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Intraneural Stimulation Using 2D Wire-Microelectrode Arrays: II. Comparison with Single-Wire Electrode Results

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Abstract **– A two-dimensional wire-microelectrode array was inserted into the peroneal nerve of the rat through an incision. For each of the electrodes in the array the corresponding twitch-force recruitment curve was recorded from the extensor digitorum longus muscle (EDL). The mean value and standard deviation of the threshold current were found to be not significantly different from those for single wire electrodes. This suggests that the incision does not introduce significant (additional) current leakage.**

Introduction

In part I of this paper the experimental procedure involved in intraneural stimulation using two-dimensional wire-electrode arrays was presented. Recruitment curves were shown which resulted from stimulation with a 6 by 4 electrode array.

Since the electrode array was inserted through an incision in the nerve, one might ask what influence this deliberate generation of a wound has on the experimental outcome. Especially current leakage via fluid accumulating in the incision may be a major disadvantage of this insertion method for electrode arrays. In this paper we will therefore compare the results (part of which were shown in part I) to those resulting from stimulation with intraneural (single) wire-electrodes as presented in [1] and [2]. Since wire electrodes can be introduced into the nerve without making an incision first, current leakage is minimal in this case.

Methods

Acute experiments were conducted on 7 Wistar rats. A two-dimensional wire-microelectrode array was inserted into the intact peroneal nerve through an incision. The incision was directed along the longitudinal axis of the nerve and long enough to allow easy insertion of the electrode array.

For each of the electrodes in the array a recruitment curve was recorded from the EDL. The experimental procedure is extensively described in part I of this paper.

In one animal a 12-channel electrode array was used. Three array positions were evaluated for this animal. In six animals a 24-channel electrode array was used. In these cases one array position was evaluated. The electrodes in the 12- and 24-channel electrode arrays are on a regular grid of 6 by 2 and 6 by 4 electrodes, respectively. Dimensions are as given in part I of this paper.

Results

A. Electrode Arrays: Threshold Current Versus Slope

A total of 126 recruitment curves was recorded from 7 animals. Among these were three complete sets of 24 curves; partial sets were obtained from the other four animals. In part I of this paper a complete set of 24 recruitment curves is shown, recorded for one position of the 24-channel electrode array in one animal.

Each curve was characterized by the threshold current and the slope in the low-force range [1,2]. The low-force range was defined as the range where the twitch-force maximum was between 4.9 mN and 147 mN (corresponding to the force associated with a weight of 0.5 g and 15 g, respectively).

The threshold current versus slope scattergram is shown in Fig. 1(a). Each marker in this plot represents one recruitment curve. The mean values, standard deviations and 95 %-confidence intervals for the means are also indicated.

B. Comparison with Single-Wire Electrode Results

A similar scattergram is presented for single wire-electrode experiments [1,2], in which the nerve was immersed in Ringer's solution (Fig. 1(b)).

Table I lists the mean values and standard deviations of threshold current and slope for recruitment curves resulting from stimulation with two-dimensional wire-microelectrode arrays (Fig. 1(a)) and single-wire electrodes (Fig. 1(b)). These data suggest there is no great difference between the data in Fig. 1(a) and 1(b).

For both the slopes and the threshold currents, a two-sample F-test was employed to check whether the variances differ significantly for the data from the two-dimensional wire-microelectrode arrays and the single wire-electrodes. We found that these variances can not be considered significantly different ($\alpha = 0.01$, two-tailed rejection region).

A two-sample t-test (assuming equal variances for slopes and threshold currents) was employed to check whether the means of both the slopes and the threshold currents differ significantly for the data from the two-dimensional wire-microelectrode arrays and the single wire-electrodes. We

