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FUNCTIONAL SIMULATION OF THE COCHLEA FOR IMPLANT OPTIMIZATION

HEAR-EU

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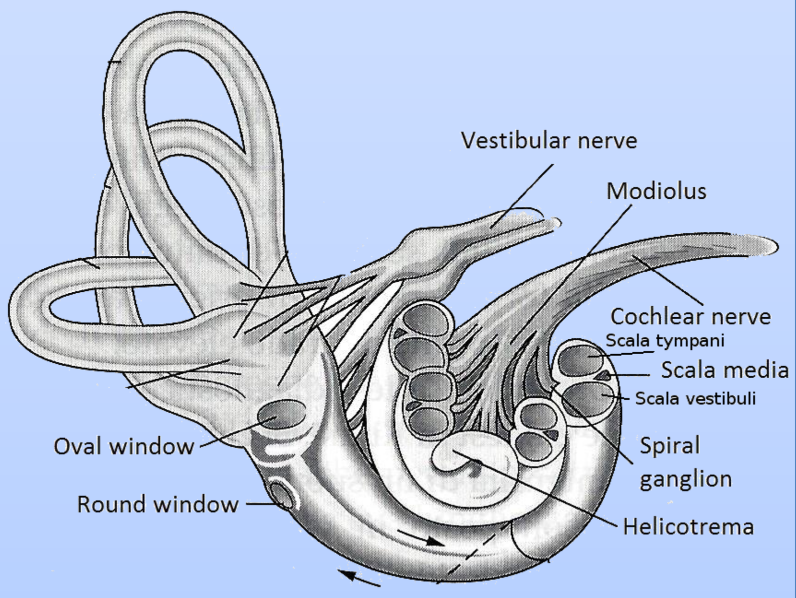
Clinical motivation

Cochlear implantation is a surgical technique which aims to **restore hearing** in people with deep hearing loss. However, **outcomes** of the surgery still exhibit a **large variability** between patients. Among the factors that **contribute** to variability the most important are **morphological differences** in anatomical structures between patients and **incorrect implant placements**. In order to address these issues, it would be desirable to have a **functional model** of the cochlea which incorporates inter-patient variability and simulates electrode placement.

Anatomy and physiology of the cochlea. **Pressure waves** that originate from the oval window **propagate** through the scala vestibuli and scala tympani and **cause vibrations** of the structures within the scala media.



We present a **finite element model** which captures the interaction between the **cochlear partition**, modeled as an elastic solid with finite deformation, and the **perilymph fluid**, modeled as a compressible, viscous fluid. Numerical results show that the **membrane** responds to **changes** in the stimulation **frequencies**.

Constitutive equations

Fluid domain

We solve the Navier-Stokes equations for viscous flows:

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = -\nabla p + \nabla\cdot\left(\mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)\right) + \nabla\left((\lambda - \frac{2\mu}{3})\nabla\cdot\mathbf{u}\right) + \rho\mathbf{g}$$

Solid domain

We use the finite deformation formulation of elasticity:

$$\begin{cases} \rho_0\ddot{u} - \nabla\cdot S &= \rho_0 b_0 \\ S &= F\bar{S}(C) \\ F &= I + \nabla u \\ C &= F^T F \end{cases}$$

