Toward understanding the impact of cochlear model curvature, insertion speed, and implant stiffness for the prediction of insertion forces

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Motivation

To evaluate different designs or insertion techniques of cochlear implant electrode carriers (ECs) insertion forces are measured by a force sensor, which is mounted directly underneath an artificial cochlea model (aCM) leading to a summed force profile (Fig. 1). One of the next steps in CI research leads from post-experimental evaluation of measured insertion force profiles to pre-experimental predictions of these profiles using analytical models based on an improved knowledge about factors impacting the insertion forces.

The current hypothesis is that the insertion forces include dynamic friction forces during the insertion process and the forces needed to bend an initially straight EC into the curved form of the model. Three likely factors were chosen for further investigation: speed, EC stiffness, and curvature of the aCM.

Material and Methods

Three aCM were fabricated out of Polytetrafluoroethylene (PTFE) blocks, each model having one constant curvature (r = 6.4 / 8.5 / 12.7 mm). Additionally EC substitutes (Fig 2) were fabricated using a two-component silicone, all with a constant diameter (0.7 mm), a total length of 20.5 mm, and embedded bare copper wires. In order to vary the stiffness of the EC substitutes, one type had four and the other six wires embedded. They were inserted into the aCM (Fig 3) with three different insertion speeds (v = 0.11 / 0.4 / 1.6 mm/s). In order to increase reproducibility, insertions were conducted using an automated insertion test bench, comprising a linear actuator to clamp the EC substitutes and move them into the aCM and the force sensor underneath the model.

For each parameter combination (curvature of the insertion model, insertion speed, stiffness of the straight EC substitute) twelve insertions were conducted. Measurements included six full insertions and six paused insertions. Paused insertions include a ten second paused time interval without further insertion movement each five millimetres of insertion depth.

