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Exploring Facial Nerve Detection Accuracy with a Novel Electrode Design in an In-Vivo Model

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Introduction

Minimally invasive direct cochlear access (DCA) is a computer assisted robotic approach to cochlear implantation [1]. The lack of direct visual control of the tool position puts structures such as the facial nerve (FN) at risk. Recently, neuromonitoring technology was integrated into a commercially available drill system enabling real-time monitoring of the FN [2]. Our group evaluated the feasibility of using this system combined with our robotic approach in a live sheep study [3]. The results of this study showed that the current implementation is neither sensitive nor specific enough to provide useful information during DCA procedures. This abstract reports on our initial efforts to optimize a stimulating electrode with the aim of detecting the FN within a very narrow distance range.

Materials & Methods

Hypothesis

The geometry of a custom made concentric probe can be optimized for focused electrical stimulation of the facial nerve (FN) within a very narrow distance range (0.1 to 0.4 mm).

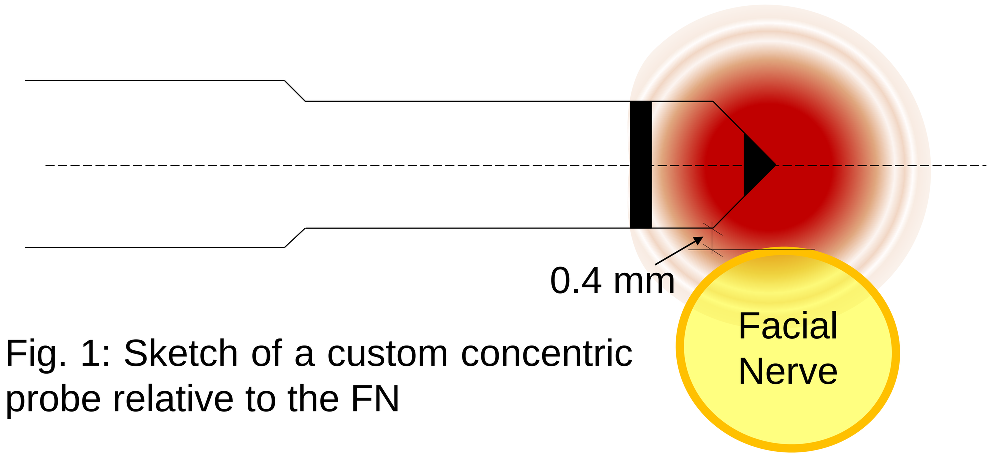

Fig. 1: Sketch of a custom concentric probe relative to the FN

Proposed Design

The variable geometrical parameters of the proposed tool are as follows (Figure 2):

- Cathode is at the tip and is a cone with a variable height h.
- Anode is a ring of 1 x Ø 1.8 mm.
- Anode to cathode distance is defined as the parameter d.

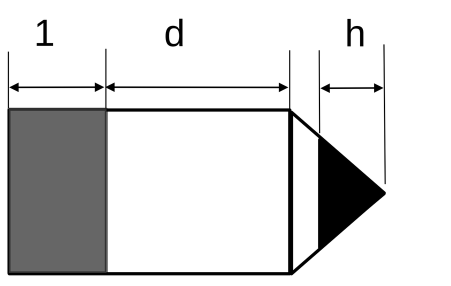

Fig. 2: Representation of the cathode and anode with variable parameters h and d

Effect of Separation Distance 'd'

A test probe with adjustable ring position was created to test the influence of cathode to anode distance in stimulation specificity. The geometry of the intermediate tool is as follows:

- A stainless steel rod (Ø 1 mm) forms a flat cathode at the tip and is the core of the probe.
- A standard shrink tube insulates the rod from the anode ring.
- A configurable anode ring (1 x Ø 1.8 mm) of stainless steel is placed around the shrink tube.
- Different distances from the anode to the cathode can be configured (e.g. d = 8 and d = 3).
- An insulated wire (copper) contacts the stainless steel ring.

