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Delayed-Onset Muscle Soreness

by Piotr Drabik

Physical exercise damages muscles, and the essence of physical training is to match this damage with rebuilding to end up with stronger muscles. Mechanical and chemical damage to muscles proceeds along a continuum of severity—from muscle fatigue to muscle soreness and eventually to muscle strain.

Piotr Drabik presented the current state of knowledge of muscle fatigue in the previous issue of Stadion News (Summer 2001). In the current issue, he presents the next level of damage—muscle soreness.

—Thomas Kurz

A typical feature of muscle soreness after muscular overuse is its delayed onset. Therefore, this type of muscle damage is usually called delayed-onset muscle soreness (DOMS).

The onset of DOMS occurs in the first 24 hours following exercise, and the intensity will generally peak by 48 to 72 hours. In cases of extreme severity, peak soreness may be delayed as long as 4 to 5 days post-exercise. DOMS tapers off thereafter and may disappear anywhere from 48 hours to 2 weeks later depending on the severity.

Generally, DOMS occurs following novel or unaccustomed eccentric exercise. Training for prevention of DOMS should include eccentric exercise, starting with a modest quantity and progressing gradually over a period of at least 2 weeks.

Although muscle soreness is familiar to every athlete, little is known yet about its pathophysiological basis. The primary changes involve the myofibrils and a question is: what causes the initial damage?

Muscle damage

Experimental evidence suggests that mechanical stress is a dominant factor in exercise-induced muscle damage. Support for this assumption is that the initial damage occurs to the contractile apparatus. Another argument in favor of mechanical stress is the observation that muscle damage is induced much easier in eccentric actions than in concentric actions. (Eccentric actions are when the muscles tense as they are being stretched. Concentric actions are when muscles tense as they shorten.)

Muscle damage and DOMS are greater after eccentric than after concentric muscle actions because in eccentric exercise a lower number of motor units—nerve cells and muscle cells innervated by them—is recruited compared with the same exercise conducted concentrically. This implies that in eccentric exercise the mechanical stress per muscle cell is higher than in

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Highlights

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AdultGymnastics.com

"There are many adults who would like to do gymnastics for the health and fitness benefits, but because most gyms emphasize the sport for children, it can be tough for adults to find clubs and competitions. Gymnastics has given me so much enjoyment I created AdultGymnastics.com to give something back to the community," says Scott Dahlem, Webmaster for AdultGymnastics.com.

The site contains a directory of gymnastics classes specifically for adults. There are classes and meets listed in Canada, the United Kingdom and 23 US states.

Athletes with questions can visit the AdultGymnastics.com discussion forum. The forum allows gymnasts to share experiences and to meet one another. The site also contains feature articles about the sport from a grown-up perspective. On the Web: http://www.adultgymnastics.com.

Delayed-Onset Muscle Soreness

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concentric exercise. The damage to the contractile elements after eccentric work is reflected in a force deficit lasting several days.

The speed of lengthening, rather than the peak force is a dominant factor inducing structural damage. It is assumed that at low lengthening speeds the crossbridge cycling can keep pace with the change in length. (Crossbridge cycling refers to oscillating movements of the myosin crossbridges that attach, rotate, and detach from actin filaments, thus moving the actin filaments in relation to myosin filaments in muscle cells.) However, at higher lengthening speeds the crossbridge cycling cannot keep pace with the change in length and damage will occur.

Initially, only focal structural damage to the myofibrils and the cytoskeleton can be found. (Cytoskeleton is the internal scaffolding that gives a cell its distinctive shape and it is formed from various proteins.)

Calcium ions released within damaged muscle cells impair their contractility, trigger further cellular damage, and are assumed to play an important role in triggering the inflammatory changes.

The initial damage is followed by secondary changes, including a cellular inflammatory response. There is strong evidence that calcium ions play a pivotal role in inducing the secondary changes. It is assumed that the mechanical overload induces an increase in intracellular calcium concentration that, after cessation of the exercise, may trigger a chain of processes contributing to a further deterioration of cellular homeostasis. Increased sarcoplasmic calcium concentration leads to a decreased relaxation, which may be the basis of the transient stiffness and decreased range of motion. Increased sarcoplasmic calcium concentration also leads to calcium accumulation in the mitochondria, which impairs the ATP generating capacity. There is some evidence that ATP levels in the muscle are decreased at exhaustion. A lower ATP generating capacity may affect membrane pumps. This may decrease sodium extrusion and lead to swelling of muscle cells. The increase in free sarcoplasmic calcium concentration can activate proteolytic enzymes and lipases, which can affect membrane integrity, resulting in an increased permeability.

