

Automated Construction of Peripheral Nerve Finite Element Models

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Background

- Neuroprosthetics can help to restore motor function by sending and receiving signals from peripheral nerves
- “Communication” relies on the **peripheral nerve interface**
- **Challenge:** selectively interface with specific neural pathways among numerous, densely packed nerve fibers
- Improved peripheral nerve interfaces requires accurate computational models

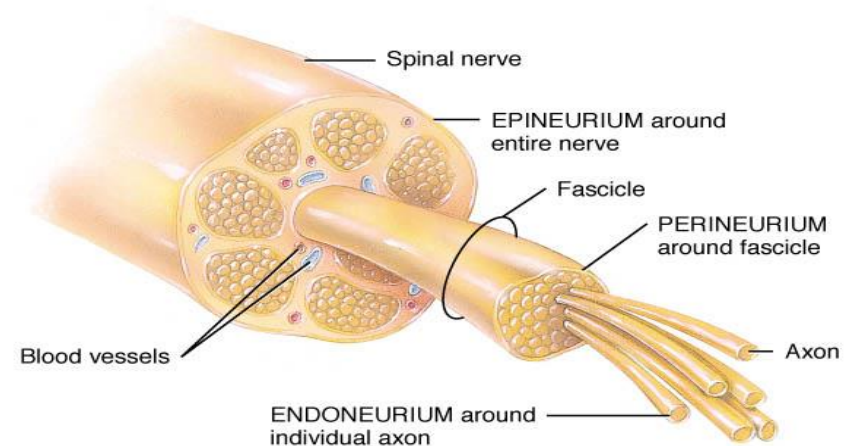
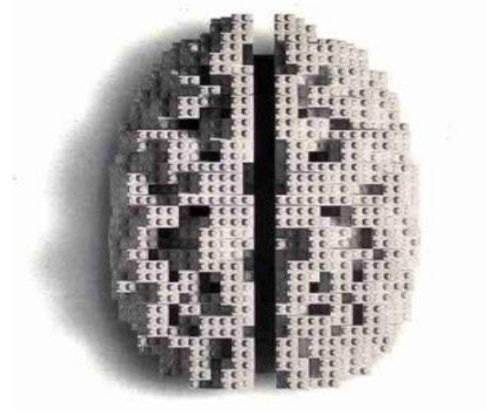


Figure 10 – 4, Introduction to the Human Body, 7th ed. John Wiley & Sons, 2007

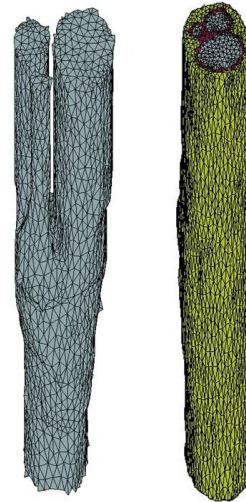
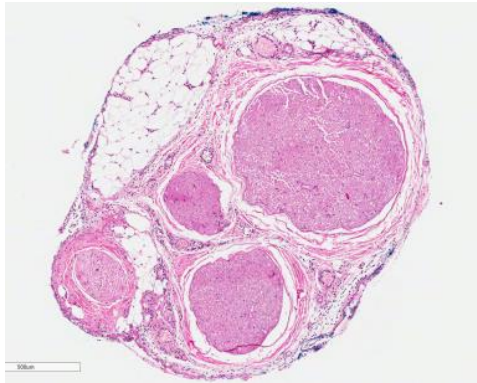
Finite Element Analysis

- **Finite element (FE) models** divide complex geometries into a mesh of smaller elements which can be easily analyzed



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Garai et. al., *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2017

- FE models of nerves can be used to simulate bioelectric activity at nerve interfaces

Project Motivation

- Nerve anatomy varies across the population, creating a need for numerous FE models
- Creating peripheral nerve FE models is currently a manual process, which is inefficient and time-consuming

Project Motivation

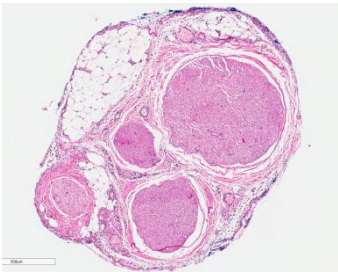
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- Creating peripheral nerve FE models is currently a manual process, which is inefficient and time-consuming

