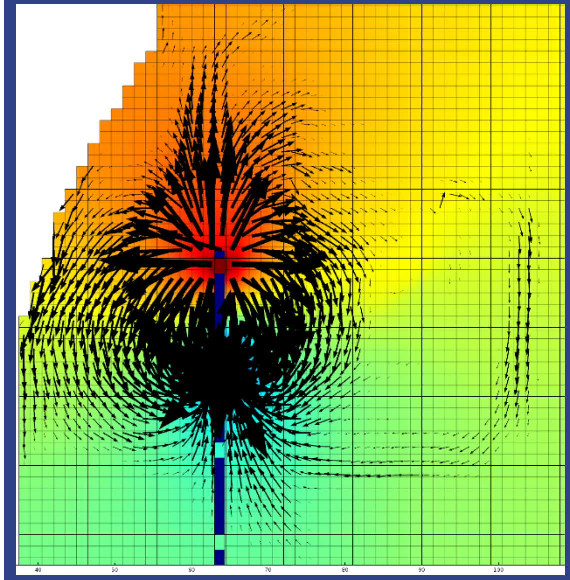
Anisotropic model



Non-Uniform E-Field solution



Current density solution



Current densities followed anatomical boundaries not apparent in the isotropic model.

Conclusions

- Conductivity models
  - Isotropic model
    - 3D models
    - Conductivity assignation relies on database
      - Uniform conductivity between domains.
  - Anisotropic model
    - Computer intensive
      - 2D models
    - Patient specific conductivity
    - Conductivity obeys direction in a tensor field
    - Improved results