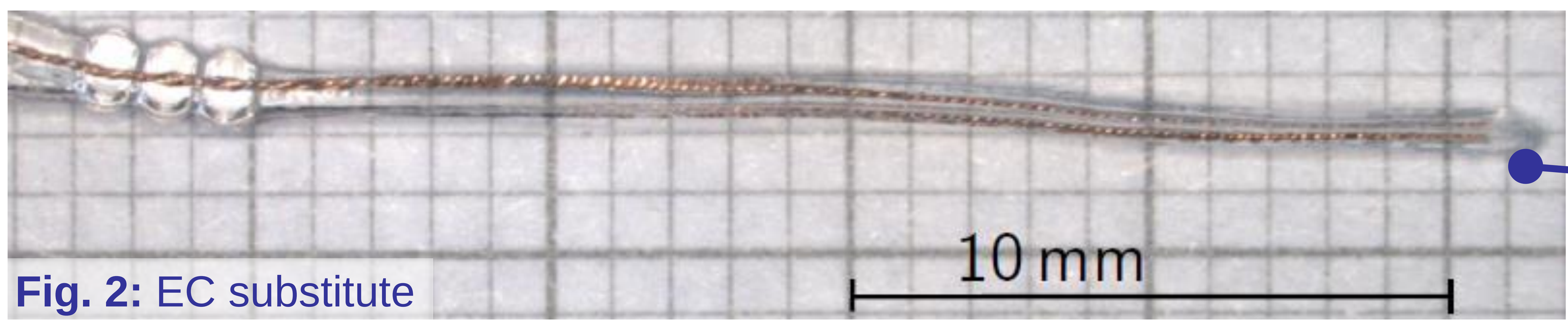


Fig. 2: EC substitute

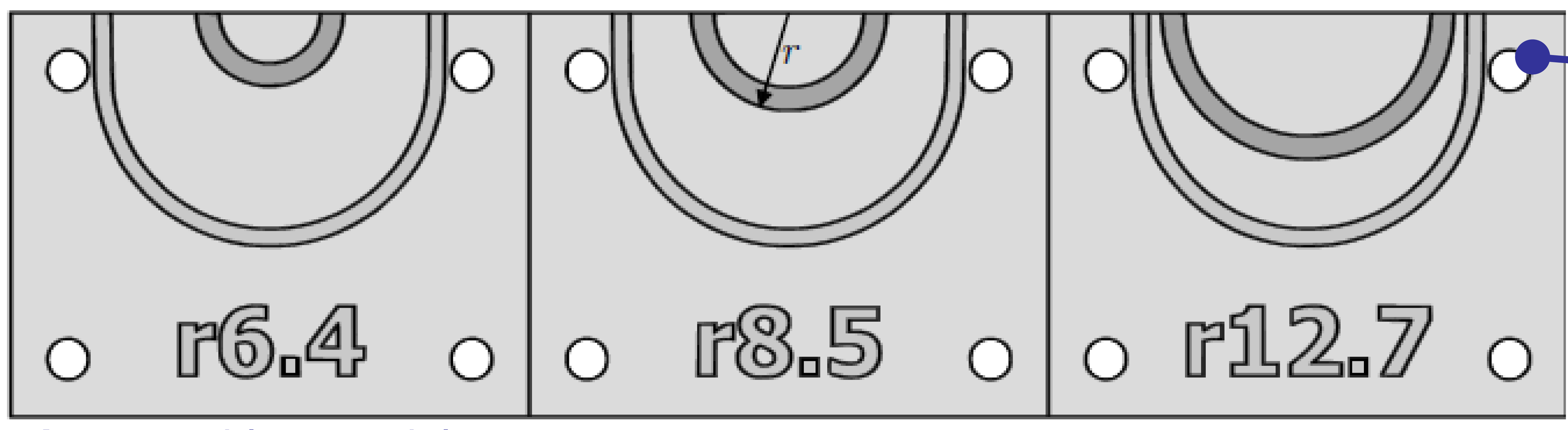
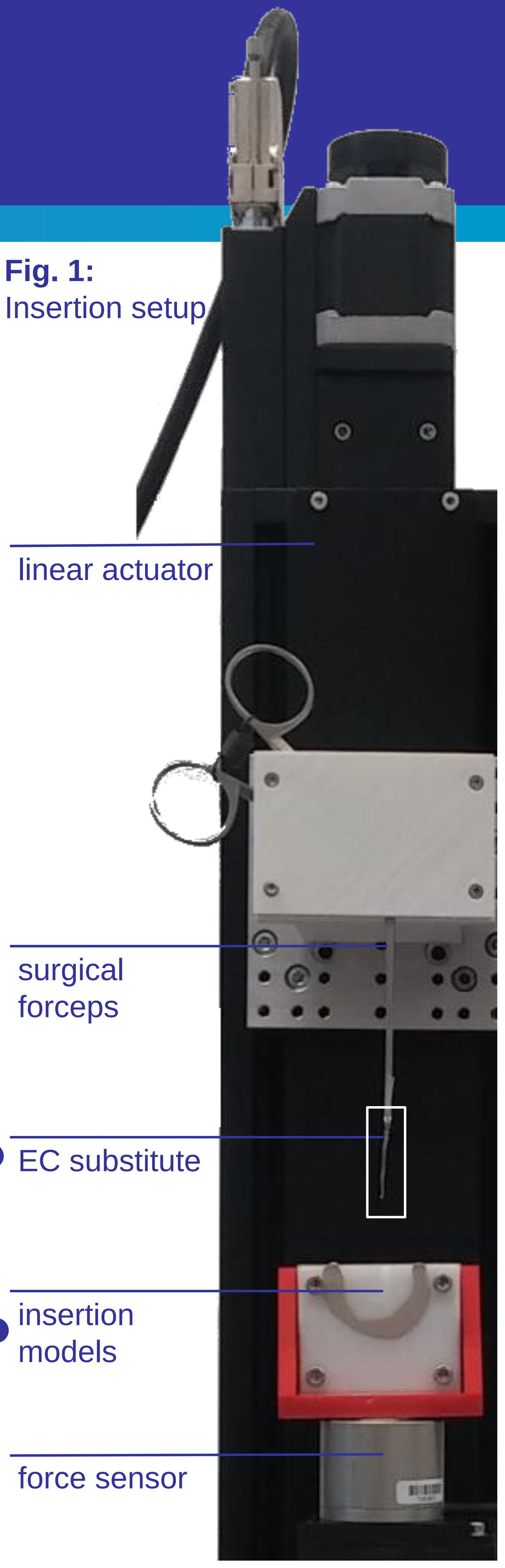


Fig. 3: cochlear models

Fig. 1: Insertion setup



Results

In total, 216 insertions using 36 EC substitutes (each 18 samples per stiffness) were successfully conducted. In accordance with theoretical considerations all varied factors showed effects on the insertion force profiles. Increased insertion speed and sample stiffness increased the insertion forces, whereas an increased model radius decreased the insertion forces (Fig. 4). After the insertion, the EC substitutes showed a curved shape, which indicates a plastic deformation of the embedded wires through the insertion into the curved models (Fig. 5).

