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Transverse Intrafascicular Multichannel Electrode (TIME) an Interface to Peripheral Nerves: Preliminary In-vivo Results in Rats

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Abstract

This paper presents a new concept of intrafascicular multichannel electrode designed to be transversally inserted into the peripheral nerve. The ultimate goal of this electrode is to achieve high spatial fascicular and sub-fascicular selectivity, with minimal or no damage to the neural tissue. Acute in-vivo measurements on rat sciatic nerves during stimulation are presented.

Keywords: Electrode, intrafascicular, rat, peripheral nerve

1. Introduction

In recent years, many different approaches in the field of functional electrical stimulation (FES) arose to interface with the peripheral nervous system. The most widely investigated are probably the cuff electrodes, which encircle the nerve completely. Longitudinally intra-fascicular electrodes (LIFEs) are a different class of electrodes, which penetrate the nerve in a longitudinal direction and are capable to selectively stimulate single nerve fascicles [1,2]. Each has its inherent advantages: Stability for the cuff electrode, and selectivity for the LIFE, but, there are still some disadvantages to consider. (1) since a cuff encircles the whole nerve, only superficial fascicles can be selectively activated using a low current levels; (2) due to its longitudinal direction within the nerve, a LIFE can only selectively access fibers in its vicinity and would require multiple implants to access the entire nerve trunk (3) multiple implants of several LIFEs in different fascicles of the nerve is surgically challenging and therefore it would be challenging to selectively stimulate fiber bundles to different muscle groups [3].

In this paper a new electrode design is thus presented and first preliminary in-vivo results within a rat animal model shown. The transversal multichannel electrode (TIME) is designed to cross a peripheral nerve transversally to yield high spatial selectivity over the nerves cross section and to address single fascicles or even subgroups of those. Due to this transversal orientation a TIME should have superior properties regarding selectivity with the same invasiveness than LIFEs and incorporate a similar implantation procedure with the difference that only one device should be capable of innervating the whole nerves cross section of fascicles.

2. Methods

2.1 Electrode Design

The TIME is a multi-contact electrode array comprised of ten

active electrode sites and two indifferent electrodes. The device is implemented as a metalized (platinum) and microfabricated polyimide (UBE U-Varnish S by UBE Industries, Bad Homburg, Germany) substrate using state of the art technologies (Fig. 1).

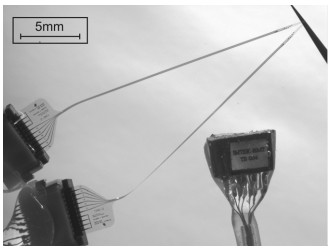

Fig. 1. Photograph of an assembled TIME device, composed of ZIF connectors, the thin-film substrate and a lead-out socket connector.

The active sites of the electrode have an effective diameter of 60 μm (80 μm metallization) and incorporate an impedance of approximately 30 kΩ with a phase angle of -68° at 1 kHz. Geometrical dimensions of the electrode were chosen to match the anatomy of the rat sciatic nerve at the thigh (Fig. 2). Prior to implantation, the electrode was kinked in the mirror line to form a V-shape with a width of merely a hundred microns, which ensures an easy penetration into the nerve. Zero insertion force (ZIF) connectors are used in the prototype for improved handling during implantation, since the electrodes can be implanted in a first step and contacted later on, and for reduced costs for this phase of development.

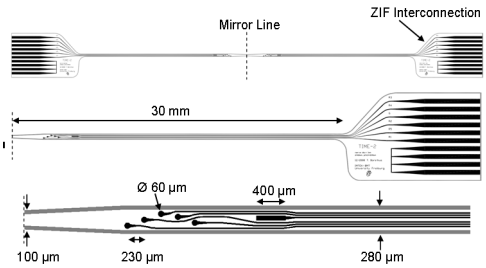

Fig. 2. Schematic design of a TIME electrode.

