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Can neuromonitoring protect the facial nerve during image-guided cochlear implantation?

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Introduction

Image-guided robotic minimally invasive cochlear implantation, requires the drilling of an access tunnel at small distances from the facial nerve (0.1 to 0.5 mm) [1-2]. Within these ranges of proximity, neuromonitoring tools lack the necessary sensitivity and specificity to protect the facial nerve. It has been previously reported that insufficient sensitivity may be due to current shunting of the uninsulated stimulating drilling tool [3]. In order to verify this hypothesis and to facilitate the use of neuromonitoring as a safety mechanism for minimally invasive cochlear implantation, a stimulation probe enabling bipolar and monopolar stimulation of the facial nerve has been developed.

Materials & Methods

A neuromonitoring probe enabling bipolar stimulation could enable a mechanism to detect an impending collision (<0.3 mm) of the drill bit with the facial nerve during image-guided robotic cochlear implantation.

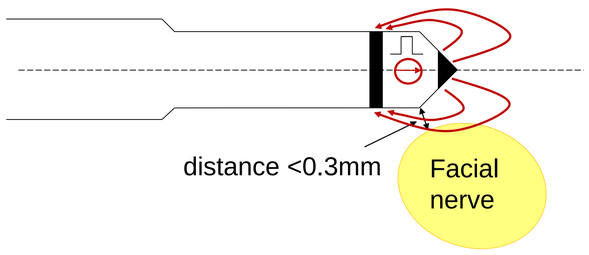


Fig. 1: Sketch of the neuromonitoring probe relative to the FN

Probe Design

Replicates the geometry of custom drill used in robotic direct cochlea access (DCA)

- Cathode at the tool tip (stainless steel)
- Three stainless steel ring anodes along the shaft
- Anodes placed at distances d = 2, 4, 7 mm
- Cathode-anode configuration is denoted by distance d

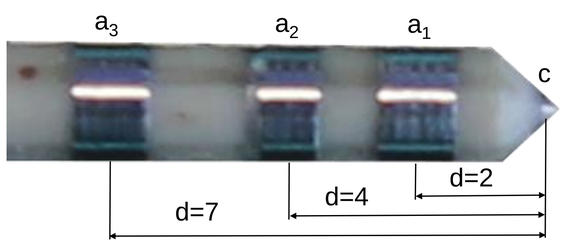


Fig. 2: Developed probe with the cathode at the tip and the 3 anodes (a_i)

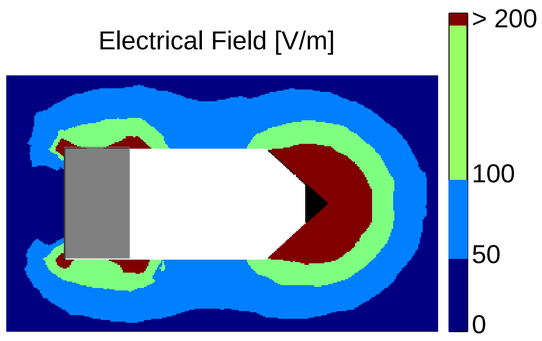
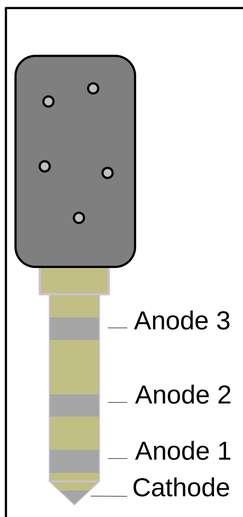
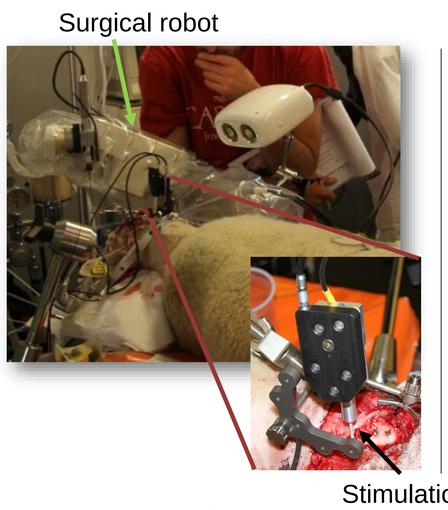
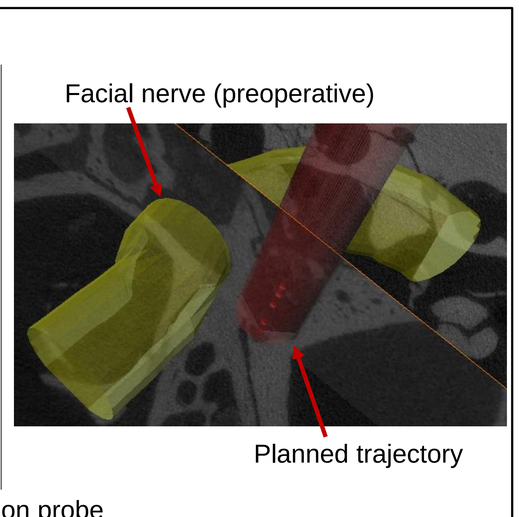


Fig. 3: Example of potential field distribution at cathode-anode configuration (d=4)







