Whole Sensory Nerve Recordings With Spiral Nerve Cuff Electrode

T. Sinkjær(1), B. Hinge(1), A. Jørgensen(1), M.L. Jensen(2), M. Haugland(1)

(1) Department of Medical Informatics and Image Analysis, Aalborg University, Fredrik Bajersvej 7D, DK-9220 Aalborg
(2) Institute of Pathology, Aalborg Hospital, DK-9000 Aalborg, Denmark.

Abstract - **We have used a self-curling nerve cuff electrode to record sensory information from a cutaneous nerve. This type of cuffs has previously been used only for stimulation, but its mechanical properties could make it very suitable for recording also, since it can be fitted closer to the nerve than traditional cuffs without compromising the nerve. In this study we show that it is possible to record neural signals with at least the same quality as traditional cuffs.**

INTRODUCTION

In the intact organism, the central nervous system uses sensory feedback information from specialized sensors in the skin, muscles and joints to continuously regulate its motor output. It has been suggested [1] and shown in animal experiments [2] that it is possible to record and use this natural sensory information in a system for Functional Neuromuscular Stimulation (FNS). The previous nerve recordings have all been done with nerve cuffs with a fixed size ("split-cylinder" cuffs), reviewed by [3]. To reduce the risk of nerve damage due to constriction of the nerve, these cuffs need to have an inner diameter about 20% larger than the diameter of the nerve. For recording purposes, it is important to get the electrodes as well as the insulating cuff as close to the nerve as possible. For fixed-size cuffs this increases the risk of nerve damage, if the nerve diameter increases, e.g. due to post-surgical swelling. An alternative cuff design, the so-called spiral nerve cuff, or self-curling cuff, was suggested by [4]. It has the ability to change its diameter as a function of the nerve diameter, and may thus be fitted closer to the nerve without the risk of constricting the nerve if swelling occurs.

The spiral nerve cuff has until now only been used for stimulation purposes, having one or more button electrodes inside the cuff. The purpose of the work presented here was to design a spiral cuff electrode for recording of compound nerve activity to be used as a feedback signal for an FNS system, as has previously been done with fixed-diameter cuffs.

METHODS

Cuff design

The design of the 'standard' cuff electrodes has been thoroughly described in [3]. It consists of a length of silicone tubing with an inner diameter about 20% larger than the diameter of the nerve. Inside it, three circumferential electrodes are placed symmetrically, -one in the center and one in either end of the cuff. The electrodes are flexible multistrand stainless steel wires, that are deinsulated and sewn to the inside wall. The cuff(s) used in this study had an inner diameter of 1 mm and a length of 10 mm, and the electrodes were stainless steel wire (Cooner AS 632) with 20 strands.

The spiral cuff has been described in detail by [4]. It consists of two sheets of silicone that have been glued together, one stretched and the other slack. Depending on the amount of stretching, the two sheets will curl into a cuff with different diameters, -the more initial stretch, the smaller diameter of the finished cuff. The electrodes for stimulation have usually been button electrodes, 4.0mm^2 of platinum foil, 25µm thick. For recording, the electrodes should be circumferential, and for the initial experiments the recording electrodes were made of three pieces of platinum foil (25µm), cut in a 1.0 mm wide and 9 mm long piece. Teflon coated stainless steel wires (Cooner AS 631) were microwelded onto the outer surface of the electrodes for external connection. The cuff had a length of 10 mm, and the amount of stretching was 54%, giving a theoretical inner diameter of 1 mm [4].

Surgical implantation

Two rats (360g) were anaesthetized with Mebumal (5mg/100g) and chronically implanted each with a nerve cuff on the right sciatic nerve. One was implanted with a fixed-diameter cuff and the other with a spiral cuff. The lead wires (Teflon coated stainless steel, Cooner AS 631) were put in a pocket under the skin and the wound closed. The rats were administered subcutaneous Morphine at least 24 hours after surgery to releave post-surgical pain.

Data collection

Signals were recorded first immediately after implantation of the cuff, and then again 4 weeks after implantation. The rat was then anaesthetized as for surgery, the skin opened and the wires pulled out for recording. The two end electrodes were connected, and the difference between the center and the two end electrodes was amplified and bandpass filtered between 80Hz-24kHz. The skin on the foot was mechanically stimulated with a hand held force transducer. The force and the neural signal (electroneurogram or ENG) were recorded on tape together with the rectified and lowpass filtered ENG, representing the envelope of the raw ENG signal. The signals were then sampled off-line into a personal computer.

