Analysis of Real-Time Changes of Rat Dorsi-Flexor Forces during Injurious Stretch-Shortening Cycles *In Vivo*

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Abstract- **The purpose of this study was to quantify, in real-time, variations in muscle performance during 150 stretch-shortening contractions. The analysis of the dynamic muscle response was used to predict the onset of muscle injury. The isometric performance recovery and tissue response after exposure levels of 30 and 70 repetitions, respectively, indicated that injury occurred after 70 repetitions. This result supported the predictive utility of the analytical analysis.**

INTRODUCTION

Muscle damage and concomitant changes in performance due to stretch-shortening contractions (i.e., reciprocal eccentric/concentric contractions) is one of the major concerns in sports and occupational-related activities. Various studies suggest that stretch-shortening exercise produces muscle damage in humans. However, the dynamics of the movement were not controlled and muscle response was not quantified during the movement in these studies [1]. The effect of controlled oscillatory loading (repeated eccentric/concentric muscle actions) on muscle injury has not been investigated [2]. In addition, real-time changes in muscle performance (i.e., eccentric, isometric, and concentric components of muscle actions) have not been investigated during an injury-producing protocol.

If injury is associated with variations in skeletal muscle response during dynamic loading, we hypothesized that decomposition of the dynamic force response into discrete mechanical properties may aid in determining which factors are most sensitive to muscle injury during stretch-shortening cycles and thus give indications of the onset of injury.

METHODS

A. Experimental Protocol

All testing was performed with anesthetized male Sprague-Dawley rats (N=18) on a custom-designed rat dynamometer [3]. Rats were randomly assigned to three groups. The first group was exposed to 150 stretch-shortening contractions and the second and third groups were exposed to 70 contractions and 30 contractions, respectively. The response of the dorsi flexor muscles to isometric and stretch-shortening contractions were quantified *in vivo*. The testing consisted of either 15 sets, 7 sets, or 3 sets of 10 continuous stretch-shortening contractions performed at an angular velocity of 500°/s from 70° to 120° ankle angle for a total of either 150, 70, or 30 stretch-shortening contractions (see Table 1). The injury sets were administered at one-minute intervals. Isometric tests were used as a measure of static muscle performance. Concentric tests were performed to evaluate proper muscle activation and positioning in the dynamometer (see Table 1). There was a two-minute rest period between steps in the experimental protocol to allow for metabolic recovery of force.

Table 1. Experimental Protocol

Step	Stretch-Shortening Injury	Angular Position
1	1 Isometric Test	90°
2	1 Concentric Test	120° – 70°
3	3, 7, or 15 Stretch-Shortening Sets	70° – 120° – 70°
4	1 Isometric Test	90°
5	1 Concentric Test	120° – 70°
6	48 Hour Recovery	
7	1 Isometric Test	90°
8	1 Concentric Test	120° – 70°

B. Force Evaluation

Isometric testing was used to evaluate the change in muscle performance due to exposure to stretch-shortening contractions. In addition, four force parameters were used to evaluate the force changes between and within sets during the stretch-shortening cycles: 1) Peak force was the maximum force achieved in the eccentric contraction. 2) Average force was defined as the average eccentric force. 3) Minimum force was the force value prior to the eccentric contraction. 4) Cyclic force was the difference in the magnitude of force between the peak and minimum force. The four force parameters were recorded for the first stretch-shortening cycle in each set to evaluate the changes between sets. To evaluate the force changes within the sets, the four force parameters were fit to an exponential curve for the ten stretch-shortening cycles (1),

$$Y=e^{-\alpha X} \tag{1}$$

where Y is the force output, X is the repetition number, and α is the decay constant. These parameters were quantified for the four force parameters indicating the rate of change of the force parameters within a set.

A histological analysis was performed on non-injured tibialis anterior muscles from the contralateral limb and exposed muscles from the 3, 7, and 15 set groups to compare muscles exposed to varying repetitions of stretch-shortening cycles to muscles that were not exposed. They were evaluated with H&E stain at 40x objective by a board certified veterinary pathologist blinded to the study.