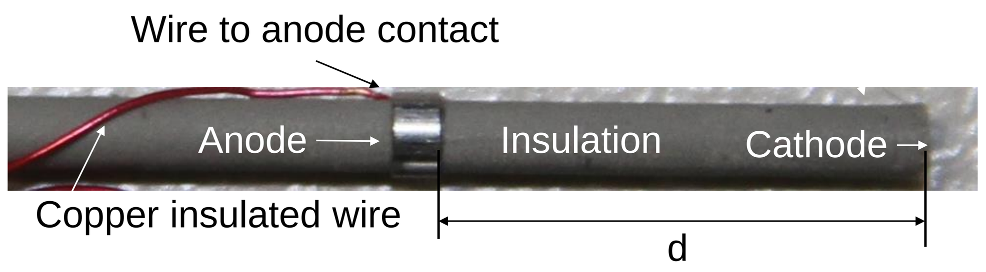

Fig. 3: Concentric test probe

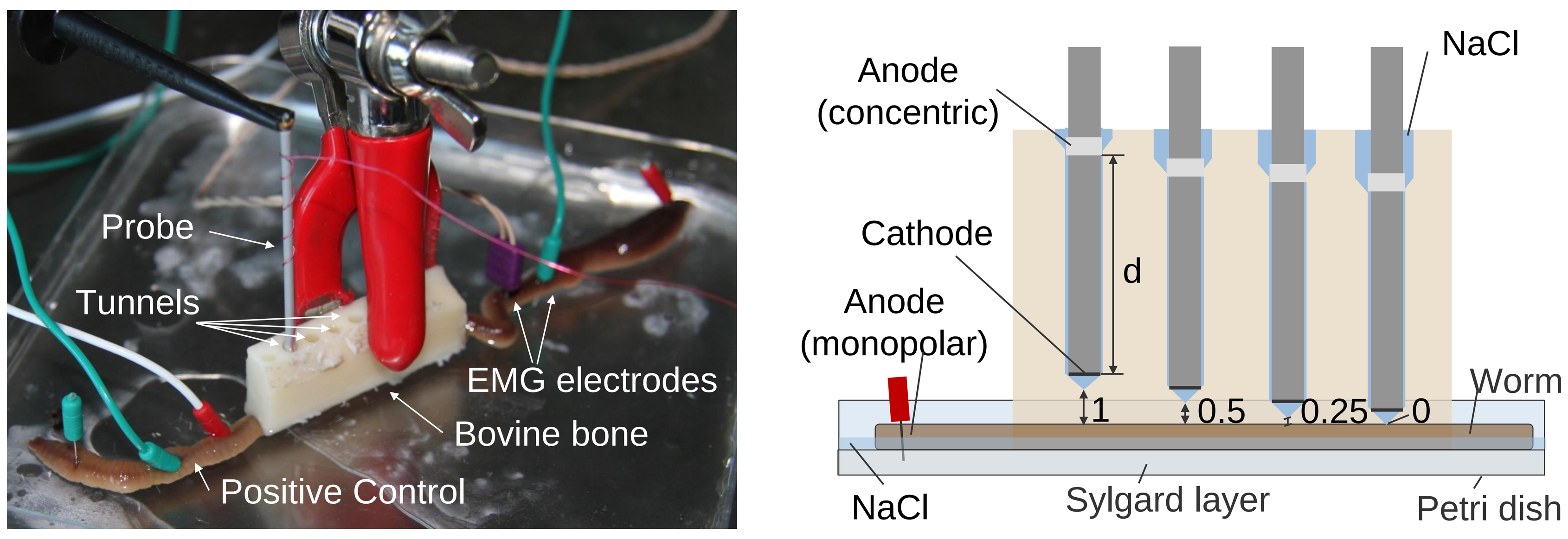

Fig. 4: Setup of the earthworm model used to test the effect of anode-cathode distance 'd'

Earthworm Nerve Model

The rain worm model has been used previously in studying action potential velocities and offers a simple, low-cost model for testing various stimulation parameters [4]. The model was prepared as follows:

- 2 rain worms were anesthetized using a 10% ethanol bath during 10 min.
- A cortical segment of bovine tibia was prepared with a channel simulating the fallopian canal.
- 4 tunnels were drilled with different distances to the canal (1, 0.5, 0.25, 0 mm).
- The bone was held in place directly contacting the worm by using a laboratory adjustable arm.
- The probe was placed in each tunnel and the stimulation protocol was applied.

Stimulation Protocol

- 1 Hz frequency repetition rate.
- Pulse widths (P_w) = 50, 100, 150, 200, 250 µs.
- Current was increased (0 to 30 mA) until first EMG was observed (stimulus threshold).

Data Analysis

- Threshold-duration curves recorded.
- Thresholds extracted per duration.
- Threshold-distance curves plotted.

