3D PRINTED COCHLEA MODEL FOR ELECTRODE INSERTION BENCH TEST

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Introduction

Lower the forces during the electrode's insertion in the cochlea is extremely important to avoid damaging the interior structures of the Scala Tympani (ST), as the Basilar Membrane (BM), and consequently, to avoid the loss of residual audition in patients [1] [2].
These force measurements can be performed in synthetic models or in cochlea of cadavers, for design verification purpose.

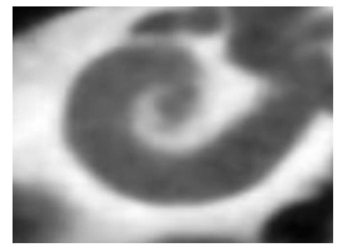
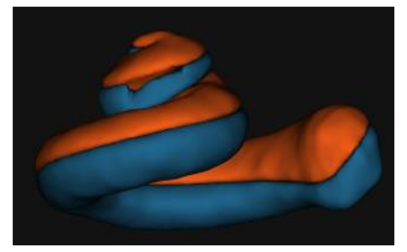
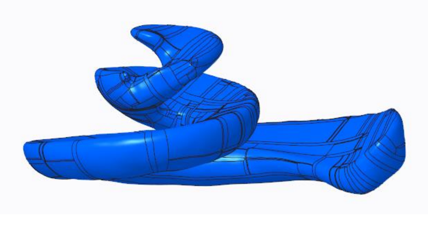
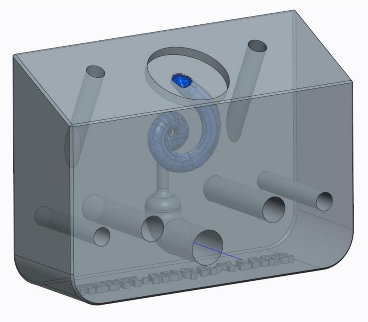
Objectives

The objective of this study was to develop a more realistic 3D printed cochlea model to integrate into our insertion force measurement testbench, and then provide a tool for the evaluation of new electrode designs. In this work, the model replicated the ST and the opening was located at the RW site.

Methods to generate a 3D printed cochlea model

Nautilus → Creo CAD software → 3D printing → Finishing

CT-scan import → Cochlea reconstruction → ST export → ST cuting off → STL export → High-precision SLA → Polishing & control

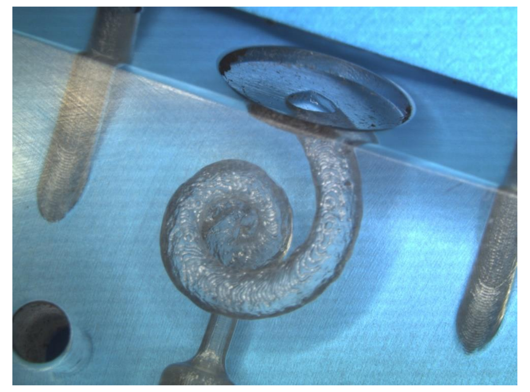





- Nautilus is Oticon Medical proprietary software [3] that is able to import Dicom format files from CT-scans and automatically generate cochleas comprising SV and ST. Nautilus provides a lot of measurements that can be used by ENT or experts in the medical imaging field.
- The ST file is checked, eventually repaired (Autodesk Meshmixer), and then transformed (Autodesk RecapObj and Fusion 360) into a volumic file that can be imported directly into the CAD software (PTC Creo Parametric) with a high accuracy. The volumic ST shape is cut off from template cochlea model and a customed cochlea model is obtained.
- The customed cochlea model is exported to STL format for 3D printing with a high accuracy (Chord height ≈1µm). Cochlea models were 3D printed (LAAS-CNRS) layer-by-layer using a 3D printer with a high-speed, high-precision stereolithography process (SLA) with a resolution down to 20µm (x,y,z). The system uses a 405 nm laser controlled by galvanometers. All reported designs were fabricated using a commercial DS3000 photosensitive polymer (DWS) according to previously reported processes [4].

