

Muscle Damage and Soreness: An Overview

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You need a little soreness—it means you're adapting, getting stronger. But too much means you're risking injury or overtraining. Here's why.



From my interactions with other CrossFitters, I've found that muscle soreness seems to be treated like the stereotypical mother-in-law. You're not really sure if you like her or not (or maybe you're very sure that you don't like her!) but you accept that she's part of the deal, she'll keep coming back, and you just find a way to deal with her until she goes home. As CrossFitters we understand the meaning of *real* muscle soreness. The kind of soreness that makes you hobble out of bed in the morning and clutch at handrails when walking down stairs. It seems as though it is almost a rite of passage in this sport. But have you ever stopped to think about why you are getting sore? Why do some workouts cause severe muscle soreness and others not? What could one do to prevent or reduce it? If these thoughts have crossed your mind at some point, read on.

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Technically, the kind of soreness we are referring to is called “delayed onset muscle soreness” (DOMS) in the scientific literature to distinguish it from more “immediate” soreness that might be experienced as a result of injury. There is a lot of SB (or *silly bullshit*, to use a Rip expression) swirling around the topic of DOMS in the fitness industry. For example, it is often taught by fitness experts, and even by many sport coaches, that muscle soreness is a sign of having “overdone” it, to be avoided where possible. It is also taught that lactic acid is the cause of soreness and that post-exercise static stretching will reduce or eliminate DOMS. More on these points later. For many specialized athletes, muscle soreness tends to be an issue only after prolonged layoffs from their sport or after training sessions that have been unusually tough or substantially different from normal. In CrossFit, of course, there is no “normal,” just constantly varied functional movements performed at high intensity: the perfect recipe, as it turns out, for ongoing muscle damage and soreness.



Mechanisms of muscle damage: Eccentric overload

For something so commonly experienced by us all, you may be surprised to know that the exact mechanisms of muscle damage and the cause of the subsequent soreness are still unclear. It has been, and still is, a source of quite active debate amongst muscle physiologists. There are essentially two hypotheses for what initiates muscle damage in the first place: a “metabolic” hypothesis and a “mechanical” hypothesis.

The “metabolic” hypothesis, predominant for many years, states that muscle damage is caused by metabolic deficiencies or excesses. It was believed that lactic acid (generated during high intensity exercise) was the cause of muscle soreness. While it is fair to say that muscle burn or discomfort during high intensity exercise has been linked to lactic acid, there is no evidence to suggest that this is in any way linked to subsequent muscle damage or soreness. Therefore this idea has been disproved (I will elaborate on this point a little more below).

While there are undoubtedly many metabolic consequences of muscle damage, most in the scientific community now agree that its initial cause is mechanical in nature.



The “mechanical” hypothesis points to *eccentric* actions of muscles as the main cause of muscle damage. What are eccentric actions? Well, there are essentially three types of muscle action (note I am using the word action as opposed to contraction – read on to find out why). There are *concentric* muscle actions where a muscle shortens when it generates tension, a true “contraction.” This usually refers to the actual lifting phase or acceleration phase of any movement: think of the “up” phase in a squat or shoulder press for example – muscles are shortening and the weight is lifted. There are *isometric* actions when muscles generate tension but there is no change in length: think about holding a handstand position or attempting a deadlift which is simply too heavy for you to move – lots of muscle tension but no movement. And there are *eccentric* muscle actions usually associated with the lowering phase or deceleration phase of any movement. During an eccentric muscle action there is tension in the muscle but it is actively lengthening at the same time. The “down” phases of a squat or shoulder press are examples. It turns out that eccentric actions are structurally much more stressful for muscle fibers than any other form of muscle action. The exact reason

why is unclear, but it appears that during eccentric actions the weak links in the microstructure of the muscle fibers are more likely to “pop” or “tear” than during other forms of muscle action. This can actually be seen in the muscle fibers under a microscope. At very high magnification, there is a characteristic array of regularly repeating bands (Figure A) within healthy muscle fibers. After severe eccentric exercise these bands can be seen to be disrupted (Figure B).

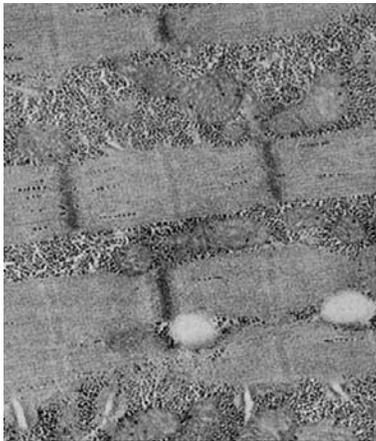


Figure A
Electron micrograph showing the normal arrangement of muscle proteins. Note the regularly repeating bands called Z discs.



