

# Effects of strong magnetic fields on recovery processes in nerve excitation

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## ABSTRACT

We investigated the effects of 8 Tesla (T) magnetic fields on frog sciatic nerve excitation processes. The conduction velocity was not significantly affected by 8 T magnetic fields. However, the peak of the compound action potential (CAP) during the refractory period was gradually enhanced by 8 T magnetic field exposure for 3 hours. Although the mechanisms have not yet been clarified, we hypothesize that the recovery process of membrane excitation was immediately accelerated by the magnetic fields just after Na channels were inactivated. These results reveal the possible effects of static magnetic fields on the peripheral nervous system, particularly the behavior of ion channels associated with nerve fibers.

## INTRODUCTION

Recent technological developments in medicine, such as magnetic resonance (MR) imaging have increased human exposure to strong magnetic fields. The effects of static magnetic fields on nerve excitation have been investigated; however, the results obtained were contradictory. Schwartz found no significant effects of parallel or perpendicular 1.2 Tesla (T) magnetic fields on the conduction velocity of isolated lobster giant axons [1]. In another study by Gaffy and Tenforde, no effects on the action potential amplitude, conduction velocity, and refractory period of frog sciatic nerves after continuous exposure to perpendicular or parallel 2.0 T magnetic fields for 4 h were also reported [2]. Satow and Matsunami, on the other hand, demonstrated that 0.7 T magnetic fields increased excitability during the recovery period of bullfrog sciatic nerves in a conditioning-test stimulation paradigm during exposure for 3 h [3]. Hong also reported that a magnetic field with an intensity higher than 0.5 T for more than 30 seconds increased the amplitude of the submaximally evoked compound muscle potential in the tail nerve of anesthetized rats [4]. In these reported studies, the biological effects of static magnetic fields were not significant, but the effects of magnetic fields on nerve excitation were discrepant. A theoretical analysis concluded that a magnetic field of approximately 24 T is required to produce a 10 % reduction in conductivity [5]. Therefore, further studies must be carried out to examine the effects of stronger static magnetic fields on the nervous system to resolve the discrepancies and to clarify the mechanisms of magnetic field effects. This study focuses on the dynamic membrane excitation and refractory characteristics of bullfrog (*Rana catesbeiana*) sciatic nerve fibers exposed to 8 T strong static magnetic fields.

## METHODS

Adult bullfrogs, *Rana catesbeiana*, (weight = 500 ~ 800 g; length = 150 ~ 180 mm) were used in this study. The dissected sciatic nerve bundle (diameter = 2.5 mm; length = 60 mm) of a bullfrog was laid over twelve platinum electrodes spaced 5 mm apart in an acrylic moist nerve chamber (70 × 20 × 25 mm)(Fig. 1). The chamber was placed at the center of a superconducting magnet (Oxford, U.K.), 100 mm in diameter and 700 mm long, which produced magnetic fields of up to 8 T at its center (Fig. 2A). Although this system had a field distribution along the bore axis (Z axis), the chamber was exposed to a nearly homogenous magnetic field of 8 T (Fig 2B). The ambient temperature in the magnet was maintained at 24°C ± 0.2°C by circulating temperature-regulated water in a coiled tube. Fig. 3 shows the micrograph of a transverse section of a bullfrog sciatic nerve. The star indicates myelinated nerve (diameter 5 ~ 8 μm). The arrowhead indicates unmyelinated nerve (diameter about 1 μm). The myelinated nerve, which has higher conduction velocity and larger amplitude, was mainly examined in this study.

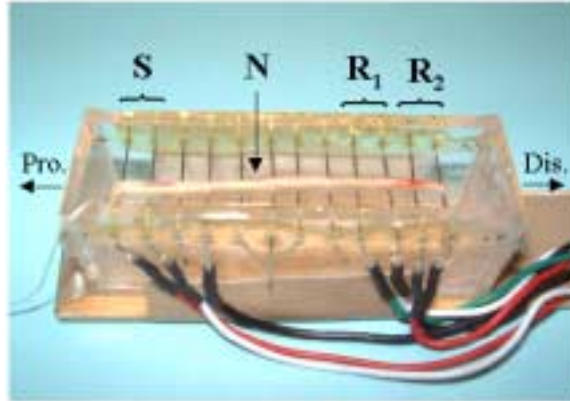


Fig.1. The moist nerve chamber ( $70 \times 20 \times 25$  mm). Twelve platinum electrodes were spaced 5 mm apart. A sciatic nerve bundle (N), laid over the platinum electrodes, was stimulated by paired electrodes at the proximal end (S). Compound action potential (CAP) was measured across two recording electrodes at the distal end ( $R_1$  and  $R_2$ ).

