About the Author

Karl Hamouche is the founder of Swim Smart. He moved to Iowa from Lebanon when he was 12 years old, joined the local swim team, and instantly was part of a family in a place 8,000 miles away from home. Years later, he ended up coaching for that same team, expanding it by starting a new satellite, and helping them win their first club state title.

Karl studied biology and exercise science at Iowa State University and received his medical degree at the University of Iowa. With his coaching and swimming background, Karl is the intersection of theory and practice, the book and the real world.

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Introduction

I was asked once by a swimmer "**why is that other swimmer so much faster than me?**" I told him that all of competitive swimming can be summed up in one statement:

The swimmer who wins the race had the best Power to Drag ratio…period.

All technique, training, and biology feed into that ratio. Now, you can go online and find all kinds of articles, DVDs and videos about technique and training. They answer questions like:

"How often should I breathe in the fly?"

"What should my stroke count be for a 100 breast?"

"What's the best training method: USRPT, HIT, garbage yards?"

But what about these questions:

"Why am I sore…again? I've been training like crazy!"

"Why is workout so much harder in a hot pool than a cold one?"

"I'm a miler… why do I have to do these sprint sets?!"

It has to do with your biology. Don't be scared! The word "biology" to most of us signals boring lectures and impossible homework. **But this is not biology class, this is swimming class** that teaches you everything you need to know about your Swimming Machine. **This machine adapts, grows and changes depending on how you challenge it**. Imagine a car, say a regular family car. In the real world it never changes on its own, no matter what roads you drive it on, how fast you drive or what you use it for. Imagine now if that car could adapt. If you drove it off-road, the next day its wheels got bigger. If you drove it at 100 miles an hour, by next week it added two more cylinders to make more power. **That's what your body does…every single workout.**

You can find resources that talk about this stuff, even in swimming terms. But unless you plan on reading a 600 page textbook or are majoring in exercise physiology you are sort of on your own.

NOT ANY MORE.

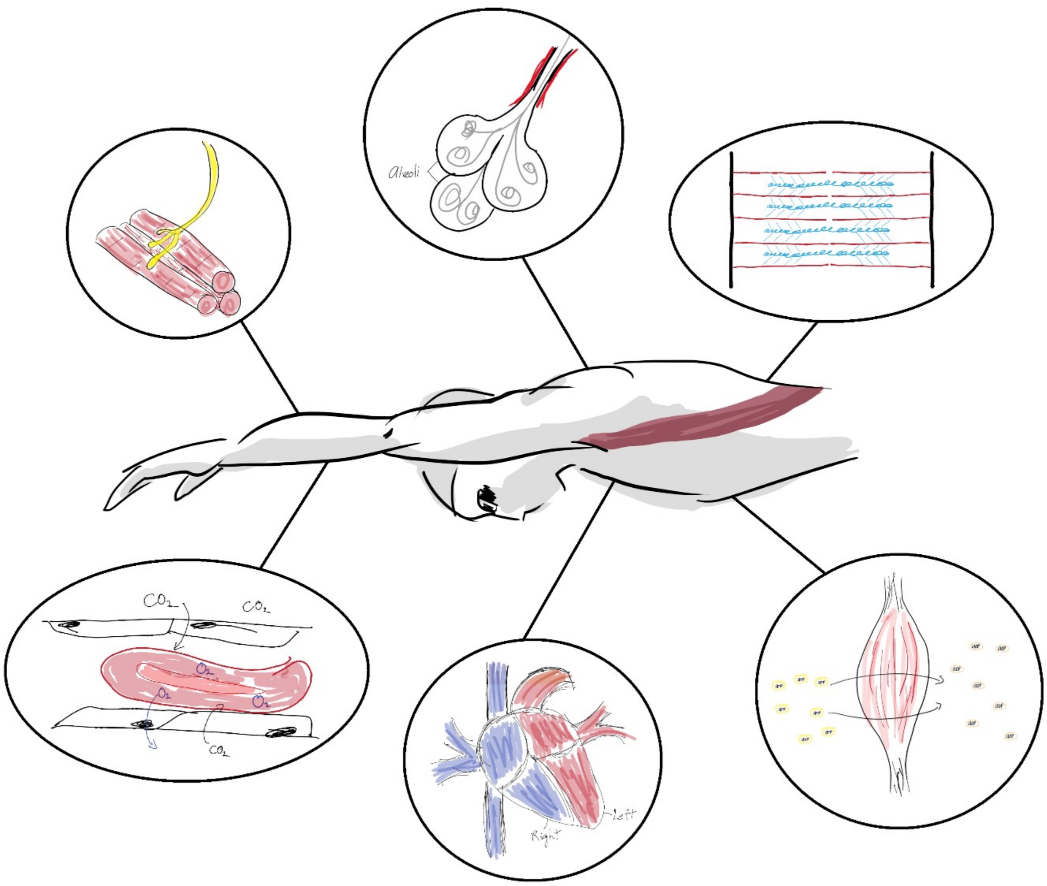
That's what we are here for. We are going to leave behind the complicated lingo of the science world, and bring all explanations of the biological world to the pool. **We are going to go through the Swimming Machine one step at a time, using as many pictures as we can, and simplified as much as possible** (but not any simpler)!

