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A Prototype Setup for 4D Micro-Computed Tomography Imaging of the Intracochlear Movement of Cochlear Implant Electrode Carriers

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Motivation

Automated insertion studies are used for characterization of newly developed electrode carriers (EC) or the investigation of the insertion process. Typically artificial cochlea models (ACM) are used, enabling visualization of the EC behavior during insertion. However, ACM are a strong simplification of the cochlea anatomy. They have only one scala, no intra-cochlear membrane and insufficient frictional and mechanical material properties. In contrast, cochlea specimens are the gold standard in EC evaluation but go along with a hidden insertion process due to encapsulating bone.

High resolution micro-computed tomography (µCT) seems to be a suitable imaging modality to provide detailed visualization of the intracochlear movement while using cochlear specimens. The aim was to develop a set up combining automated, stepwise insertion of an EC into a cochlea specimen while imaging the process, to be able to correlate trauma regions in the cochlea to insertion steps.

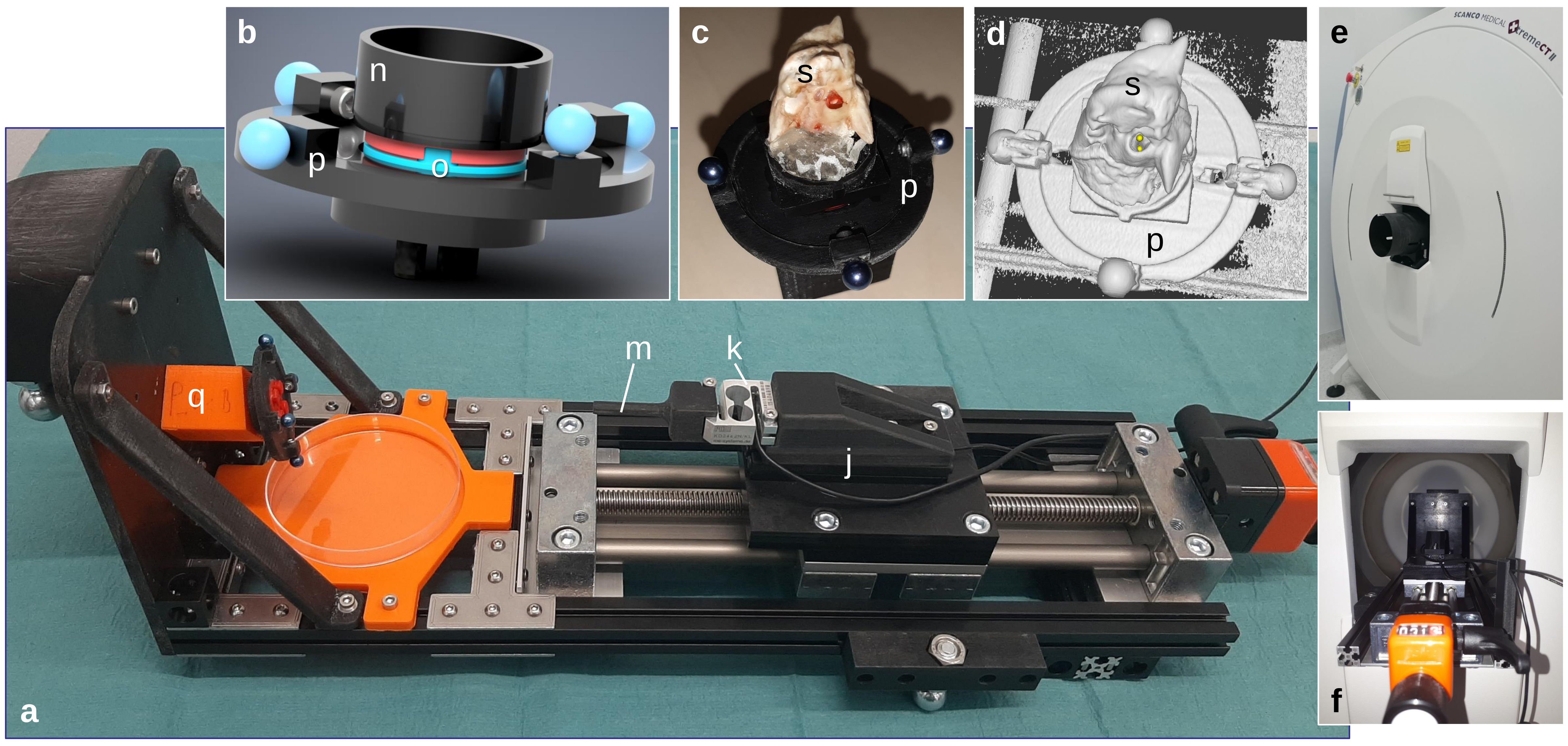
Results

A horizontally oriented automated insertion test bench was designed (Fig. a) which fits into the opening of the in-vivo µCT system (e,f; XtremeCT II, Scanco Medical, Switzerland). Additionally, a method for correct orientation and fixation of the cochlea specimen with respect to the insertion axis was implemented (b-d).

