Realistic Simulation of Electric Potential Distributions of Different Stimulation Modes in an Implanted Cochlea

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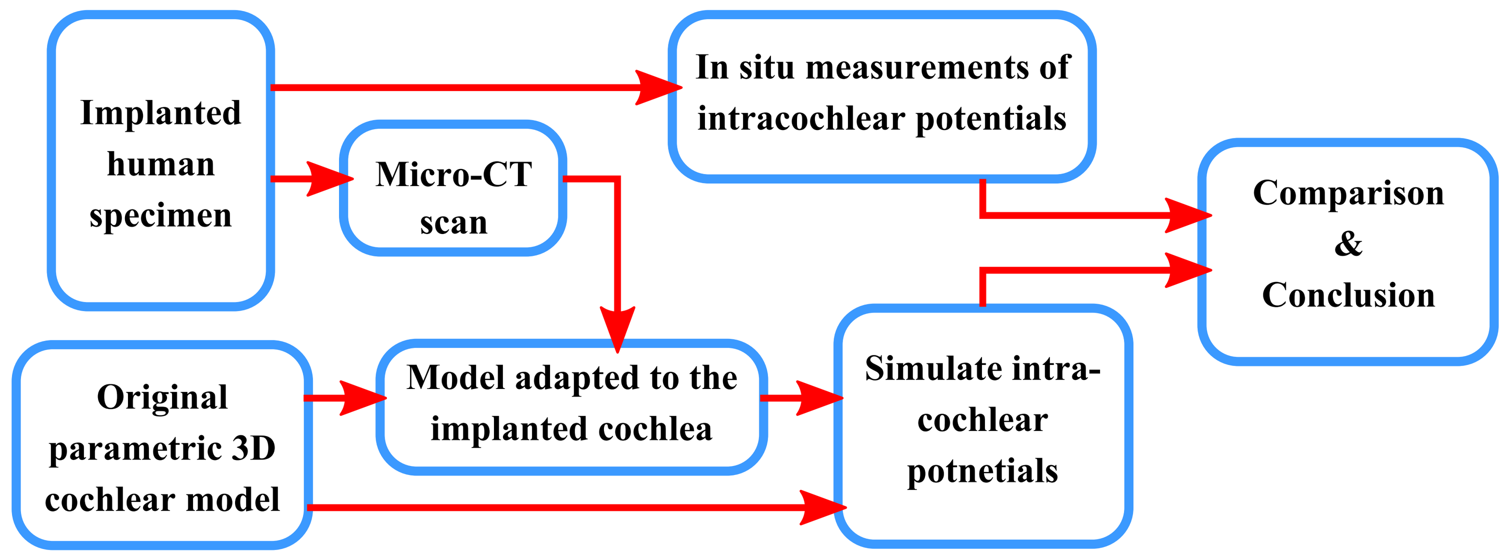
Introduction

Simulation of the intracochlear potentials is an important approach to study the activation of auditory nerve fibers under electrical stimulations.
However, it is still unclear to which extent the simulation results are affected by precision in reproducing the exact cochlear geometry.

In this study, we address to this question by comparing the actual electric potential measured from implanted human specimen with the simulation outputs from two different parametric 3D cochlear models. One of the model is created from the default values[1] while the other is adapted to the micro-CT scan data of the implanted cochlea.

The sequence of tasks is shown in the figure below:



Geometrical adaptation

The purpose of adaptation is to reflect the anatomical features of the implanted cochlea in the parametric 3D model, thus increasing the precision of the simulation.

Here we extract the geometric informatin of the cochlea through a **Post operative 3D Micro-CT scan** on the impalnted human specimen.The resolution of the scan is 24.8μm in each direction.

Cochlear coordinate system[3]: as the first step of adaptation, a cylindrical coordinate system is placed into the scan data.
Figure 2(a) gives the position of the polar axis (yellow arrow) in relation to the implanted electrodes. The image is acquired by projecting the 3D electrode scan onto a plane perpendicular to the longitudinal axis, which is defined by the centrial axis of the modiolus.