Now, no more intros…let's get to work.

Part One:

How the Swimming Machine Works

Your body is a machine. An engine that requires energy, maintenance and healing. The more you understand about how this machine works the better you can understand how your training works.

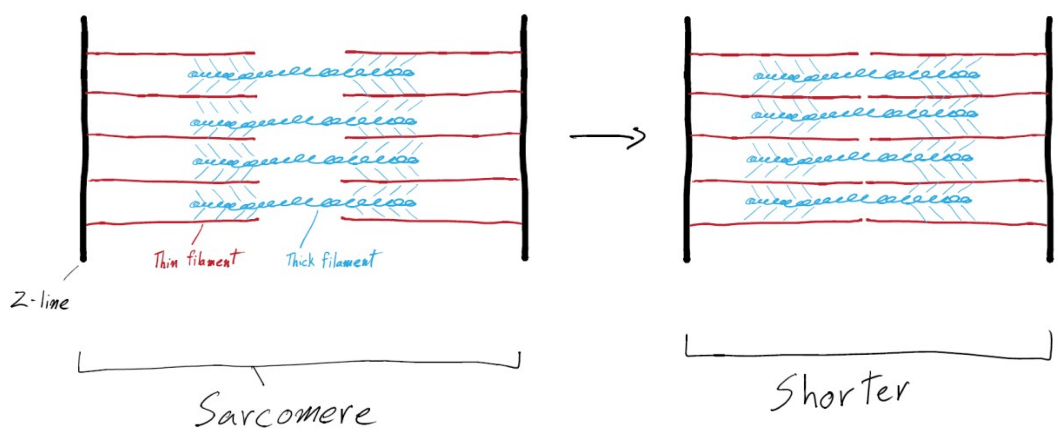


Muscle- How it Works

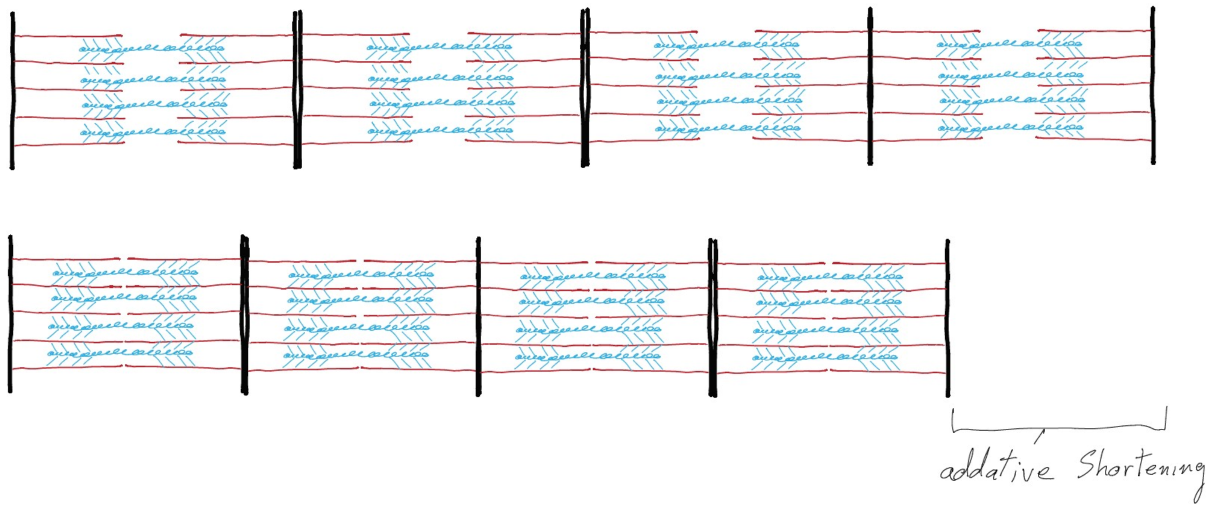
Did you know **muscle's only job is to get shorter**? That's it. That's its whole job and understanding how it does that, why it does that and what limitations it has can help you understand how your body works in the pool. While there are three types of muscle in the body, we are only going to talk about skeletal muscle, aka striated muscle (we will know why shortly). The other two types are smooth muscle and cardiac muscle, both of which do not produce movement and you have no voluntary control over. As you can imagine, skeletal muscle attaches to the skeleton. It almost always crosses a joint (or two joints) and **brings those two bones closer together**. That's how you move, simple right?