Figure B
In this micrograph after eccentric exercise, note that the bands are now disrupted. This is called Z disc streaming.

I return for a second here to the old metabolic theory that suggested lactic acid caused muscle damage: The interesting aspect of eccentric muscle actions is that they

are *metabolically* less stressful than concentric muscle actions. In other words, they generate less metabolic by-products such as lactic acid than concentric actions, yet they still manage to cause more damage and soreness. This has been a convincing line of argument which helped to disprove the metabolic theory.

It is important to understand that eccentric actions are a key ingredient in order for muscles to adapt effectively to a strength or power training program. These are the actions that break down the muscle to a greater degree, thus stimulating greater eventual repair and adaptation. In comparison, concentric actions just do not have the same anabolic effect. Studies have shown that muscles loaded with only concentric contractions fail to respond to a strength training program to the same degree (in both strength and size) as muscles that are exposed to both concentric *and* eccentric actions. In the CrossFit FAQs Greg Glassman estimates that CrossFitting will build greater mass than bodybuilding, assuming that both are done clean (without steroids). He attributes this to the greater neuro-endocrine response elicited by CrossFit workouts. I would suggest that the major emphasis on fast, full range of motion multi-joint movements, and the associated eccentric muscular breakdown and repair could also be an important contributor.

Consequences of muscle damage: Temporary swelling and pain, lower power and range of motion, and tremor

The main consequence of muscle damage that we all feel is DOMS. This is soreness that first appears about eight hours after the exercise bout and typically peaks about 24-48 hours later. It's particularly noticeable when you get out of bed in the morning. We experience muscle tenderness, pain when we touch the muscle, and stiffness that causes pain when we move or stretch it. With some gentle movement the pain usually subsides, but after prolonged periods of little movement (sitting in front of a computer, for example) it rears its ugly head again. Usually the DOMS will have mostly disappeared after about four to five days, but can persist for longer in some cases, as most CrossFitters can tell you.

So why do we get sore? It seems reasonable to speculate that it evolved as a way to tell us to “ease off” while the muscle is recovering. To repair the microdamage to the muscle fibers the body initiates a local inflammatory response that starts the healing process. As we all

know, inflammation is usually accompanied by pain, swelling, and redness. Since the inflammation is inside the muscles themselves, we can't see the redness (increased blood flow) or the swelling, but we can sure feel the pain! So you might be thinking, "Maybe I should just pop an anti-inflammatory?" Well, not so fast - we'll discuss that later.

In addition to soreness there are a number of other things that happen as a result of muscle damage. In most cases after muscle damage, the membranes of muscle fibers are compromised, allowing substances to spill out into the bloodstream. These include muscle proteins like creatine kinase and myoglobin, and certain electrolytes such as potassium. In the vast majority of cases, these effects are entirely normal and reversible, but in very rare cases the spillage is excessive and can lead to serious medical complications. This is the exertional rhabdomyolysis that many have heard of. In severe cases, "rhabdo" can lead to cardiac arrhythmias (due to blood electrolyte imbalances) and/or potential kidney failure (when the muscle proteins accumulate in the kidneys and prevent them from filtering the blood normally). If your urine looks like Coca Cola in the hours or days after a hard workout, this may be a sign of rhabdo (go to the ER immediately!). Rhabdo has been covered eloquently in previous issues of the CFJ by Eugene Allen (#33) and Greg Glassman (#38), so I will say little more on this topic. The key to avoiding rhabdo is judicious and gradual introduction to intensity for athletes who are unaccustomed to training that involves significant eccentric muscular stress.



Further consequences of muscle damage include loss of muscle function - the muscle does not recover its strength and power capabilities for at least several days after the exercise bout. One may assume that the muscle is fully recovered when the soreness has disappeared, but the time course of soreness and strength loss is not as closely linked as one might think. The muscle may feel fine but may not recover its full force capability for a few more days. Loss of muscle function in the days after a hard muscle workout can also be seen in the form of shortened (contracted) muscles at rest and an inability to contract fully. In other words, the range of motion through which the muscle can effectively operate is significantly reduced while it is recovering. Studies have also shown that during recovery from muscular overload there are significant changes in our gait biomechanics, and that there are significant decrements in sprint and endurance performance. There is also evidence that damaged, sore muscles have reduced insulin sensitivity and thus are less able to recover their normal glycogen levels.