The initial damage and inflammatory response are eventually followed by regeneration. Exercising when sore interferes with that regeneration and prolongs the inflammation, which then spreads to surrounding cells and weakens them. Prolonged inflammation may weaken connective tissue of the muscle so much that either the muscle or its tendon is torn.

Soreness—and why you feel it

One hypothesis to explain DOMS is that damage to muscle ultrastructure, which transfers mechanical forces within single cells and from cell to cell, initiates inflammation. There are many inflammation-like responses following the damaging exercise including pain, swelling, elevation in white blood cell count, particularly the neutrophiles, increased intramuscular and circulating levels of acute phase mediators (various substances released as a result of damage to cells)—particularly interleukin-1—and accumulation of monocytes (7 to 14 days post-exercise) and lymphocytes in damaged and regenerating muscle cells. Monocytes infiltrate the damaged tissue and differentiate to become macrophages to phagocytize debris. The macrophages also release prostaglandins that sensitize local pain receptors so that painful chemical and mechanical stimuli are intensified.

To date, DOMS has not been satisfactorily explained, and different mechanisms have been suggested to be responsible for it. Increased tissue pressure from tissue swelling may be associated with the soreness perception. It is hypothesized that prostaglandins may increase the sensitivity of free nerve endings and that movement causes a sudden increase of the already elevated tissue pressure, leading to pain.

Research shows that taking non-steroidal anti-inflammatory drugs (NSAIDs) relieves pain and improves muscle function in the short term (during initial inflammatory response) but may cause a loss of strength in the long term. This suggests that NSAIDs interfere with regeneration of damaged muscles.

Conclusions

- Exercising when sore interferes with regeneration of muscle cells and prolongs the inflammation, which then spreads to surrounding cells and weakens them. Prolonged inflammation may weaken connective tissue of the muscle so much that either the muscle or its tendon is torn.
- Taking non-steroidal anti-inflammatory drugs when sore results in short-term relief of pain and improvement of function, but in the long term it may interfere with muscle regeneration.

Self-Defense Tip

This self-defense tip continues the issue of the necessity to be proficient in the methods of attack for developing effective defensive skills.

In the previous self-defense tip (*Stadion News* Summer 2001) I gave an example of an unrealistic grappling attack. Striking and kicking attacks are also botched in demos and workouts.

Often the strikes and kicks are done wrong—along the wrong path, from a wrong distance—or targets are wrong for a given type of strike. For example, a looping strike with a fist against the side of the head instead of a palm strike to the jaw or ear—a small difference that considerably changes the distance and path of the strike. (A looping fist strike, while risky, may work but its best target is the tip of the jaw. Otherwise, hitting the head with a bare fist is foolhardy.) But the most common training error is launching single punches or kicks, holding the extended limb without retracting it immediately and hitting with other limbs. This looks as if the attacker forgot that he or she has more than one limb. Defenses against such unlikely attacks are presented by demonstrators who either themselves have no common sense or count on the spectators not having any.

In a realistic self-defense technique, the defender must position him- or herself so deflection of one strike puts him or her out of the way of other attacks. A control of the attacker's one arm, for example, has to be done so neither the other arm, nor legs, nor head, can strike the defender (see *Basic Instincts of Self-Defense*). Learning such skills requires familiarity with effective striking attacks. It is best to practice defenses with a partner who is good at the given type of attack—a boxer if you work on defenses against punches, for instance. Short of that, you can study the videos of fighters. It is for this purpose that a good knock-down karate fighter is shown on *Basic Instincts of Self-Defense.* He shadowboxes—throws series of punches, strikes, and kicks low and high—toward the camera so you can see how a good striking fighter does it. It also gives you an idea of what you are up against so you can mentally prepare with the *Gold Medal Mental Workout.*

Caffeine

by Piotr Drabik

Caffeine is the most widely consumed drug in the world, and coffee is its major source. It is also found in large quantities in tea, cola, and chocolate. In the world of athletes, caffeine is considered a powerful ergogenic aid.