Results

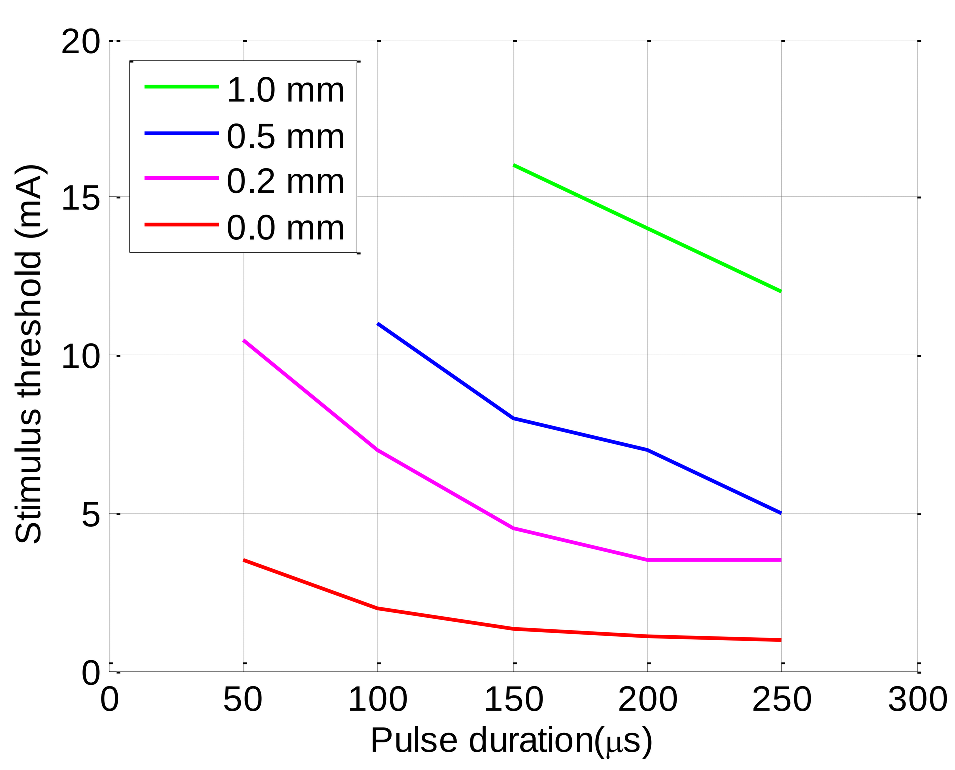

Fig. 5: Stimulus threshold curves for concentric probe d=3 mm

- For the case at 1 mm distance, responses were only observed for pulses of duration greater than 150 µs.
- For cases <0.5 mm distance, responses were observed for all pulse durations tested.

