SIGNAL STRENGTH IN NERVE CUFF ELECTRODE RECORDINGS

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Abstract-**The Nerve Cuff Electrode has been widely to record nerve signals. The correct choice of cuff dimensions and configurations has shown to be crucial for optimization of the signal to noise ratio in the recordings. Traditionally the peak-peak amplitude of the single fiber action potential is optimized through the choice of cuff dimensions. In this work the dependency of the root mean square value (RMS) of the nerve signal on the cuff dimensions was studied. This was done by superpositioning single fiber action potentials obtained from an inhomogeneous volume conductor model. The results showed that the RMS value of the nerve signal was considerably more sensitive to the cuff length than was the peak-peak amplitude.**
Keywords **- Nerve cuff electrode, ENG, action potential, cuff dimensions**

I. INTRODUCTION

Since Hoffer et al. in 1974 introduced the nerve cuff electrode for recording, it has developed into an important nerve interface both in physiological studies but also in rehabilitation engineering [1,2,3,4]. Through analysis and experimentation it has become clear that the right choice of cuff dimensions is crucial to the signal to noise ratio in the recordings [5, 6, 7]. The shape and amplitude of the single fiber action potential (SFAP) varies strongly with the cuff length and diameter, and with the diameter of the nerve fiber itself. Since the SFAP analysis of Stein [5,8] the traditional choice has been to choose the length of the cuff to achieve a high peak-peak amplitude of the SFAP. In many applications, though, the recorded nerve signal is a compound signal where many SFAP overlap, and the successive signal processing often involves some sort of averaging. In that case, the obtained information is closer related to the root mean square (RMS) of the electro neurogram (ENG). In the following we show how the RMS of the ENG depend on the cuff length and compare it with the dependency of the SFAP peak-peak amplitude.

II. METHODOLOGY

RMS values were calculated from ENG created by modelled SFAPs.

The SFAPs were modeled using an inhomogeneous volume conductor model [6]. Results were obtained for cuff lengths of 5 to 50 mm with 2.5-15mm intervals. The cuff diameter was 2mm for all calculations. All cuffs had three inner ring electrode contacts, (Fig. 1), which were combined in the traditional tripolar configuration [5]. The cuffs were modelled to have a perfect sealing. The nerve fiber diameters varied from 3 to 20μm with 1μm steps. ENG was obtained by randomly super-positioning 3000 SFAPs in a100ms window

Figure 1: *The cuff electrode with 3 inner ring electrode contacts*

The number of SFAPs was based on a combination of human tactile afferent firing rate [9] with fiber distributions in rabbit Tibial Nerve (10μm diameter fiber) [10].

Taking care of the end effects the root mean square of the ENG was calculated in the standard way:

$$RMS = \sqrt{\frac{\sum_{n=1}^{N} s_n^2}{N}},$$

where s_n is the sample n of the signal, and N is the total number of samples.

III. RESULTS

The RMS values of the modeled ENG for a 10μm diameter fiber is shown for different cuff lengths in Fig. 2. The RMS values are normalized with the maximum obtainable RMS value which is well reached for a cuff length of 50mm. For comparison the normalized peak-peak amplitude of the SFAP is also shown. For relatively shorter cuff lengths there is a high reduction of the RMS signal of the ENG as compared to peak-peak amplitude of the SFAP.

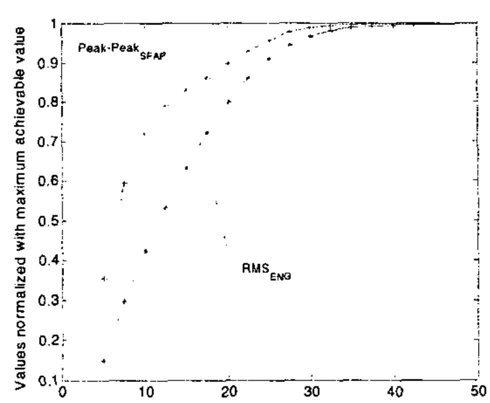

Figure 2: *Signal dependency on Cuff length for a 10 μm diameter fiber. The values have been normalized with maximum achievable values (for 50 mm long cuffs).*

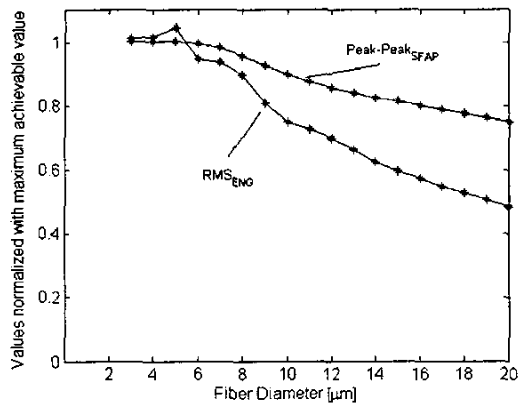

Figure 3: *Signal dependency on fiber diameter for a 20 mm long Cuff. The values have been normalized with maximum achievable values (for 100 mm long cuffs).*

For cuf lengths of 10 mm, only 42 % of the maximum achievable RMS signal is recorded whereas there is still 72% of the peak-peak SFAP available.

For longer cuff lengths the loss of RMS signal gets closer to the loss of peak-peak SFAP amplitude and at a cuff length of 40 mm the difference is less than 1%.

The dependency of the RMS on fiber diameter is shown for a 20 mm long cuff in Fig. 3, together with the dependency for the peak-peak SFAP amplitude. The values have been normalized with the maximum achievable values which were reached with a 100 mm long cuff. The lack of smoothness of the RMS-curve is caused by the randomized super positioning of the SFAPS. As could be expected there was none or only small loss of signal for the small fiber diameters, but a considerable loss of signal for larger fibers, where the loss of RMS signal was remarkably higher than the loss of peak-peak SFAP amplitude. For a 17µm diameter fiber, which is within the size of Ia and α motor fibers, the loss of the peak-peak amplitude of the SFAP was 22 % whereas the loss of the RMS value of the ENG was 45%.

IV. Discussion

The cuff length is often chosen to be in the order of the length of the transmembrane action potential. With a transmembrane action potential propagation velocity of 55800 nodes/second and a duration of 0.4ms [6] the length of an transmembrane action potential can be found to be 22 nodes. For a fiber diameter of 10 µm and an internodal distance of 100 times fiber diameter [6] this gives a cuff length of 22 mm. From Fig.2 this results in 93% of maximal peak-peak amplitude of the signal but 86% of the maximal RMS_{ENG}. To obtain 93% of the RMS_{ENG}, the cuff would have to be 6mm longer, as shown in Fig. 2.

A 20 mm long cuff which is often used for recording from fibers with diameters of 10-20µm will result in 24-50% loss of RMS signal in these fibers as shown in fig. 3.

Often cuff lengths are chosen to be 10,15 or 20 mm long. In many situations the length of the cuff is restricted by limited space available at the implant site due to anatomy. In these cases the cuff is often relatively short e.g. 10mm. Here a length increase of only a few mm to e.g. 12 mm is, if anatomically possible, worth considering since even such a small increase would increase the RMS value with 24% in the case of a 10µm diameter fiber and even more for larger fibers.

V. Conclusion

The results showed that the RMS of the ENG decreases faster with decreasing cuff length than the peak-peak amplitude of the SFAP. This was in particular prominent for relatively short cuffs or relatively large fiber diameters. In critical situations an increase in cuff length of only a couple of millimeters results in an significant increase in the measured RMS value of the signal.

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