WHOLE NERVE RECORDINGS WITH THE SPIRAL NERVE CUFF ELECTRODE

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ABSTRACT

The feasibility of whole nerve recordings from the hypoglossal (HG) nerve is demonstrated in acute cats using the spiral nerve cuff electrode. A good contact between the nerve and the electrodes, provided by the spiral nerve cuff due to its self-coiling property, should improve the signal-to-noise ratio. An instrumentation amplifier with very low input noise characteristics is also utilized. The performance of the spiral cuff is studied in terms of signal-to-noise ratios and frequency characteristics. We conclude that the spiral nerve cuff electrode can reliably be used for acute recordings in laboratory environment.

INTRODUCTION

Whole nerve recordings are frequently needed in acute experiments to obtain information about physiological functions. Traditionally these electroneurograms (ENG) have been obtained by positioning the nerve on hook electrodes. However, cutting and desheating the nerve is often required for quality recordings. An alternative is to use a cuff electrode which significantly improves the mechanical stability.

Two types of cuff designs currently exist: 1) the tubing type and 2) the spiral type. Whole nerve recordings with cuff electrodes made of silastic tubing with circumferencially threaded Teflon-coated multistrand wires have been reported earlier [1]. With cuff electrodes the contact resistance between the outer surface of the nerve and the metal electrodes becomes a crucial parameter for the quality of the recordings. Due to the fixed size of the tubing type cuff electrode, the space between the nerve and the cuff is filled with fluid after implantation, short-circuiting a major part of the extra-neural potentials to be measured. The spiral nerve cuff, initially described by Naples et. al. [2], wraps around the nerve due to its self-coiling property and adjust its diameter to the nerve size. Because the surrounding fluid is squeezed out, this spiral nerve cuff should provide a better contact with the nerve as well as a better isolation from the outside disturbances. This spiral nerve cuff electrode has mainly been used in electrical stimulation. In this paper, we demonstrate the feasibility of using the spiral nerve cuff electrode for acute nerve recordings in the laboratory environment. The tests are done on the hypoglossal (HG) and Phrenic (Phr) nerves in cats. The effect of the recording configuration of the cuff on the signals is also analyzed.

METHODS AND MATERIALS

Spiral nerve cuff electrodes are made of two layers of silastic sheet, glued together using a silastic adhesive with one layer stretched and the other in relaxed position (Figure 1). The energy stored in the stretched layer generates the self-coiling property. Platinum foil electrodes that are welded to multistranded, Teflon-coated, stainless steel wires are placed between the double-layer and windows are cut to form the contact points. In our design, three foil bands were used with 5 millimeter separations. The final cuff diameter after implantation was about 1 millimeter which was the size of the HG nerve in the cats. The windows made on the Pt bands were approximately 1 millimeter wide. A low-noise instrumentation amplifier (AMP-01 from Precision Monolithics Inc.) is utilized to amplify the signals. The two circuit configurations that are used are shown in figures 2.

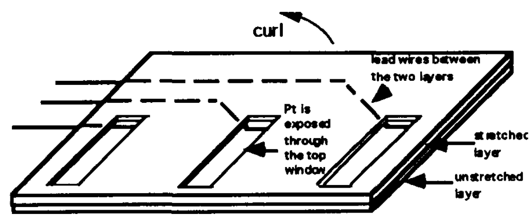

Figure 1: The spiral cuff electrode in open position. It curls in top-to-bottom direction.

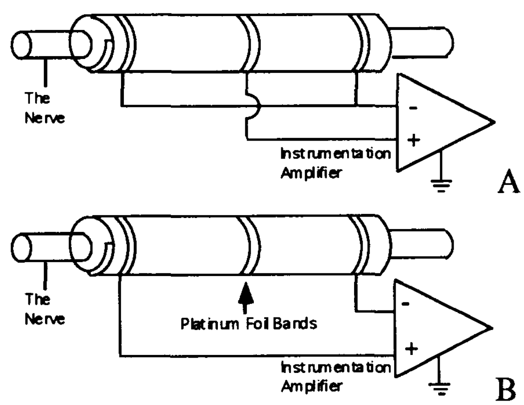

Figure 2: Recording configurations. A: Tripolar recording configuration, and B: Bipolar recording configuration.

All cats were anesthetized, tracheostomized and put on mechanical ventilator. About 2 cm. of the nerve length was carefully dissected. The spiral nerve cuff was placed around the HG nerve proximal to the bifurcation point of the branches to the muscles of the tongue. The recordings were made starting within two hours after implantation for a period of 9 to 12 hours.

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RESULTS

A typical ENG from the HG nerve recorded using a tripolar configuration (figure 2) is shown in figure 3. The phasic component of the HG nerve activity is modulated by the respiratory activity. Under hypoxic conditions the recorded amplitudes increased and were as large as 12 $\mu V_{peak\text{-}to\text{-}peak}$. The signal-to-noise ratio, which is defined as the root-mean-square (rms) value of the recorded potentials during the inspiratory period divided by the rms value during the silence period after the expiration, was 2.6. The corresponding values for two other experiments using the tubing cuff electrodes were 2.3 and 2.4.