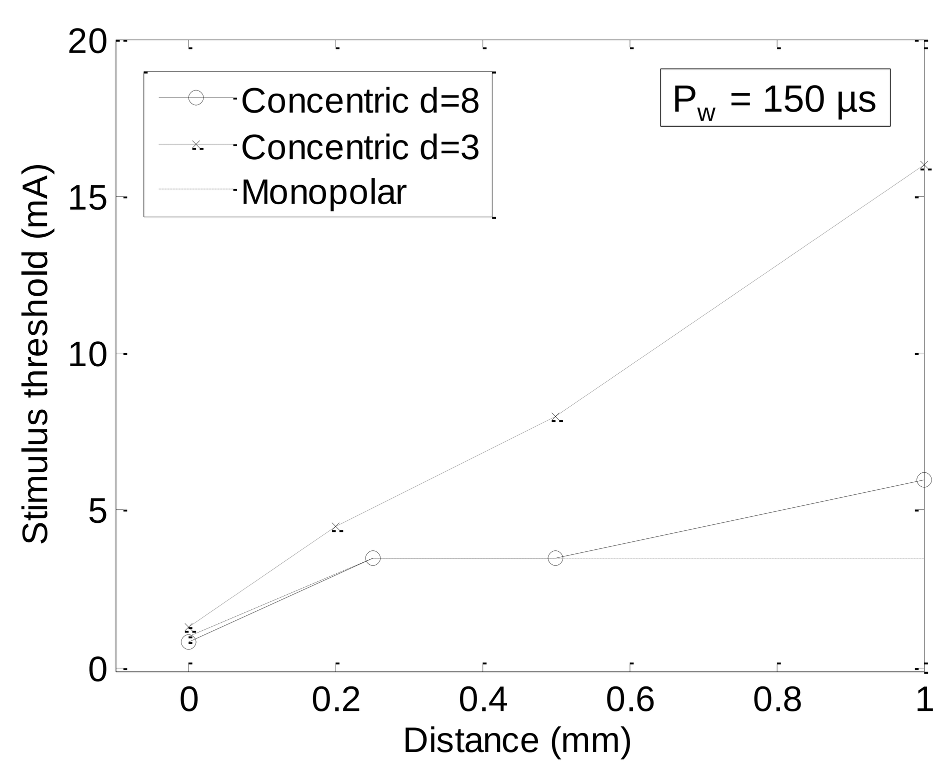

Fig. 6: Stimulus distance curves for the 150 µs pulse width

- The concentric probe, d = 3 mm, was most selective.
- The concentric probe, d = 8 mm, was sensitive, but could not differentiate between distances 0.25 and 0.5 mm.
- The monopolar probe was sensitive for all distances, but exhibited low selectivity for distances above 0.25 mm.

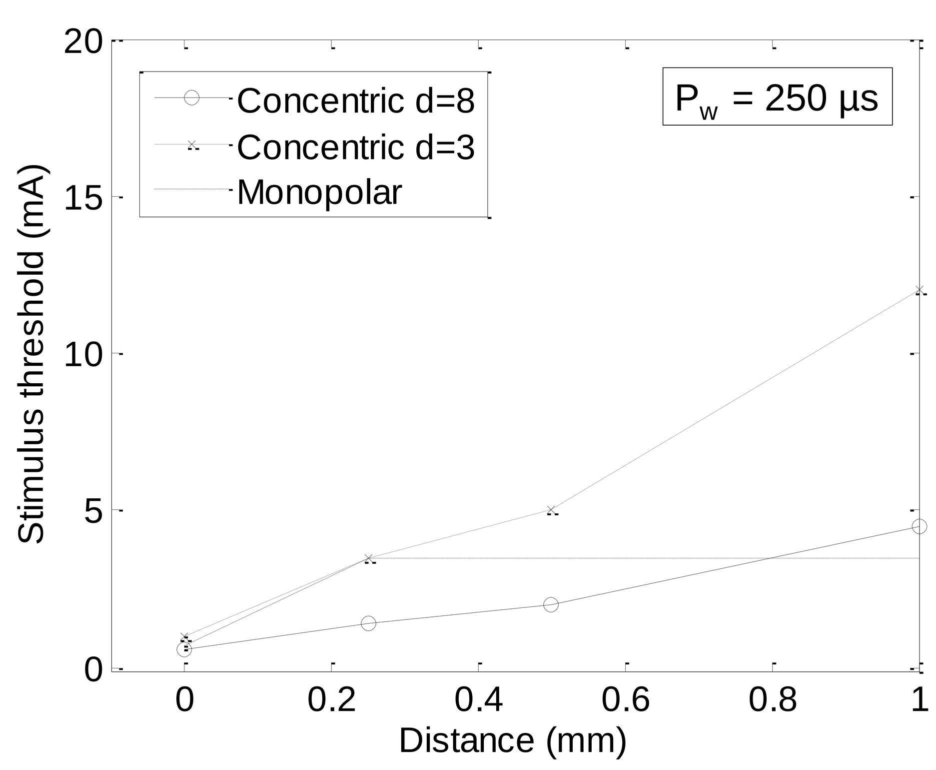

Fig. 7: Stimulus distance curves for the 250 µs pulse width

- The concentric probe, d = 3 mm, was most selective.
- The concentric probe, d = 8 mm showed similar behavior as the d = 3 mm probe, but lower selectivity.
- The monopolar probe was sensitive for all distances, but exhibited low selectivity for distances above 0.25 mm.

Conclusions

A bovine bone / earthworm model was successfully implemented to test the effect of inter-electrode distance in a concentric stimulation probe. 2 concentric (d = 3, d = 8 mm) and 1 monopolar configuration were tested in 1 bone sample and 2 different worms. The concentric stimulation presented the best spatial selectivity for all tested pulse durations, with the d = 3 mm configuration showing best overall selectivity for pulse durations greater than 100 µs.

One of the main limitations found during this preliminary study was the inability to monitor the contact of the bone sample with the worm body. Secondly, in this study a primitive probe geometry was used; future studies will implement a stimulation probe which will precisely fit into the DCA tunnel. Work is also underway to automate the stimulation protocol using a configurable system which will enable the protocol to be extended to cover more stimulation parameters, and increase the sample size for improved statistical validity. Finally, inter-electrode impedance measurements are also being implemented to determine its effect on stimulation efficacy.

References

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