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

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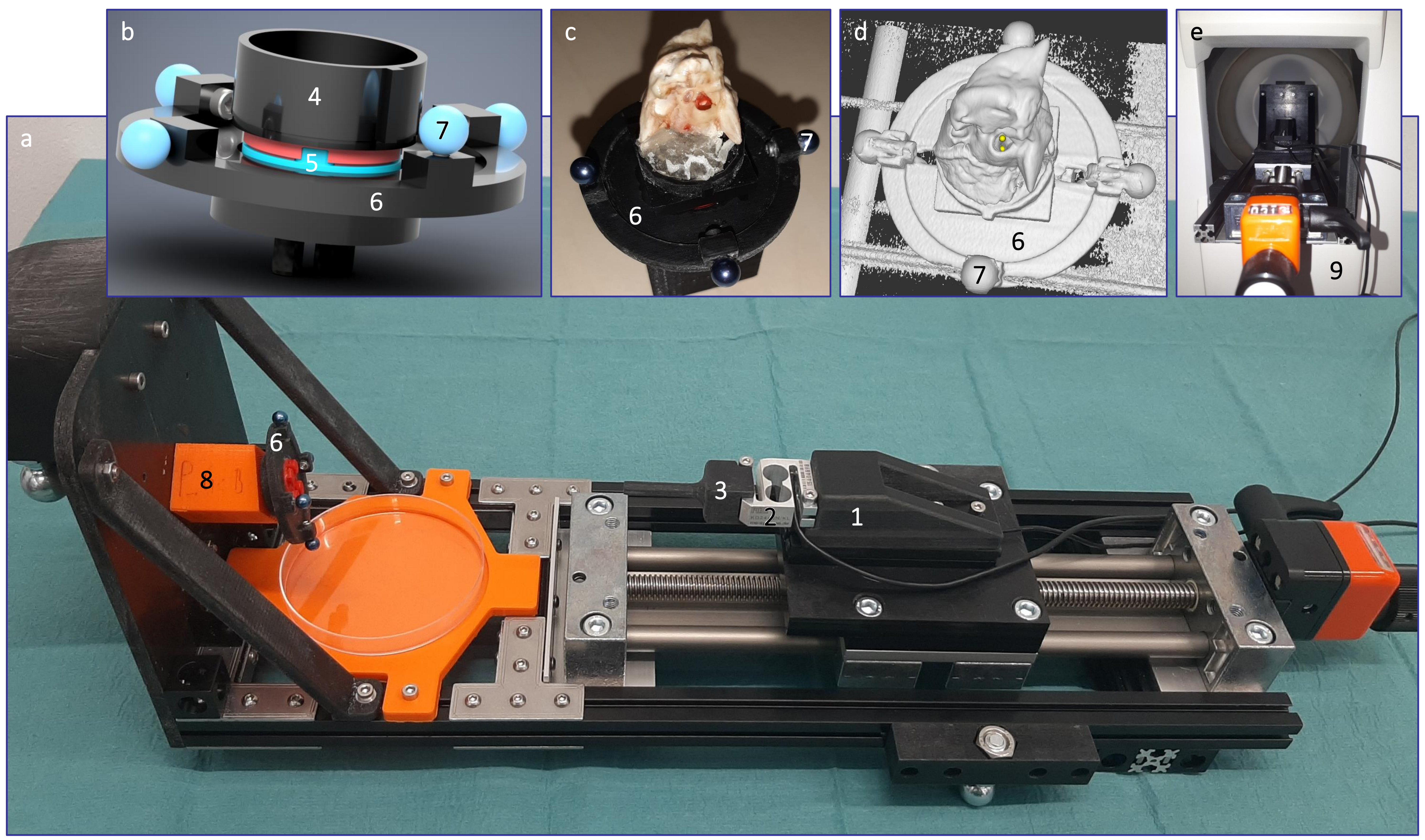
Introduction

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 behaviour during insertion. However, ACM are a simplification of the cochlear anatomy. They have only one scala, mostly as two-dimensional spiral, no intra-cochlear membranes and insufficient frictional and mechanical material properties. In contrast, cochlear 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.

Methods

An open µCT system was used and a horizontally oriented automated insertion test bench, which fits into the opening of the µCT system, was designed (Fig. 1). Additionally, a method for correct orientation and fixation of the cochlear specimen with respect to the insertion axis was implemented. A tightly connected specimen holder with four titanium spheres served for registration purpose. After imaging and trajectory planning an individual positioning adapter was modelled and finally 3D-printed. After cone beam computer tomography (CBCT) imaging of the specimen, trajectory planning and positioning of the specimen using the individual adapter a commercial slim straight EC was inserted into the cochlea (Fig. 2). A previously tested alginate coating of the EC was used to support smooth insertion behaviour, as the generally used saline solution was expected to float away due to the horizontal orientation of the setup. A total insertion of 15 mm was conducted in steps of 2 mm, each followed by µCT imaging (Fig. 3).



