HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science xxx (2018) xxx-xxx

www.jshs.org.cn

Review

Biomechanical response of skeletal muscle to eccentric contractions

Richard L. Lieber *

Shirley Ryan Ability Lab, Department of Veterans Affairs, Departments of Biomedical Engineering and Physiology, Northwestern University, Chicago, IL 60611, USA

Received 31 October 2017; revised 29 December 2017; accepted 9 January 2018
Available online xxx

Abstract

The forced lengthening of an activated skeletal muscle has been termed an eccentric contraction (EC). This review highlights the mechanically unique nature of the EC and focuses on the specific disruption of proteins within the cell known as cytoskeletal proteins. The major intermediate filament cytoskeletal protein, desmin, has been the focus of work in this area because changes to desmin occur within minutes of ECs and because desmin has been shown to play both a mechanical and biologic role in a muscle's response to EC. It is hoped that these types of studies will assist in decreasing the incidence of muscle injury in athletes and facilitating the development of new therapies to treat muscle injuries.

Keywords: Cytoskeleton; Eccentric contraction; Inflammation; Muscle injury; Muscle mechanics

1. Introduction

Based on the classic force−velocity relationship in skeletal muscle,[1] it is clear that skeletal muscle actions associated with lengthening (eccentric) contractions are associated with high muscle forces. Numerous investigators demonstrated that when eccentric exercise is performed, muscle damage and muscle soreness result. Eccentric contractions (ECs) are interesting to study, not only to understand how muscle is injured during intense exercise but also because there is evidence that these types of contractions produce high strengthening effects. This finding may be considered a 2-edged sword: ECs can produce strengthening but also injure the muscle. This review summarizes the mechanics and some biological aspects of muscle injury gleaned from animal models.

1.1. Mechanics of ECs

Evidence that ECs are unique is based on the observation that muscle behaves mechanically differently when shortening compared with lengthening. This finding shows up as a dramatic discontinuity of the force−velocity relationship for shortening compared with lengthening. For example, when a muscle shortens at about 1% of its maximal velocity, the maximum tetanic tension decreases to ~95% P_o. However, when a muscle is forced to lengthen at the same slow velocity, that is, 1% of its maximal velocity, the tension increases precipitously to >125% P_o (Fig. 1)! It is becoming increasingly clear that the classic cross-bridge theory is really not able to explain a number of mechanical phenomena that are known to occur with muscle lengthening.[2,3] Despite ECs being a normal part of the gait cycle experienced by many muscles in the body, relatively little is known about the physiology of ECs. Many investigators agree that ECs, if performed at a high intensity, can cause injury, but as the physiologist Dr. Herman deVree pointed out, "it is difficult to imagine why a structure would be injured when performing the very act for which it was designed!" EC physiology is an exciting area of research that promises new vistas in therapeutic and exercise treatment.

1.2. Human model of EC

One finding on which many agree is that, after an intense bout of eccentric exercise, muscle soreness is not immediately experienced but maximizes about 24−48 h later. This phenomenon has been termed *delayed onset muscle soreness* and is uniquely related to the EC and not to exercise itself. This property is easily demonstrated by comparing subjective impressions of soreness between individuals who have performed exercise involving ECs with those who have

* Corresponding author.
E-mail address: rlieber@sralab.org

https://doi.org/10.1016/j.jshs.2018.06.005

Please cite this article as: Richard L. Lieber, Biomechanical response of skeletal muscle to eccentric contractions, Journal of Sport and Health Science (2018), https://doi.org/10.1016/j.jshs.2018.06.005

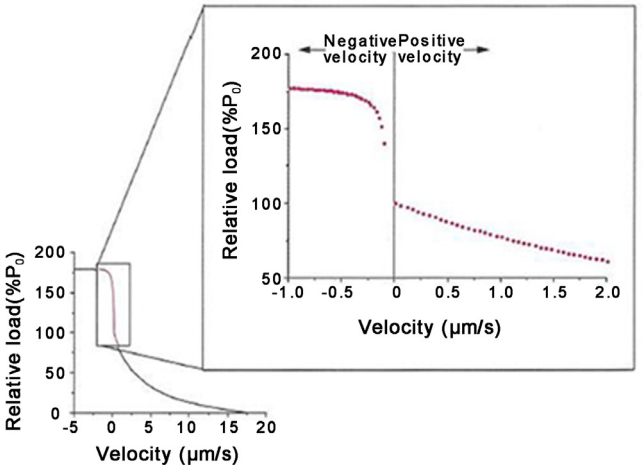

Fig. 1. Enlargement of the positive and negative force−velocity relationship in the region near the zero-velocity point. Note that the force increase per unit negative velocity is >6 times the force decrease per unit positive velocity. Thus, muscles are very stiff in resisting active stretch, which has implications in designing strengthening programs and in causing muscle injury.

