A NEW PULSE SHAPE TO OBTAIN SELECTIVE SMALL FIBER ACTIVATION BY ANODAL BLOCKING

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Abstract-**The aim of this study is to investigate the use of a new pulse shape to obtain anodal blocking. This new pulse shape requires less charge per pulse compared to the conventional rectangular pulse and would therefore be safer in a chronic application. Computer simulation, used in this study show that using modified pulse shapes, charge reduction up 30.4 % to can be achieved.**

Keywords **- Selective stimulation by nerve size, square pulse, step pulse anodal blocking, charge reduction**

I. INTRODUCTION

Electrical stimulation of nervous tissue using implanted electrodes can be used to induce muscle contraction in patients with lesions in the central nervous system. When electrical stimulation is applied, large diameter nerve fibers need a smaller external stimulus for their activation than smaller fibers [1] so electrical stimulation recruits large diameter fiber before smaller ones. However, some applications in urology, gastroenterology and skeletal muscle activation require selective activation of small fibers without activating larger ones to obtain their functional goals.

Theoretical studies [2, 3] and experimental results from animal and human studies [2, 4, 5, 6] have shown that reliable selective activation of small fibers can be obtained using the method of anodal blocking. To obtain anodal blocking a tripolar cuff electrode is most commonly used. When external stimulation is applied, the fiber membrane is depolarized close to cathode and is hyperpolarized close to anode. Due to the hyperpolarization, an action potential (AP) can be blocked near anodes, both distal and proximal to the cathode. As with the excitation, a smaller external stimulus is needed for blocking large diameter fibers than for blocking smaller fibers. Therefore, first both large and small diameter fibers are activated by external stimulation. Then, higher stimulation amplitude is applied and propagation of an AP in large fibers is blocked.

A drawback of this technique is that it requires long pulses (typically >500 μs) and currents several times higher than for the excitation. These currents may cause neural damage and electrode contact corrosion, even when the pulses are biphasic, charge balanced and when contacts are made from materials that can stand high charge delivered through them [7]. The reason for this is that the induced charge per phase is too high. Therefore, the technique of anodal blocking with square pulse might not be safe for chronic use. The method would be safer if somehow the charge per phase could be reduced.

Charge reduction might be possible with the following idea: In a tripolar cuff configuration, (cathode flanked by two anodes), an action potential (AP) is induced under the cathode. When anodal block is applied, the AP is annihilated close to the anode, due to a high anodal current.

This work was supported by Danish Technical Research Council

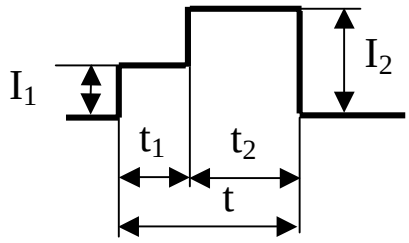

Fig.1. Stepped pulse: I_1-amplitude of the first step, t_1-duration of the first step, I_2-amplitude of the second step, t_2-duration of the second step, t-duration of a stepped pulse

However, as some time is needed for an AP to propagate from cathode to anode, it is not necessary to apply the high anodal current at the very beginning of the pulse [8]. Hence, it is possible to apply lower currents at the beginning of the pulse, so that the pulse has a shape of a step (Fig. 1).

In this study the idea of charge reduction has been explored using computer simulation.

II. METHODS

A two-part computer model was used for simulation of excitation and anodal blocking. The first part is an inhomogeneous and anisotropic volume conductor model [3]. A symmetrical tripolar cuff electrode with an inner diameter of 2 mm was placed around a sacral root of 1.4 mm diameter. The distance between contacts was 3 mm and the total length of the cuff was 8 mm.

The second part was a human fiber model [9]. With this model, it is possible to simulate excitation and blocking of an AP in myelinated fibers.

In all the simulations, a 12 μm, large fiber on axis of a nerve bundle was considered. For this fiber, one node is placed close to cathode and one node is placed close to the anode.

In order to investigate charge reduction obtained with the stepped pulse, first the parameters of a square pulse needed to block the fiber were determined. Therefore, the duration of the square pulse t and the amplitude of the blocking current I_{bl} were determined.

For the stepped pulse, amplitude I_1 and duration t_1 of the first step were given the predefined values, I_1 =0.1, 0.25, 0.5 and 0.75 I_{bl}, and t_1= 25, 50… 175, 200 μs. The amplitude of the second step I_2 was increased until blocking was obtained.

III. RESULTS

The duration of the square pulse (t=430 μs) was chosen so that the blocking current (I_{bl}=690 μA) and the induced charge Q are minimal. The duration of the stepped pulse was the same as for the square pulse t=430 μs.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle A New Pulse Shape to Obtain Selective Small Fiber Activation by Anodal Blocking	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Center for Sensory-Motor Interaction Aalborg University Aalborg, Denmark	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 3	

A. Blocking current of the stepped pulse I_2

Fig. 2 shows the relation between the amplitude of the second step I_2 and the pulse duration of the first step t_1, for four different amplitudes of the first step I_1. For all the amplitudes of I_1, the blocking current of the second step I_2 increases as duration of the first step t_1 increases. However, for I_1=0.25 I_{bl} this increase is the least pronounced and I_2 has the smallest amplitudes.