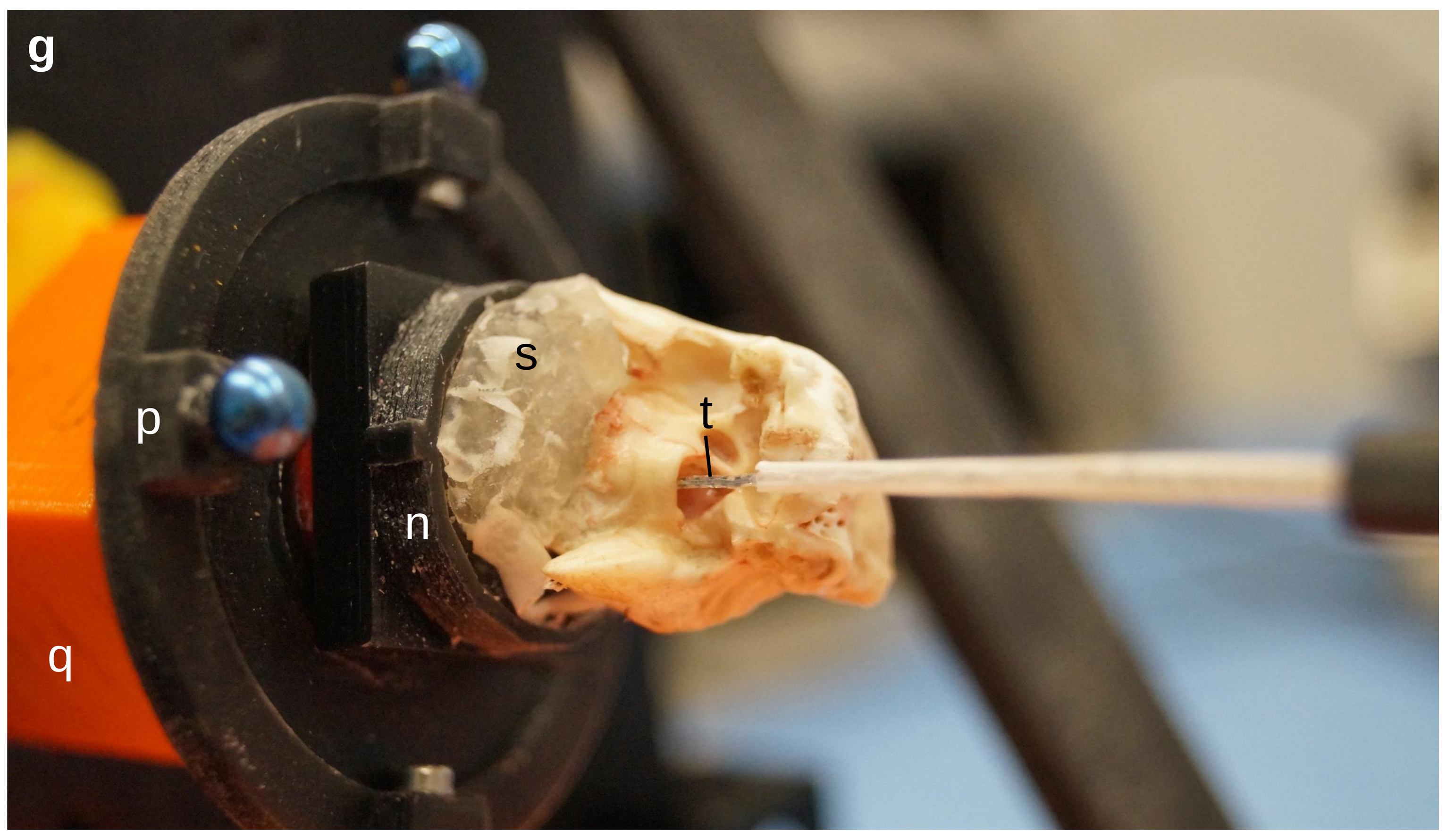
The workflow from CBCT imaging, trajectory planning, fabrication of the individual adapter, stepwise EC insertion with alternating µCT imaging was successfully tested using a porcine cochlea and a commercial EC (g). As the electrode contacts are visible within the µCT images (h), the stepwise insertion can be analyzed using this data in order to enlarge the understanding of the intracochlear EC behavior and to identify trauma mechanisms.

