Designing shape memory alloy actuators tailored to the human cochlea geometry

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Motivation

Nitinol is a shape memory alloy (SMA) widely used in medical devices and implants due to its biocompatibility and superelastic properties. The shape memory effect (SME) of this alloy can also be an advantage for cochlear implants (CIs) in implementing a specific curved geometry. Thus, thin wires made of Nitinol can be fabricated and serve as an actuator inside the electrode carrier (EC) of a CI. At low temperatures, the SMA displays a plastic state with reduced stiffness. This state can be used to straighten the EC for an insertion through the round window similar to that of a straight lateral wall EC. At high temperatures, the SMA returns to the trained shape which was imprinted during the fabrication process. By specifying a curved geometry, it is thus possible to achieve a perimodiolar final position after insertion through temperature controlled actuation.

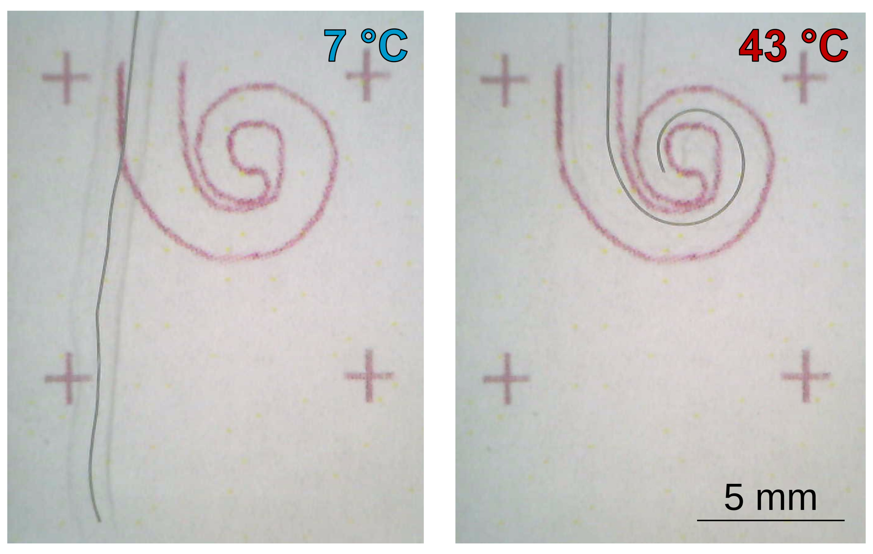

Fig. 1: Nitinol wire showing the shape memory effect.

Material and Methods

According to literature, the largest diameter (A-value) of an average-sized cochleae is 9.95 ± 0.59 mm and the largest perpendicular distance (B-value) 6.54 ± 0.40 mm [1]. For this study, an average-sized cochlea was chosen from a large number of human temporal bone samples within the workgroup based on the evaluation of the A- and B-values. The A- and B-value of the selected cochlea is 9.3 mm and 6.7 mm respectively. The geometry of this cochlea was derived from the corresponding images acquired by means of serial cross-sectioning (microgrinding) technique [2]. The cochlea was then segmented through mid-modiolar slice planes (Fig. 2) by rotating around the spiral axis in steps of 22.5° [3]. The acquired data were then transferred to computer-aided software (CAD) for designing the SMA actuator geometry. The spiral shape of the wires was designed according to the average-sized cochlea with a straight segment on the basal part followed by six circular arcs with decreasing radius covering an insertion depth of 16 mm. Nitinol wires with a diameter of 100 µm were used to fabricate the SMA actuators with the specified geometry as being the trained shape.