Parametric cochlear model: The original 3D cochlear model is defined by a set of parametric equations that describe a generalized cochlear shape[4](snapshot in figure 3). The computation of potential is achieved through the boundary element method implemented in OpenMEEG.

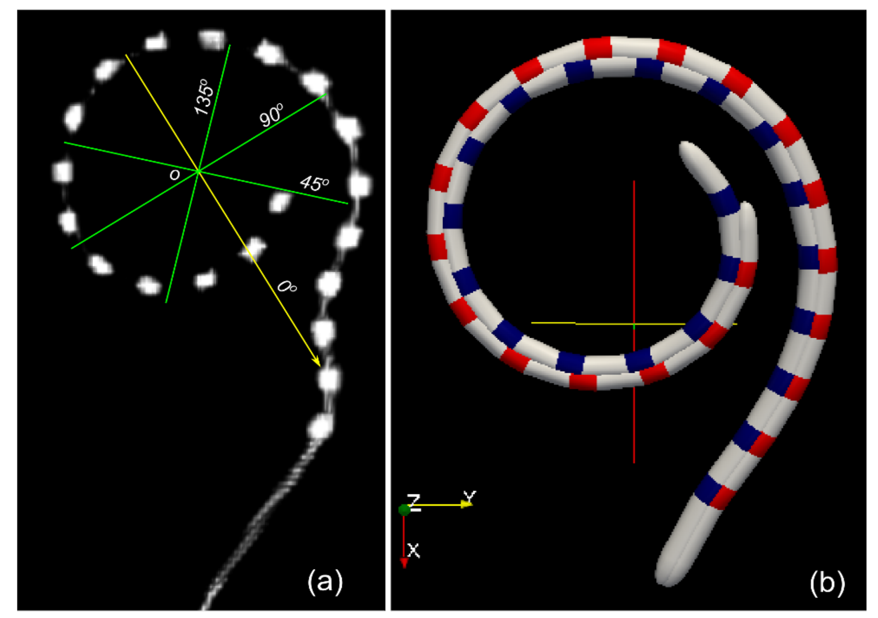


Figure 2. The cochlear coordinate system (a), and the electrode model before(blue) and after(red) adaptation (b).

4 different parameters: the **height**, **width** and **tilt angle** of the scala tympani and the **placement of the electrode array** are used to adapt the original model towards the actual geometry. Their values were extracted from the vertical cross-section images taken at different angular coordinates, as shown by the green lines in figure 2(a). Figure 4 demonstrates those images with the manually segmented scala tympani and scala vestibuli (green circle).

By measuring its location inside the scala tympani, the electrode array model is also adaped to its implanted position. Figure 2(b) shows the adapted array (red), compared with its initial position (blue).