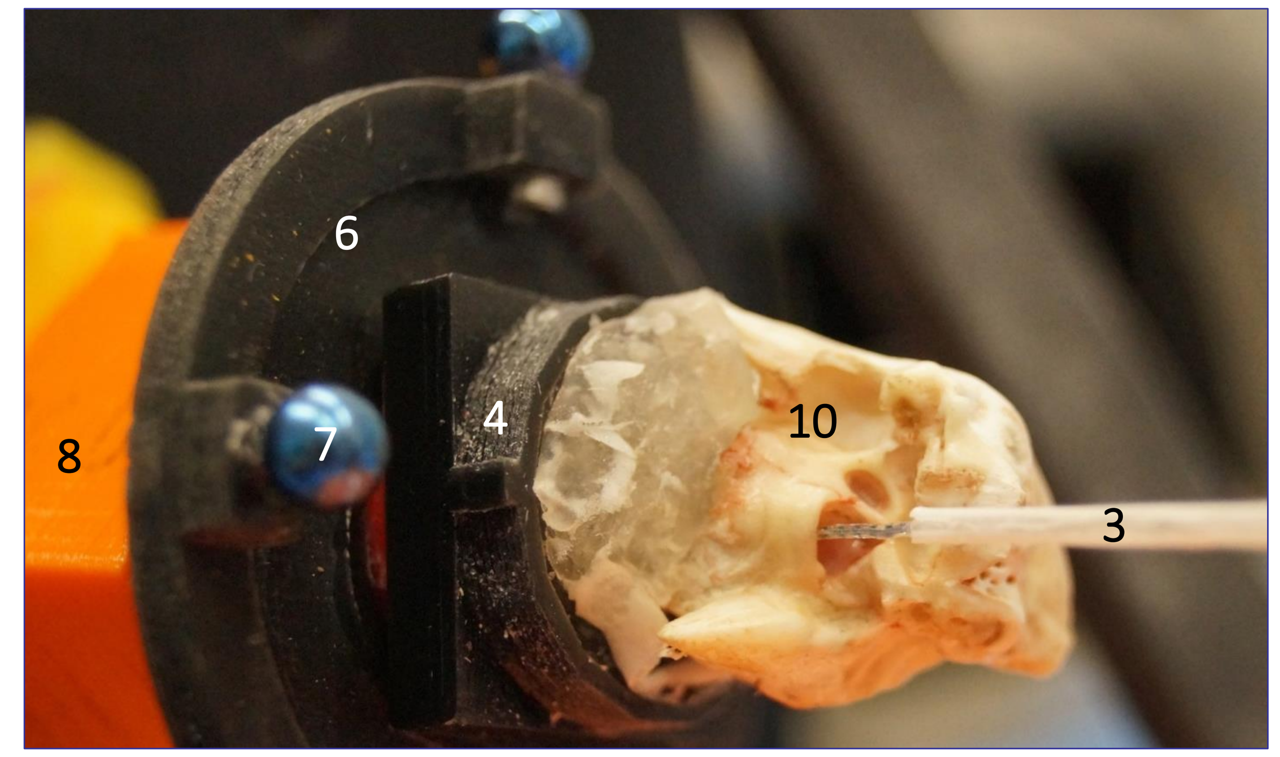


Fig. 2: *A porcine cochlear specimen was used to provide a proof of concept. After CBCT imaging of the specimen (10), trajectory planning and positioning of the specimen using the individual adapter (8) a commercial slim straight EC (Cochlear Ltd., Sydney, Australia) was inserted into the cochlea of the specimen.*