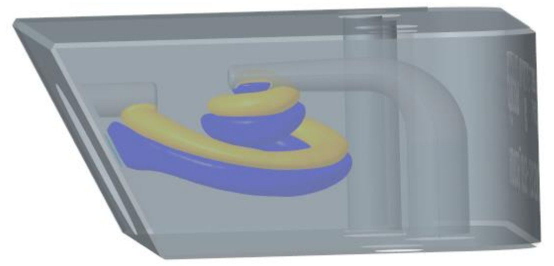
Conclusions & Perspectives

We can build and provide 3D printed cochlea models with a high accuracy from any CT-scan thanks to Nautilus software and the shown methodology.
6 cochlea models with different size and shape have been fabricated and tested.
Based on this work, we currently investigate other model functions and other applications such as :

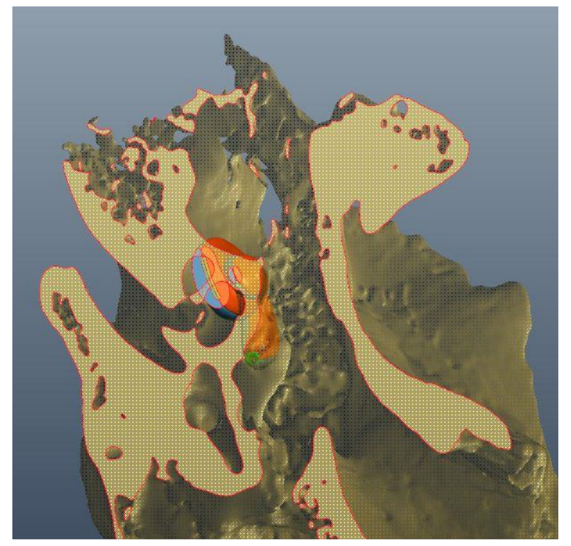
- Model validation : Cadaver <> Simulation <> 3D printed model
- Robotized insertion in 3D printed model
- 3D printed model with ST, SV and artificial Basilar Membrane (BM)
- Full temporal bone with ST and SV for surgical training and complex case



Cochlea model from cadaver temporal bone (TB8 CT scan, INSERM Paris)



Cochlea model with ST and SV



Temporal bone with highlighted ST and SV

References
[1] Yann Nguyen, Mathieu Miroir, Guillaume Kazmitcheff, Jasmine Sutter, Morad Bensidhoum, Evelyne Ferrary, Olivier Sterkers, Alexis Bozorg Grayeli; Cochlear Implant Insertion Forces in Microdissected Human Cochlea to Evaluate a Prototype Array. Audiol Neurotol 2012;17:290–298
[2] Torres R, Jia H, Drouillard M, Bensimon JL, Sterkers O, Ferrary E, Nguyen Y. An Optimized Robot-Based Technique for Cochlear Implantation to Reduce Array Insertion Trauma. Otolaryngol Head Neck Surg. 2018 Aug 7:194599818792232. doi: 10.1177/0194599818792232
[3] Jan Margeta et al. 2022. A Web-Based Automated Image Processing Research Platform for Cochlear Implantation-Related Studies
[4] Mézière, F.; Juskova, P.; Woittequand, J.; Muller, M.; Bossy, E.; Boistel, R.; Malaquin, L.; Derode, A. Experimental Observation of Ultrasound Fast and Slow Waves through Three-Dimensional Printed Trabecular Bone Phantoms. J. Acoust. Soc. Am. 2016, 139, EL13-EL18

Dimensional control

Microscopy

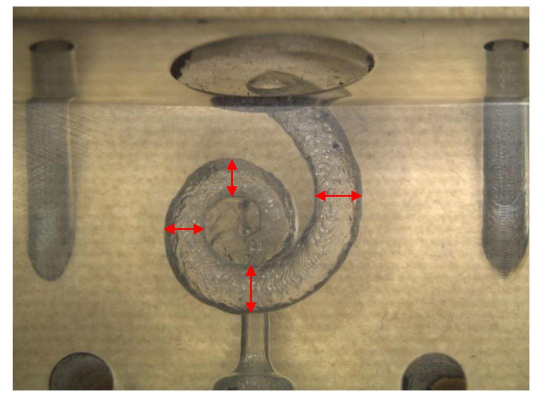
Each sample are controlled under measuring microscope. For "w" and "d" measurements, the SD was <50µm.

