Tenth Quarterly Progress Report

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Feasibility of an Intra-Neural Auditory Prosthesis Stimulating Electrode Array

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1. Introduction

The objective of this research is to evaluate the feasibility of intra-neural stimulation as a means of implementation of an auditory prosthesis. We are stimulating the auditory nerve with penetrating multi-channel electrode arrays and monitoring the thresholds and tonotopic spread of activation in the central nucleus of the inferior colliculus (ICC) of cats.

2. Summary of activities for the quarter

The major objective in the present quarter was to test prototypes of chronically implantable stimulating and recording arrays in acute experiments in four cats. We also met with otologic surgeons Alex Arts and Mark Wiet to discuss a manuscript that they are preparing that describes an infra-labyrinthine approach to the auditory nerve in humans and to discuss plans for a study of a trans-fenestral approach in humans. Invited presentations were given at the University of California at Irvine (by Middlebrooks) and the Conference on Implantable Auditory Prostheses (by Snyder; at Lake Tahoe, California).

The principal accomplishments of this quarter were the following:

- *Evaluated custom chronic ICC recording probes and chronic intra-neural stimulation arrays.* The custom probes and arrays were manufactured by NeuroNexus Technologies, Inc. Both probes and arrays consisted of a single silicon-substrate shank and a polyimide ribbon cable. The recording probe had 32 1200-μm^2 recording sites spaced at 100-μm intervals with a 3-cm cable. The stimulating array had 16 1200-μm^2 stimulating sites and a 1.5-cm cable. In both cases, the cable was connected to the silicon shank with rivet bonds, and the bond area was positioned within a length of stainless-steel tubing, 625-μm outside diameter. In this first run of probes and arrays, there was a difficulty with the rivet bond-pads pulling off the silicon shank, so most of the data are marred by many missing stimulation and/or recording sites.
- *Evaluated a custom stereotaxic guide-tube system for placement of a chronic ICC recording probe.* A second generation guide tube system was designed and fabricated. The system was designed to permit stereotaxic positioning of the 32-site recording probe at a desired position through the ICC. Insertion is achieved without aspiration of overlying brain tissue and visualization of the ICC as we have done in previous acute experiments. The guide-tube system consists of two parts: a stainless-steel guide tube (~1.5 mm long, 900 μm outside diameter) with a stainless-steel flange and a removable stainless steel trocar with an identical flange. The two parts are held together by a stainless steel removable clip. The sharpened stainless-steel trocar is inserted during implantation to penetrate overlying cortex and membranes and to provide a means of holding the device in a stereotaxic apparatus. After insertion and fixation of the guide tube, the trocar is removed and replaced with the recording probe. Except for its distal 6 mm, the recording probe is encased in a 12.5-mm-long stainless-steel tube. This tube serves three functions: it fits snugly inside the guide tube and guides the recording probe down the guide tube, it allows an insertion force to be applied to the recording probe cable, and it insulates the rivet bonds between the electrode and the ribbon cable from the surrounding intracranial fluids.

  The recording probe was positioned successfully in the ICC in each of the 4 animals in which it was attempted. Contact with the tentorium was successfully avoided and insertion into the ICC was achieved. Good responses to acoustic stimuli were recorded at most of the

32 sites in two of the animals. In the other two animals, technical problems with the probe and its connection to the headstage limited the number of active sites. These trial insertions were sufficiently successful that we plan to attempt chronic stereotaxic placement of ICC recording probes in the next quarter.

- *Evaluated an intra-neural stimulating array that could be placed chronically.* In acute experiments in two animals, we evaluated a stimulating array that is intended for chronic intra-neural implantation. As described above, the bond between silicon shank and polyimide ribbon cable is positioned within a stainless-steel tube. As in the chronic recording probe, the tube protects the rivet bonds and provides a structure that can be held in a micropositioner. After an initial trial insertions, it was found that the length of the stainless-steel tube was too long, effectively occupying most of the length of the flexible cable, while allowing insufficient clearance for visually controlled insertions. Also, that array had only a few working sites. Nevertheless, ICC activation by electrical stimulation of the auditory nerve was achieved at a few sites. After these first trials, we shortened the stainless-steel tube to 3 mm and our machinist fabricated a custom device for holding the tube while permitting a clear view of the implantation site. Several good stimulation sites were available in that test. The new system used in another animal was a substantial improvement, but was still rather cumbersome. Further improvements to the stimulation system will be attempted in the near future.
- *Compared intra-neural stimulation using lateral (i.e., trans-labyrinthine) and intra-cranial approaches.* We compared quantitatively results obtained with a lateral approach to the auditory nerve (in 10 animals, as documented in Middlebrooks and Snyder, *JARO* 8: 258-279, 2007) and an intra-cranial, posterior-fossa, approach (in 8 animals, not yet published). Our impression during the intra-cranial experiments was that thresholds were higher and spread of excitation greater than those obtained with the lateral approach, but statistical analysis failed to show significant differences. The most conspicuous difference between the approaches was the inter-animal variation in tonotopic organization. With the lateral approach, we consistently observed a progression of CF tuning from proximal to distal activation of probe sites in the nerve corresponding to basal-, to apical-, to middle-turn activation. In contrast, the intra-cranial approach showed a wide variety of patterns. Some cases looked just like the lateral approach. Others showed a monotonic progression from basal to apical or basal to middle, and some showed only a limited tonotopic range across the 1.5 mm of stimulation sites. We plan to write up that work for publication in a special issue of *Hearing Research*.

Plans for next quarter:

- Chronic implantations of 32-site recording probes in two cats. We will implant our chronic recroding system using sterile techniques in at least two animals. We will recover these animals and stimulate them acoustically and record the responses evoked in the ICC for the following two weeks or longer. We will conduct a terminal acute intraneural stimulation experiment at the end of the chronic stimulation period. At the end of the acute experiment, we will perfuse the animals with histological fixatives and conduct histological examination of the inferior colliculus.
- Continue to refine the chronic intra-neural stimulating array, with acute tests in two cats.

- Conduct and document dissections of human temporal bones to define a trans-fenestral approach to the auditory nerve. Prepare a manuscript.
- Prepare a manuscript comparing intra-neural stimulation using lateral and intra-cranial approaches to the auditory nerve.