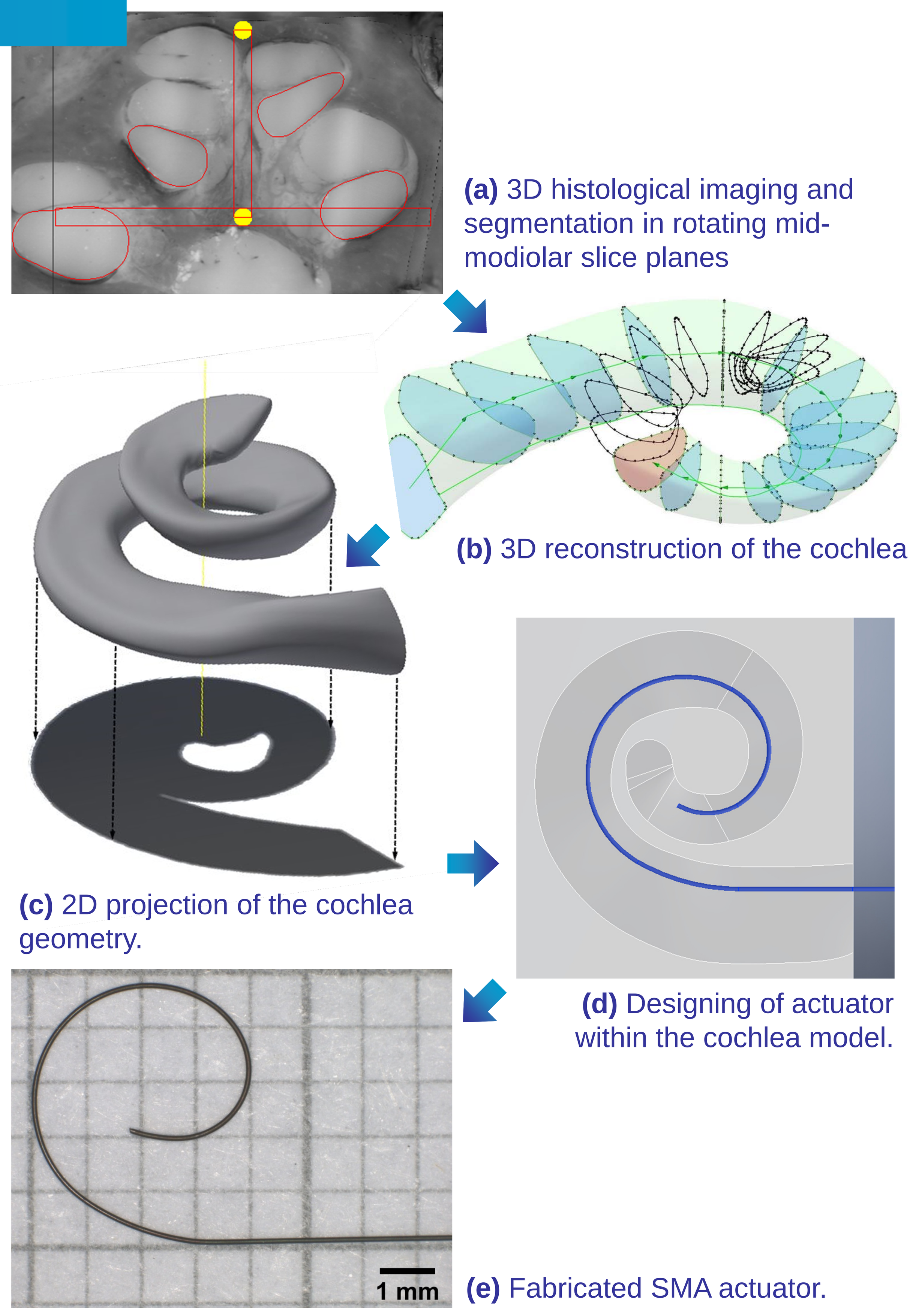

Fig. 2: Workflow of design process of shape memory actuators tailored to the shape of a human cochlea specimen.

Results

Geometry deviations of the fabricated SMA actuators (n=10) compared to the designed geometry (Fig. 3) were evaluated along the length of the SMA. Based on the evaluation made, the fabricated geometry lies within a tolerable range.