Objective: Develop an automated process to generate peripheral nerve FE models

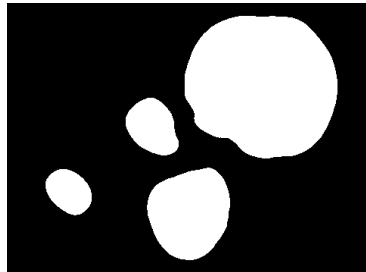
- Accurately represent key structures
- Eliminate manual supervision
- Rapidly create models of varying structures
- Ready for simulation

Methodology

**Histology
Image**



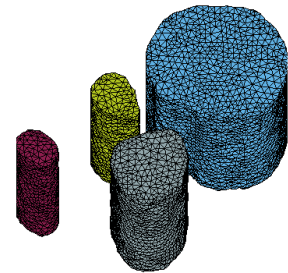
**Binary
Masks**



**3D FE
Mesh**

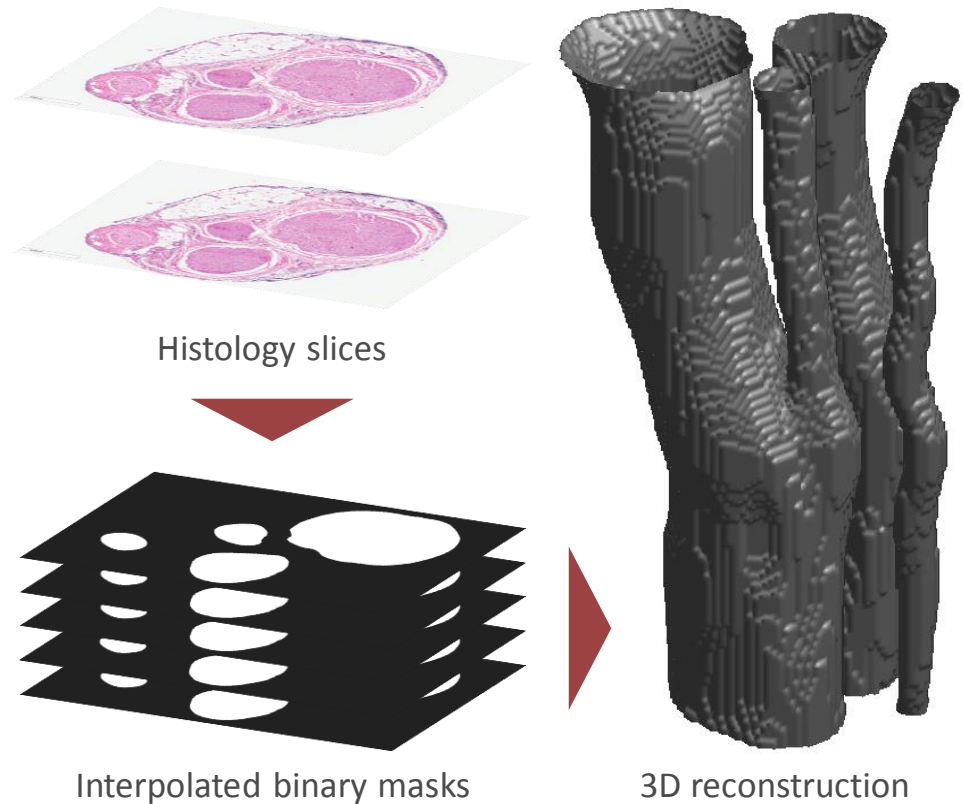


**Finite
Element
Model**

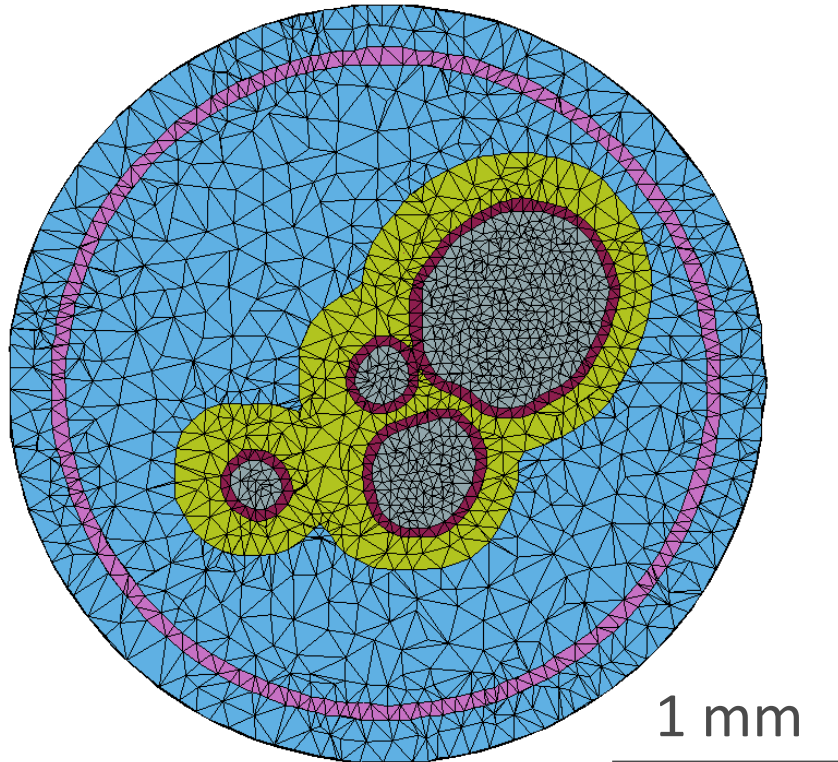


3D Reconstruction

- 10 rat sciatic nerve histology slices representing a 2.85 mm section
- The endoneurium was traced