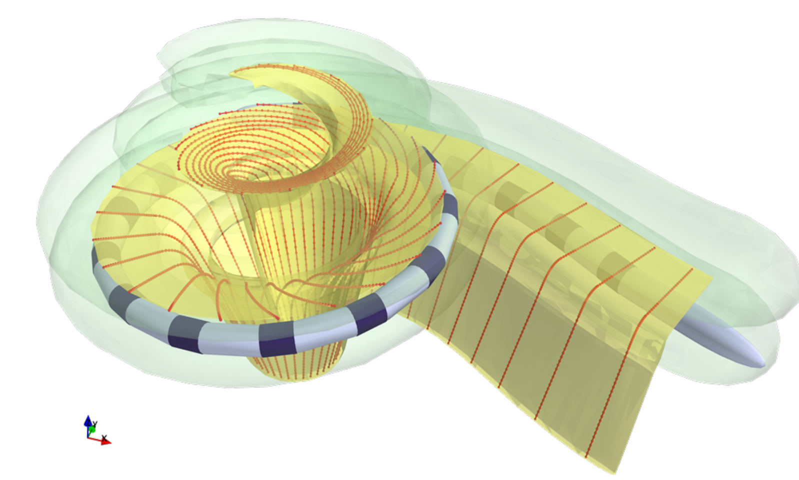


Figure 3. Snapshot of the parametric cochlear model

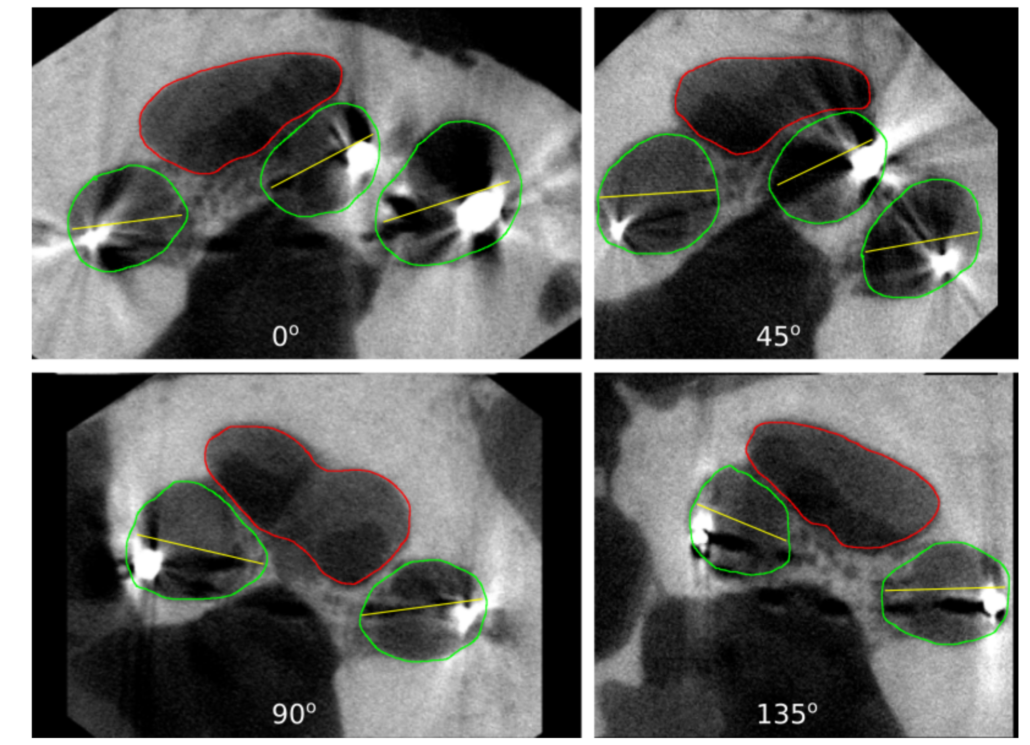


Figure 4. Cross-sections of the cochlear scan at 4 different angular coordinates

Acquisition of intracochlear potentials

Implant: The human specimen has been implanted with the EVO electrode array and the XP implant system produced by Oticon Medical. 20 cylindrical platinum contacts are placed at a 1.2mm pitch on the electrode array. Another spherical contact (d=1.6mm) has been placed between the skull and the scalp near the implanted cochlea as the reference electrode.

Stimulation: Each contact of the EVO electrode array is connected to an independent current source inside XP through a DC blocking capacitor (C_b=47nF). During the experiment, both the monopolar and the bipolar configurations have been used to stimulate the cochlea from all contacts. The stimulation waveform adopted is the biphasic pulse with 1mA amplitude and 120μs pulse duration.

Recording: The contacts were also linked to the input of an analog multiplexer which directs the input signal to the acquisition device. The waveforms were digitalized with 5MHz sampling rate and a minimal amplitude resolution of 2mV/bit.
This design enables the system to record potentials on all contacts, including the working contacts, at different stimulation modes.