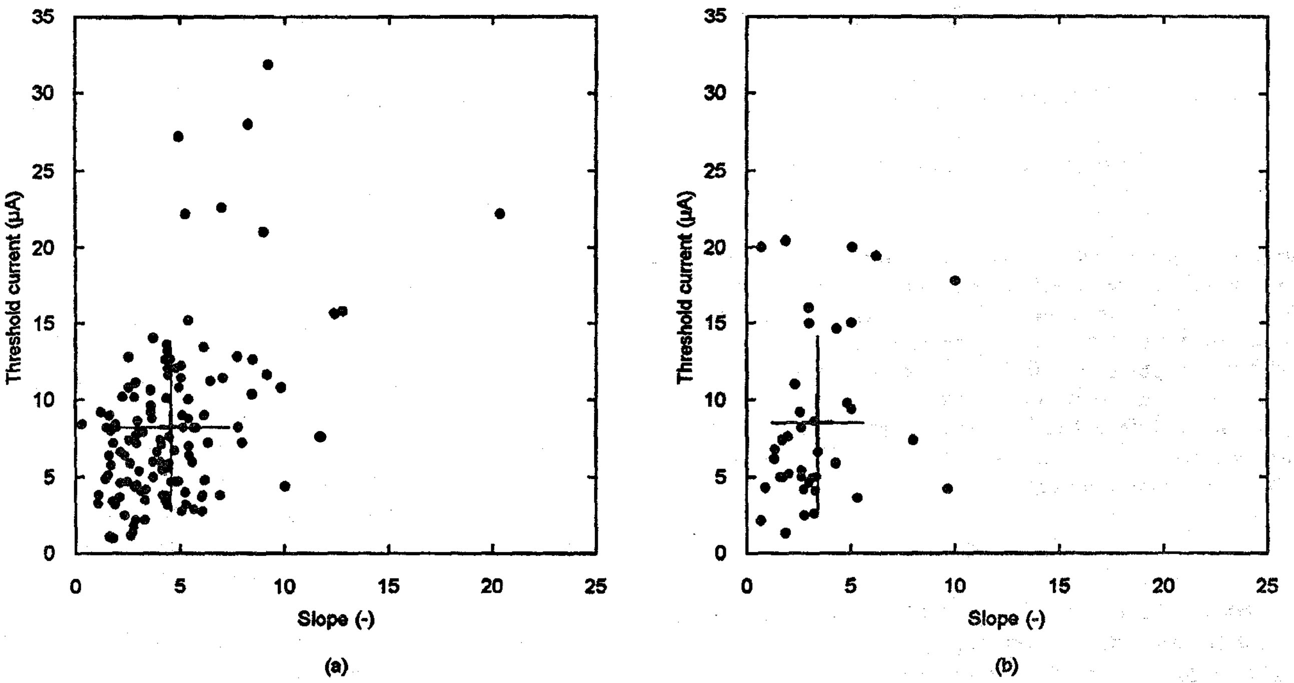

Fig. 1. Threshold current versus slope for recruitment curves resulting from stimulation with two-dimensional wire-microelectrode arrays (a) and single wire electrodes (b). Each data point corresponds to one recruitment curve. The mean values, standard deviations (light crosses), and 95 %-confidence intervals for the means (heavy crosses) are also indicated for both parameters. Note that both scattergrams are plotted on the same scale.

found that these means can not be considered significantly different ($\alpha = 0.01$, two-tailed rejection region).

Discussion

Although the means of the data points in Fig. 1(a) and Fig. 1(b) are not significantly different, Fig. 1(a) contains some extremes with threshold currents higher than 20 µA which are not seen in Fig. 1(b). We found that 6 out of these 7 data points were recorded for the same electrode array in the same animal. This might be an indication of excessive current leakage through the incision in this particular case.

TABLE I

MEAN VALUES AND STANDARD DEVIATIONS OF THRESHOLD CURRENT AND SLOPE FOR RECRUITMENT CURVES RESULTING FROM STIMULATION WITH TWO-DIMENSIONAL WIRE-MICROELECTRODE ARRAYS (2D-WMEA) AND SINGLE-WIRE ELECTRODES (SWE)

	Slope		Threshold current	
	2D-WMEA	SWE	2D-WMEA	SWE
Mean	4.6	3.4	8.2 (µA)	8.5 (µA)
Standard dev.	2.8	2.2	5.4 (µA)	5.6 (µA)
Observations	126	39	126	39

Conclusions

The threshold currents for intraneural simulation with an electrode array are not significantly different from those for stimulation with single wire electrodes. This suggests that the incision created for inserting an electrode array does not introduce significant (additional) current leakage.

Acknowledgment

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References

[1] W.L.C. Rutten, T.A. Frieswijk, J.P.A. Smit, T.H. Rozijn, and J.H. Meier, "3D Neuro-electronic interface devices for neuromuscular control: Design studies and realisation steps," *Biosensors & Bioelectronics*, vol. 10, pp. 141-153, 1995.

[2] J.P.A. Smit, W.L.C. Rutten, T.A. Frieswijk, and R. Busschers, "The influence of nerve fiber distribution on the recruitment behavior resulting from intraneural stimulation," in *Proc. 15th Ann. Int. Conf. IEEE Eng. Med. Biol. Soc.*, pp. 1198-1199, 1993.