In vitro Assessments of Vascular Damage and Tissue Deformation Following the Insertion of Silicon Neural Probe

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Many kinds of micromachined silicon neural probes are developed and applied to brain research by using invasive method of surgical technique. While these micromachined silicon devices produce acceptable experimental results, the full potential of neuroprosthetic devices is presently limited by biological reactive responses that begin immediately upon their insertion into the body. The magnitude of these responses is affected by many insertion-related parameters, such as the insertion speed, device size, and tip design. A neuroprosthetic device inserted into a neural structure will disrupt the natural structure to some extent causing tearing, cutting, stretching, or compression. The goal of this paper is to improve our understanding of the relationship between insertion mechanics and vascular injury and tissue deformation in the brain.

1 In vitro experimental setup with living brain slices

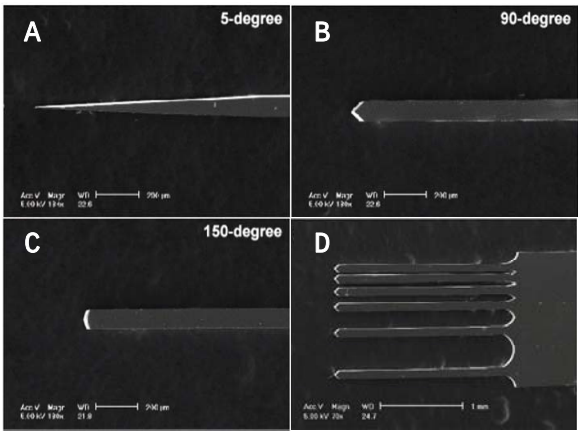

Fig. 1 Scanning electron micrographs of the tips of fabricated silicon probes with different sharpness(A: 5degree-sharp probe, B:90degree-medium probe and C:150degree-blunt probe) and multishank array with various intershank spacing(D)

Fig. 1 shows scanning electron micrographs of the tips of fabricated silicon probes with different sharpness and multishank array with various intershank spacing. All devices used for this experiment had a 2-mm-long shaft, and the cross section dimensions of the shaft were 60μm(thickness) x 100μm(width). The schematic of the *in vitro* insertion and image capture

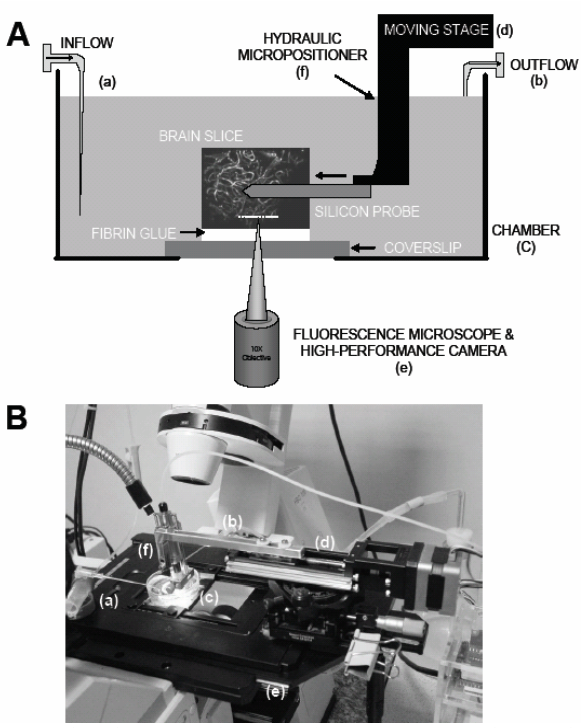

Fig. 2 The schematic of the in vitro insertion setup(A). Photograph of the setup mounted on the microscope(B).

setup are depicted in Fig. 2. Time-lapse images were collected during probe insertion and withdrawal into 500μm thick brain slices using a fluorescence microscope. The speed and moving distance of the device were automatically controlled with commands pro-

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grammed into the microcontroller. To determine the mechanical behaviour during insertion and retraction of the probe into the dura meter of the brain surface, a high-sensitivity silicon strain gauge was used. And then immunohistochemistry for laminin was used as a measure of tissue trauma.