For the longer duration of the first step t_1>100 μs, the difference between blocking currents for lower (0.1 and 0.25 I_{bl}) and higher (0.5 I_{bl} and 0.75 I_{bl}) I_1 is more pronounced.

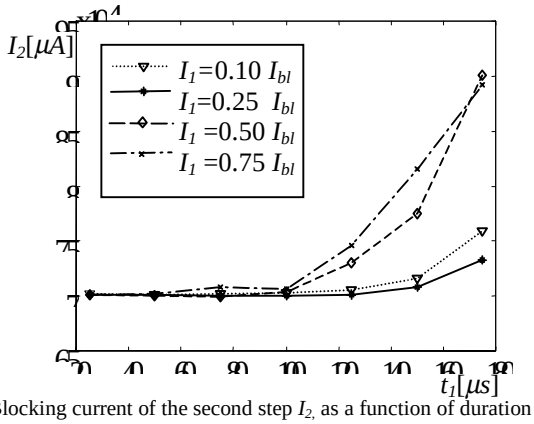

Fig.2. Blocking current of the second step I_2, as a function of duration of the first step t_1, for four different values of the amplitude of the first step I_1.

B. Charge reduction with the stepped pulse

Fig. 3. shows the charge induced by the stepped pulses with characteristics given in Fig. 2. Mark **o** for t_1=0 denotes charge induced with the square pulse of duration t=430 μs and amplitude I_{bl}. With the amplitude of the square pulse I_1=0.1 I_{bl} and t_1=175 μs a maximum charge reduction of 30.4 % was obtained.

For I_1= 0.1 I_{bl} and 0.25 I_{bl} the induced charge decreases with increasing duration of the first step. For I_1= 0.5 I_{bl} and 0.75 I_{bl}, the induced charge first decreases with increasing duration of the first step but starts to increase for t>100 μs.

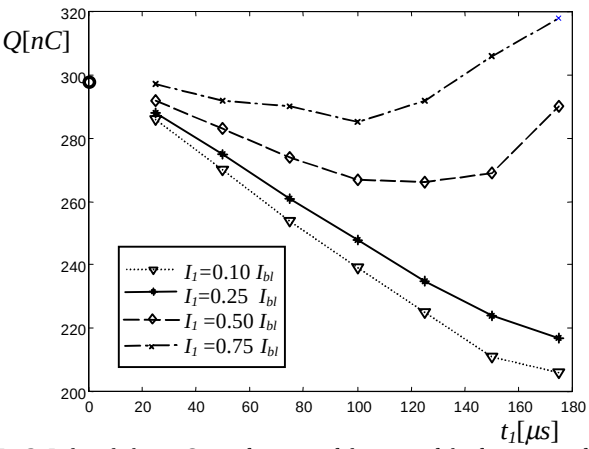

Fig.3. Induced charge Q as a function of duration of the first step t_1, for four different values of the amplitude of the first step I_1. The induced charge for the square pulse is given for t_1=0 μs and is marked with **o**.

For t_1≥175 μs it is not possible to obtain blocking with the stepped pulse for any amplitude of the first step I_1 although for lower currents induced charge decrease when duration of the first step is increased form 25 to 175 μs.

IV. Discussion

This paper shows that it is possible to reduce the charge per pulse by applying the stepped instead of the square pulse to obtain the anodal blocking.

For I_1=0.25 I_{bl} it is possible to obtain the lowest blocking current. For I_1=0.1 I_{bl} and 0.25 I_{bl} the current of the first step is too low to induce an *AP*, but only depolarizes the membrane. The *AP* is generated during the second step. Although it would not be possible to obtain blocking with the square pulse of amplitude I_2 and duration t_2, the rise time of the AP is shorter so it needs less time to propagate from the cathode to the anode because of the previously depolarized membrane. For I_1=0.25 I_{bl} depolarization in the first step is the highest so amplitude of the second step is the lowest.

Although blocking current is the lowest for I_1=0.25 I_{bl}, induced charge is the smallest for I_1=0.1 I_{bl} because of the lowest charge induced in the first step (Fig. 3). Charge reduction is possible with all stepped pulses for t_1≤150 μs.

Although duration of high amplitude pulse was decreased, it was long enough to produce excitation of small (5 μs) fibers.

In order to validate these theoretical predictions, we plan to do acute animal experiments.

V. Summary and Conclusion

The anodal blocking technique for selective activation of nerves requires both a relative high current and long pulse duration. Such a pulse induces to the underlying tissue a charge that may damage the nerves and produce contact corrosion in long-term applications.

Changing the pulse shape from square to the stepped pulses will make it possible to reduce the induced charge by almost a third.

Acknowledgment

The authors would like to thank to J. J. Struijk for the basic versions of simulation models.

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