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INFLUENCE OF THE MAGNETIC FIELDS ON FROG SCIATIC NERVE

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SUMMARY

The constant magnetic field (1000-7120 gauss) was applied to previously stimulated frog sciatic nerve. The following was observed : a) There is no instantaneous effect of either parallel or perpendicular magnetic field on compound action potential amplitude. b) Parallel magnetic field of 1000-7120 gauss does not change the amplitude of compound action potential significantly with time. c) When perpendicular magnetic field was applied to the nerve, an increase in the amplitude of compound action potential was observed, which can mean that the nerve exhibits some sort of magnetic anisotropy.

INTRODUCTION

The influence of the magnetic field on the living organism was noticed as far back as 200 years B.C.(1). In the 18th century F.A. Mesmer (2) applied magnetic field to treat the different states of nervous sickness, but more serious studies started at the beginning of the 20th century, when d'Arsonval (3) found that A.C. magnetic field produces the so called magnetic phosphens phenomena. Later it was shown that the magnetic field modified the growth of bacteria (4). In a recent study it was reported that "the external segments of frog retinal rods may orient parallel to the direction of a constant and homogenous magnetic field" (5). This fact was described in the terms of magnetic anisotropy (6). If the magnetic anisotropy is present in a membrane structure it may become an interesting experimental parameter in the study of the intramembranous phenomena.

Abbreviation: Compound Action Potential = CAP

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The purpose of this work is to study the effect of magnetic fields on the electrical properties of an excitable tissue like nerve : we have therefore applied parallel and perpendicular magnetic fields to previously stimulated frog sciatic nerve.

We have chosen the frog sciatic nerve because this represents the simplest model for measuring the compound action potential (CAP) with external electrodes. The term CAP we define as the sum of the action potentials in single fibers.

MATERIALS AND METHODS

The nerves, 5-7 cm long, carefully dissected, were placed on four platinum electrodes. Two of them were used for stimulating, and two for recording the CAP. The nerve was moistened with Ringer's solution (111 mM NaCl, 2.5 mM KCl, 1.8 $CaCl_2$, 2.4 mM $NaHCO_3$) buffered with CO_2 to pH 7.4) and closed in a plexi box containing also Ringer's solution. To activate the nerve, constant voltage pulses were applied by a stimulator Tekelek Airtronc. The amplitude and duration of these pulses were chosen (1-2 V with duration 0.05-0.2 msec and frequency 1Hz) to activate only a part of nerve fibers and to obtain a CAP of 7-10 mV.

To detect the possible effects of the perinerium and Ringer's solution the nerve was injured and then constant voltage pulses were applied to it without magnetic field and in the magnetic field. No changes were detected in the amplitude of these pulses.

CAP was amplified by Keithley 604 amplifier and recorded on the storage oscilloscope Tektronix D11.

RESULTS AND DISCUSSION

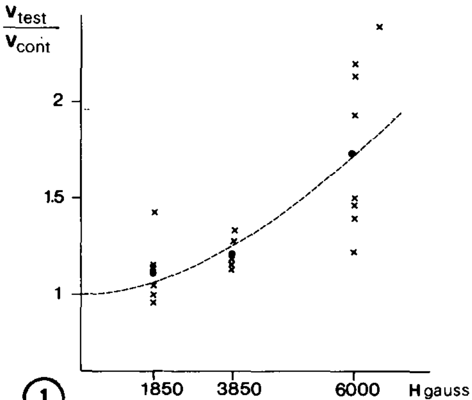
In preliminary experiments it was found that if the CAP amplitude (V_{cont}) had been constant during the first 10-20 min. then it remained constant for at least 3 hours. Therefore after a control period of 10-20 minutes in which CAP varied less than ± 0.5 mV homogeneous and constant magnetic field was applied with a Drush electromagnet parallel or perpendicular to the nerve axis. The measurements of CAP amplitude were carried out for 20-130 minutes.

The following was observed :

1°) There is no instantaneous effect of either parallel or perpendicular magnetic field on CAP amplitude.

2°) Parallel magnetic field of 1000-7120 gauss does not change the amplitude of CAP significantly with time.

3°) When perpendicular magnetic field was applied to the nerve an increase in the amplitude of the CAP was observed (we will



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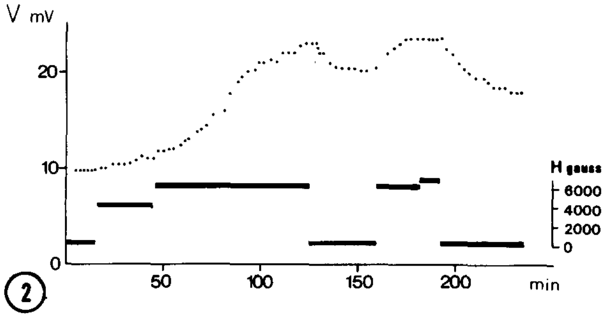

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Figure 1

The dependence of the ratio V_{test}/V_{cont} (details in the text) upon intensity of the magnetic field. Crosses (x) represent single measurements of the total action potential ratio ; dotts (o) are the mean values of all measurements in a given magnetic field.