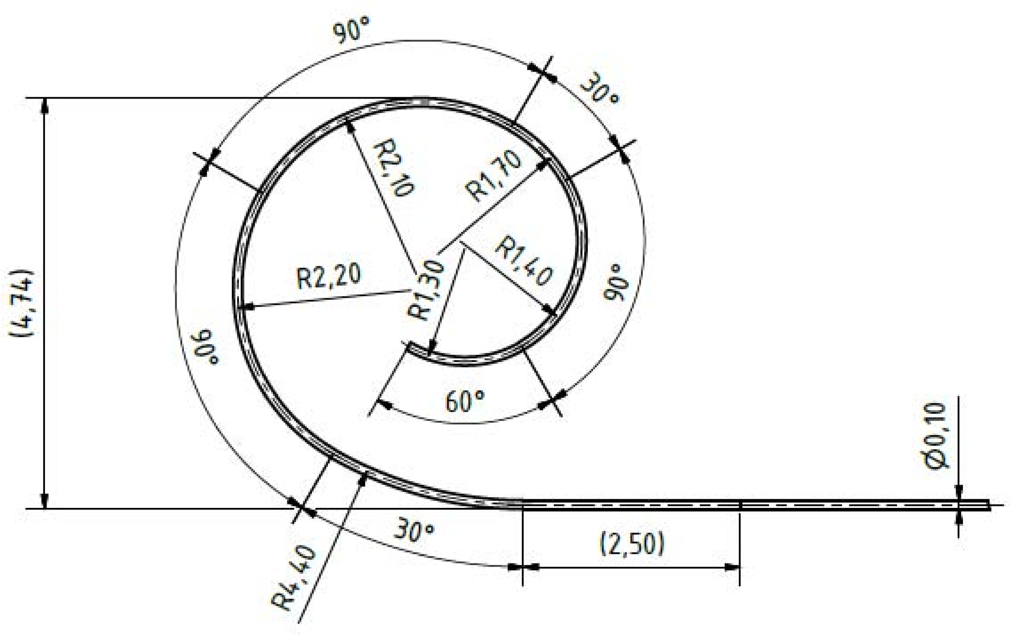

Fig. 3: Designed geometry of the SMA actuator.

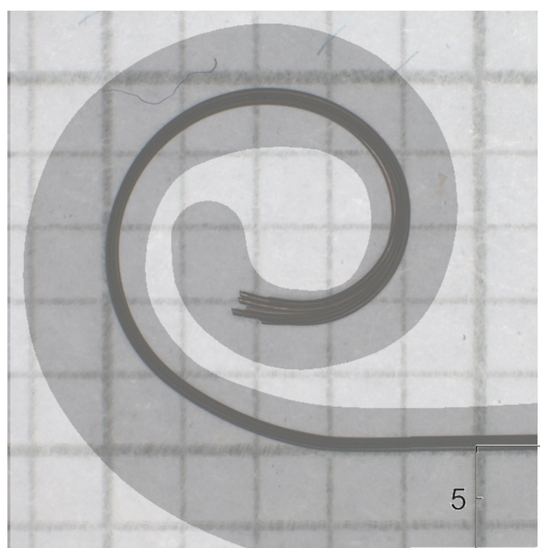

Fig. 4: Overlay images of 10 SMA actuators with a sketch of the cochlea model.