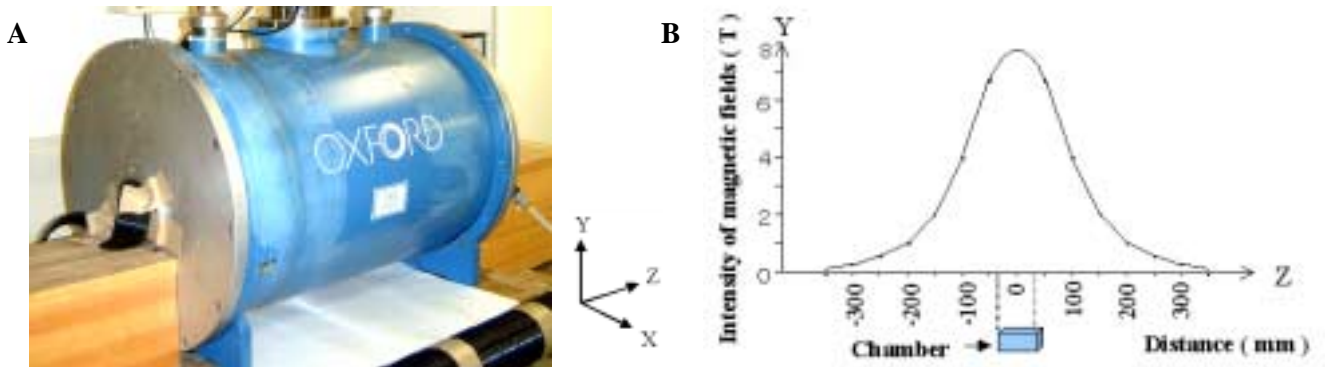


Fig. 2. The superconducting magnet (Oxford, U.K.), 100 mm in diameter and 700 mm long (A). Distribution of magnetic fields (B) along the bore axis (Z axis). The chamber was exposed to a nearly homogenous magnetic field of 8 T.

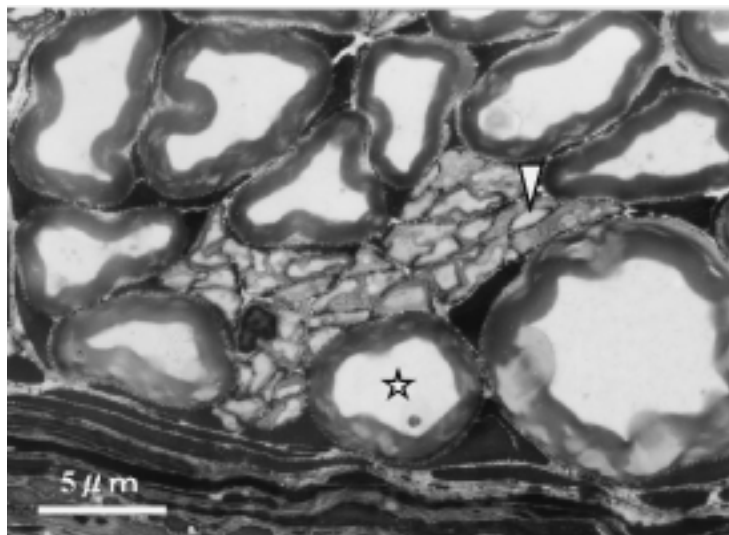


Fig. 3. A micrograph of a transverse section of the bullfrog sciatic nerve. The star indicates myelinated nerve. The arrowhead indicates unmyelinated nerve.