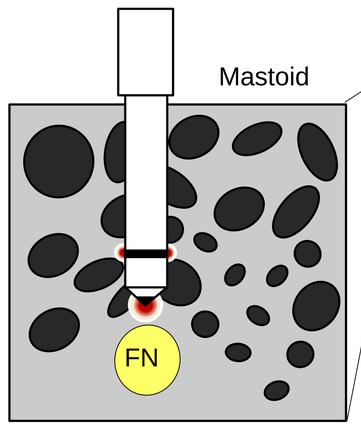
a) b) c)

Fig. 4: a) Sketch of the probe with the attached optical reference. b) The surgical robot at the resting position. c) A planned trajectory and the 5 target points relative to the preoperative FN

Animal Study Workflow

5 subjects, per animal:

- Image guidance
- Drill 9 trajectories to a defined target
- Targets at FN distance (0..1) mm
- Place stimulation probe
- Apply stimulation protocol
- Different electrode spacing



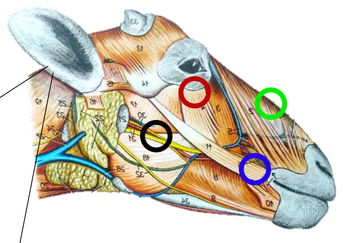
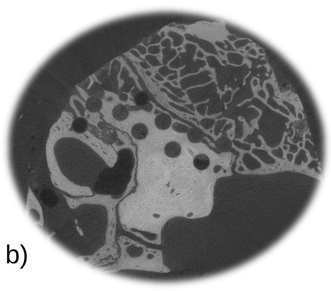


Fig. 5: Position of EMG electrodes relative to the sheep anatomy

Fig. 6: a) Probe relative to FN during the stimulation

Results

a)



b)

Fig. 7: a) Postmortem temporal bone with fiducial screws and drilled holes. b) Micro-CT slice with the holes

Data analysis

- 42 trajectories drilled in 5 subjects
- Micro-computer tomography µCT
- Accurate segmentation of fallopian canal
- Co-register positions of stimulation points to µCT
- Measure FN distance at stimulation points
- Extract stimulation thresholds (ST) from raw EMG
- Correlate ST to FN distance measures
- Sensitivity & specificity of FN distance estimation

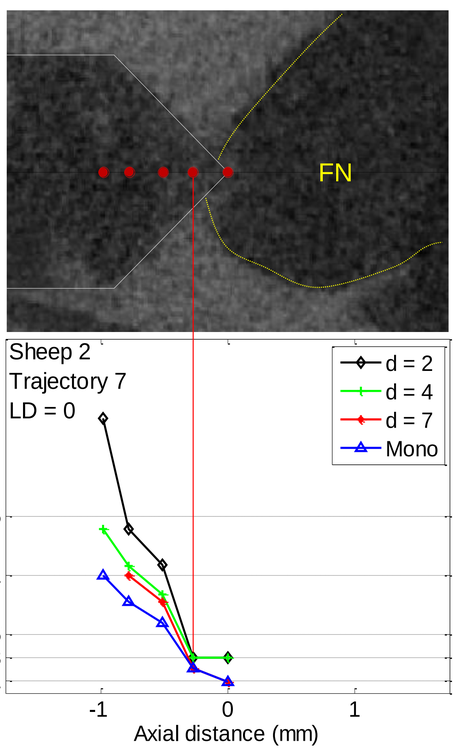


Fig. 8: Example of NM probe detecting the FN

Example of sensitivity and specificity analysis for:

- Three different stimulus threshold levels: 0.3, 0.5 and 1 mA
- A facial nerve distance < 0.2 mm

Table 1: Decision matrix for the sensitivity analysis

	FN distance < 0.2 mm	FN distance > 0.2 mm
EMG response	True positive (TP)	False positive (FP)
No EMG response	False negative (FNe)	True negative (TN)

$$Sensitivity = \frac{TP}{TP + FNe} \qquad Specificity = \frac{TN}{FP + TN}$$

Table 2: Sensitivity and specificity results for a FN detection distance below 0.2 mm

	Sensitivity (%)			**Specificity (%)**		
Electrode configuration	0.3 mA	0.5 mA	1 mA	0.3 mA	0.5 mA	1 mA
d = 2	93	93	100	100	53	13
d = 4	93	100	100	93	33	0
d = 7	93	100	100	80	13	7
Monopolar	100	100	100	33	0	0

Conclusions

- No correlation was found between stimulus threshold values and FN distance when the drill passes the FN laterally between 0.1-0.5 mm, likely due to patient-specific anatomy variances
- The bipolar probe configurations at intensities of 0.2-0.3 mA produced 100 % sensitivity and specificity at distances to the FN below 0.1 mm
- It is proposed that the presented neuromonitoring probe could enable a “last line of defense” mechanism to avoid drilling through the FN during image-guided cochlear implantation

References

[1] B. Bell, N. Gerber, T. Williamson, et. al. “In Vitro Accuracy Evaluation of Image-Guided Robot System for Direct Cochlear Access.,” Otol. Neurotol., vol. 34, pp. 1284–1290, Aug. 2013.

[2] W. Wimmer, F. Venail, T. Williamson, et. al., “Semiautomatic cochleostomy target and insertion trajectory planning for minimally invasive cochlear implantation.,” Biomed Res. Int., 2014.

[3] J. Ansó, C. Stahl, N. Gerber, et al., “Feasibility of Using EMG for Early Detection of the Facial Nerve During Robotic Direct Cochlear Access.,” Otol. Neurotol., vol. 35, no. 3, Mar. 2014.