Caffeine affects the central nervous system and many other systems of the body. It acts directly on the nervous system by stimulating the release of beta-endorphins and hormones that modify perception of pain and discomfort caused by physical effort. Other potential ergogenic effects of caffeine are improved muscle contractility and faster resynthesis of ATP—the most important energy carrier within all cells, including muscle cells.

At the cellular level, these effects are mediated by three main mechanisms of action: intracellular mobilization of calcium from sarcoplasmic reticulum and increased sensitivity of myofibrils to calcium (which improves the process of muscle contraction); inhibition of phosphodiesterases degrading the cyclic-3',5'-adenosine monophosphate (cAMP), which leads to an increased cAMP level in various tissues, including muscle; and antagonism at the level of adenosine receptors, mainly in the nervous system. (Adenosine, a product of ATP breakdown, is present in every cell of the human body and in the extracellular fluid. It regulates many physiological processes through binding to its receptors on cells' membranes. In the nervous system it mainly sedates.) These last two mechanisms—inhibition of phosphodiesterases and antagonism at the level of adenosine receptors—speed up resynthesis of ATP by causing faster burning of fat and sugar.

It seems that the most important molecular mechanism of influencing exercise metabolism is connected with cAMP—an activator of fat breakdown. The increased intracellular level of cAMP activates protein kinase A (an enzyme necessary for glycogen utilization). This protein kinase phosphorylates both phosphorylase kinase (an enzyme for breaking down glycogen) and glycogen synthase (an enzyme for synthesizing glycogen). The phosphorylation of both enzymes is the basis of the coordinated regulation of glycogen synthesis and breakdown. In practical terms, caffeine helps the organism obtain energy from whatever source is the best in a given situation—sometimes from lipids (fat) to spare glycogen and sometimes from glycogen. Usually, however, caffeine speeds up breakdown of glycogen to glucose, and the effect is that resynthesis of ATP is speeded up.

The other main mechanism of influencing exercise metabolism by caffeine, at the level usually encountered in everyday life after the ingestion of a few cups of coffee, is linked to the antagonism of caffeine at adenosine receptors. Caffeine also increases synthesis of plasma catecholamines that allow the body to adapt to the stress created by physical exercise. Catecholamine production, in turn, probably increases the availability of free fatty acids as muscle substrates during work, thus allowing glycogen sparing.

In activities that last more than a few minutes, caffeine has been shown to increase endurance or power and speed. Caffeine can also improve physical performance and endurance during prolonged activity. Glycogen sparing resulting from an increased rate of lipolysis could contribute to the prolonged time to exhaustion.

In very brief intensive efforts, caffeine can help if the movements are simple and well automatized, but it may not improve performance if movements require precise coordination. It is so because caffeine increases muscle contractility and the time before exhaustion but does not help with fine regulation of motor unit recruitment. Examples of brief efforts that caffeine may help include punches, strikes, kicks, and track-and-field jumps and throws.

Caffeine's half-life time is rather long (1.5–9.5 hours). Generally, caffeine should be taken 1 hour before exercise because its concentration in blood is highest 1 hour after ingestion. For endurance events it may be better to take it earlier because the peak release of fatty acids occurs 3 hours after ingestion. It is much easier to develop an ergogenic effect by taking pure caffeine than drinking coffee. For the International Olympic Committee, the highest acceptable level of caffeine concentration in urine is 12 µg/ml. The efficient dose is about 3 mg/kg or a little more. Taking such a dose keeps the concentration of caffeine in urine safely below the permitted level. Caffeine effects are transient—there is no evidence that long-term use may permanently enhance endurance.

Downsides

Caffeine nullifies the effect of supplemental creatine.

Under some circumstances, it may cause irritation of the stomach and intestine walls. Thus, to minimize this effect, caffeine should be taken with fluids.

Other unwanted effects of caffeine are difficulty falling asleep and reduced sleep efficiency. These result from caffeine being the adenosine antagonist. Even a little caffeine is enough to disturb sleep—the next night after ingesting 100 mg of caffeine, falling asleep is delayed and slow-wave sleep is reduced. (One 6 oz cup of coffee has from 54 to 180 mg of caffeine, one cup of tea from 40 mg to 100 mg.) Sleep disturbance interferes with nightly growth hormone secretion, which leads to insufficient rebuilding of muscles, bones, and joint cartilage. (More on sleep and various aspects of performance is in *Science of Sports Training.*)

In some people, caffeine disturbs the function of the ileocecal valve (a sphincter between the small and large intestine) and makes them sick. (The symptoms are listed in the Spring 2001 issue of *Stadion News.*)

Regardless of how it is taken (coffee, tea, capsules), caffeine stiffens arteries, raising blood pressure and increasing the risk of heart attack or stroke. 100 mg of caffeine in a capsule raises blood pressure up to 10 mm for several hours.