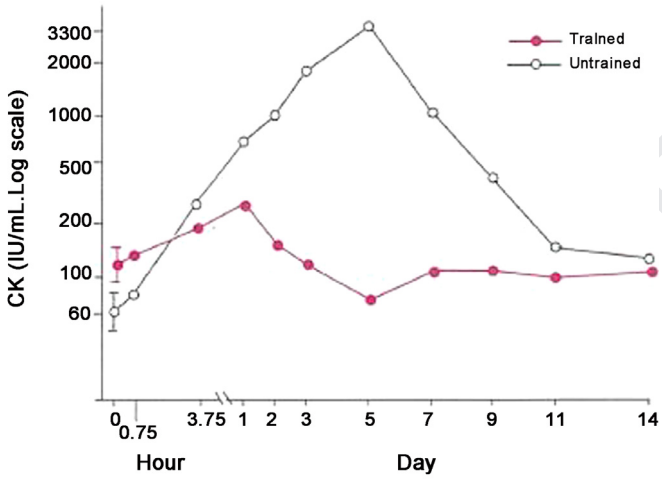

Fig. 2. Time course of serum CK levels after eccentric exercise in untrained and trained subjects. Note the delay between the exercise bout and subsequent peak serum enzyme levels. These data demonstrate that the injury, as indicated by CK levels, is delayed relative to the exercise bout and that training attenuates injury owing to exercise. CK = creatine kinase. Adapted from Evans et al.[4] with permission.

performed exercis‘e involving isometric contractions (ICs). Unfortunately, it is difficult to quantify soreness; therefore investigators have searched for other, more objective parameters to study eccentric exercise. One such parameter that is measurable in both animals and humans is the circulating level of creatine kinase (CK), an enzyme found in striated muscle that catalyzes the conversion of adenosine diphosphate to adenosine triphosphate (ATP) according to the reaction:

Creatine Phosphate

$$+\ \text{Adenosine Diphosphate} \rightarrow \text{Creatine} + \text{ATP}$$

(In fact, ATP is so rapidly regenerated from adenosine diphosphate by CK that ATP levels remain almost unchanged during muscle contraction, even during very intense anaerobic exercise). CK is located inside muscle fibers and, under normal conditions, remains there. However, when exercise is extremely intense and a cell is injured, CK is released into the bloodstream where it can be detected. Therefore, CK is often used as an indirect biomarker of myofiber integrity and injury.

2. *Serum CK Levels after EC*

In a seminal work on injury and training, Evans et al.[4] measured serum CK levels after intense eccentric exercise in young college students. Subjects performed eccentric exercise consisting of a single 45-min bout of high-intensity work. They reported 2 major findings. First, they showed that CK levels did not immediately increase after eccentric exercise but were elevated a few days after the exercise bout, peaked 5 days after the exercise bout, and remained elevated for several days thereafter (untrained, Fig. 2). These data suggest that muscle fibers do not simply break in response to exercise and release their contents (like a popped water balloon). The CK data suggest that muscle fibers experience some type of injury that then initiates a cascade of events that includes a loss of intracellular muscle components. The cascade may involve events that continue for several days, as illustrated by the protracted elevated CK levels shown in Fig. 2.

Evans et al.[4] also demonstrated that, when subjects had been trained by performing the same eccentric exercise training protocol before the eccentric exercise bout, the magnitude and duration of the increased CK levels were greatly attenuated (Fig. 2, filled circles). These trained subjects also had increased CK levels before the experimental exercise bout, suggesting that they were experiencing greater muscle fiber turnover, probably owing to the eccentric training. The Evans et al.[4] study presents 2 important results on which most investigators agree: (1) muscle damage and soreness owing to EC is delayed and prolonged and (2) prior eccentric training provides a protective effect against further muscle damage.

Studies of serum CK levels have provided information regarding the types of exercise that cause injury (those that are biased toward ECs) and the protective effects of prior eccentric training (as described elsewhere in this article). A dramatic demonstration of the muscle adaptations that occur with repeated exercise bouts was provided by Newham et al.[5] They studied the effects of eccentric exercise of elbow flexor muscles performed three different times separated by 2 weeks.[5] After the first bout, as expected, the maximum strength dropped precipitously (Fig. 3A) and CK levels began to increase dramatically (Fig. 3B). However, 2 and 4 weeks later, a different result was observed. A significant decrease in maximum strength again occurred (Fig. 3A, arrows), but there was no corresponding change in serum CK levels (Fig. 3B). These data indicated that some type of muscle remodeling occurred owing to the initial EC and that remodeling persisted even 2 weeks later. This striking result made the muscle physiology community think long and hard about both the nature of muscle adaptation and

Please cite this article as: Richard L. Lieber, Biomechanical response of skeletal muscle to eccentric contractions, Journal of Sport and Health Science (2018), https://doi.org/10.1016/j.jshs.2018.06.005