- 1000 interpolated **binary masks** to form 3D reconstruction
 - Inputted into meshing process



Generating Key Structures



- Endoneurium**
 - Inputted 3D images
- Perineurium**
- Epineurium**
 - Generated using dilation functions
- Electrode**
- Saline**
 - Extruded as cylinders

Generating Key Structures

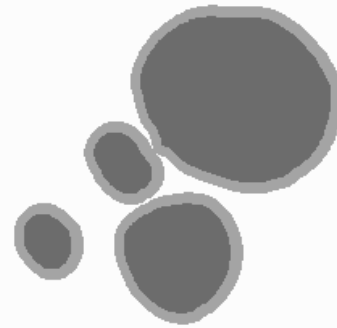
- Binary masks of the 5 regions were added



Endoneurium

Generating Key Structures

- Binary masks of the 5 regions were added



Perineurium

Generating Key Structures

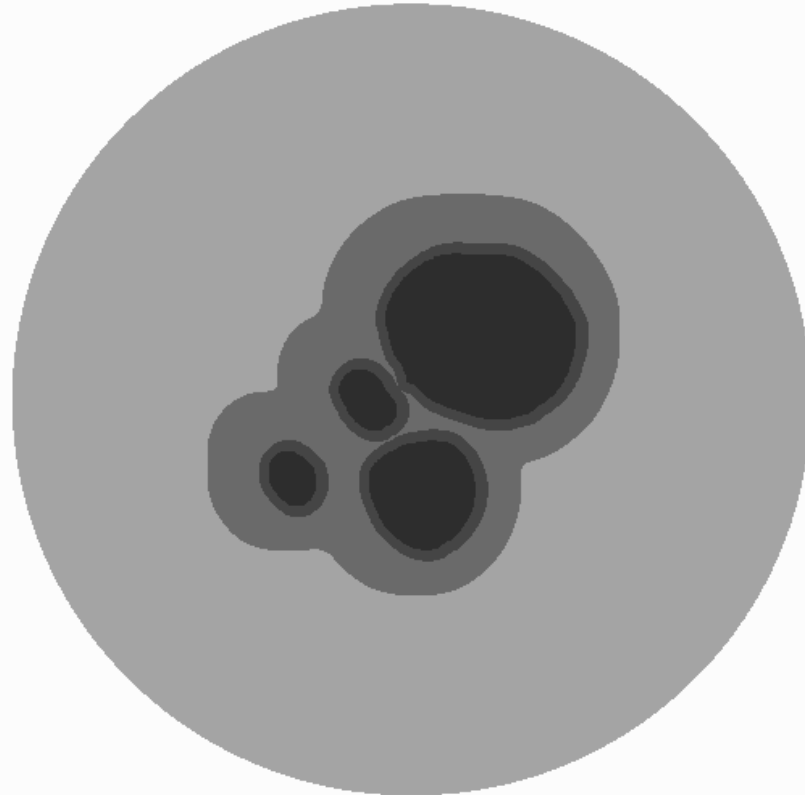
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Epineurium