The dashed line is a hand drawn curve to show the increase of V_{test}/V_{cont} ratio.

Data are statistically analysed by Student t test.

a) In the magnetic field of 1850 gauss the difference between the mean V_{test}/V_{cont} ratio and 1 is not statistically significant (p = ns).

b) In the magnetic field of 3850 gauss : $p < 0.02$

c) In the magnetic field of 6000 gauss : $p < 0.001$

Figure 2

The results from one of the experiments showing the changes of total action potential amplitude in different magnetic fields and as a function of time.

One dott (o) represents a single total action potential amplitude measurement ; the thick daşhes (—) indicate magnetic field values.

call this V_{test}). The increase of the CAP amplitude was as follows ; (a) in 1850 gauss V_{test}/V_{cont} = 1.15 ± 0.15 SD, (b) in 3850 gauss V_{test}/V_{cont} = 1.32 ± 0.27 SD, (c) in 6000 gauss V_{test}/V_{cont} = 1.78 ± 0.3 SD. The (a) results were obtained in n = 6 measurements, the (b) for n = 5, the (c) for n = 7 (figure 1). However, in one measurement in 6600 gauss V_{test}/V_{cont} was equal 2.4 (figure 2).

4°) The maximum CAP amplitude(V_{max})was in the range of 20-30 mV. The action of magnetic field increased the CAP amplitude so that V_{test}/V_{max} = 0.6 to 0.8.

As it can be seen from figure 2 the effect appeared 15-20 minutes after applying magnetic field, CAP increased slowly for 30-60 minutes finally reaching a stable value. When the magnetic field was reduced to zero, the CAP remained constant during the first 6-9 minutes, then decreased slowly, but without attaining the control value V_{cont}. This means that either the time of observation was too short to see the complete effect or the process is irreversible.

In summary it can be seen that the parallel magnetic field does not affect nerve excitability and the perpendicular magnetic field produces significant variation of the CAP amplitude. This shown that the nerve exhibits some sort of magnetic anisotropy.

The influence of perpendicular fields could be explained by assuming either a change of ion movement itself across the membrane or a change of ion trajectory. However a direct effect of the magnetic field on the ions should be excluded because the CAP change is not immediately but appears after some delay (15-20 minutes).

Thus we are inclined to think that only a change in the membrane itself accounts for the observed results.

Although the Hodgkin-Huxley model describes the action potential in single fibers, it may be extended to a multifiber system. The increase in the CAP amplitude corresponds in terms of the Hodgkin-Huxley model to an increase in sodium permeability P_{Na}. However this increase, if any, can not explain observed phenamenon.

We can consider two possibilities :

1°) The fibers resistance decreased and in consequence the current crossing the fibers between two stimulating electrodes increases (constant voltage pulses were applied to the nerve) More fibers generate action potential thus CAP increases.

2°) The fibers not activated in the control state, become activated in a magnetic field because the field has changed their threshold potential. This is the most likely explanation, although not exclusive, since the V_{test}/V_{con} ratio was as high as 1.8 in 6000 gauss fields.

It is well known that during the depolarization impulse, the inward sodium current I_{Na} increases; in the same time other currents, leaky outward current, I_L, and potassium outward current, I_K, increase as well but not in the same way.

After a time Interval Δt, $I_{Na} = I_K + I_L$; thus the instantaneous membrane potential reach the threshold potential.

If (a) $I_{Na} > I_K + I_L$ the action potential is generated by the axon, whereas (b) $I_{Na} < I_K + I_L$ the membrane potential repolarises and comes to the resting potential value.

The sodium ions cross the membrane through specific channels/ gates/ which in steady state are mostly closed. The gates open if the depolarization impulse injects into the membrane enough of electrical energy to create the so called gating current (7,8).

The magnetic field applied to the nerve may modify the threshold potential of single axon which become closer to the membrane potential. To satisfy the condition (a) less gates need to be open. Some of the fibers no activated in the control state begin to generate the action potential in the magnetic field. Hence CAP amplitude is observed to increase.

Further investigations will show which hypothesis is the most probable.

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REFERENCES

1. Frei E., (1972), IEEE Transactions on Magnetics MAG-8, 407-413.
2. Messmer F., (1971), in Magnetisme Animal, (Edit. Payot).
3. D'Arsonval M., (1896), C.R. Soc. Biol. Paris 48, 450.
4. Gerencser V.F., Barnothy M.F. and Barnothy J.M., (1962), Nature 196, 539-541.
5. Changneux R., Changneux H. and Chalazonitis N., (1977), Biophys. J. 18, 125-127.
6. Hong F.T., Mauzerall D., Mauro A., (1971), Proc. Nat. Acad. Sci. USA 68, 1283-1285.
7. Hille B., (1976), Ann. Rev. Physiol. 38, 139-149.
8. Ulbrich W., (1977), Annu. Rev. Bioph. Bioeng. 6, 7-31.