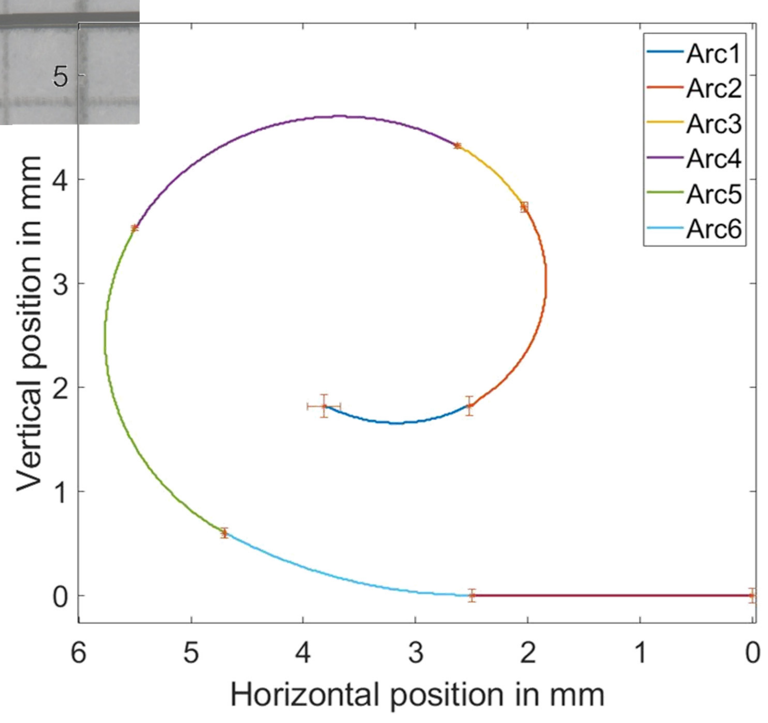

Fig. 5: Evaluation of the six circular arcs with the first arc starting from the apex.

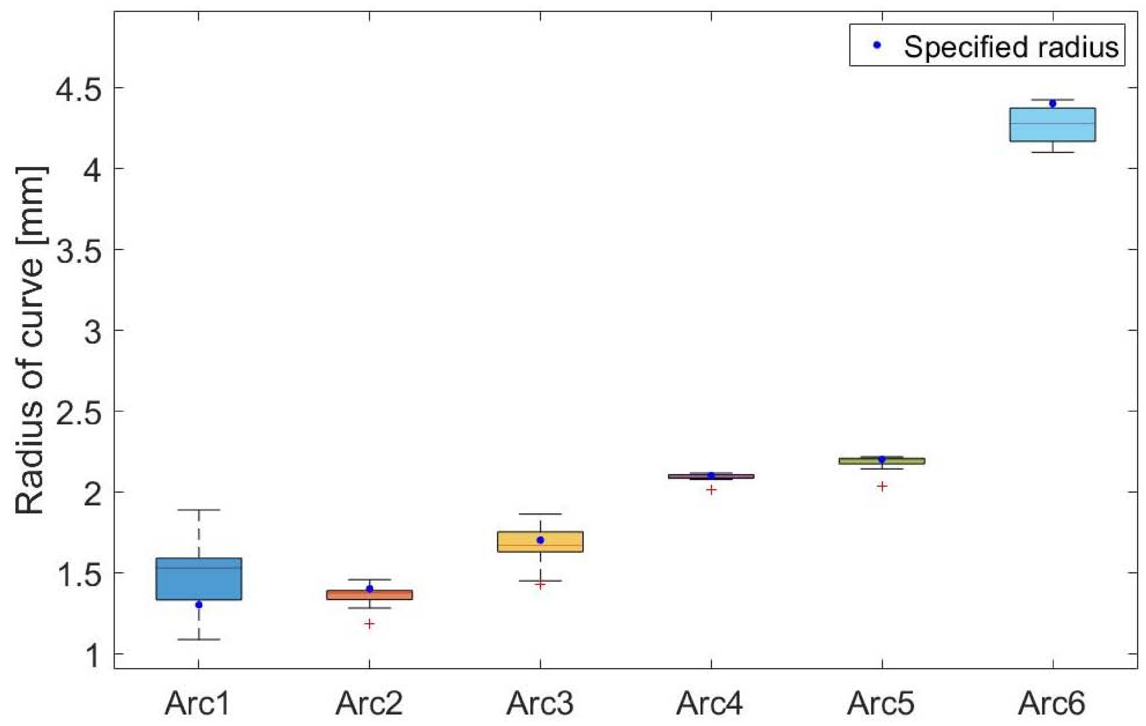

Fig. 6: Radius of the six circular arcs measured from the fabricated SMA actuators. The blue dots show the specified radius for each circular arc according to the design geometry.