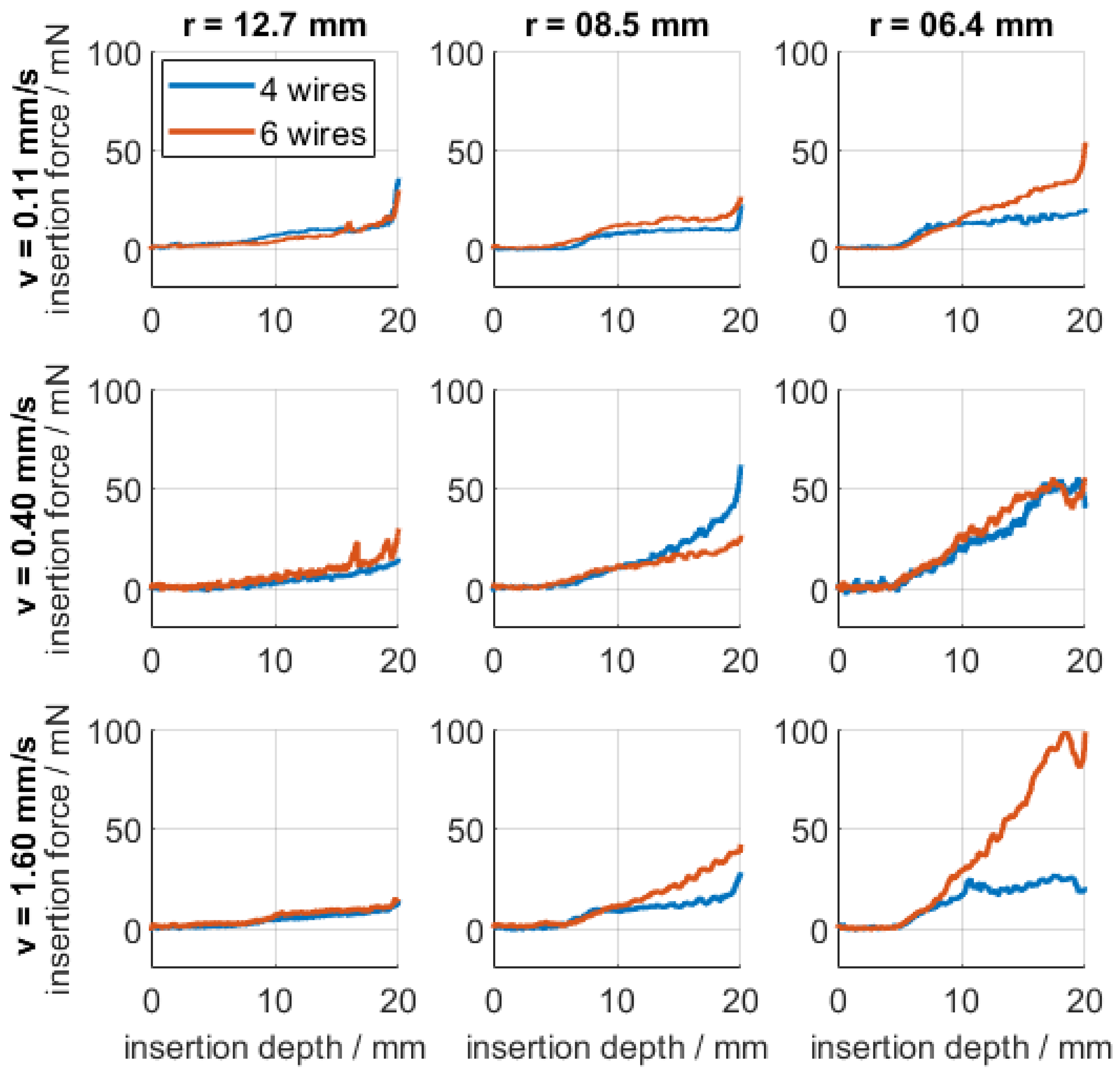
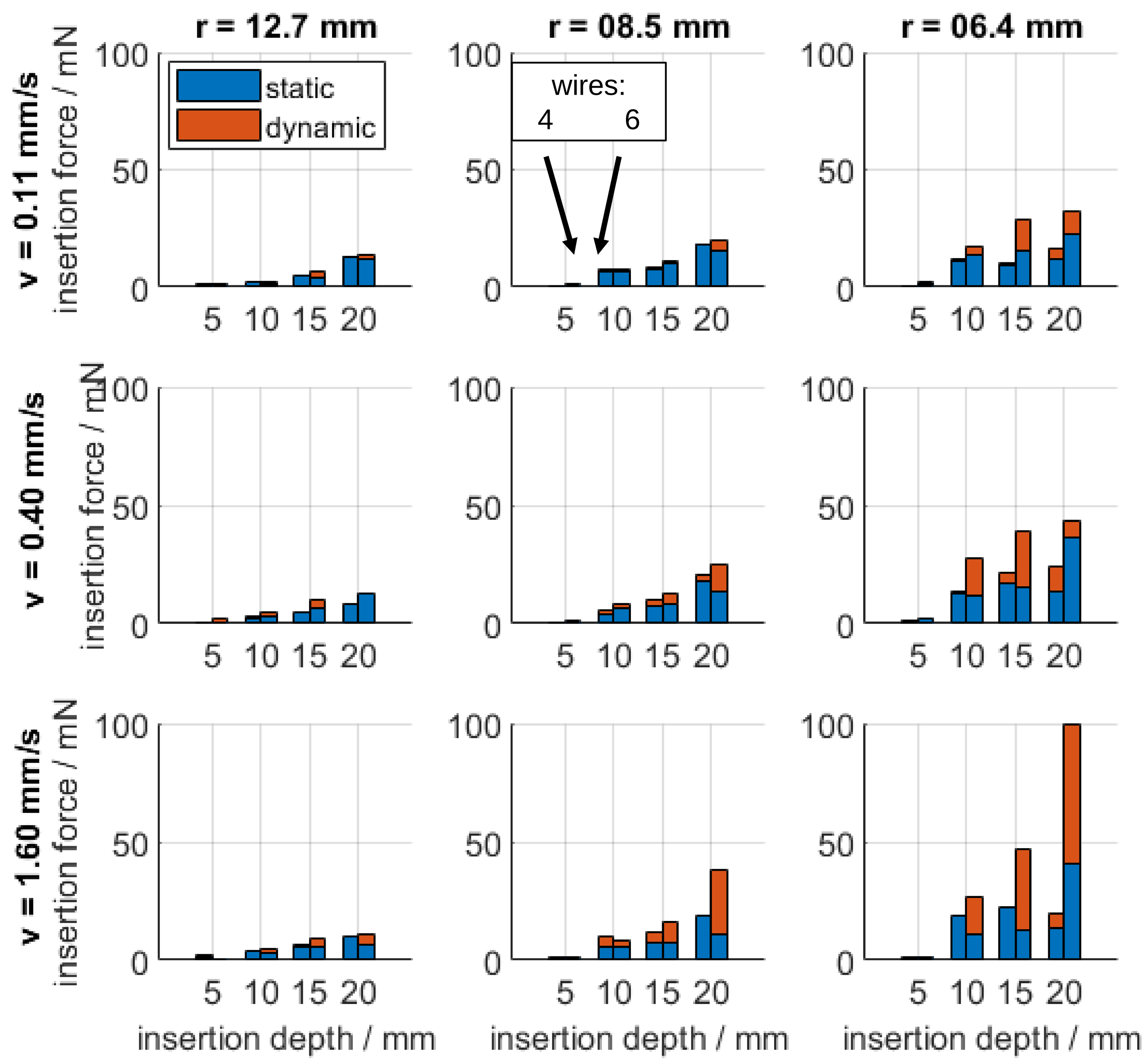


Fig. 4 (left) : Insertion forces measured during the continuous insertions. Each rows shows the insertions done with one of the three insertion speeds (0.11, 0.4, 1.6 mm/s). EC substitutes with 4 embedded wires show lower insertion forces than the stiffer EC substitutes (6 wires).

Fig. 5 (right) : Comparing force profiles with continuous and paused insertions at each pausing position (5, 10, 15, 20 mm). The static force component shows no correlation to the EC substitutes stiffness. That implies a plastic deformation of the EC substitutes and their embedded wires.



Conclusion

The results can be used for further research on an analytical model to predict the insertion forces of a specific combination of selected parameters (as insertion speed, used lubricant and type of EC), combined with given factors as the cochlear model geometry and its material. Further mechanical parameters, e.g. the friction coefficient of silicone and PTFE lubricated by the fluids used for the filling of the model, need to be determined within further experiments.

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