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Hydrogel-Based Automatic-Closing Cuff Electrode for Vagus Nerve Stimulation

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Abstract

We developed a hydrogel-based electrode device that can be deformed on its swelling to automatically wrap around a nerve (Fig. 1). A carbon fabric was sandwiched between the dried sheets of poly vinyl alcohol (PVA) hydrogels, one of which was previously stretched. The contraction force of the stretched PVA on the swelling caused the device to form a tubular shape. The carbon fabric electrode showed a capacitance of 0.54 mF/cm^2, which is larger than that of platinum, and was flexible enough to follow the deformation of PVA substrates. Attachment of the electrode to the nerve bundle took about 40 seconds and is expected to make the surgery of vagus nerve stimulation (VNS) more efficient.

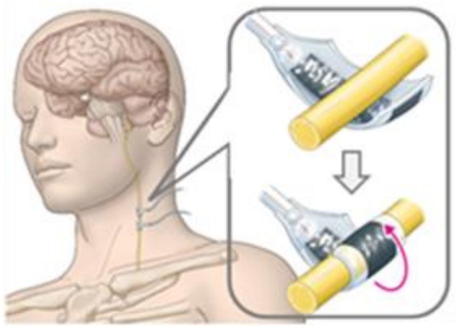

Fig. 1 Diagram of the vagus nerve and schematic diagram of attaching cuff electrodes.

1. Introduction

VNS is an effective treatment for epilepsy and depression by electrical stimulation of the left cervical nerve[1)]. We have previously developed an electrode device made of a conducting polymer-based electrode and PVA hydrogels, which wraps around and fixes itself to the nerve[2)]. The constituent materials are soft and safe for living organisms, and the organic electrode did not generate heat during MRI imaging. However, the operability of such hydrogel-based cuff electrode had not been considered. Since the surgical field is narrow and the electrodes are small, there is a risk of damaging the nerves during surgery. Therefore, in this study, we developed an electrode that can automatically wrap around the nerve on its swelling.

2. Experiment (or Theory)

The electrode was fabricated using PVA hydrogel for the base and a carbon fabric for the electrode body. PVA was mixed with dimethyl sulfoxide (DMSO) and water and thawed to obtain a gel precursor solution, which was then gelatinized by the freeze-thaw method. The gel was immersed in the solution to displace the solvent in the gel. The gels were then stretched and dried. The other PVA hydrogel was gelatinized by spin-coating the solution mixed with water and melted onto glass using the cast-dry method. Carbon fibers were sandwiched between the stretched and dried PVA hydrogel and the unstretched and dried one. The elasticity of hydrogel decreases as it dries and retains its shape when stretched. When swollen again, it regains its elasticity and recovers its original shape. This electrode utilizes this property to wrap around the electrode by simply pouring water on it (Fig. 2). The electrode was attached to the vagus nerve of a pig, and changes of heart rate were recorded.

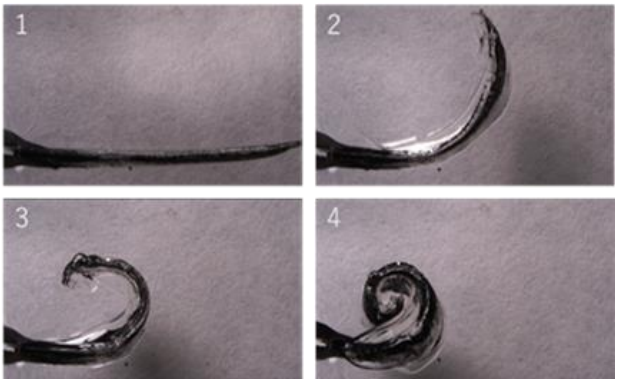

Fig. 2 Sequential images of the cuff electrode automatic closing.

3. Results and discussion

Fig. 3 shows an image of an electrode wrapped around a pig vagus nerve. When the dry hydrogel substrate absorbed water, it began to deform. The carbon fabric was flexible and did not inhibit the deformation of the hydrogel substrate. The electrode was placed under the vagus nerve and then covered the nerve within 40 s. The vagus nerve is known to bradycardia as a side reaction to the application of electric current, and Fig. 4 shows the change in heart rate when the nerve was stimulated with a current of 2 mA. The heart rate was bradycardic immediately after the start of stimulation, and recovered after the end of stimulation. This indicates the effect of stimulation.

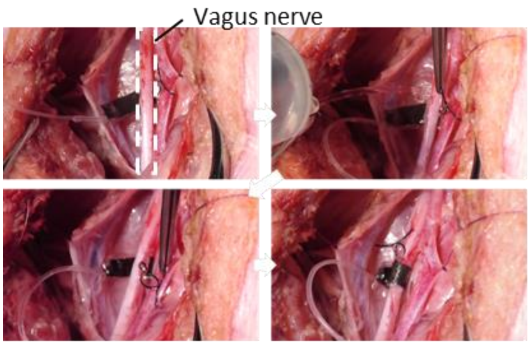

Fig. 3 Procedures of the Electrode attachment.

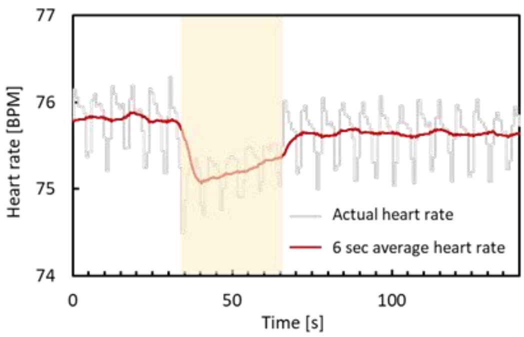

Fig. 4 Heart rate changes in a pig.

4. Conclusions

Drying of the PVA hydrogel improved the ease of operation of the hydrogel electrode. The carbon fabrics were flexible and wrapped around the nerve as the gel swelled, allowing the electrode to be attached in a simple procedure. Efficacy was demonstrated by stimulating the vagus nerve in a pig.

References

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