Generating Key Structures

- Binary masks of the 5 regions were added



Saline

Generating Key Structures

- Binary masks of the 5 regions were added



Electrode

Generating Key Structures

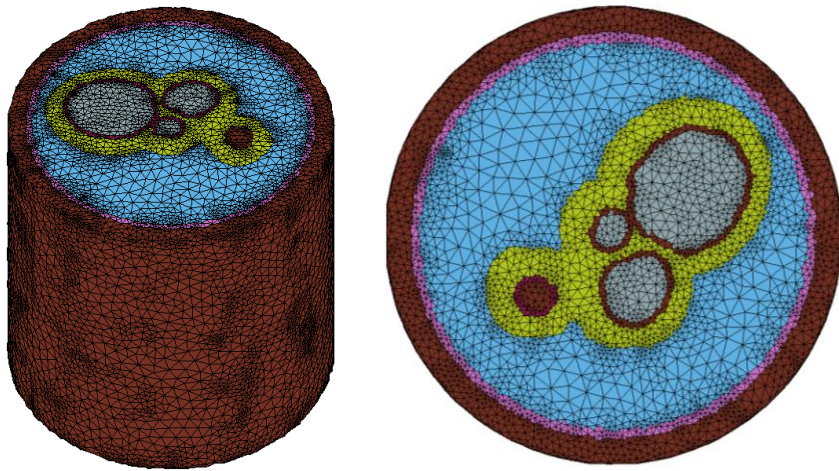
- Binary masks of the 5 regions were added
- Each region was assigned a different mesh element size



Full 3D image

Challenges with Mesh Generation

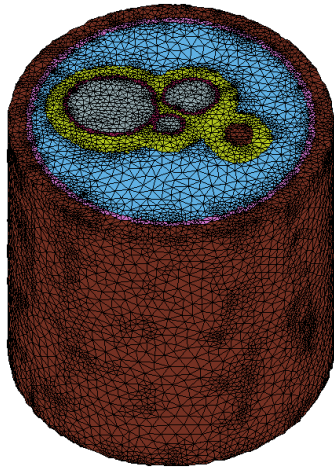
- The initial mesh produced contained errors associating regions of the same material
- Meshing function only recognizes **continuously** connected regions



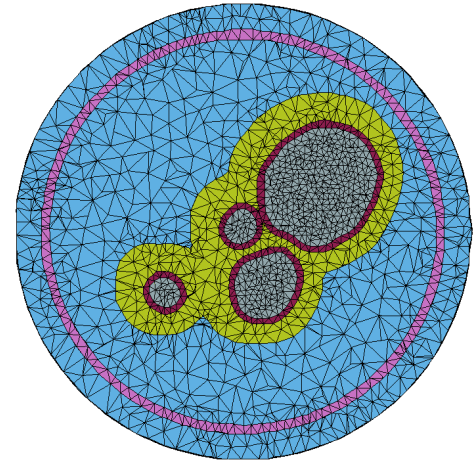
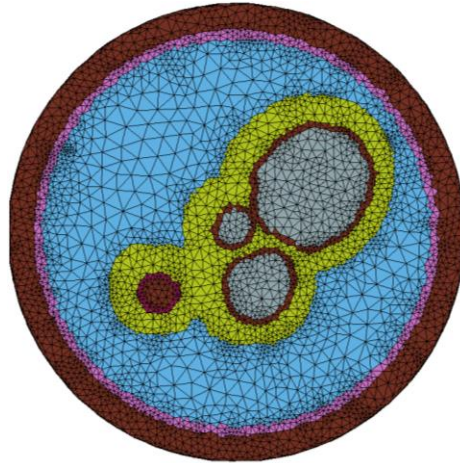
Initial mesh

