Chapter 20
Repetitive Firing and Bursting due to Different Bifurcation Mechanism in Unmyelinated Fibre

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ABSTRACT
In neural science, different action potential (AP) firing patterns are typically considered to be dominated by different dynamical mechanisms. Different AP firing patterns in unmyelinated fibres can contribute to pain and sensory information transmission. Experiments in rabbit unmyelinated nerve (axon) show some interesting phenomena, mainly concerned with the AP firing patterns that changed regularly. Investigating the dynamical mechanism of unmyelinated fibre during various kinds of AP firing patterns is useful to understand the neural information processing in axon and pain information transmission. Here, we reproduced these phenomena by constructing a mathematical model, where the discharge of the Hodgkin-Huxley (H-H) neuron under square wave stimulation was studied by simulation. It is shown that square wave can induce bursting firing, especially with long time-course duration. This is different from the popular theory that explained repetitive and bursting firing due to stimulus intensity and instantaneous fluctuation. Through dynamical analysis, we found that the mechanism of the action potential pattern changed according to Hopf bifurcation, a dynamical behavior that emergence and stability of limit cycles of bifurcating from a stable equilibrium. The finding may support the neural information coding hypothesis in unmyelinated axon.

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INTRODUCTION

It is commonly agreed that different regions of the neuron perform specific signaling tasks. The pattern of firing is determined in a number of special regions responsible for signal integration, such as receptors, axon hillock and synapse. In contrast, the axon is usually believed to be specialized for carrying signals faithfully over long distances and to work as a relatively simple relay line (Mackenzie, et al., 1996). Recently, some experimental and theoretical data suggest that the functional capabilities of axons are much more diverse than traditionally thought. In other words, the function of the axon is no longer limited to the conduction of the action potential, but is also involved in the regulation of patterns of firing (Debanne et al., 2004; Philip et al., 2006).

Our previous experiment (Zhu et al., 2009) investigating the changes in action potential (AP) firing patterns in C-fibres of rabbit suggested that information processing may occur in the axonal region. The C-fibers are unmyelinated fibers, and have a slower conduction velocity (compared with myelinated fiber). The fibers are associated with sensations of warmth and chronic or dull pain. These fibers are archaic in evolution and maintain some basic characteristics related to AP propagation. Therefore, investigating the mechanism of AP pattern changes in C-fiber axon is important to understand elementary neural information processing principles, pain information transmission rules, etc.

In our experiment, we observed some interesting phenomena in AP firing pattern changes in C-fiber by electrophysiological method (we exposed about 10 cm of rabbit’s unmyelinated nerve, stimulated the nerve bundle at one terminal, and recorded single nerve firing at the other terminal). Its results can be concluded from three aspects:

The first firing pattern is irregular when stationary stimulation is imposed on the nerve bundle. We called this pattern irregular firing pattern, which was shown in Figure 1.

The second firing pattern is regular when stationary stimulation is imposed on the nerve bundle. In this case, the action potential is maintained in stable status even in a high stimulus frequency (50 Hz). Normally, the range of normal biological condition in the unmyelinated nerve fiber is from 4 to 32 Hz (Derjean et al., 2003). We called this pattern the repetitive firing pattern, which was shown in Figure 2.

The third firing pattern has repetitive firing and silence occurring in turns when stationary stimulation is imposed on the nerve bundle. We called this pattern the bursting firing pattern, which was shown in Figure 3.

Figure 1. Irregular firing pattern of C-fiber
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