EXTENSION RATE AND MUSCLE-TONUS DEPENDENCE OF THE FAILURE PROPERTIES OF RABBIT TIBIALIS ANTERIOR MUSCLE

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INTRODUCTION

Skeletal muscle injuries are frequently observed in traffic and sports accidents. Muscle injuries are rarely life threatening, but cause a great decrease in personal QOL and social loss because of deteriorated ability in ADL and long periods of healing and rehabilitation. Therefore, it is important to develop techniques for prevention of skeletal muscle injury based on biomechanical study.

The mechanical properties of biological soft tissue depend on strain rate. Especially in muscular tissue, the mechanical properties can also be expected to depend on muscle tone. Many experimental studies [1-2] have been done on the static properties of skeletal muscle in active state. However, there are a few data on the dynamic mechanical properties of skeletal muscle in active states at such the high strain rate seen in traffic and sports accidents [3].

Against this background, we examined the dynamic failure properties of skeletal muscle in an in situ animal experiment to obtain basic knowledge for muscle injury prevention.

MATERIALS AND METHOD

Preparation for Experiments

Tibialis anterior (TA) muscles of 15 Japanese white rabbits (2.58 ± 0.16 kg, mean ± S.D.) were used for the experiment. The TA muscle and deep peroneal nerve were exposed under deep anesthesia with pentbarbital sodium. Then the length of TA muscle was measured in situ. The in situ length was defined as the muscle length when the angle of the ankle is 90°. After this measurement, the distal tendon of TA muscle was cut.

Tensile Tests

The tests were conducted using an originally designed tensile test system that has two actuators, an AC servomotor and a gas actuator [4]. A schematic drawing of the system is shown in Figure 1. Quasi-static tests are performed with the AC servomotor and dynamic tests with the gas actuator. The distal tendon was gripped directly by a jig with tooth-like processes on the crosshead of the tester. A Kirschner's wire was inserted in the tibial condyle with the proximal end of the TA muscle, and the wire was fixed on the holder. We conducted tensile tests for TA muscle under two strain-rate conditions (17 %/sec and 1500 %/sec). We also examined the effect of muscle contraction on the mechanical properties of TA muscle in each strain-rate condition. TA muscle was activated by an electric pulse of tenfold the minimum voltage with which muscle twitching was observed. One electrode was inserted on the distal end of the muscle belly and the other was directly attached on the deep peroneal nerve. During the tensile test, the movement of markers put on the surface of the muscle was recorded by a high-speed digital video camera (MEMRECAM fx-K3, NAC) to measure the strain.

The muscle was treated by swabbing with a physiological saline solution at 36 °C during the preparation and tensile test.

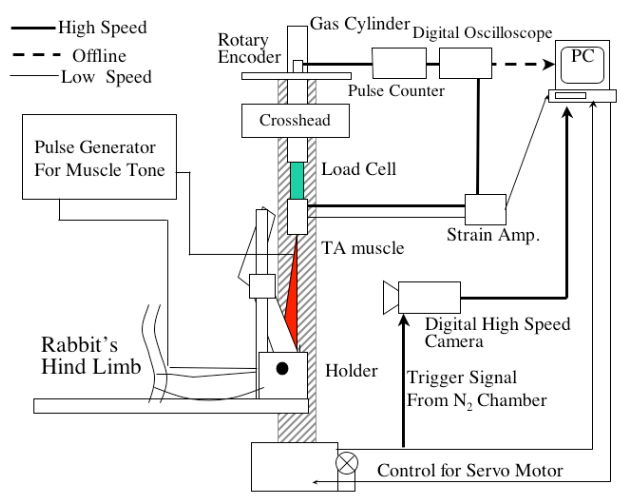

Figure 1. Schematic diagram of the tensile test system

RESULTS

The load-extension relations of the tibialis anterior muscle are shown in Figure 2. The load was normalized by the muscle weight and the extension ratio is the ratio of stretch to the in situ length. In the active states, the load-extension relations were almost linear, while typical non-linear relations were observed in a passive state. The failure load increased with the extension rate ($p<0.05$) but was independent of muscle contraction. With the 7 %/sec extension, the failure extension ratio did not depend on muscle contraction, while muscle tonus increased the failure stretch ratio with the 1500 %/sec extension. Ruptures of specimens were observed in muscle-tendon junction (MTJ) or muscle belly; there was no rupture in the tendon.