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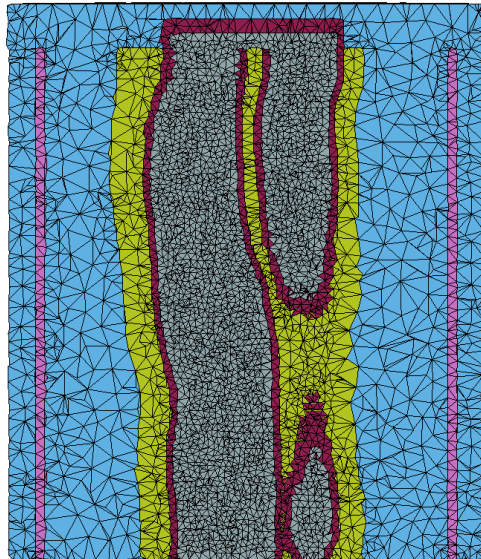
Initial mesh



Desired

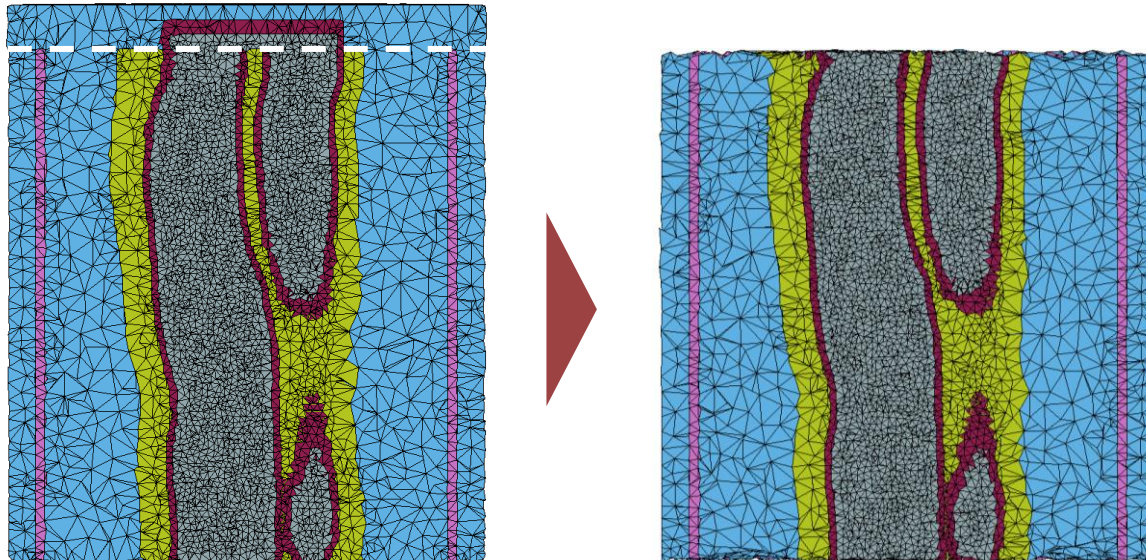
Challenges with Mesh Generation

- Discontinuous nerve regions were connected by “caps” in added layers to be recognized by meshing functions