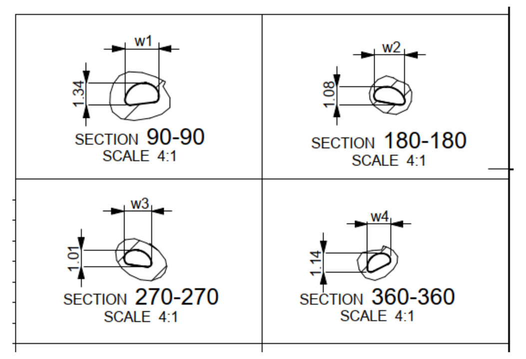
- ST cross section "w"

The width of the ST inner canal is measured every 90°, corresponding to the dimensions noted "w" in the drawings.

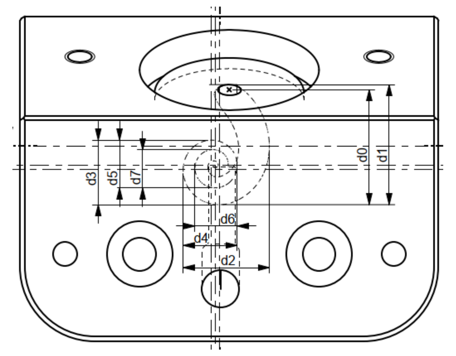
- Wrapping "d"

Then the overall shape of each model were measured, corresponding to the dimension "d" in the drawings.





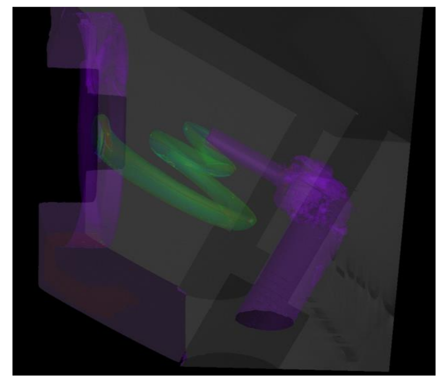
ST cross section



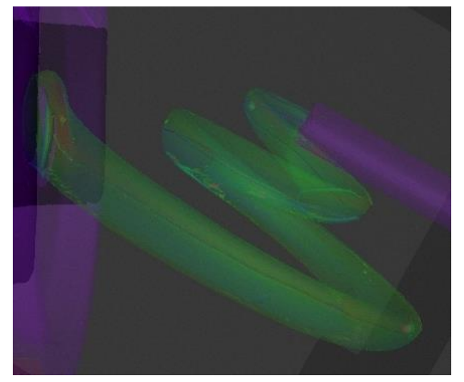
Wrapping dimensions

3D micro-tomography control

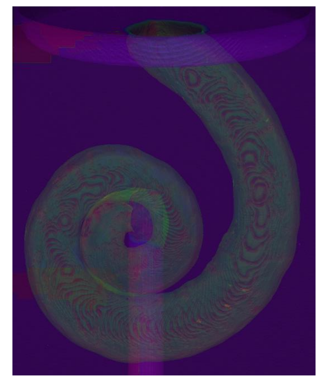
To confirm the dimensional control by microscope, we decided to use the 3D micro-tomography in order to control the overall 3D shape.
Some samples were shipped for being control by 3D micro-tomography (RX-Solutions, Chavanod, France). The supplier provided the results of scan and the freeware to analyse in detail the results. The freeware allowed to visualize the data in volume (3D) and in projection plans (2D). The deviation from the 3D theoretical model is given with a coloured scale. The cross-section plan was swiped along the model, and we stopped on several cross sections following an X-axis and a Y-axis: at the RW + every 90° as indicated into the drawing. A yellow circle has been added to the images and represents a D0.4mm.



