Exploring the Brain Vessel:
Spreading Nano Wire Electrodes for Intravascular Neural Recording

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1. Introduction

An intravascular neural recording is believed promising to measure neural activities less invasively from any portion in the brain [1]. A rich vascular bed in the nervous system is an attractive space to put an electrode array for our neural interface.

In this study we design and fabricate a nano wire electrode that can advance through capillary in a blood stream. For the fabrication, we invent a novel manipulation method to handle a Wollaston wire with a sub-μm diameter and 1-mm length. In addition, we evaluate the mechanical and electrical property of the electrodes through *in vivo* experiments.

2. Material and methods

2.1 Intravascular neural recording

Fig.1 shows a conceptual scheme of the intravascular neural recording. In the recording, we introduce neural probes into cerebral vessels using a microcatheter and have the probes flow through capillaries toward the destination.

2.2 Design of Nano wire electrode

The sub-μm wire electrode requires the following functions: i) sufficiently flexible wire that can advance along the winding vessel in a blood flow, ii) sufficiently thin probes to wander into a capillary on the order of 10μm in a diameter, iii) sufficiently long wire to reach a target area in the brain, iv) sufficiently low impedance to measure neural activities in the vessel with proper insulation except for the recording point at the tip. On the basis of these requirements, we employed a sub-μm-diameter Wollaston wire, *i.e.*, a 0.6-μm-diameter 10,000-μm-long Pt wire (The nilaco corp., PT-351015), and coated the wire with a 100-nm-thick insulation layer. In addition, we plated a 5-μm-diameter, 30-μm long platinum black at the wire tip to decrease the impedance.

2.3 Manipulation of Wollaston wire

Wollaston wire is protected in a silver jacket for a Pt fine wire not to be broken and coiled. Once the jacket is removed, the exposed fine wire with an aspect ratio of 10,000 or more is so fragile and long that a wind or static electricity can easily break and coil the wire. Therefore each process requires proper manipulation to keep the exposed wire under control.

First, we used a specially designed thermostatic chamber to protect the wire against a wind throughout the process. Second, we used a drop of water with a surface tension like a forceps to trap the wire in the chamber. Third, in a high temperature, we produce laminar airflow by vacuum to straighten the wire. Finally, we put the wire in a catheter filled with water and make a water flow to straighten the wire.

2.4 Process flow of producing wire electrode

As shown in Fig.2, the process flow of producing the wire electrode consists of 3 steps: i), etching; ii), insulation; iii), platinization. In the etching process i), we first dipped an Ag-coated Wollaston wire in a drop of nitric acid (6.7 M - HNO_3) and remove the Ag sheath [2]. During this process we held the tip of the wire with a drop of water to keep the wire straight. In the insulation process ii), we dipped the wire in a drop of insulation fluid and moved the drop from the Ag root to the Pt tip to make the insulation layer. We then baked the insulation layer in the high temperature laminar airflow. In the platinization process iii), we held the tip of the wire with a drop of platonic acid (3% Hydrogen hexachloroplatinate (IV) hydrate, A.C.S. reagent Sigma-Aldrich; 0.03% Lead (II) Acetate Wako) and plated platinum black.

2.5 Evaluation

We used xenopus to evaluate mechanical and electrical property of the wire electrodes. In the preparation, xenopus was anesthetized with MS222 (meta aminobenzoic acid ethylester methanesulfonate).

Mechanical property: We evaluated the flexibility of ϕ 1-μm Pt wire in xenopus mesentery vessels. The microcatheter with an infusion of saline introduced the electrode into the vessel. The flow velocity was 0.3 mm/s. The CCD camera observed the behavior of electrode at a vessel branch with a 400-μm curvature radius.

Electrical property: The multifrequency LCR meter (Yokogawa Hewlett Packard, 4274A) first measured the impedance of electrodes. We then introduced the 1-μm-diameter, 100-μm-long Pt wire electrode into the vessel on the spinal cord of a xenopus, and measured electrically evoked the neural responses. For reference, we also measured the response with Ag surface electrode on the spinal cord. The spinal cord was superfused with a Ringer's solution that contained 115-mM NaCl, 2.5-mM KCl, 1.8-mM $CaCl_2$ and 3.0-mM Hepes.

3. Results

Figs.3 (b) and (c) show Pt wire of ϕ 1 μm and ϕ 10 μm in the mesentery artery, respectively. The ϕ 1-μm wire could pass through the branch along the wall, while the ϕ 10-μm wire was too stiff to bend at the branch and penetrated the vessel wall.

The impedance of the electrode was 3 MΩ at 1kHz. Fig.4 shows neural responses measured with the intravascular and conventional surface electrodes. Both electrodes could obtain neural responses with negative and positive peaks at 0.75 ms and 1.50 ms, respectively.