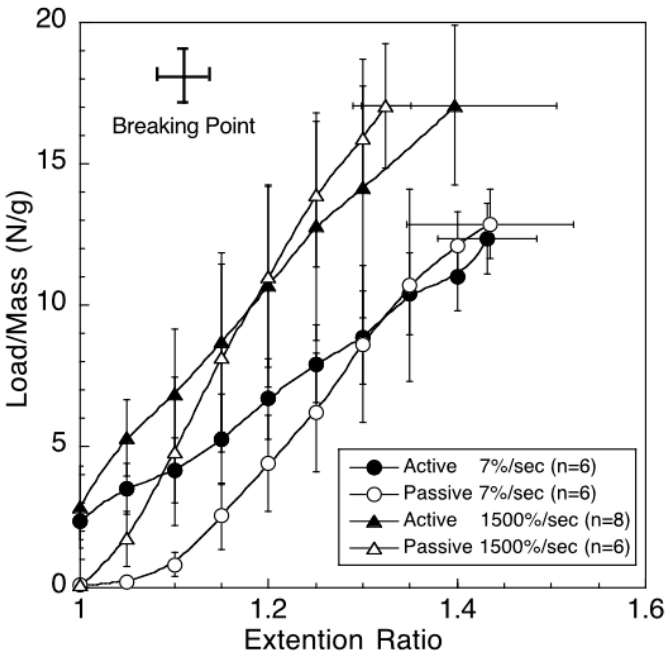

Figure 2. Load-Extension Curve of TA Muscle

The distribution of the site of failure is shown in Figure 3. Under the 1500 %/sec extension condition, the site of failure was mainly MTJ in the active state.

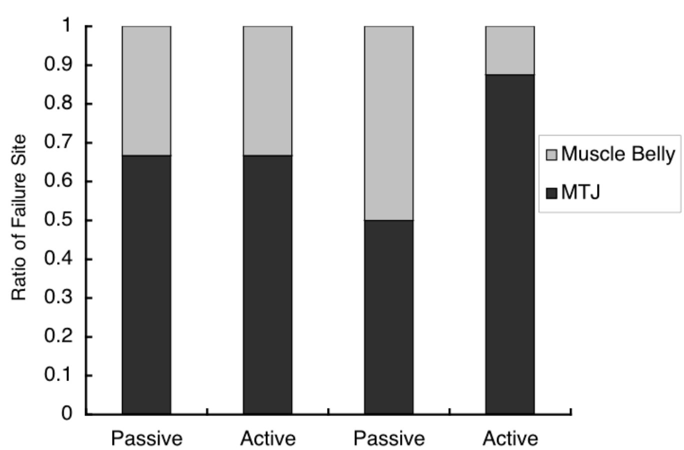

Figure 3. Site of failure in various test conditions

DISCUSSION

The relation between the failure stretch ratio and the site of failure are shown in Figure 4. From the reduction of the failure stretch ratio in the low extension rate condition in a passive state, it was considered that the failure extension ratio depends on the site of failure. In the condition with a high extension rate and passive state, the failure extension ratio in the specimens ruptured in the muscle belly was smaller than that in the specimens ruptured in MTJ, but it showed opposite tendency in the condition with active state. Thus, it can be considered that the rate dependence of the failure extension ratio is one in the factors of the rate dependence of the rupture site, but more numbers of specimens for statistical analyses for further discussion.

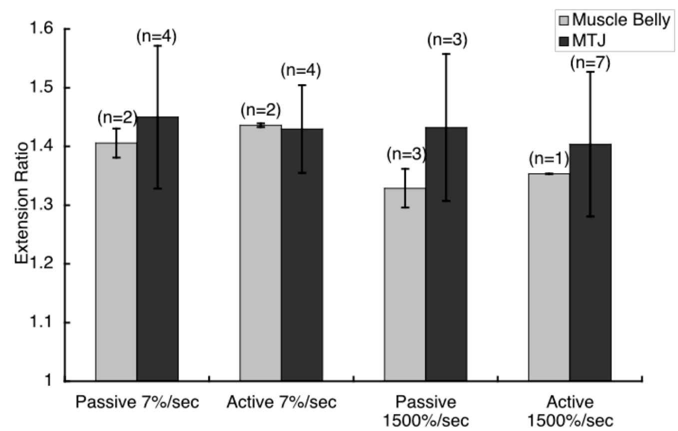

Figure 4. Failure extension ratio in various test conditions

CONCLUSIONS

We evaluated the dependence of the extension rate and muscle tone on the mechanical properties of the TA muscle. As a result, we found an extension-rate dependence on failure load, independent of muscle tone. The failure site depended on the extension rate and muscle tone. These results may be used as basic data in developing measures for muscle injury prevention.

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