2 Brain damages according to the sharpness of the tips and speed of insertion

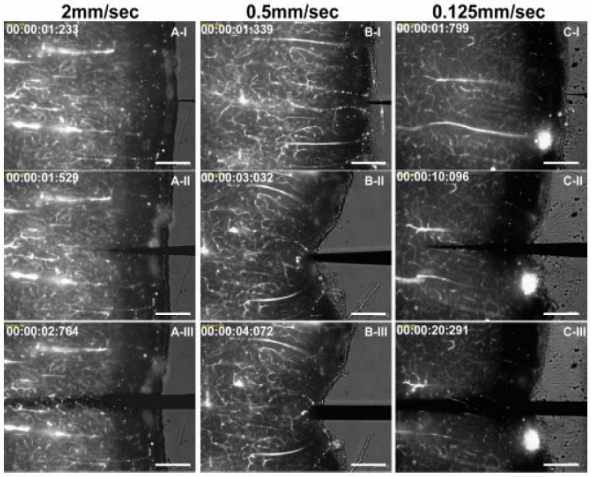

Fig. 3 Time-lapse images of the surface deformation and haemorrhaging in the cortical area during insertion of a sharp probe with a tip angle of 5 degrees. These images were obtained during probe insertion at 2 mm/sec (left panels), 0.5 mm/sec (middle panels), and 0.125 mm/sec (right panels Scale bars are 200 µm.

To study the effects of sharpness of the tips on tissue damage, three kinds of tips(5-, 90-, 150-degree) were inserted into the living brain slice with the speed of 2mm/sec(high), 0.5mm/sec(intermediate), 0.125mm/sec(low) respectively. Time-lapse image of the surface deformation and haemorrhaging in the cortical area during insertion of a sharp probe are shown in Fig. 3. The results shows that sharp tips, faster insertion are better than blunt tips, slower insertion for penetrating the brain surface with less tissue compression, and although they can cause severe vascular rupture they cause less crush damage to neural cells. This may suppress the vascular response and inflammation in chronic applications.

3 Tissue-deformation forces during the insertion of neural probe array with multishanks

The insertion force required to fully advance the array was found to increase with decreasing insertion speed: when the high-density array with a shank spacing of 100 µm was inserted at 2, 0.5, and 0.125 mm/sec, the insertion forces were 88±39 (mean±SD), 270±97, and 962±171 mN, respectively (Fig. 4); and a similar dependence on probe velocity was observed for devices with shank spacings of 300 and 500 µm. The number of vascular elements presented by laminin expression was greatest for the tissue samples from the 100-µm-spacing insertion group, and least for the tissue sample from the 500-µmspacing insertion group.

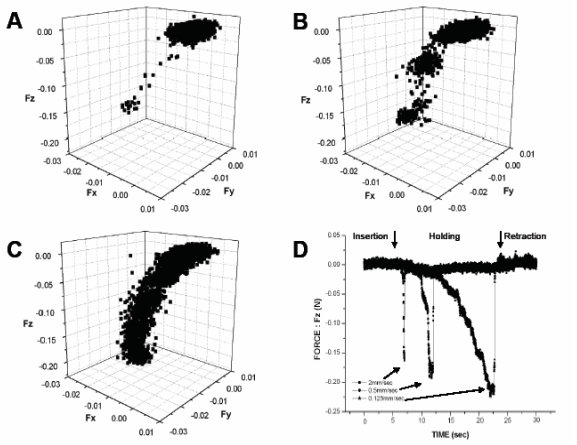

Fig. 4 Raw data of distribution of insertion force in three-axes during epidural insertion using a type I probe (ten shanks, 100-µm spacing) into the brain at 2 mm/sec (A), 0.5 mm/sec (B), and 0.125 mm/sec (C). (D) Z-axis components of the insertion force at the each speeds. Z-axis is the direction of insertion.

4 Summary

In this paper, we successfully showed how insertion force and tissue trauma occur during epidural insertion of the multi-shank silicon arrays. The results presented here clearly demonstrate that the force required to insert an electrode array can be dramatically reduced by the use of high-velocity insertion. The experimental model developed and knowledge of geometry effects from the experimental data obtained can be used in the design of multishank arrays for large-scale neural interfaces.

Acknowledgement

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