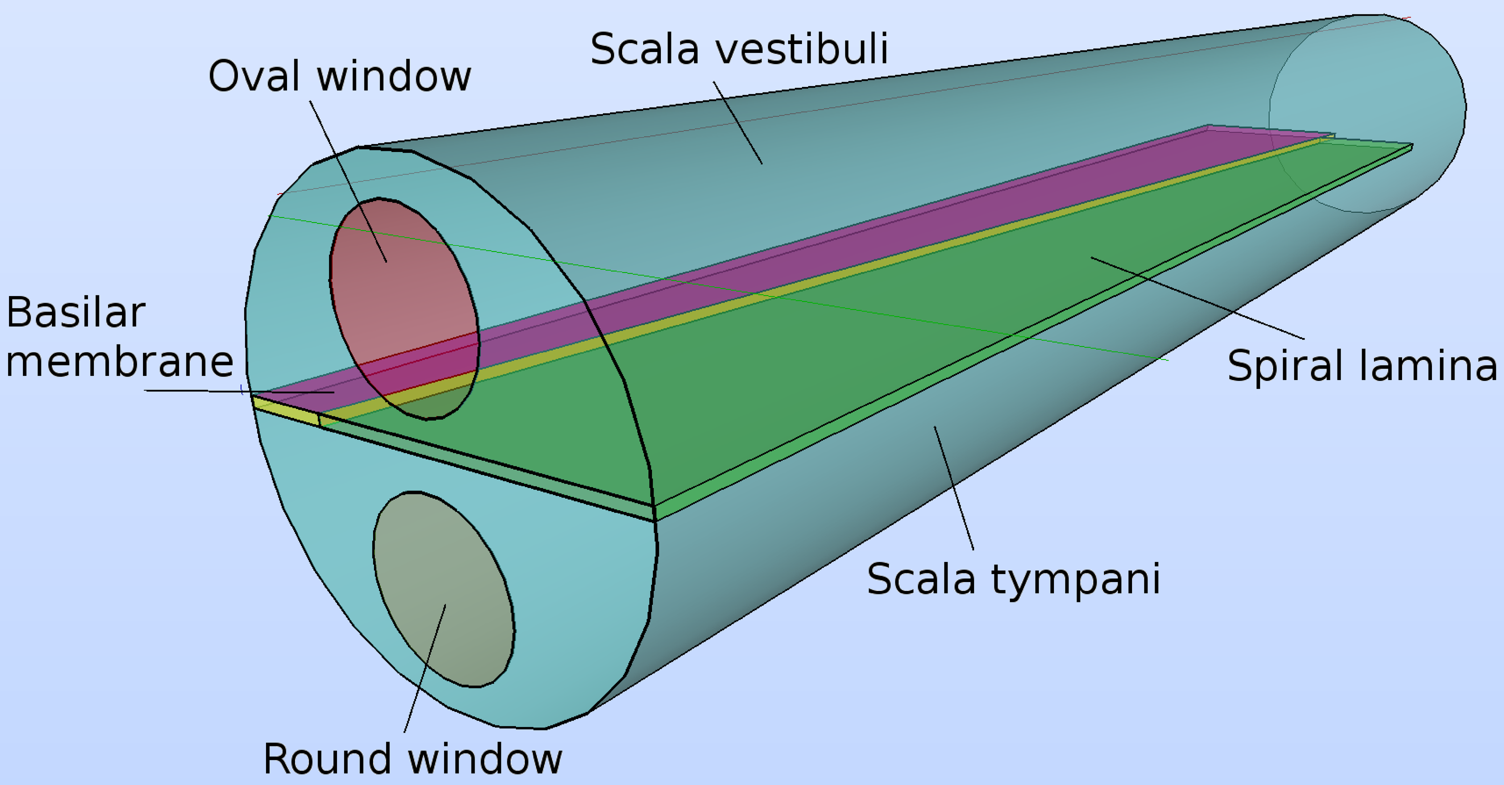
Because in a near future we plan to include in the simulation also electrode insertion, that could result in large deformation

Boundary conditions

- Input is a sinusoidal pressure in the oval window.
- The amplitude of the input pressure signal was 1 Pa.
- The walls are modeled as rigid.
- No-slip conditions on fluid-solid interfaces.

Model of the cochlea

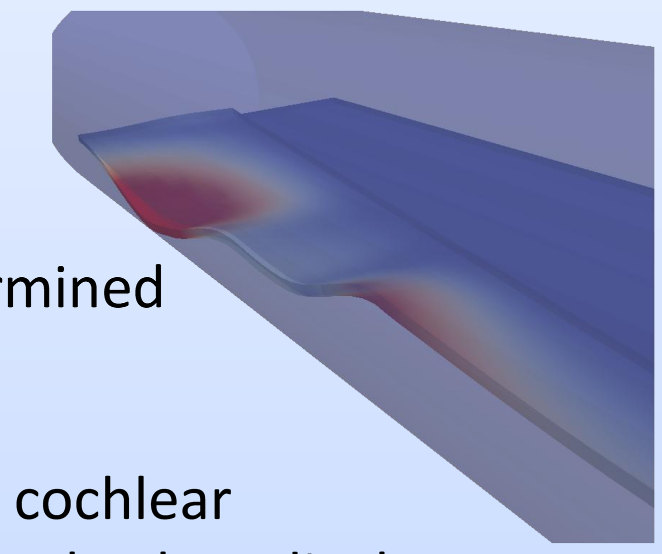
Simplified 3D uncoiled model of the cochlea. The **fluid domain** is composed by **scala tympani** and **scala vestibuli**, while the **solid domain** is made up by **spiral lamina** and **basilar membrane**. The scala media is not included in this simplified model. The coiling of the cochlea is a secondary effect and we neglect it.



