# Magnetic Field Produced by Compound Action Potential of Degenerated Human Nerve

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**Abstract**— In this study, we discussed about a new diagnostic technique of peripheral nervous disturbance using biomagnetic measurement. The magnetic field around a limb after nerve stimulation was simulated for the cases when some of the nerve fibers composing the nerve are lacked. As a result, disappearance of a pair of peaks of in- and out-flux was observed. The magnetic field seems to be reflective on the change of the distribution of the number of nerve fibers inside a nerve.

## 1. INTRODUCTION

The nerve conduction velocity test is a general method to diagnose diabetic neuropathy or any other malfunctions of peripheral nerves. Usually in this test, the conduction velocity of skin potential generated by the compound action potential of the nerve is measured. However as the most part of the skin potential is contributed to by thick nerve fibers, degeneration of thin nerve fibers is difficult to find with this test [1].

Measurement of magnetic field as the substitute of skin potential has an advantage to analyze the property of compound action potential. The action potential of a nerve fiber is possible to generate a pair of positive and negative peaks, whose location reflects the depth and the thickness of the fiber. On the contrary, the magnetic field of it has two pairs of peaks of in- and outmagnetic flux [2]. As each location reflects the depth and the thickness of the fiber, the more implications about morphology seemed to be obtained. To investigate the relationship between compound action potential and the magnetic field of its produce, the magnetic field around a limb after electric current stimulation was simulated.

## 2. METHODS

A human nerve was modeled as a straight cylindrical tube of 2 mm in diameter. The nerve was composed of myelinated nerve fibers with different diameters (1–14 µm). The fibers of each thickness were distributed uniformly inside the nerve arrayed in parallel inside the cylinder. Each fiber was assumed as a straight chain of a node of Ranvier, connected with an axoplasm electrical resistivity (Fig. 1). The parameters of membrane characteristics were referred to the experimental data of human nerve measurement in vitro [3], corrected with $Q_{10}$ values [4, 5] into 37°C. The relationship between the diameter of a fiber and the diameter of the axon and internodal distance was followed to a precedent nerve fiber model [6] proposed according to a morphometric study of human sural nerve [7].

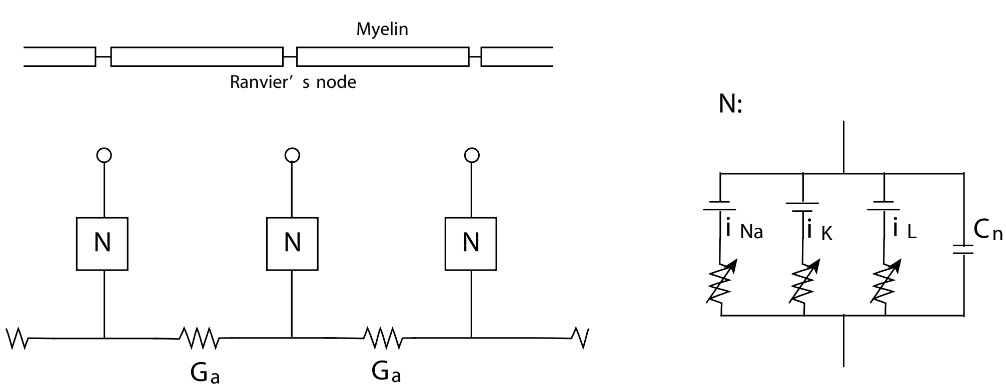


Figure 1: The nerve fiber model used as components of a nerve. $G_a$: Axoplasm conductance; $i_{Na}$, $i_K$, $i_L$: Nodal currents of potassium, sodium, and leakage; $C_n$: Nodal capacitance.

Electric current stimulation was given as a rectangle current pulse with duration of 100 µsec at a single point 10 mm off from the core of the nerve. As the fibers were assumed to be immersed in the liquid of uniform conductivity, the potential given to every node was determined as inversely proportional value to the distance of the node from the stimulation point [8].

Although the primary current source of the magnetic field around a limb is every axonal current of nerve fibers inside the stimulated nerve, a plenty of computer resources are required to calculate the current for some hundreds or thousands of nerve fibers. To reduce the amount of calculation, excitation rate e was defined as

$$e = S/\pi r^2 \tag{1}$$

where

$$S = R^2\left(\theta_1 - \frac{\sin(2\theta_1)}{2}\right) + r^2\left(\theta_2 - \frac{\sin(2\theta_2)}{2}\right) \tag{2}$$

$$\theta_1 = \cos^{-1}\left(\frac{l^2+R^2-r^2}{2lR}\right), \quad \theta_2 = \cos^{-1}\left(\frac{l^2-R^2-r^2}{2lr}\right) \tag{3}$$

In these equations, $R$ is the distance from the stimulation point to the farthest excitable nerve fiber for the stimulation pulse. $r$ is the diameter of the nerve. $l$ is the distance between the stimulation point and the core of the nerve cylinder. On the orthogonal plane to the nerve including the stimulation point (Fig. 2), $e$ denotes the rate of the common area of two circles to the area of cross-section circle of the nerve.

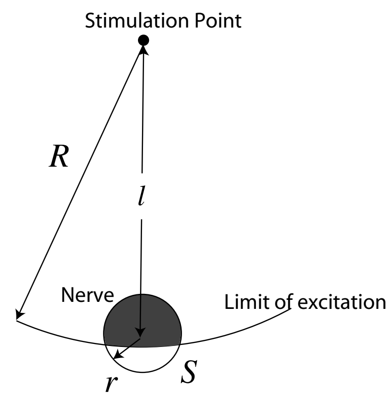


Figure 2: The orthogonal plane to the nerve including the stimulation point to make definition of excitation rate $e$.

