Mechanical Characterization of Microelectrodes: Used for Auditory Cortical Prostheses

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I. INTRODUCTION

Microelectrodes implanted in human cortical tissue are neuroprosthetic devices, known as cortical neural prosthetics (CNPs), systems designed to stimulate areas of the brain where function has been reduced, or lost [7]. Mechanical disruption of the electrode-cortical tissue interface may cause adverse reactions to both electrode performance and/or biological tissue. Studies of the penetration of single shaft microelectrodes will reveal data illustrating the kinds of mechanical forces at work upon this junction. Studies of the penetration of polyimide insulated stainless steel single shaft microelectrodes (125 um) into human and rat cadaver brain tissue have been done, which revealed data illustrating the kinds of mechanical forces at work upon this junction.

The usage of electrodes allows bypassing biological pathways and the CNS to establish a direct communication between computer systems and the brain, (fig. 1)[7]. Force relaxation traces were obtained across human cadaver primary auditory cortex, Heschl's gyrus (HG) (fig. 2a, b) and rat cadaver auditory cortex located in the posterolateral neocortex (fig. 2c, d) [1, 4]. Upon establishment of an optimal protocol of measurements, it will be applied to the flexible polyimide-based cortical microelectrode arrays currently being fabricated in the Rousche lab.

QUESTIONS:

1. What forces are experienced by the electrode upon insertion into various types of tissue?

2. What forces are experienced by the electrode when it is within the tissue?

3. What cortical property differences exist between formalin fixed and non formalin fixed rat tissue brain?

4. How does low oscillation (3 Hz) affect the forces experienced by the tissues?

Brain Machine Interface Intended for use in Auditory Cortex

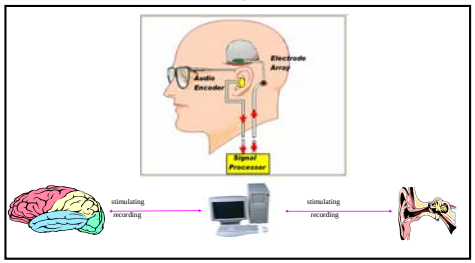

Figure 1. Brain Machine Interfaces allows bypassing biological pathways and the CNS to establish a direct communication between computer systems and the brain.[modified image from R.A. Normann et al.]

Location on Auditory Cortex within Human and Rat Brain Tissue

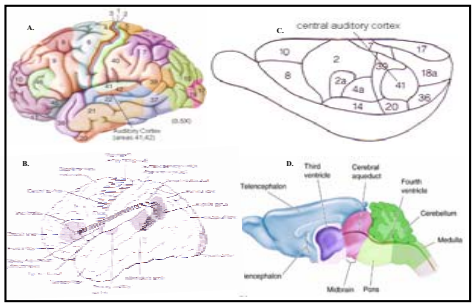

Figure 2a,b. Anatomy of Human Brain Tissue. 2c,d. Anatomy of Rat Brain Tissue. [1,4]

II. METHODS AND MATERIALS

A. Tissue Sample
•FHB (10% formaldehyde) Formalin Fixed Human Brain Tissue
•FRB (10% formaldehyde) Formalin Fixed Rat Brain Tissue
•NRB Non Formalin Fixed Rat Brain Tissue

***B. Mechanical Set Up* (fig. 3a)**
•A 500 mN thin film strain gage load cell A ±10V DC power supply was utilized as an excitation voltage.
•125 um polyimide insulated stainless steel single shaft microelectrodes (fig. 5) were attached to the load cell.
•Operational Amplifier (AD 620) to amplify and filter signals. (fig. 3b)
•12- bit Data Acquisition System (Model #158 UP, Windaq)

C. Experimentation Procedures (fig. 4)
•Calibration and analysis was performed on the load cell.

Three Dimensional Mechanical Experiment Set Up

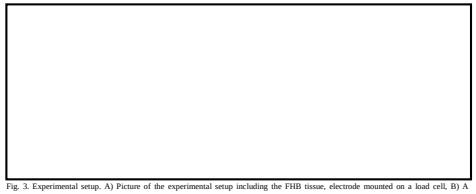

Fig. 3. Experimental setup. A) Picture of the experimental setup including the FHB tissue, electrode mounted on a load cell, B) A schematic of the operational amplifier AD 620 used to amplify and filter the signal with a gain of 1000.

Table of Tissue Experimentation

Tissue	Trial	Insertion (mm)	Increment (mm)	Rows (mm)	Separation (mm)	Actuate (Hz)
Formalin	1	3.5	10.0	2.0	5.0	3.0
Human	2	1.0	5.0	2.0	5.0	3.0
Brain	3	1.0	2.0	3.0	2.0	3.0
Formalin	A1	1.0	2.0	2.0	2.0	3.0
Rat	A 2	1.0	2.0	3.0	2.0	3.0
Brain	B 1	1.0	2.0	3.0	2.0	3.0
Non Formalin	A 1	1.0	2.0	2.0	4.0	3.0
Rat	B 1	3.5	1.0	3.0	1.0	3.0, 7.0, > 7.0
Brain	C 1	1.0	1.0	2.0	1.0	3.0, 7.0, >7.0

Figure 4. Table of Tissue Experimentation. Table summarizing the variables addressed per tissue sample throughout experimentation.

Cross Sectional of Stainless Polyimide Insulated Steel Single Shaft Electrode

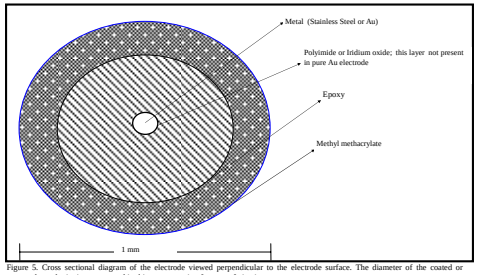

Figure 5. Cross sectional diagram of the electrode viewed perpendicular to the electrode surface. The diameter of the coated or uncoated metal wire is exaggerated in this representation for ease of viewing.