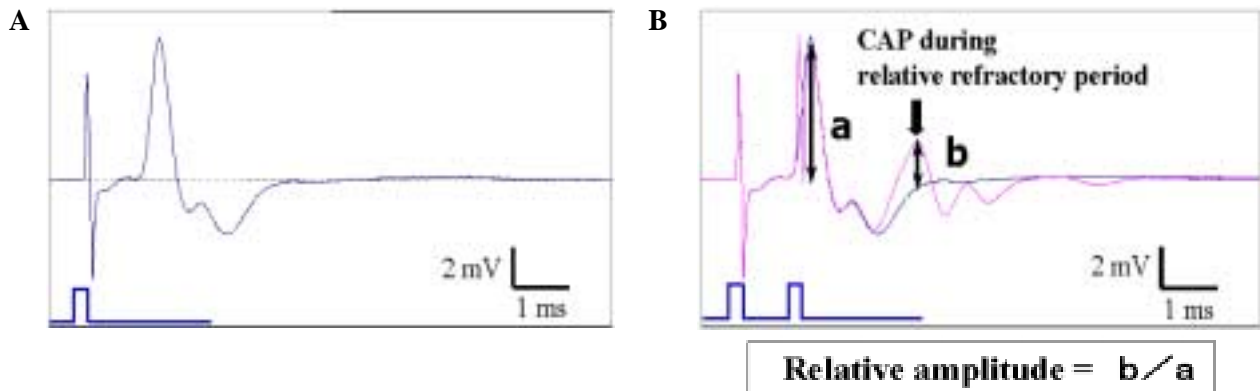


Fig. 4. Compound action potential (CAP) stimulated by a single pulse (A). Compound action potential (CAP) stimulated by a double pulse (B). Relative amplitude refers to the amplitudes of the CAP during the refractory period normalized to the maximal peak of CAP at varying interpulse intervals.

The nerve bundle was electrically stimulated and then exposed to 8 T static magnetic fields for the long axis of the nerve bundle parallel to magnetic field during the nerve excitation processes. A current was applied to the sciatic nerve bundle (N) through 2 stimulus electrodes at the proximal end (S) and the compound action potential (CAP) was measured across paired recording electrodes at the distal end (R<sub>1</sub> and R<sub>2</sub>). A measurement instrument (MEB-5508, Neuropack, NIHONKOH DEN Co., Ltd) was used to stimulate (stimulus intensity = 4.0 mA; duration = 0.1 ms) the nerve bundle and to record the CAP. To investigate the possible magnetic field effects on refractory processes, double pulse stimulation with varying interpulse intervals (1.0 ms, 1.1 ms, 1.5 ms, 2.0 ms) was applied to the nerve bundle, and the CAPs were measured before and after magnetic field exposure. We measured the changes in relative amplitude, which refers to the amplitudes of the CAP during the refractory period normalized to the maximal peak of the CAP at varying interpulse intervals (Fig. 4). The CAPs were measured for two groups, the control group (without magnetic field exposure) and the exposed group (with magnetic field exposure for 3 h).

## RESULTS

Fig. 5A shows the time-course of changes in relative amplitude. The peak of the CAP during the relative refractory period for each interval was gradually enhanced by 8 T magnetic field exposure for 3 h compared to the control group. The effects were deemed statistically significant during magnetic exposure ( $p < 0.01$  at 1.0 ms and 1.1 ms,  $p < 0.05$  at 1.5 ms and 2.0 ms) by repeated measures of ANOVA. Fig. 5B shows that the increase of the relative amplitude of each interval after exposure for 3 h was statistically significant by about 10% compared to the control group ( $p < 0.05$ ) as indicated by the Wilcoxon signed rank test. On the other hand, conduction velocity ( $37.83 \pm 6.36$  m/s before vs.  $39.66 \pm 7.87$  m/s after magnetic exposure) was not significantly affected by magnetic exposure in the exposed group.

## DISCUSSION

Our result indicates that conduction velocity is not significantly affected by 8 T magnetic field exposure. This result agrees with earlier studies by Schwartz (1.2 T)[1] and Gaffey and Tenforde (2.0 T)[2]. However, we showed that the peak of the CAP during the relative refractory period is gradually enhanced by 8 T magnetic field exposure for 3 hours. The mechanisms responsible for this increase have not yet been clarified. One possible explanation is that the stronger magnetic fields (8 T) used in this study compared to previous studies affected the nerve excitation processes. Another possible explanation is that we focused on an unstable state of the nervous tissue membrane during the refractory period, when the Na and K channels opened and closed. The ion channels on the excitable membrane may be susceptible to functional changes by the magnetic fields that affect nerve excitation processes. As established by Satow and Matsunami, increased excitability during the recovery period in bullfrog sciatic nerve results from a decrease in threshold, probably due to a dysfunction of the Na-K pump [3].