Another example of loss of muscle function after strenuous eccentric exercise is greater tremor and impaired performance of fine motor tasks. Ever noticed that you feel a little shaky after a hard workout? The exact reason for this has been difficult to determine but is probably due to some subtle changes in the function of the nervous system "wiring" that connects the brain to the damaged muscles. These changes probably also contribute to the loss of proprioceptive function that is seen in damaged muscles, i.e., a loss of ability to "sense" where our limb is in space. It also appears that after unaccustomed eccentric exercise we are unable to gauge the force output from our own muscles with normal precision. Better make sure if you are going in for delicate surgery that your surgeon is not a CrossFitter who has PR'ed on Linda that morning!

Silver lining: Less damage and pain next time

I know it all seems very negative to this point. But there is a silver lining. It's called the "repeated bout effect." This refers to the fact that another similar bout of exercise will not have the same consequences as before. We all intuitively know this. This is what training is all about: improving our muscular work capacity and recovery capabilities. The exact "black box" adaptations within the muscle that are contributing to the repeated bout effect have not yet been elucidated, but they

are probably a combination of increased structural strength of muscle fibers, metabolic adaptation and neuromuscular changes. A key point is that if we go back to being a couch potato all that good work and adaptation will disappear within a few weeks.

Pain a la CrossFit: Fast, high-rep, full-range movements are a potentially potent cause of DOMS

You probably don't need me to explain that the major reason why DOMS is a recurring theme in CrossFit is the emphasis on constantly varied movement patterns. A specialized athlete will typically use similar muscle groups day in and day out. Thus, the specific muscles concerned will adapt and become quite resistant to muscle damage and DOMS. The CrossFit athlete is using a far greater diversity of muscle groups with constantly differing movement patterns. The result is that we will regularly be hitting muscles with unaccustomed exercises. *Voila!* DOMS is inevitable in this scenario.

Think about the types of CrossFit workouts that make you sore. What are they? The thing that has surprised me most about CrossFit is the degree and depth of soreness that one gets from the high repetition bodyweight workouts. I remember the first time I did the pull-ups/pushups/squats of Cindy (it wasn't even a full Cindy - only 12 minutes). I thought I was reasonably fit, but that was close to being the most soreness I have ever experienced in my life! I was initially surprised that the heavy strength days (workouts with rep schemes like 1-1-1-1-1-1 or 3-3-3-3-3) while tiring, didn't produce the same level of soreness as some of those other bodyweight workouts. So what might be the explanation?

Research has shown that *faster* eccentric contractions tend to cause greater strain and thus greater damage within muscle. This is why many people really notice soreness after workouts that involve explosive and/or jumping type movements. With a high repetition bodyweight workout such as Cindy, I think the degree of soreness can probably be attributed to two things: first, the high number of total repetitions/work done (20 rounds of Cindy equates to 100 pull-ups, 200 push-ups and 300 squats) and, second, the relatively high speed at which these repetitions are performed. Compare these numbers to a heavy back squat day

of 3-3-3-3-3. Yes, the tension in the muscle will be higher with the heavier weights but the total repetitions with the heavy weight are only 15 and, critically, those repetitions cannot be performed at the same speed as during an unloaded Cindy, thus resulting in potentially less intramuscular strain and thus damage.



There is also good evidence to suggest that there is a length-dependent component in the development of muscle damage. Muscles that are stressed quickly and eccentrically *while simultaneously being close to their fully stretched position* (think about the quads, adductors and glutes in the full squat position during wall ball for example) are more likely to become damaged than if the eccentric action occurs only during the mid-range of movement or earlier (i.e., if you fail to squat down adequately between reps). Thus CrossFit's emphasis on quality *full range* movements performed at high intensity is a perfect recipe for muscle damage and repair, i.e. adaptation.

Practical recommendations: Go easy on extremely sore muscles, don't expect much from stretching and massage

Let's address some practical issues and some of the SB out there regarding muscle damage and DOMS.

Muscle Damage and Soreness... (continued)

Should you train if your muscles are sore? There are many fitness experts who would tell you a flat “no.” Well, the real answer is: *it depends*. You are the owner of your body and you need to make that call for yourself. Mild to moderate DOMS is unlikely to be a problem. However, if you have severe soreness in a particular muscle group I would suggest that you provide that body part with some relative rest. An example: if you have severe soreness in your legs from squatting during Cindy, then you would be prudent to avoid attacking a workout with heavy back squats the next day (a very similar movement pattern). I see less of a problem if you *run* on those sore legs, as the movement is quite different from what caused the damage. Just be aware that your run performance will probably suffer in comparison to running on fresh legs.