Insertion of Electrode into Various Cortical Tissue

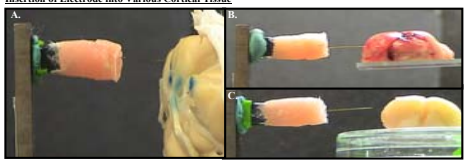

Figure 6. Lateral views of Electrode Insertion. Polyimide insulated stainless steel single shaft electrode mounted on a load cell was controlled by a micromanipulator into the tissues. A) FHB, B) NRB and C) FRB.

III. RESULTS

•The 12-bit data acquisition system (Model #158 UP, Windaq) was used to acquire the signal at 240 Hz. (fig. 7).
• The data was analyzed using software custom-written in Matlab (MATLAB 7, Mathworks, Inc.)
• Fitting Analysis (modified program with MATLAB 7) was done to data pertaining to stress relaxation with the formula : $F = x(a + be^{(-t^*u)/\tau})$

Electrode Insertion Force Data Traces

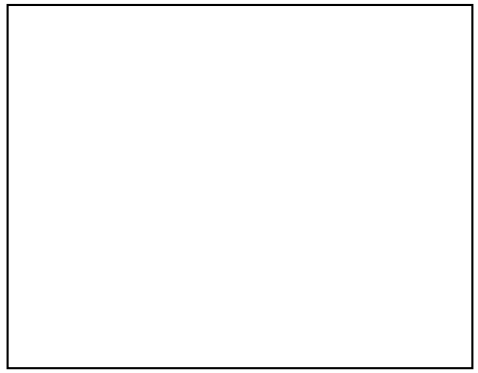

Figure 7. Force Data Evaluation with parameters numbered as: 1: initial baseline, 2: peak upon insertion, 3: steady state, 4: actuation at 3 Hz., 5: neg. peak upon retraction, and 6: final baseline. Polyimide insulated stainless steel single shaft electrode insertion and actuation applied in A) FHB, B) FRB, and C) NRB.

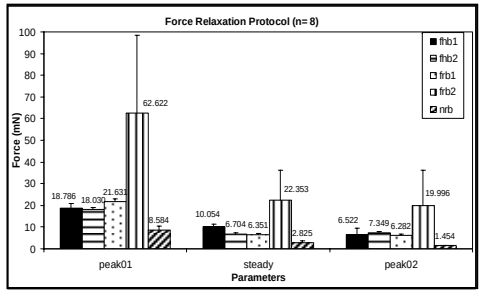

Figure 8. Force Relaxation in all Samples. Parameters highlighted are peak01 (insertion forces), steady (steady state forces), and peak02 (retraction forces). The graph is based on an average taken from the set samples converted from Voltage (volts) (output of the lead cell measurements) into Force (mN) by conversion factor established from calibration of 2.959 mg/mV.

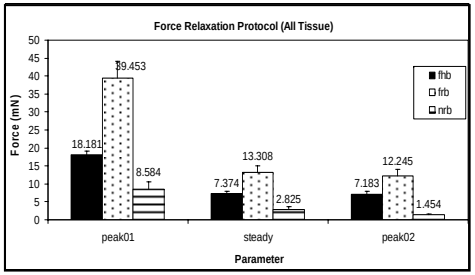

Figure 9. Force Relaxation in Brain Tissues. Parameters highlighted are peak01 (insertion forces), steady (steady state forces), and peak02 (retraction forces). The graph is based on an average taken from the set samples converted from Voltage (volts) (output of the load cell measurements) into Force (mN) by conversion factor established from calibration of 2.959 mg/mV.

IV. CONCLUSION

1A. INSERTION FORCES

During penetration of microelectrode into cortical tissue, the electrode experiences insertion forces of :

•18.2 mN for Formalin Fixed Human Brain Tissue

•39.5 mN for Formalin Fixed Rat Brain Tissue

•8.6 mN Non Formalin Fixed Rat Brain Tissue

In order for polyimide insulated stainless steel single shaft electrode to penetrate through tissue, it must be able to withstand the insertion forces.

1B. STRESS RELAXATION

Upon penetration, the insertion forces decay into a stress relaxation. The alpha average is :

•0.4 ± .12 for Formalin Fixed Human Brain Tissue

•0.5 ± .27 for Formalin Fixed Rat Brain Tissue

•0.6 ± .16 for Formalin Fixed Human Brain Tissue

•*The alpha value varies within a tissue however the change is consistent throughout the various tissues so the viscosity of the tissues is not constant within the tissue itself.*

2. STEADY STATE FORCES

After insertion, while the electrode is within the tissue it experiences steady state forces of:

7.374 mN for Formalin Fixed Human Brain

13.308 mN for Formalin Fixed Rat Brain

2.825 mN for Non Formalin Fixed Rat Brain

The electrode must be effective electrically while being exposed to a constant exposure of forces of the steady state forces.

3. FORMALIN FIXATION

Formalin fixation causes the cortical membrane to be tougher .(fig. 8 and 9):

• During penetration, FRB tissue required more force than NRB tissue by a factor of 5.

•During steady state, the electrode experienced more force within FRB than NRB by a factor of 5.

If insertion is carried out on tissue with formalin fixation, the actual tissue will place less force on the electrode than the formalin fixed tissue.

4. ACTUATION

•Data revealing actuation will be analyzed to conclude on the affect it has on the mechanical forces within the cortical tissue- electrode interface.

ACKNOWLEDGEMENTS

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