Conclusion & Outlook

To conclude, it is possible to design and fabricate SMA actuators that fit a specific cochlea geometry. The design of the curved geometry for the SMA actuator depends on good image segmentation of the cochlea from the image data provided. Further parameters besides the thermomechanical properties of the SMA need to be taken into consideration for future EC featuring a shape memory effect. One important parameter which requires further investigation is the influence of the EC stiffness on the thermomechanical properties of the fabricated SMA actuators. To determine the thermomechanical properties of these SMA actuators, a measurement setup has been developed (Fig. 7).

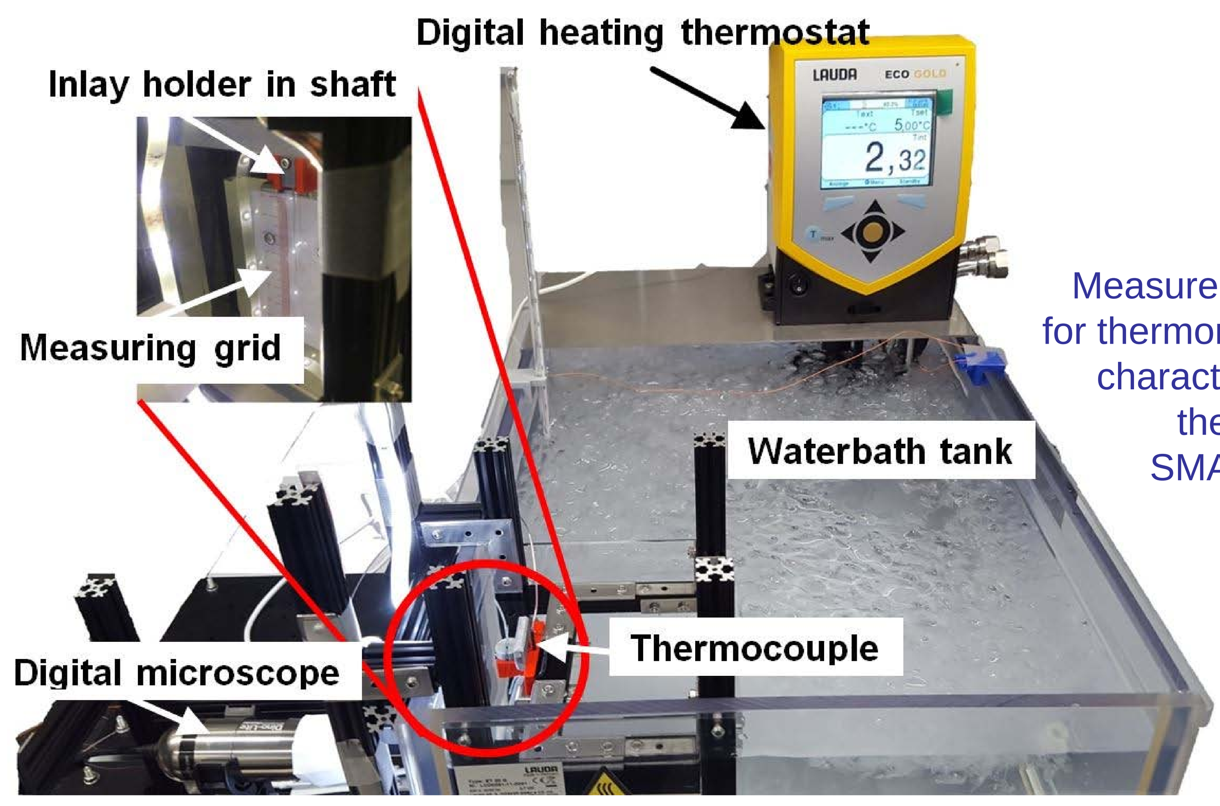

Fig. 7: Measurement setup for thermomechanical characterization of the fabricated SMA actuators.

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References

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