2.2 In-Vivo measurement

The TIME devices were implanted in the sciatic nerve of rats (n=8). Under anesthesia, the sciatic nerve was surgically exposed; then the structure was transversally inserted across the three main fascicles of the sciatic nerve (tibial, sural and peroneal nerves) proximal to the knee. The electrode was inserted with the help of a small straight needle attached to a 10-0 loop thread which was used as a guide to pierce the nerve and then pull the thin-film structure through it. Insertion was monitored under a dissection microscope to ensure that the electrode sites were located inside the nerve (Fig. 3).

The structure was then tested under stimulation via a remotely controlled stimulator [4].

Programmed series of pulses, consisting of stimuli between 10-1000 μA with pulse widths of 5-20 μs, were delivered through each contact in the TIME while the EMG signals were recorded from tibialis anterior, gastrocnemius and plantar muscles, innervated by different fascicles of the sciatic nerve [5]. The amplitude of the M wave of the EMG signals was measured to construct the recruitment curves of the three muscles.

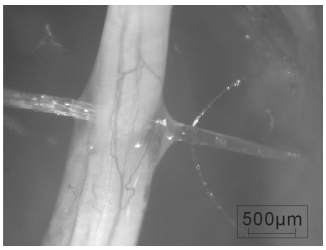

Fig. 3. Photograph of the rat sciatic nerve with a TIME device transversally implanted.

3. Results

The TIME devices induced no noticeable damage to nerve or tissue. Nerve conduction and behavioral tests proved that no functional impact was produced on the implanted nerves. Histological examinations of the distal segment of the nerve did not show significant evidence of axonal degeneration. In acute stimulation tests, the three tested muscles could be selectively activated at thresholds of 40-100 μA. Selective activation of one muscle was observed at low intensity stimulation, due to the close contact of one electrode site with the muscular nerve fascicle, whereas at higher intensities the stimulus spread and activated also other muscular fascicles. Recruitment tests proved that stimulation excited different axonal populations of the sciatic nerve, depending upon the electrode contact and the orientation of the implant (Fig. 4).

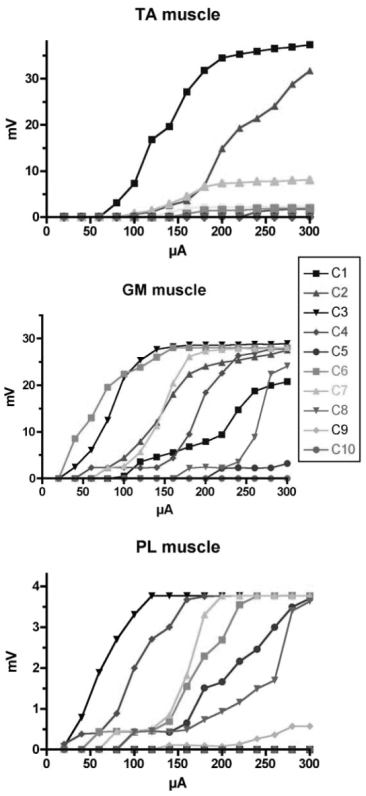

Fig. 4. Recruitment curves of the activation of tibialis anterior (TA), gastrocnemius (GM) and plantar (PL) muscles following stimulation through each one of the 10 contacts of a TIME implanted in a rat sciatic nerve.

4. Discussion and Conclusions

We are establishing the feasibility of the TIME for selective activation of motor fascicles in acute anaesthetised rat experiments. The results are promising and indicate that fascicular selectivity can be achieved. The transversal placement of the electrode may allow for access to several distinct nerve fascicles, thus minimizing the number of devices with respect to the longitudinal intrafascicular electrode (LIFE) concept [6].

It will also enhance selectivity and reduce the amount of stimulation current needed to activate the nerve fibers in comparison with extraneural electrodes, such as cuff-type electrodes. Further chronic studies are in progress assessing the stability of the implanted electrodes and the amount of foreign body reaction.

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