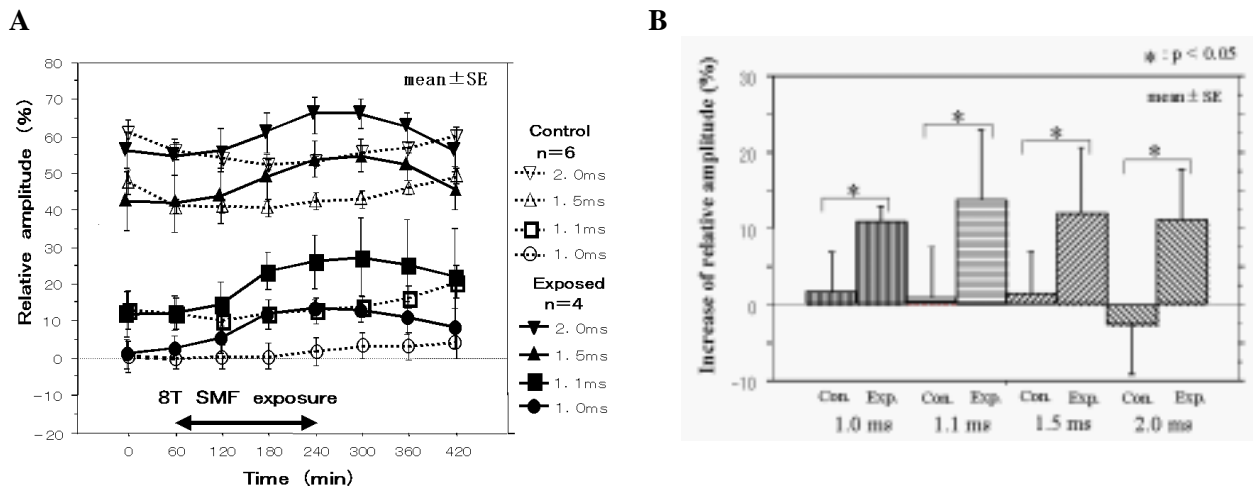


Fig. 5. Effects of magnetic fields on compound action potential (CAP) during the refractory period. The time-course of changes in relative amplitude during double pulse stimulation at varying interpulse intervals (1.0 ms, 1.1 ms, 1.5 ms, 2.0 ms) in exposed - control groups (A), and the increases of relative amplitude at each interval after 3 h exposure in exposed - control group (B). The data are expressed as mean  $\pm$  SE. The peak of the CAP during the relative refractory period at each interval was gradually enhanced by 8 T magnetic field exposure for 3 hours compared to the control group. \*  $P < 0.05$  was considered statistically significant.

We hypothesize that the recovery process of membrane excitation was immediately accelerated by the magnetic fields just after Na channels were inactivated. In conclusion, these results provide insight into the possible effects of static magnetic fields on the peripheral nervous system, particularly the behavior of ion channels associated with nerve fibers. Further studies are needed to clarify the detailed mechanisms responsible for the behavior of ion channels.

## REFERENCES

- [1] J.L. Schwartz, "Influence of a constant magnetic field on nervous tissues: . Nerve conduction velocity studies, IEEE Trans. Biomed. Eng. 25 : 467-473, 1978
- [2] C.T. Gaffey, T.S. Tenforde, " Bioelectric properties of frog sciatic nerves during exposure at stationary magnetic fields , " Radiat. Environ. Biophys. 22 : 61-73, 1983
- [3] Y. Satow, H. Satake, K. Matsunami, " Effects of long exposure to large static magnetic field on the recovery process of bullfrog sciatic nerve activity , " Proc. Japan Acad., 66, Ser B : 151-155, 1990.
- [4] C.Z. Hong, D. Harmon, J. Yu, " Static magnetic field influence on rat tail function," Arch. Phys. Med. Rehabil. 67: 746-749, 1986.
- [5] J.P. Wikswo, Jr, J.P. Brach, " An estimate of the steady magnetic field strength required to influence nerve conduction, " IEEE Trans. Biomed. Eng. 27: 722-723, 1980.