On the Development of Realistic Artificial Cochlea Models

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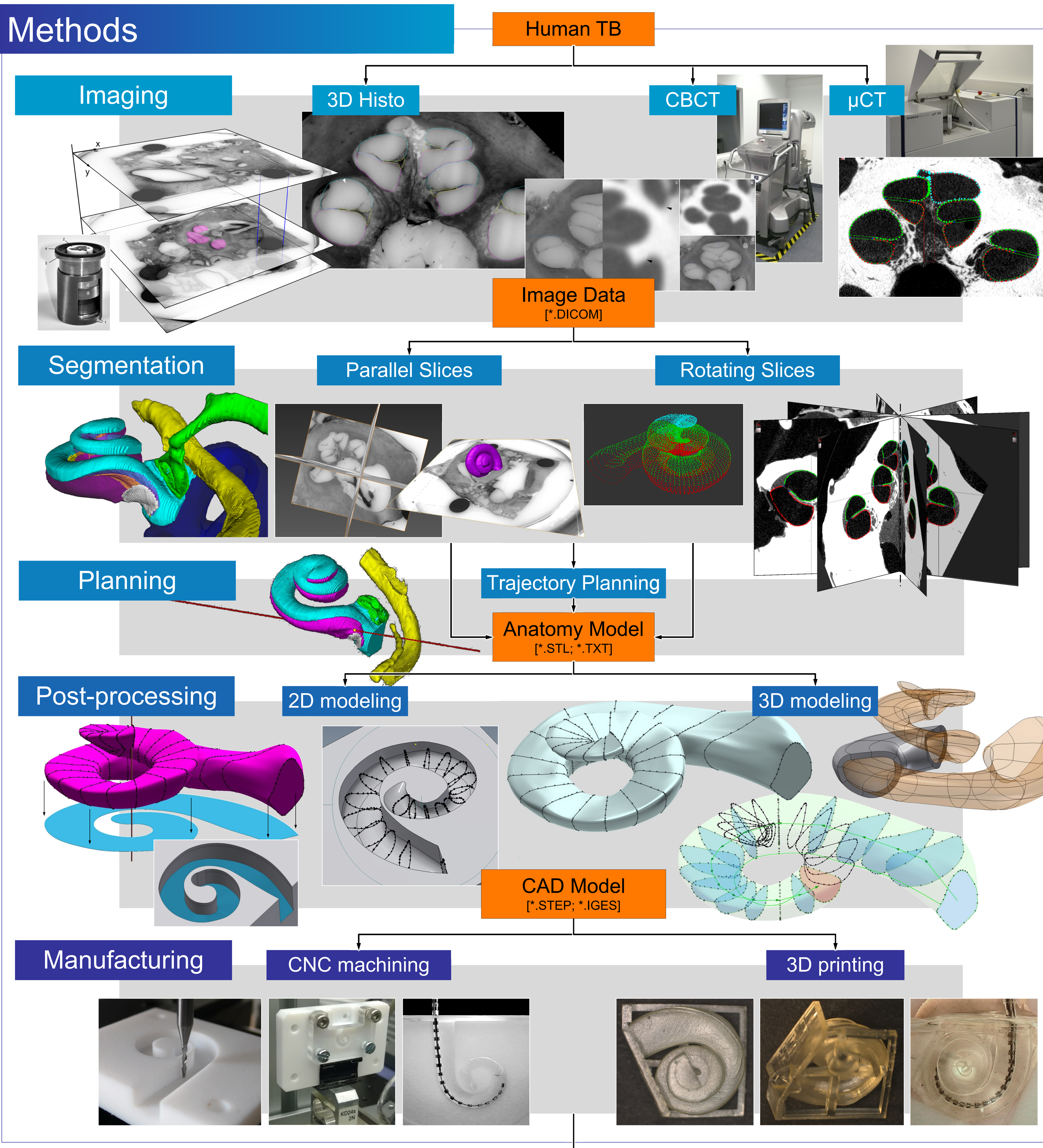
Motivation

Development of new electrode arrays of cochlear implants (CI) requires thorough evaluation of different design concepts. Of particular interest is measurement of insertion force, which is believed to be predictive of insertion trauma and ability to preserve residual hearing. Human temporal bone (TB) specimens remain the ‘gold standard’ for evaluation of CI electrode arrays, however they suffer from several drawbacks: limited availability, anatomical variability and limited or single use. Therefore, the use of artificial cochlea models (ACM) is well-established and widespread. However, reliability of decisions made within the development process directly depends on the reliability of the results obtained with these ACMs. Therefore, there is a high demand for realistic replications of the human inner ear in terms of geometry and frictional properties. In order to reduce the gap between fresh TB specimens (which are considered as best match of a living cochlea) and ACM fabricated out of engineering materials, different methods of imaging, segmentation, computer-aided modeling, and manufacturing are being developed or applied.

Methods



Quality of the ACMs strongly depends on the imaging and segmentation methods. In our lab best results have been achieved using an in-house developed experimental 3D histological imaging method [1, 4, 5] as well as micro computed tomography (µCT) [7]. Clinical cone beam computed tomography (CBCT) was used when need of patient data or fast specimen processing out-weighed requirements for spatial resolution and soft tissue differentiation.

Segmentation in parallel slices was performed to generate models of the whole lateral skull base including the posterior tympanotomy. Within these anatomical models trajectories were planned describing the surgically chosen access directions.

In contrast, for highly accurate segmentation of the spiral shaped inner ear a special visualization and segmentation software was developed [2], featuring a rotating slice plane around the modiolus. This dedicated software provides a sequence of mid-modiolar views with adjustable angular step along the angular length of the inner ear. In these rotating sectional views the intracochlear structures, such as the shape of scala tympani (ST), can be segmented.

Post-processing of these data was performed using computer-aided design (CAD) software including: projection of the ST’s inner and outer wall into a plane for derivation of 2D models [3], and modeling the spatial shape of the ST as a loft of subsequent profiles for 3D models. In addition, the mentioned trajectory can be incorporated into the anatomical model as surgical insertion axis as a realistic reference for future studies on the impact of entry angles.

For manufacturing of the ACMs several 3D printing technologies as well as conventional CNC (computer numerical control) machining have been tested.

Physical Model

Results and Discussions

Multiple methods and tools have been developed and applied successfully in the past in order to get the properties of artificial cochlea models closer to reality. Our models accurately replicate the geometry of human scala tympani. Preliminary results with ACMs milled out of a polytetrafluoroethylene (PTFE) plate are promising in terms of realistic friction conditions when compared to fresh temporal bone specimens [6].

Although continuing progress in 3D printing could be observed over the last years, unsuitability of available materials and the unavoidable stepped nature of the surfaces still limit replication of vital friction conditions. However, synthetic replication of soft tissue, intracochlear compliance, and rupturable structures for more realistic ACMs is still a completely unsolved issue. It may be overcome by advanced multi-material 3D printing in the future.

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