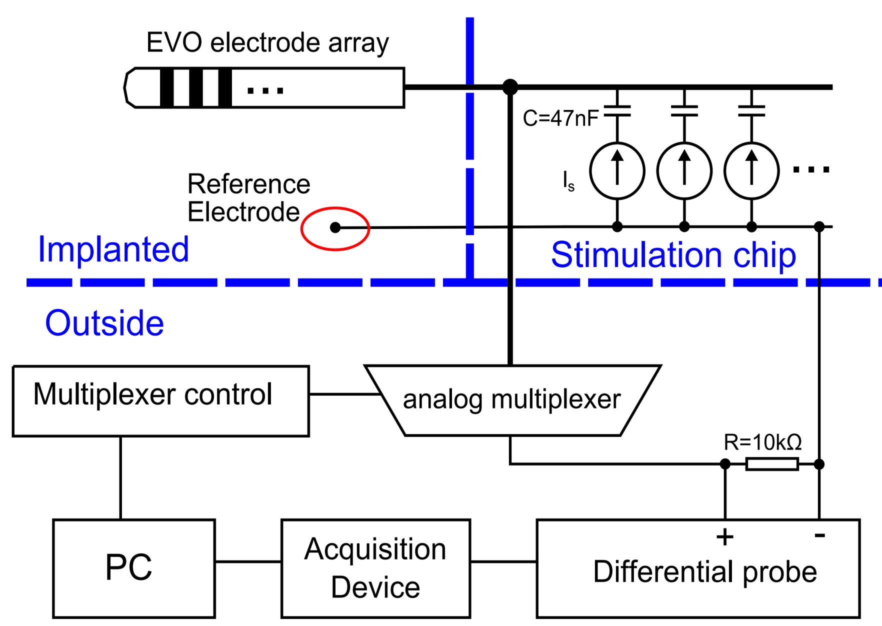


Figure 1. Diagram of the stimulation - recording system[2]

Results & discussion

Figure 5 and 6 each gives the simulation error in monopolar and bipolar mode respectively.
The x-axis of the plot is the index of the stimulating electrode while the y-axis is the error computed by the Relative Difference Measre (RDM).
Electrode + geometry indicates both the electrode and the cochlear geometry have been adapted to the micro-CT scan, etc.

In both figure 5 and 6, the models with only the geometrical adaptation give the highest error on average, even more than the models without adaptations.
This phenomenon suggests the mismatch between the cochlear shape and the electrode placement is an noticeable source of error.

The decrease in the simulation error brought by adaptation is more obvious when stimulating from near the middle of the electrode array. This can be explained by the fact that the array does not drift much from its position in the original model at the basal part of the cochlea, while at the apex of the cochlea, the relatively small size of the scala tympani (see figure 7) limits the movement of the implanted array.