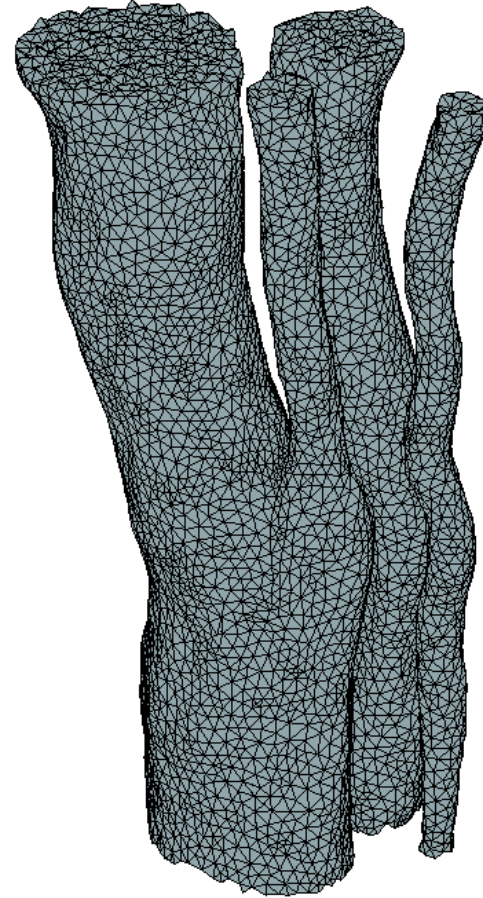
Challenges with Mesh Generation

- Discontinuous nerve regions were connected by “caps” in added layers to be recognized by meshing functions
- Added layers were removed using a cropping function