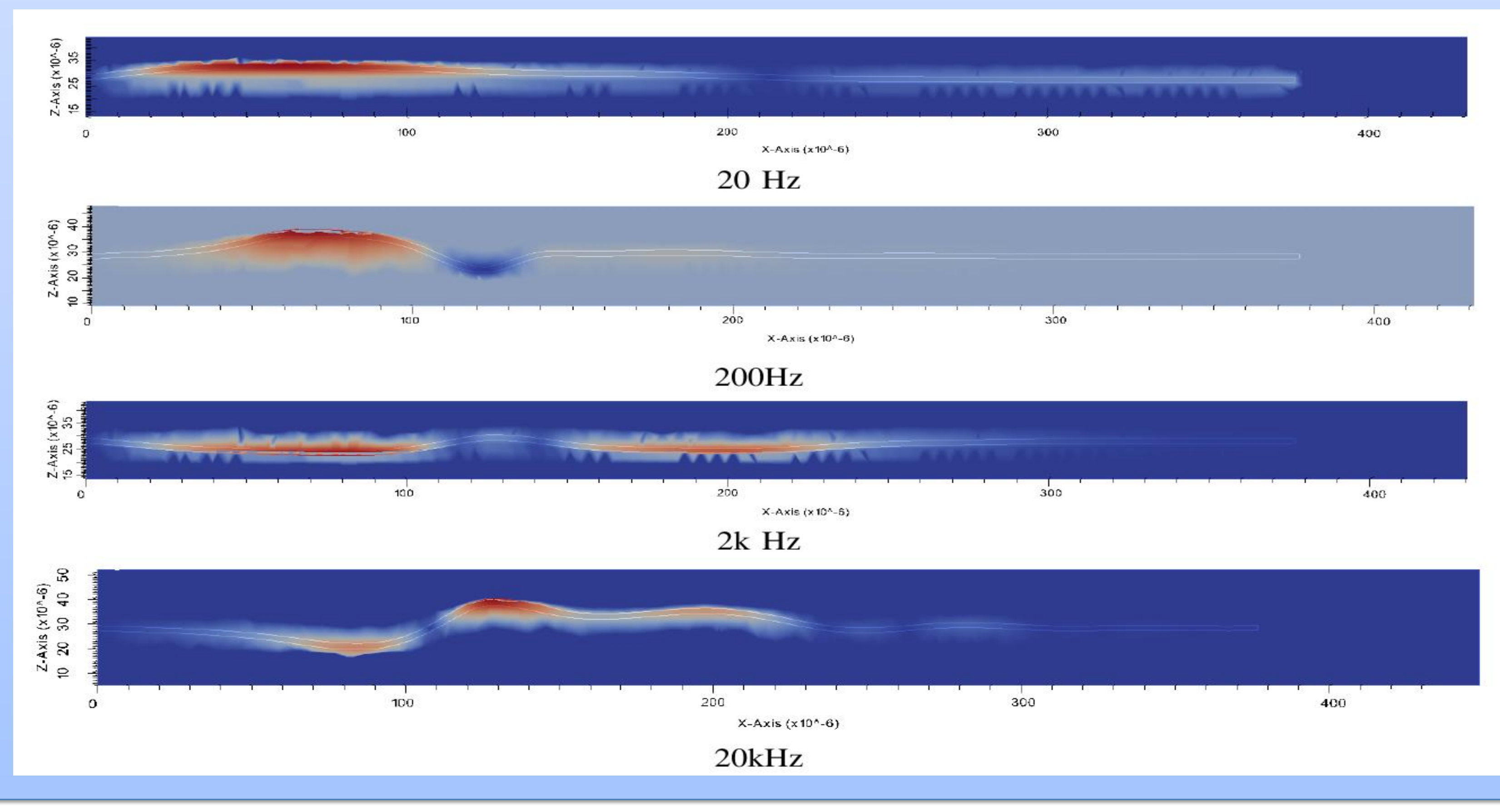
- The geometrical model is meshed with **SALOME and NetGen.**
- The FE-model is assembled using **Elmer**.
- The **Navier-Stokes** equations for the **fluid domain** are solved first and under the assumption of a constant geometry.
- The surface forces acting on the solids are used to **calculate stress** and **displacement** of the **elastic structure**.
- The fluid domain is solved again using the membrane displacements as fixed boundary conditions.
- The procedure **continues until** the solution has **converged**.

Results

- Detail of a traveling wave in a 3D simulation of the entire cochlear domain.



- Membrane oscillation is strongly determined by the input frequency.
- Here we present the configuration of the cochlear membrane corresponding to the maximum absolute displacements along z axis for 20, 200, 2k and 20k Hz.



Conclusions

- The proposed model simulates the interactions between the **sound pressure**, the **fluid** and the **internal structures of the ear**
- Acoustical waves in the lymph and **traveling waves** in basilar membrane were observed
- This **supports** the use of **FE modeling** in study of cochlear dynamics

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