Methods

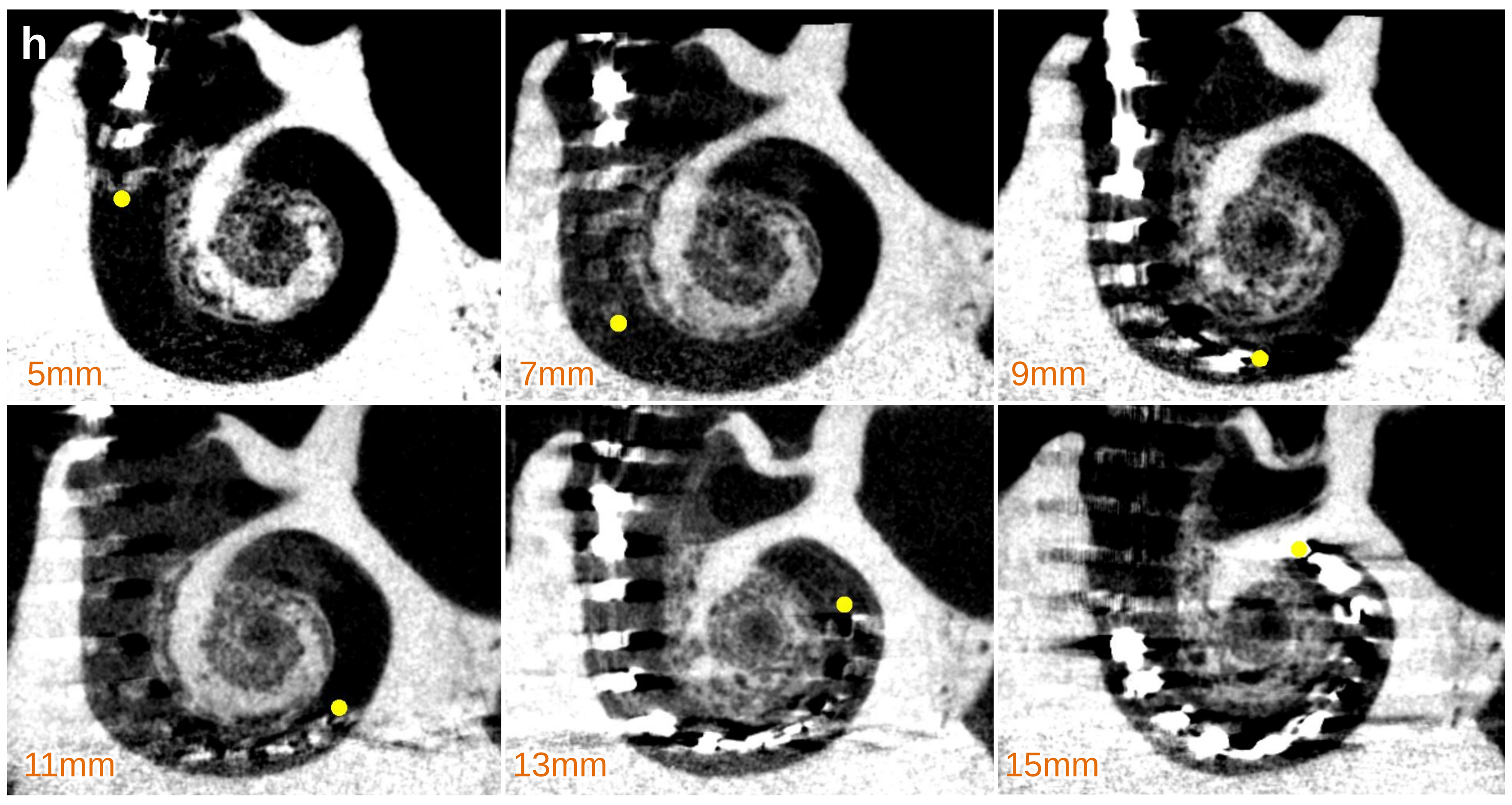
A modular test bench for automated electrode insertion was designed and a first prototype was built (a). One module serves for automated feed motion of the EC using a stick-slip linear piezo stage (j, SLC-2475-S, SmarAct GmbH, Germany). A force sensor (k, KD24S, ME-Meßsysteme GmbH, Germany) is installed between the EC holder (m) and the actuator (j). It can be used to explore insertion forces in the future.



A second module enables image-guided alignment of the specimen to the insertion axis (b-d). Therefore, the specimen is glued into a small plastic dish (n). LEGO bricks (o) are used to enable a tight but detachable connection to a reference frame (p) with four titanium spheres serving for registration purpose. Based on pre-experimentally planning of the insertion axis an individual positioning adapter (q) is modelled and finally 3D-printed (fused deposition modeling, FDM).



A porcine cochlea specimen (s) was used to provide a proof of concept. After cone beam computer tomography imaging of the specimen (d), trajectory planning and positioning of the specimen using the individual adapter a commercial slim straight EC (t, Cochlear Ltd., Sydney, Australia) was inserted into the cochlea of the specimen.



A previously tested alginate coating of the EC was used to support smooth insertion behavior as the generally used saline solution was expected to float away. As a proof of concept a total insertion of 15 mm was conducted in steps of 2 mm, each followed by µCT imaging (h).

Conclusion

The developed insertion setup is feasible for application within a µCT. This successful proof of concept enables future studies to analyze the insertion process into human cochlea specimens by combining automated insertion and high-resolution µCT imaging.

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