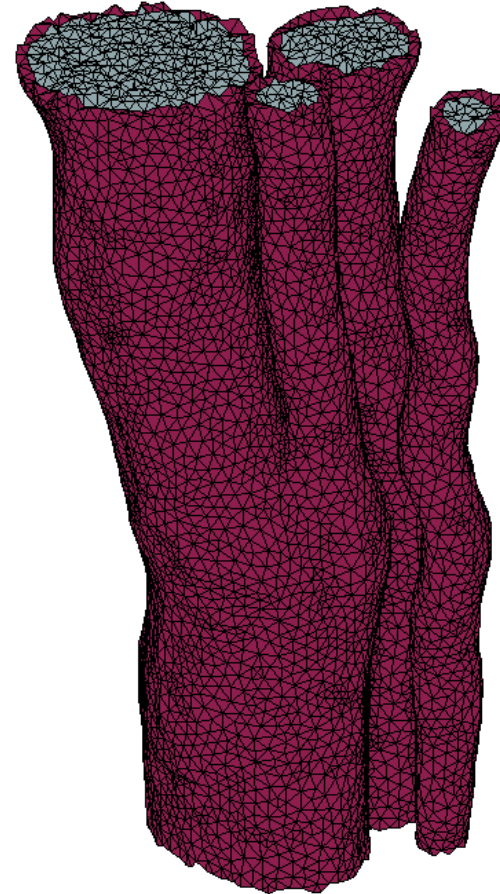
Final Mesh

 Endoneurium






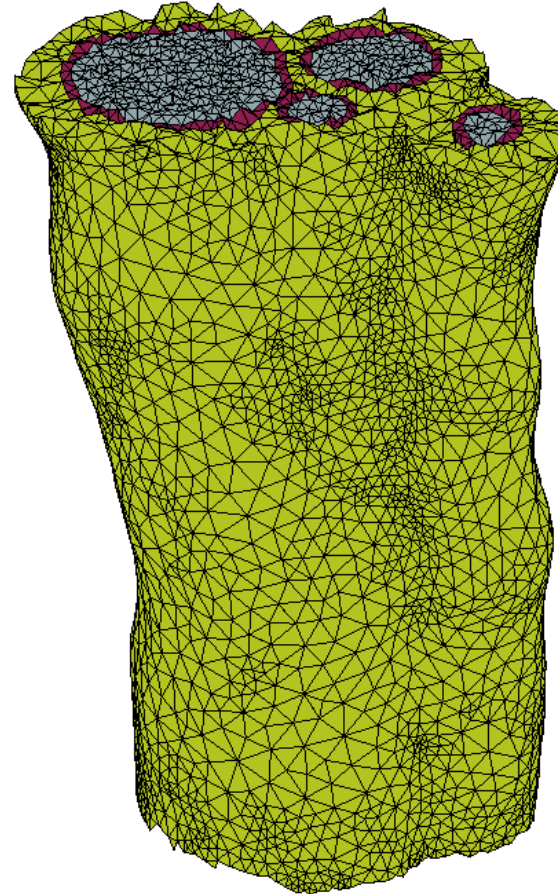
Final Mesh

-  Endoneurium
-  Perineurium








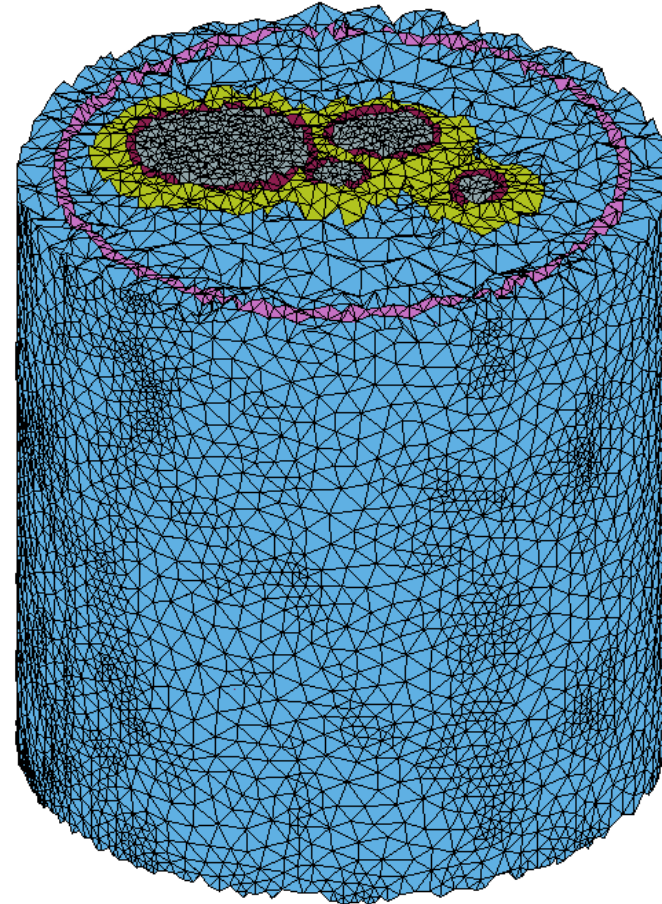
Final Mesh

-  Endoneurium
-  Perineurium
-  Epineurium








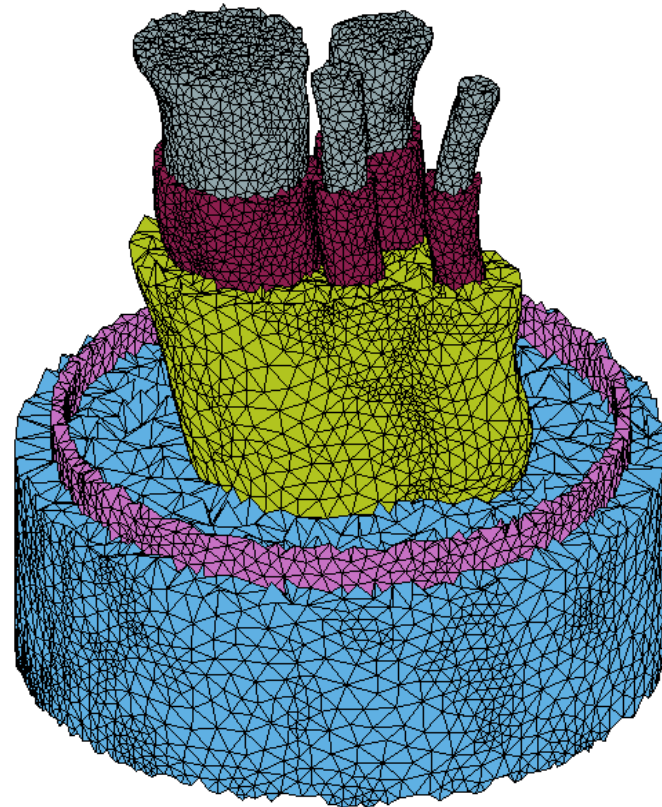
Final Mesh

-  Endoneurium
-  Perineurium
-  Epineurium
-  Electrode
-  Saline



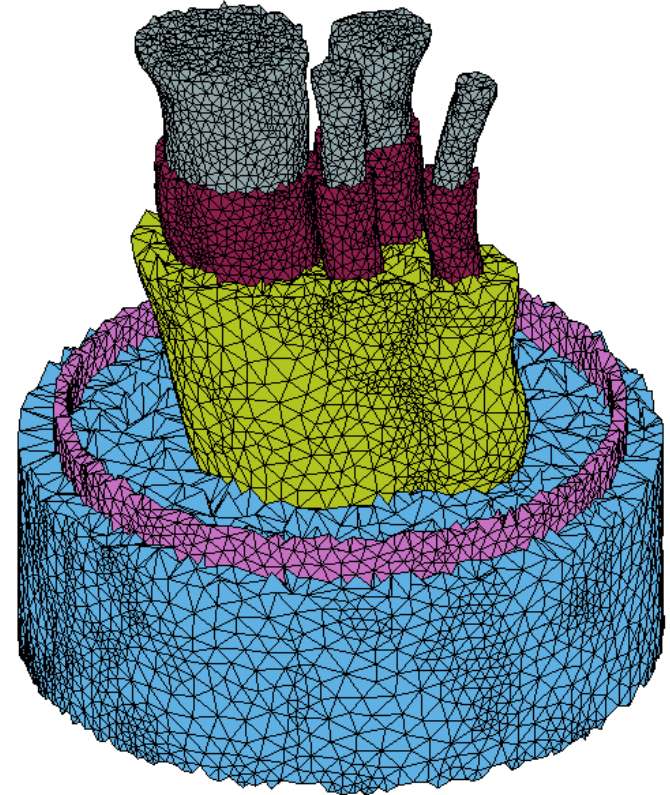
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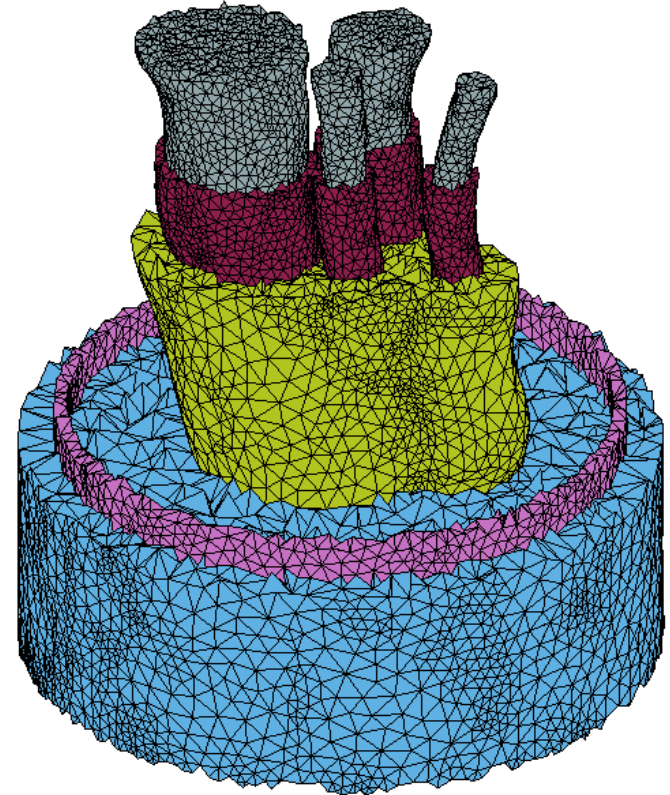
Final Mesh

- The final FE model was exported, including:
 - Node and element coordinates
 - Region indices for each element
 - Conductivities of each region



Discussion

- Process greatly reduces time, especially when generating nerve features
- Scalable with additional computing power rather than manpower
- Databases of nerve FE models can aid in nerve interface design and closed-loop control in prosthetic limbs



Future Work

- Run peripheral nerve recording simulations on the exported model
- Test and adapt the process on human peripheral nerve datasets, which have additional nerves and increased complexity
- Use a wider range of datasets to test the process' versatility for variations in nerve structure across populations

Thank you.

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