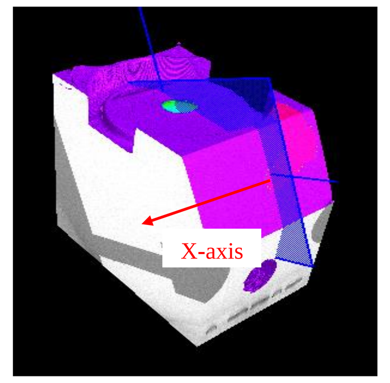
General view of 3D printed model



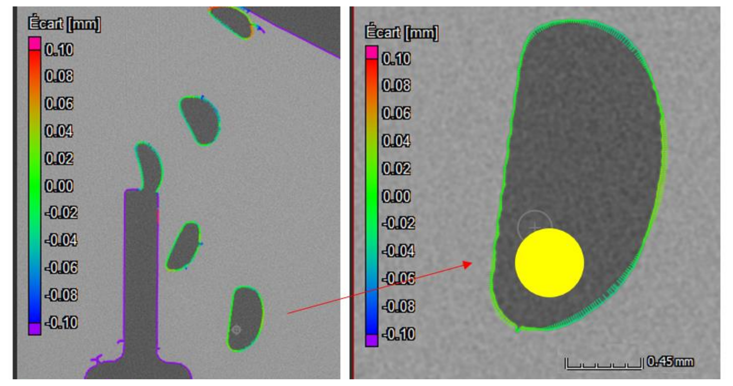
Lateral view of ST



Front view of ST



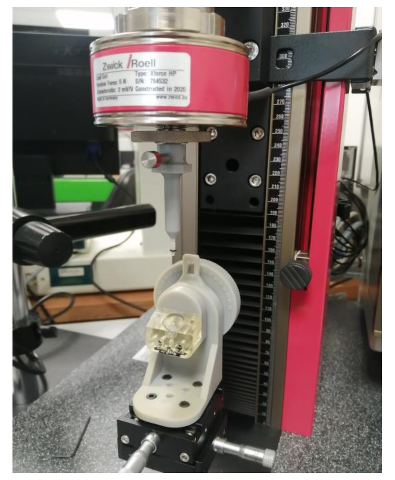
X-axis cross section



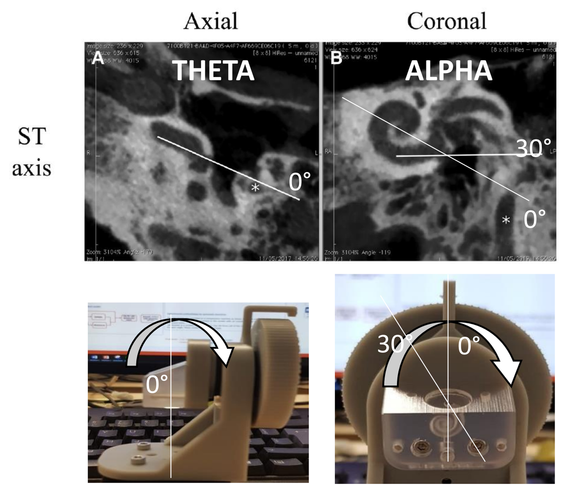
Colored scale of gap between reference model and sample
Yellow circle represent D0.4mm

Insertion Force Measurement Testbench

Any 3D printed model can be mounted on the insertion force measurement test bench. Several parameters can be set and controlled : Speed, Depth, Angles, Lubricant and optionally an artificial RW.
Outcomes can be compared and challenged : Insertion force, insertion depth, buckling force, success rate of insertion.
In these examples: EVO electrode, 0.5mm/sec, 30° alpha angle, in glycerine, 100µm RW.
S, M and L cochlea models correspond respectively to A (in mm) = 8.25 (-2σ) ; 9.25 (Aver.) and 10.25 (+2σ).