Note that chronic muscle soreness that seems to linger for longer than usual may be a sign of over-training, or under-recovery, whichever way you choose to look at it. If you are feeling unusually unenthusiastic about your training, and you are noticing chronic muscle soreness, you would be well advised to listen to your body and take appropriate rest until your body and mind are back in the game.

Remember that muscle damage and soreness are essential and probably unavoidable pre-requisites for optimal muscular adaptation. If you have an aversion to feeling sore, you can either stop doing CrossFit (not an option for most!) or reframe your attitude. How? Try any or all of the following:

1. DOMS can make you feel less guilty about taking rest days.
2. DOMS is a sign that your body is adapting.
3. DOMS gives you valuable delayed feedback about your performance in the exercises concerned.

As an explanation for point 3, let’s say you have done a heavy deadlift 3-3-3-3-3 WOD. You can expect that you will feel some soreness/fatigue in the lower back muscles in the days after this workout, as it is primarily a low back exercise. But if you notice excessive soreness in an unusual place this may be a signal that your technique might need some work. If you keep a log or record of your workouts, you should make a note of where you felt sore and use this information to help you tweak your technique the next time.

How about stretching? Can it reduce muscle damage and DOMS? There are some good discussion points here. First, *gentle* stretching of a muscle that is already sore is perfectly acceptable, is not likely to negatively affect muscle recovery, and can be used to minimize the short-term sensation of pain and soreness. But what about post-exercise static stretching? It is often claimed that static stretching after a hard workout can reduce muscle soreness in the coming day(s). Well, now that you understand the initial cause of muscle damage (microtears within the muscle fibers) you should also appreciate that this claim simply does not make sense. Is stretching after a hard workout going to “undo” the damage in some magical way? Clearly not. And scientific studies have also consistently failed to find an effect. Static stretching after a workout when the muscles are warm is an excellent idea and, when done on a regular basis, can significantly improve muscle extensibility. This improved flexibility may assist in improving performance and probably assists in preventing strain type injuries. But let’s be careful about claims that we make for post-exercise stretching and short-term DOMS.



How about warming up and stretching *prior* to a workout? Can this influence the DOMS that we may experience? It would seem logical to suggest that warming up might offer some protection against muscle damage by increasing muscle temperature and "loosening" up the muscle(s) concerned. Unfortunately, there is minimal evidence to support this either! Of course, this should not be interpreted as a reason not to warm up - warming up can improve subsequent performance and potentially minimize the chances of muscle strain injury. Just don't expect that you will necessarily be protected from DOMS in the days afterwards. While on this topic, most CrossFitters are well aware that the best form of stretching prior to explosive or powerful exercise is dynamic stretching, i.e., controlled movements that challenge a muscle's range of motion. Prolonged static stretching prior to exercise has consistently been shown to reduce the subsequent explosive ability of the muscle and is best left to the post-exercise period, as I mentioned above. Ballistic stretching (repetitive bouncing near the end range of motion of a muscle) is less effective at improving flexibility than either dynamic or static stretching, may predispose to injury and is not recommended for most athletes.

What about massage after exercise? While it may be very relaxing and assist in general recovery, there is no conclusive evidence that this will reduce the extent of DOMS. Cryotherapy (ice) also appears to have minimal effect. And this brings us to anti-inflammatory medication. Popping an ibuprofen or other non-steroidal anti-inflammatory drug to reduce DOMS might seem like a good idea but is not recommended. It may indeed reduce the amount of discomfort that you feel, but (a) soreness is there for a reason and by artificially reducing it you run the risk of further injury to a muscle, and (b) there is good evidence that anti-inflammatory medication can slow down the adaptive processes in muscle.

Conclusions: Progress sensibly and don't take long layoffs

So the bottom line, as with other things in life, is that there is no easy ticket. Muscle damage and soreness should be accepted as what it is - useful feedback from your body telling you to give the muscle(s) concerned some relative rest. Everybody has a different body and you must learn to listen to yours. As a novice or intermediate CrossFitter

your best bet is to progress gradually in your workouts in terms of weight and repetitions used. Reel in that ego: don't ski with the experts on a double black diamond run if you are a green run skier. Also, don't take long layoffs from CrossFit-style training. You are probably better off doing fewer WODs more consistently than overdosing on WODs and taking long breaks in between. One of the beauties of the CrossFit approach is that if you are away from your gym for a significant time it is easy to concoct workouts consisting of air squats, push-ups, pull-ups and sit-ups, etc. If performed at high intensity, these will prevent your muscles from "de-adapting." Oh, and a final word of advice: take at least 10-15 minutes to stretch after your workouts. Though this may not necessarily protect you from DOMS, the increased flexibility will make you feel better and may improve your performance.



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