Theses results indicate that the fine-wire electrode was properly designed for intravascular neural recording.

4. Conclusion

We designed and fabricated Wollaston wire electrode with a ϕ 1-μm diameter for intravascular neural recording. We invented novel manipulation methods to handle Wollaston wire during the process. We verified though experiments *in vivo* that ϕ 1-μm electrode met the fundamental required functions in terms of mechanical and electrical properties.

Reference

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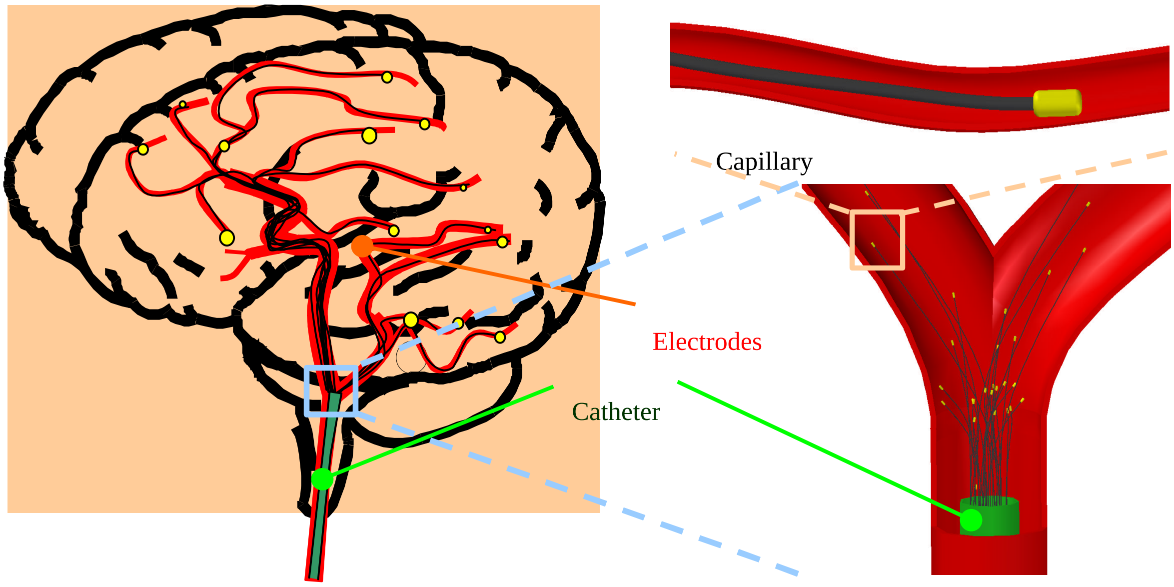

Fig.1 Conceptual scheme of intravascular recording

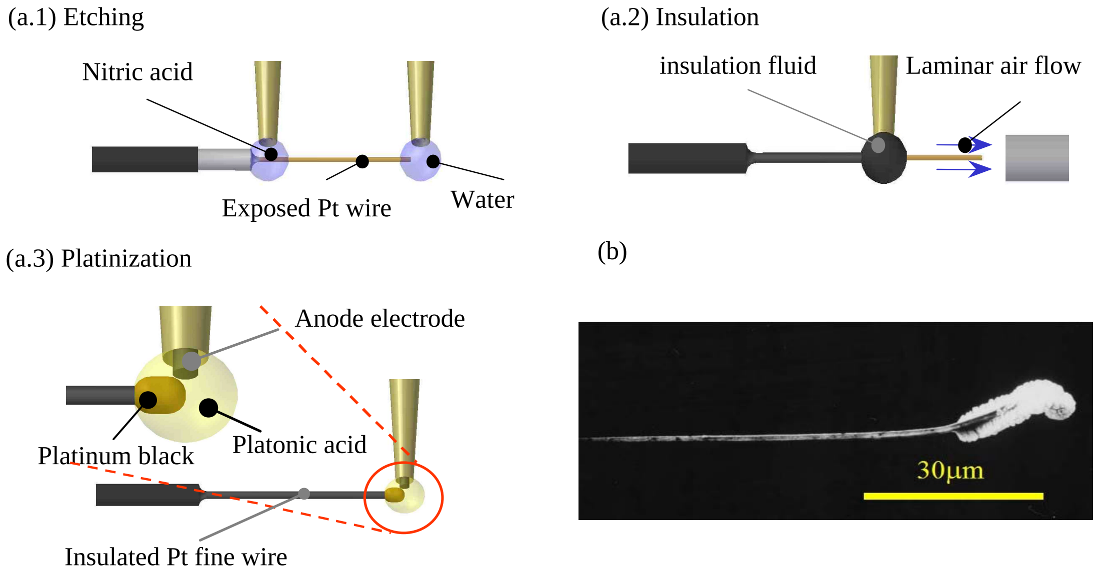

Fig. 2 (a) Process flow of fabrication. (b) SEM view of nano wire electrode.