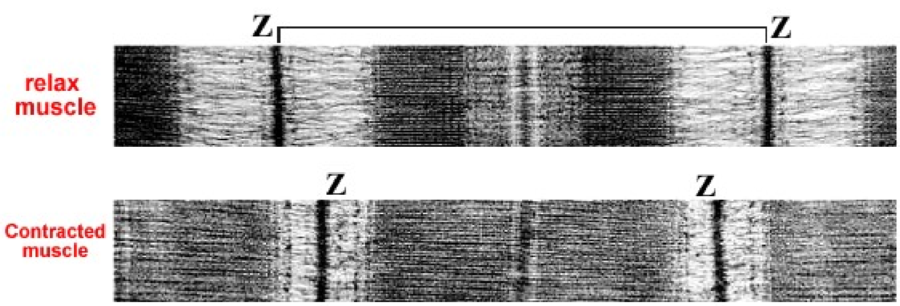
Sarcomeres: The Base Unit of Muscle

Alright, let's zoom in to see the basic functioning unit of all muscle. **What the cell is to the organism, a sarcomere is to each muscle cell.**

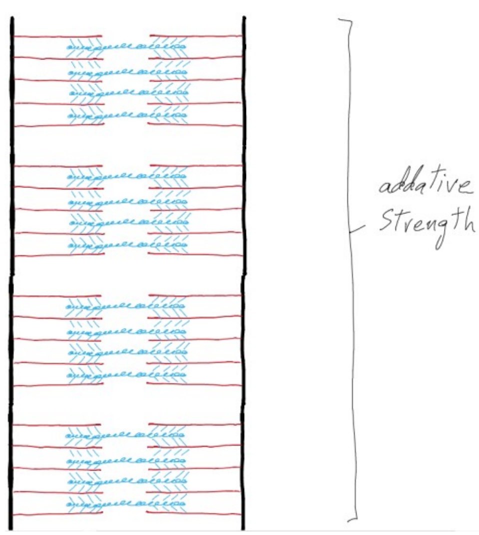


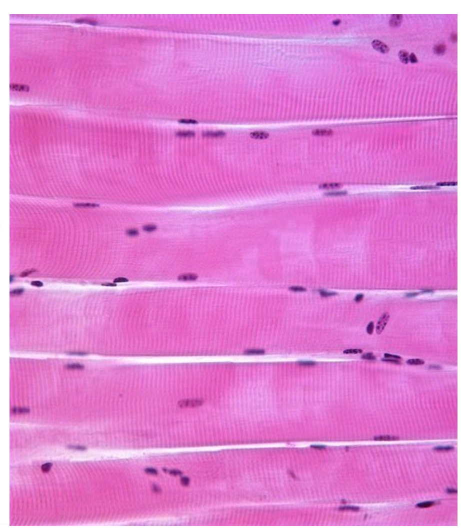
See those **Z-lines** on the sides? That's what comes closer to each other. Even though each sarcomere is only micrometers long and only shortens a few nanometers, when you place millions of them end to end (as below), you get an **additive effect, allowing each muscle cell to shorten many inches**. This is also what give skeletal muscle its "striated" quality.



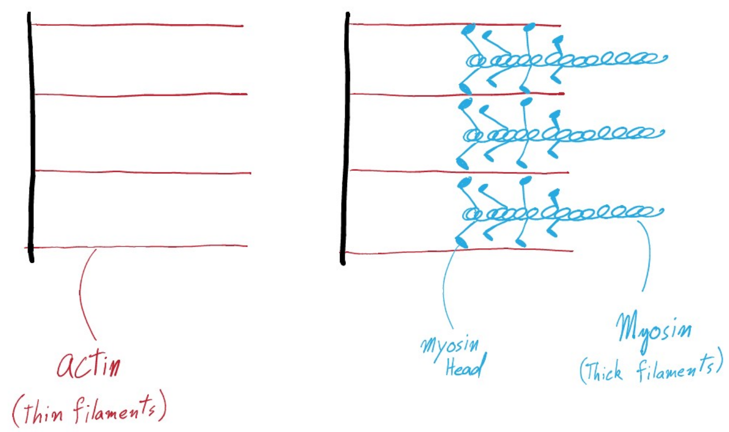


Of course, one long train of sarcomeres (in "series") can't move much weight or water, so we need a whole bunch of sarcomeres in "parallel," or all next to each other working together. The **raw strength of a muscle is determined by how many sarcomeres are in parallel…otherwise known as bigger muscles.**

