INTRODUCTION

The physiological mechanism of the hardness change in fatigued or damaged muscle has been unknown. Muscle fiber that has suffered damage by eccentric exercise, shows a remarkable increment of muscle hardness (Murayama et al.; 2000). Therefore, it is necessary to understand whether or not the physiological reason of this increment depends on the change of muscle fiber itself. This study was carried out to investigate the mechanism of fatigued muscle hardness in frog muscle by means of different electrical stimulation patterns that caused tetanic contraction including the gradual falling phase.

METHODS

Experiments were carried out according to procedures approved by the Animal Ethics Committee of the Juntendo University. The gastrocnemius muscle and the sciatic nerve was dissected from a frog (Rana catesbeiana), and submerged in Ringer’s solution. At first, muscle was mounted horizontally and a force transducer was attached to the Achilles tendon to measure the maximum tetanic force (MTF). The sciatic nerve was placed on platinum plate electrodes and stimulated by a rectangular current pulse of 2ms duration. A pulse train of appropriate frequency (30-40Hz) was used to produce a fused tetanus of 1-2 sec duration. After MTF measurement, the tendon was detached from the force transducer and loaded with a weight at 20% or 40% MTF through a string. Muscle was fatigued with pulling up a weight using two type of modulated tetanic pulse stimulation (Fig. 1). A trapezoid stimulation pattern might induce damage to a part of the muscle fiber.

To evaluate muscle hardness, a mechanical pressing method was used, in which the response force required to deform the muscle belly was recorded. A 3.5 mm vertical pressure was applied to the muscle belly, and the muscle hardness value was determined from the peak response force. Muscle hardness was measured before and after the fatigue task and recovery time for 10 min.

RESULTS AND DISCUSSION

In the saw-tooth pattern and trapezoid pattern at 20% MTF loading, the time course curve of muscle hardness after the fatigue showed a slight decrement. Otherwise, it was flat. However, in the trapezoid pattern at 40% MTF loading, the increment of muscle hardness was observed within 10 minutes after the fatigue (Fig.2). Since muscle stiffness change would affect the muscle hardness change detected by the vertical pressure method (Murayama et al.; 2001), this result suggested that the hardness change was contributed to by some essential change in the muscle cell. During the falling phase in the trapezoid pattern some muscle fibers should be damaged by forced extension before the derecruitment. This study, at least showed that muscle hardness was increased in the fatigued frog muscle having contraction with gradual falling phase.

![Figure 1](image1.png)

**Figure 1:** Schemas of two types of stimulation pulses for muscle fatigue task. Upper: saw-tooth pattern (gradual increase for 1sec at 40Hz; interval 0.5sec). Lower: trapezoid pattern (gradual increase for 1sec, held for 0.5sec and gradual decrease for 2sec at 40Hz; interval 0.5sec).

![Figure 2](image2.png)

**Figure 2:** Percent changes of muscle hardness from pre-fatigue level during recovery period using trapezoid stimulation pattern. Upper; 20%, Lower; 40% MTF loading.

REFERENCES


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