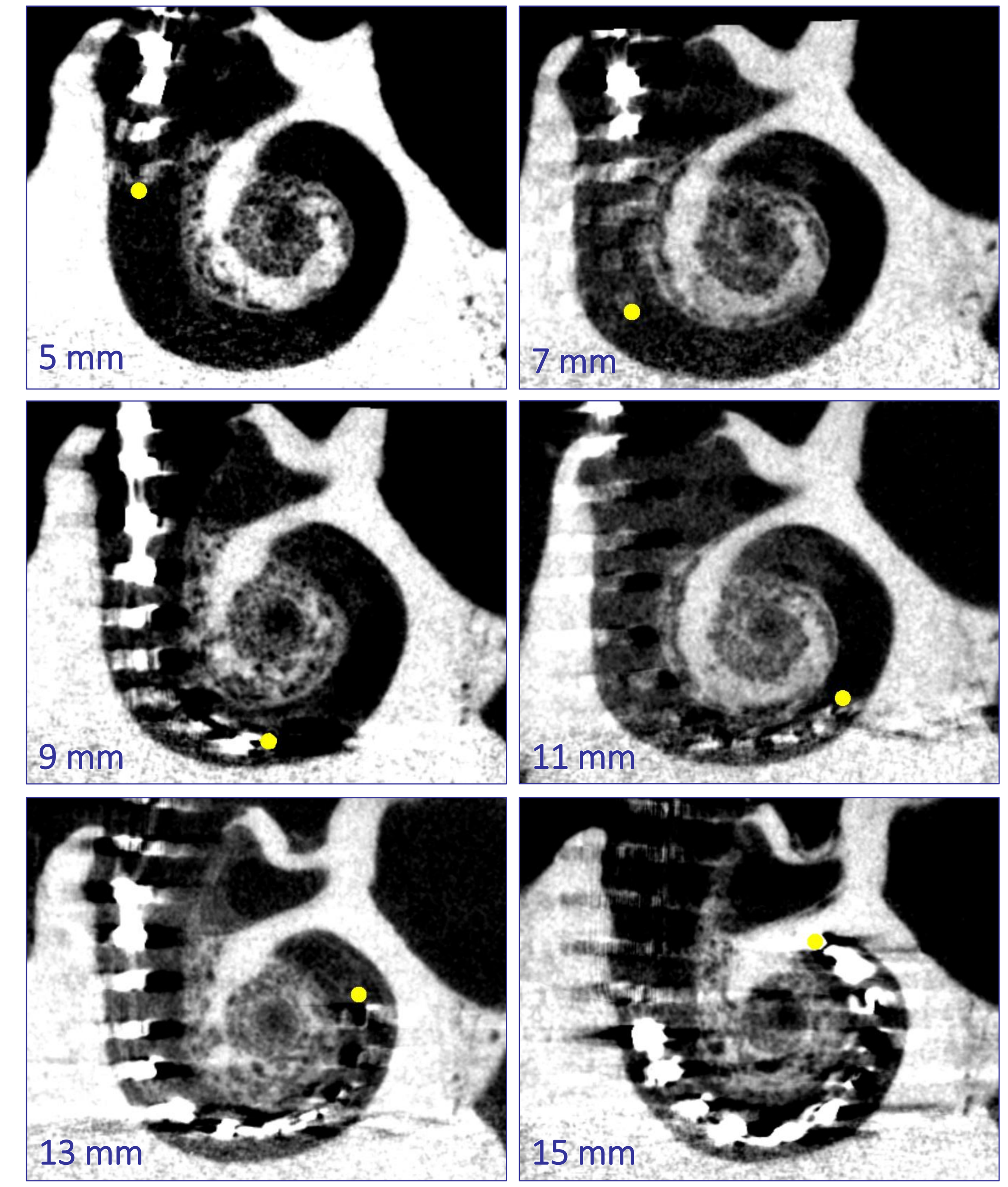


Fig. 3: *µCT imaging of the insertion process in steps of 2mm. The tip of the EC is indicated by the yellow marker.*

Results

The workflow from CBCT imaging, trajectory planning, 3D-printing of the individual adapter, stepwise EC insertion with alternating µCT imaging was successfully tested using a porcine cochlea and a commercial EC (Fig. 2). As the electrode contacts are visible within the µCT imaging (Fig. 3), the stepwise insertion can be analyzed using this set-up in order to enlarge the understanding of the intra-cochlear EC behaviour and to identify trauma mechanisms.

Fig 1: *Modular test bench for automated electrode insertion.* ***(a)*** *One module serves for automated feed motion of the EC using a stick-slip linear piezo stage (1, SLC-2475-S, SmarAct GmbH, Germany). A force sensor (2, KD24S, ME-Meßsysteme GmbH, Germany) is installed between the EC holder (3) and the actuator. It will be used to explore insertion forces in the future.* ***(b-d)*** *A second module enables image-guided alignment of the specimen to the insertion axis. Therefore, the specimen is glued into a small plastic dish (4). LEGO™ bricks (5) are used to enable a tight but detachable connection to a reference frame (6) with four titanium spheres (7) serving for registration purpose. Based on pre-experimentally planning of the insertion axis an individual positioning adapter (8) is modelled and finally 3D-printed .* ***(e)*** *The test bench was designed to fit into the opening of an in-vivo µCT system (9, XtremeCT II, Scanco Medical, Switzerland).*

Conclusion

The developed insertion setup is feasible for application within a µCT. This successful proof of concept enables future studies to further analyze the insertion process in human cochlear specimen by combination of automated insertion and live µCT imaging.

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