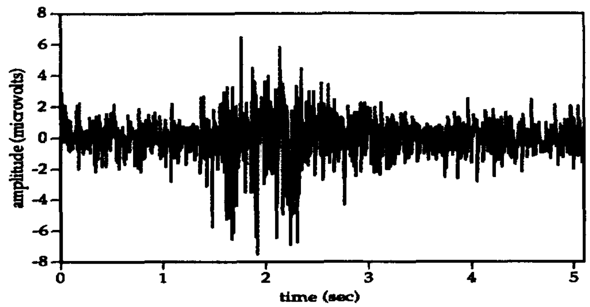

Figure 3: A typical ENG recorded from the hypoglossal nerve using the spiral nerve cuff electrode. The signal is filtered using a 300 Hz-10 KHz band-pass filter. Note that the input referred noise amplitude for the instrumentation amplifier is measured as 0.6 μVrms after filtering.

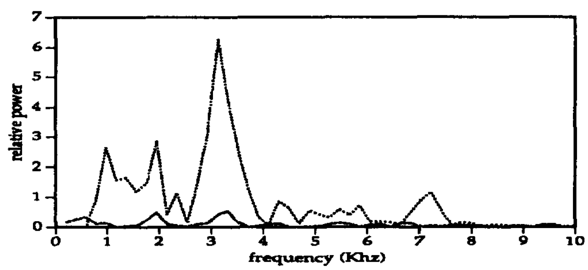

Figure 4: Power spectrums of two recordings from time windows taken during inspiration (dotted line) and silence (continuous line) periods using the tripolar mode. Each time signal is 20 msec long.

The power spectra calculated from epochs taken during inspiratory phase and the silence period are shown in figure 4. With the tripolar configuration the majority of the power is found between 600 Hz to 8 KHz. In figure 5, the effect of the recording configuration on the power spectrum of the signal is illustrated. Although the power peak between 2.5-4 KHz stayed approximately the same a very large component emerged between 500-2500 Hz with the bipolar configuration. This could be explained by the fact that the longer electrode separation of the bipolar configuration matches the spatial distribution of the action potentials from the larger fibers better. The tripolar configuration is mainly used for its superior immunity for disturbances.

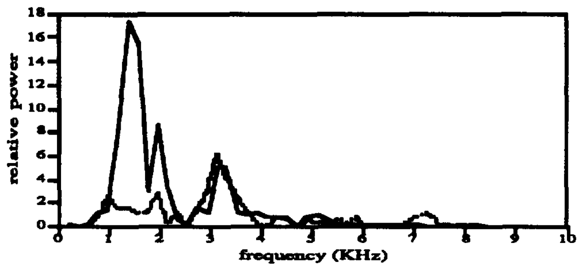

Figure 5: Comparison of the tripolar configuration (the broken line) with the bipolar configuration (the continuous line) during inspiration in terms of the power spectrums.

Finally, a filtered (300-3000 Hz), rectified and integrated (200 msec electronic averager) multiple breath HG recording, together with the Phrenic (Phr) activity, is shown in figure 6. The figure shows the increase in HG activity (after a delay) with hypoxia (8% O_2) and the post-hypoxic depression (apnea), thus, the ability of the spiral nerve cuff to record under different respiratory conditions.

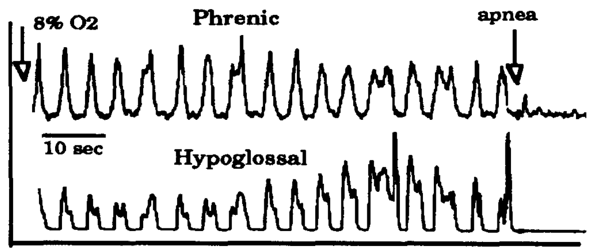

Figure 6: Rectified and integrated (200 msec time-averager) multiple breath HG and Phr activities. This demonstrates the increase in the HG activity due to hypoxia and the post-hypoxic depression (apnea). HG activity is recorded with the spiral cuff electrode.

CONCLUSION

We conclude that the spiral nerve cuff can give reliable ENG signals from the HG nerve under different respiratory conditions in acute laboratory experiments. It provides stable mechanical contact and gives workable signal-to-noise ratios without desheathing the nerve. The effective frequency band and the signal amplitudes depend on the electrode separation and the configuration being used. The self-sizing property of the spiral electrode should make it an ideal tool for chronic recordings of nerve activity.

REFERENCES

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2. Naples, G.G., Mortimer, J.T., Scheiner, A., and Sweeney, J.D. (1988) A Spiral nerve cuff electrode for peripheral nerve stimulation. IEEE Trans. BME, 35: 11, p. 905-16.

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