RESULTS

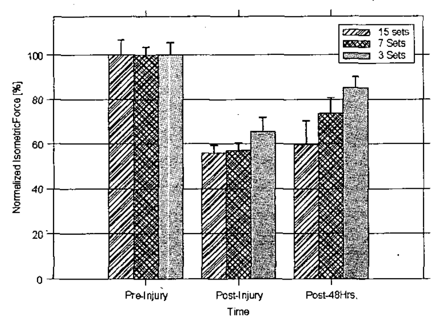

Fig. 1. Isometric force test for three groups of animals.

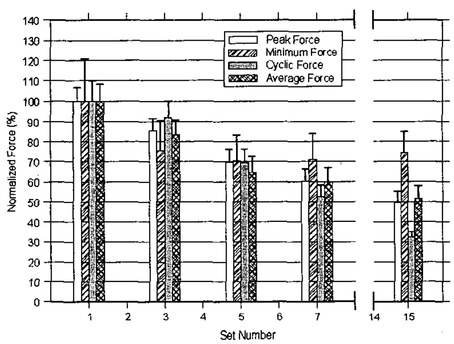

Fig. 2. Force parameters quantified from the dynamic muscle response.

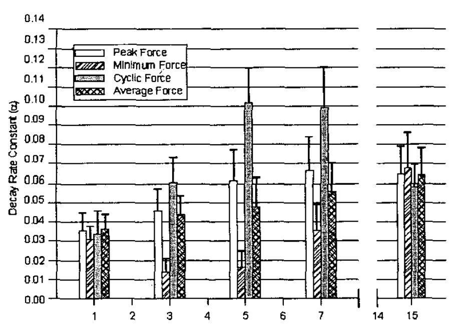

Fig. 3. Exponential decay rate constants of the force parameters.

The non-recoverable isometric force decrement (40%) of the first group 48 hours after exposure to 150 stretch-shortening contractions indicated evidence of myofiber injury while the second and third groups exhibited more force recovery (Fig 1). When the force signature during the 15 sets of stretch-shortening cycles was decomposed, the cyclic force showed the greatest change over the experimental protocol. The minimum force changed very little over the experimental protocol. The change in peak and average force followed each other closely both between and within sets but at a rate slower than the cyclic force (Fig 2). Based on the changes in the force parameters, the decay of the cyclic force was evaluated. Cyclic force decayed significantly at the 5th and 7th sets thus suggesting this may be an indicator of the onset of muscle injury (Fig 3). Based on the decay rate data, the histological response was evaluated after exposure to 30 repetitions and 70 repetitions to evaluate the predictive utility of the model. The severity of the myofiber degradation ranged from none to mild in the group exposed to 30 repetitions group (Fig 4B), while the 70 (Fig 4C) and 150 repetitions groups (Fig 4D) showed moderate to severe disruption.

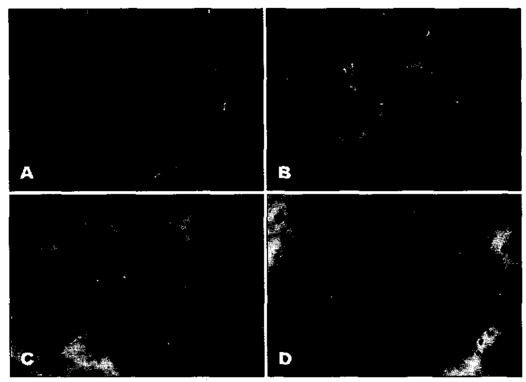

Fig. 4. Histology of control muscle with no injury (A) and injury groups of 3 sets (B), 7 sets (C), and 15 sets (D).

DISCUSSION

The decomposition of the dynamic force response during stretch-shortening muscle actions has been helpful in elucidating changes in real-time mechanical properties and the onset of muscle injury. The change in magnitude and the decay rate of cyclic force appears to be the best indicator of the onset of muscle injury.

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