Contrary to common opinion, caffeine is not a source of oxygen free radicals. Actually, it is a scavenger of some, but not of all, free radicals present in the coffee, such as superoxide (O_2^-).

Coffee contains lipids called biterpenes. These fats increase total cholesterol level and LDL concentration, which may lead to health problems if large quantities of coffee are consumed. However, there is an easy way to get rid of those biterpenes—filter the coffee. Biterpenes are adsorbed to filter paper used in coffee percolators.

Q and A on STRETCHING and TRAINING
(continued from previous issue)

Study these typical questions on stretching and training carefully. You may find information that relates to your questions. Questions are in ***italic boldface.***

- ***I work night shift. Other women who work with me say that having no energy to exercise and gaining fat are a given when you work at night. What can I do to keep my metabolism normal—change diet or exercise more?***

Lower energy and resulting fat gain during periods of night shift work have to do with the lack of night sleep on growth hormone and cortisol secretions. To rebuild tissues, releases of growth hormone have to be coupled with low levels of cortisol. Both day and night sleep increase secretion of growth hormone, but only healthy night sleep simultaneously inhibits secretion of cortisol. (See also the information on downsides of caffeine on page 3 of this newsletter.)

No diet can reverse the effect of an unnatural daily cycle, but you may lessen the damage by following the principles of nutrition given in chapter 4, "Nutrition" of the book *Science of Sports Training* (http://www.stadion.com/science.html).

Working out during periods when you work night shift may simply tear you down and lead to overtraining rather than strengthen you. Working out when rebuilding is inefficient will make you old very quickly. The issues of sleep (and other factors affecting recovery) and overtraining are covered in depth in chapters 5, "Natural Means of Recovery" and 17, "Control of the Training Process" of the book *Science of Sports Training.*

- ***I am a boxer in Australia who saw the question recently from a martial artist regarding specific weights he was doing (second question on page four in Stadion News Fall 1998). I am doing a similar program to him and if the exercises mentioned are not appropriate which are? I was also wondering if incline fly is more suitable to boxing than flat and also incline press as opposed to flat? Any extra strength exercises that I should be doing in a boxing workout would be appreciated.***

The exercises the martial artist was doing (lying leg raises, squats, dumbbell bench press, military press or dumbbell lateral raises, dumbbell bench rows or close grip lat pulls, good mornings, reverse crunch, crunch or sit-ups) are not inappropriate. In martial arts and combat sports, these are general strength exercises that are good for beginners or for people in poor shape but not sport-specific enough to improve performance of advanced fighters or martial artists. For sport-specific exercises for boxing, I suggest those shown in *Explosive Power and Jumping Ability for All Sports* (http://www.stadion.com/explosive.html). In this book, you will see exercises for developing explosive power with barbells that no bench presses can match.

- ***I have the book Stretching Scientifically. How many times a week should I do strength exercises before I perform the isometric stretches?***

The most accurate answer is: As many times as it takes to get strong enough for the isometric stretches.

Strength training is not treated in depth in *Stretching Scientifically* because it is a guide to flexibility training for athletes—people already familiar with strength training. This book is for athletes who want to update their knowledge of flexibility training and maximize its effectiveness. For strength training information, see either chapter 6, "Strength" of the book *Science of Sports Training* or the book *Explosive Power and Jumping Ability for All Sports.* All an athlete needs to know about strength training as it relates to isometric stretches is on pages 61–64 of *Stretching Scientifically* (http://www.stadion.com/stretch.html).

A simple rule for those new to strength training: Typically, strength exercises for a given muscle group are done two or three times per week. How often you should do strength exercises depends on your reaction to them. If your muscles are sore the next day after every strength workout, even if you make some progress, it means that you exercise too often or too much. If you do not get muscle soreness but make poor progress, it may mean that you should exercise more often or you should increase the resistance or number of repetitions.