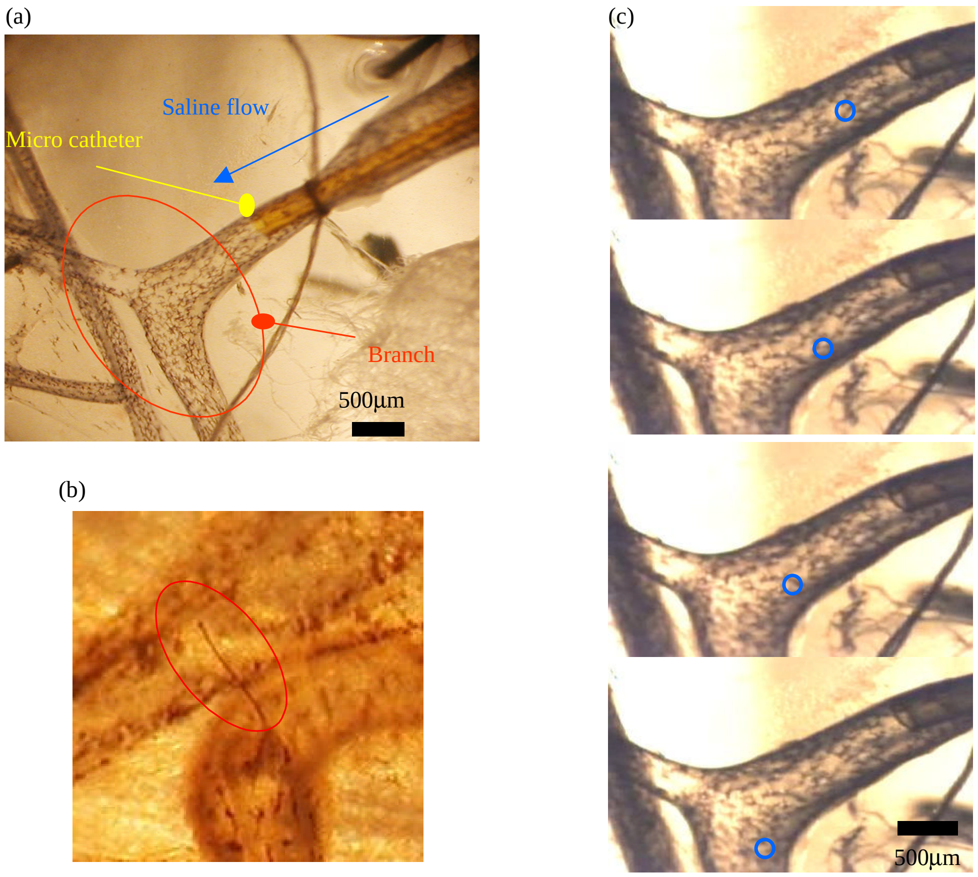

Fig. 3 (a) Experimental setup to test the wire flexibility in the gut intestine of Xenopus. (b) Vessel wall penetrated by ϕ 10-µm Pt wire (c) Movement of ϕ 1-µm Pt wire in the vessel.

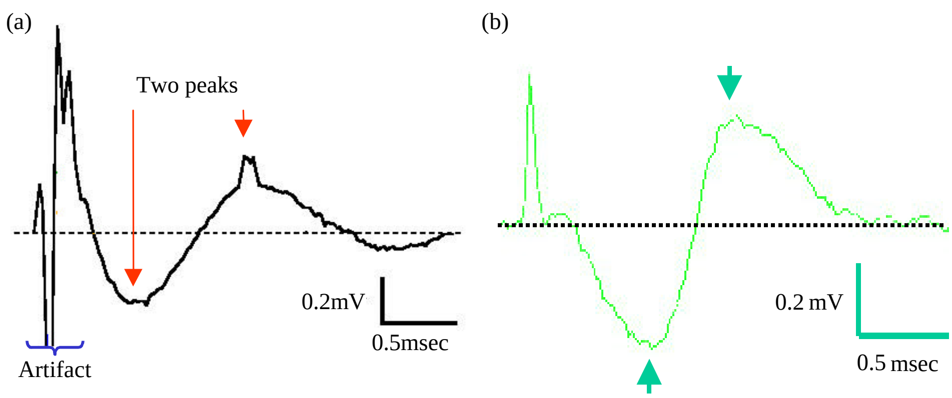

Fig. 4 Electrically neural response measured with an intravascular electrode (a) and conventional surface electrode (b).