RESULTS

The design of the spiral nerve cuffs as described above showed to have an obvious problem. The combination of the small length and the three circumferential platinum

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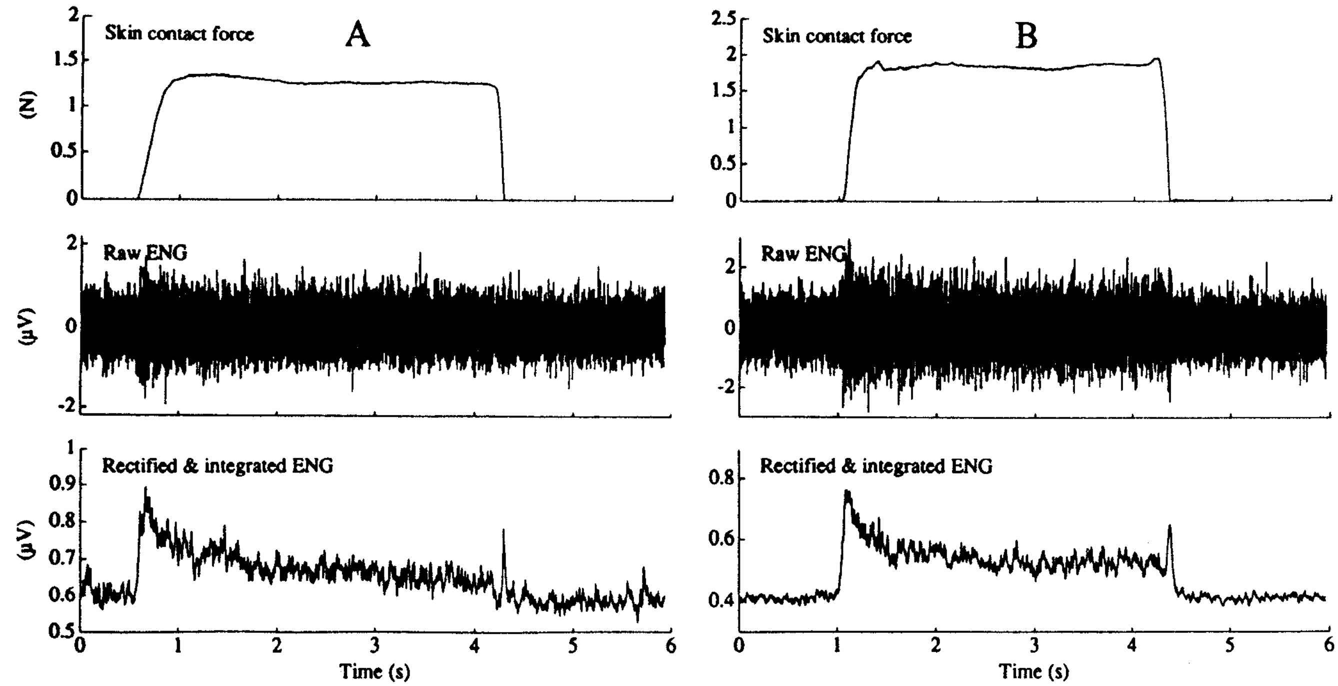

Fig. 1 Example of compound nerve activity recorded with a self curling cuff electrode implanted on the sciatic nerve of a rat. A: Traditional, fixed-diameter cuff. B: Spiral cuff.

electrodes caused the flexibility of the cuff to drop considerably. This meant that the cuff had to be fitted manually around the nerve during implantation, and thus the actual diameter of the cuff is not known exactly. It probably also meant that the mechanical advantages of this cuff design were reduced significantly.

Raw signals during a step-like application of force on the skin of the foot of the anaesthetized rats are shown in Fig. 1. In both cases, the ENG had a relatively constant amount of background activity, consisting of spontaneous nervous activity as well as amplifier and thermal noise, in agreement with results from previous studies with larger cuffs. The length of the cuffs used here was small compared to the cuffs previously used for the purpose (10 mm compared to 30-40 mm). Furthermore, the sciatic nerve is a mixed nerve, containing motor, as well as sensory fibers, the sensory fibers being not only cutaneous nerves but also muscle spindle fibers and joint afferents. These factors in combination caused the neural response to a touch of the skin to be very small (and barely visible in the raw signal) compared to the background activity. However, the nerve did respond to the stimulation, which is visible in the rectified and filtered ENG. This signal showed a similar response to a step force as has been observed in cat as well as in human experiments [5], starting with a strong phasic response followed by a smaller tonic level of activity, ending with a short positive peak when the force was removed.

DISCUSSION

The results of this study should be regarded as preliminary, since there are obvious necessary improvements in cuff design as well as in the investigatory method. One improvement will be to make the electrodes inside the cuff more flexible, for example by making them as a layer of conductive elastomer, as has previously been used for stimulation [6].

However, the results do show that it is possible to record signals from natural mechanoreceptors with the spiral cuff electrode, that are comparable to signals recorded with a more traditional fixed-diameter cuff. With improvements in the design of the electrodes, the mechanical properties of the spiral cuff promise better recording of neural signals (because of the possible closer electrode/nerve distance) and smaller risk of nerve damage. This work is in progress, and within the very near future more conclusive results regarding an optimal design of spiral cuffs for recording should be available.

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