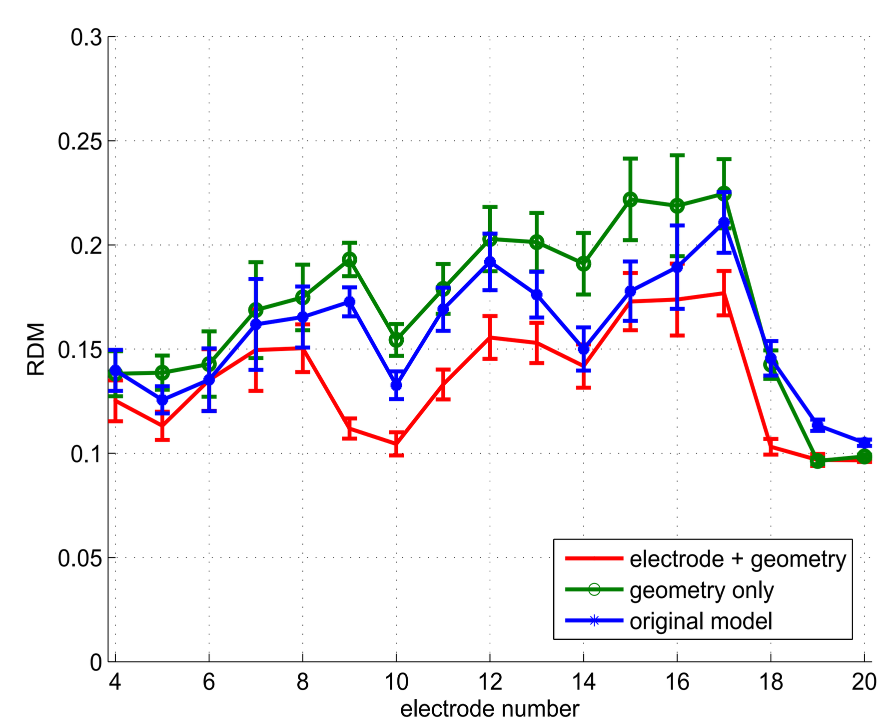


Figure 5. Simulation error under bipolar stimulation mode

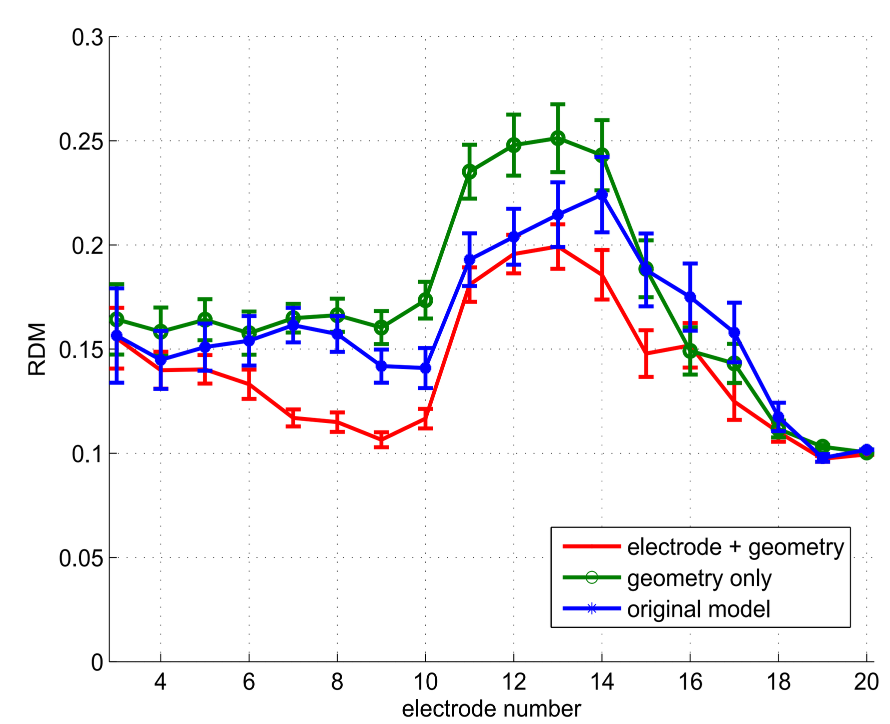


Figure 6. Simulation error under monopolar stimulation mode

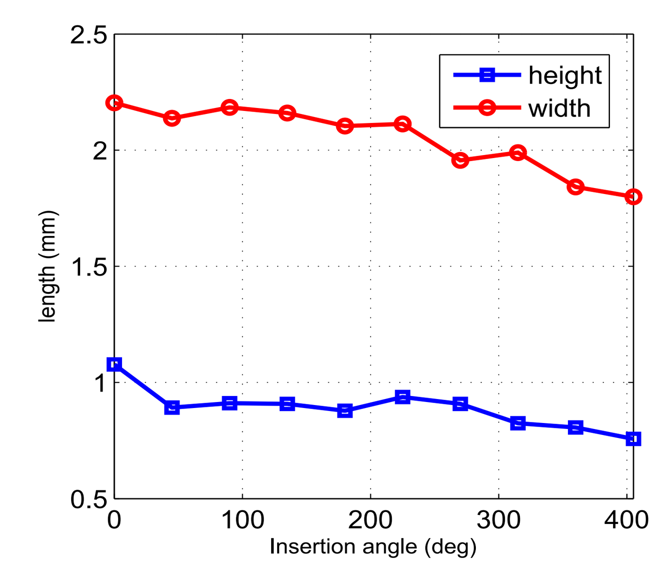


Figure 7. Width and height of the scala vestibuli measured from micro-CT scan

Conclusion

Compared with a generalized 3D cochlear model, models that have been adapted with subject specific information reduces the error of intracochlear potential simulation, on the premise that the adaptation process takes both the cochlear geometry and the electrode placement into consideration.

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Acknowledgements

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