Using $e$, the total axonal current $I_c$ inside the nerve may be described as

$$I_c = \int I_f(k)e(k)n(k)dk \tag{4}$$

where $I_f(k)$ is the axonal current of an active nerve fiber with diameter $k$ µm, $e(k)$ is the excitation rate for the diameter, and $n(k)$ denotes the number of fibers inside the nerve. The distribution of the number of nerve fiber $n(k)$ assumed as Fig. 3.

The limb was assumed as a cylinder of 100 mm in diameter. The nerve was laid at the depth of 10 mm from the surface. The magnetic field on the surface of the cylinder induced by the total axonal current $I_c$ was calculated with boundary element method.

### 3. RESULT

The magnetic field after 5 msec from stimulation is shown in Fig. 4. The magnetic field after 5 msec from stimulation is shown in Fig. 4. For the case of (a), (d), (e), (f) and (h), two pairs of in- and out-flux were observed obviously, however in (b), (c) and (g), a pair of in- and out- flux seems to be disappeared. Although a preceding experimental study showed that the magnetic field consists of two pairs of in- and out-magnetic flux [9], this result can be read that the pattern of magnetic field around limbs is possible to be reflective on the degeneration of nerve for some cases when the disappearance of nerve fiber has a relationship to the diameter of the fiber.

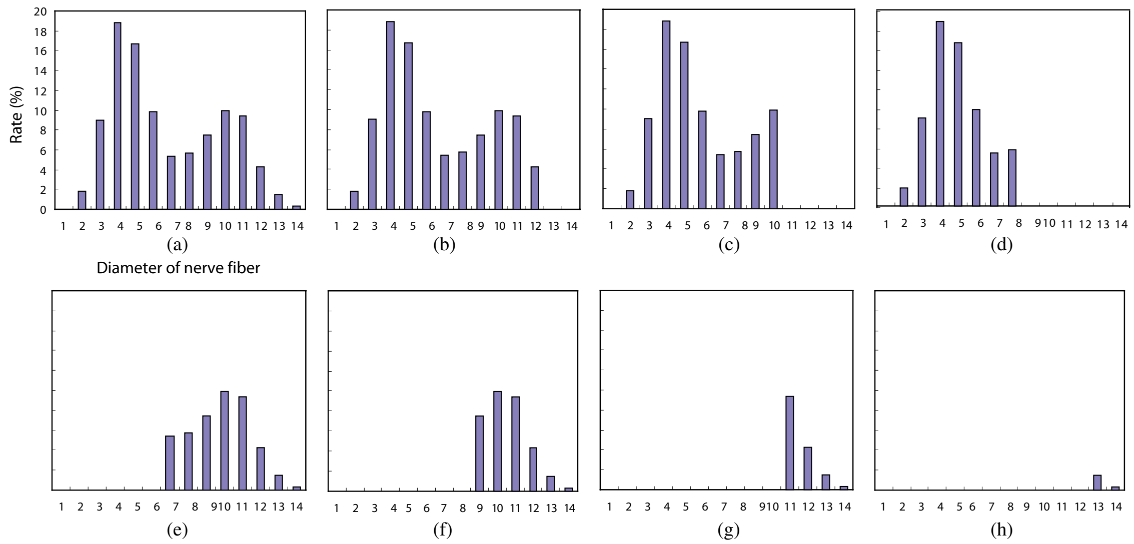


Figure 3: The distribution of the number of nerve fiber $n(k)$ tested in this simulation, (a) General distribution [7], (b)–(d) Maximum diameters are limited to 12-8 μm respectively, (e)–(h) Minimum diameters are limited to 6-12 μm respectively.

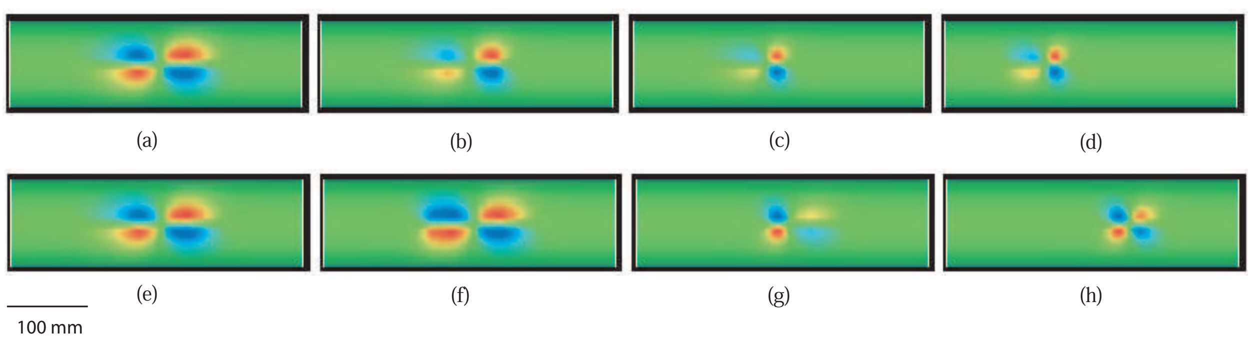


Figure 4: The normal component of the magnetic field around the cylinder at 5 msec from the stimulation.

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