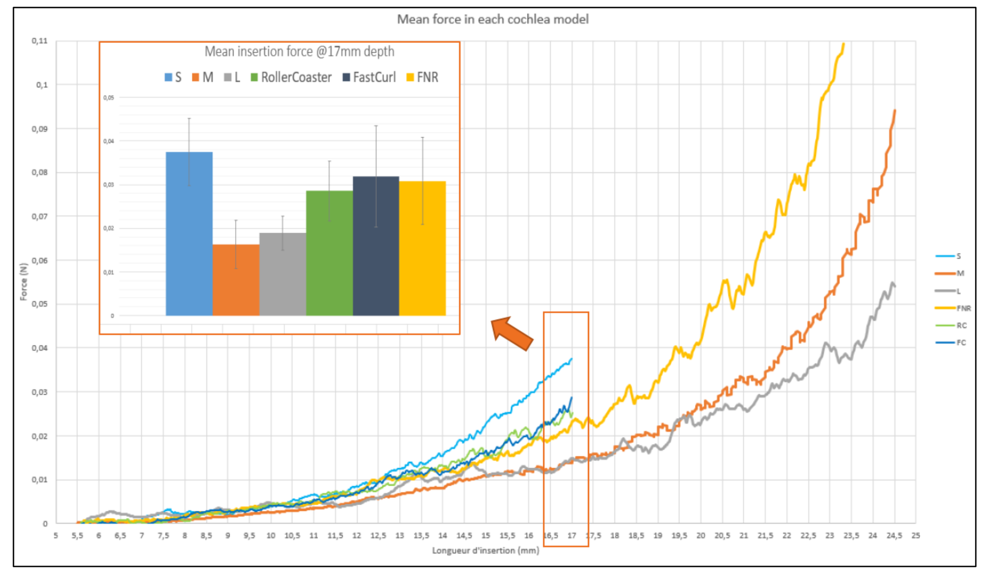


Insertion testbench on new Zwick Roell equipment

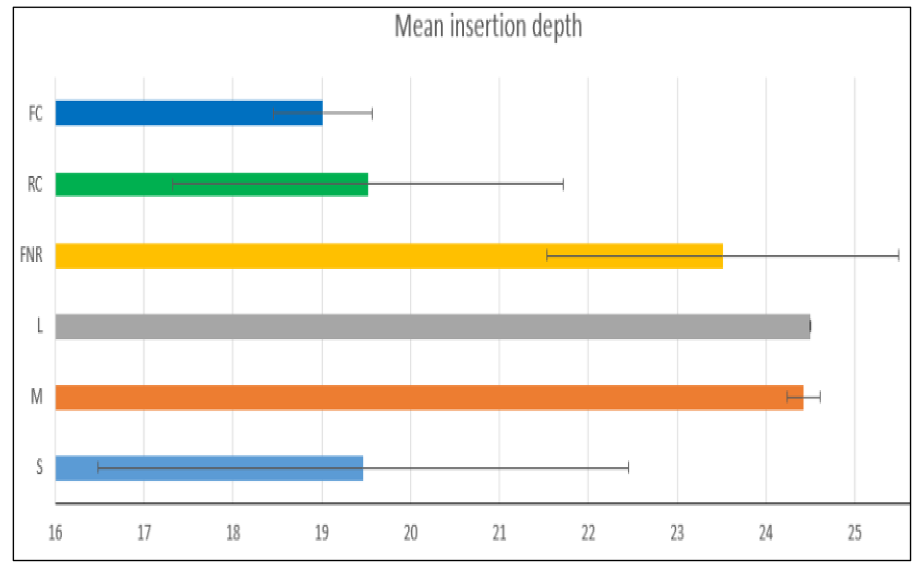


Theta angle control

Alpha angle control



Force = f (insertion depth) for different cochlea model



Insertion depth = f (type of cochlea)

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