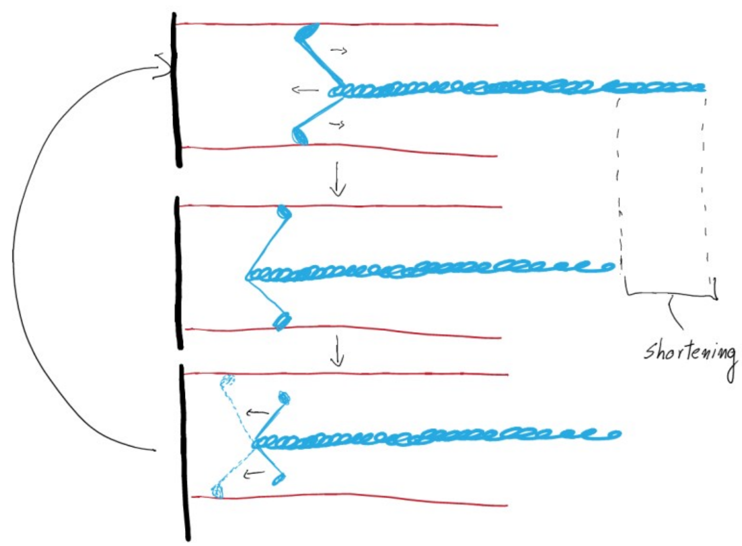




Ok, so muscle gets shorter by moving the Z-lines together…but how does that happen? Let's take a closer look at **what goes on between the Z-lines**, where those thin and thick filaments are the picture.



The thin filaments, called actin, are attached to the Z-lines from both ends of the sarcomere. The thick filaments, called myosin (myo=muscle) overlap the actin from the middle, but they do NOT attach to the Z-line.



Here is where the magic happens. **Coming off all along the myosin proteins are the myosin heads which act like caterpillar legs and "crawl" their way towards the Z-line along the actin filaments.**

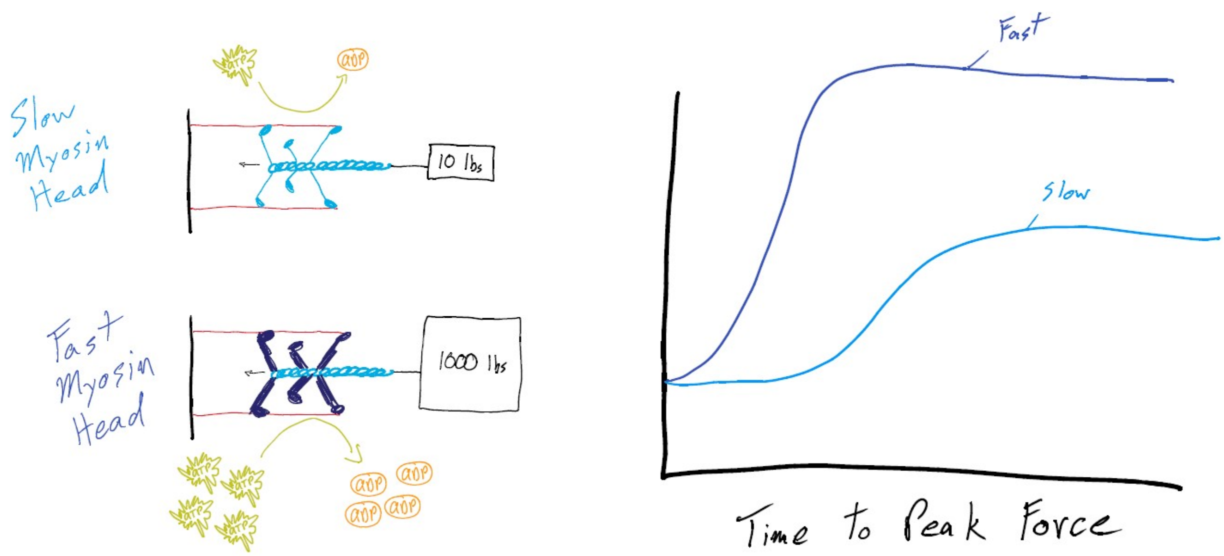
Tangent: It's kind of like swimmers pulling on the lane lines (actin) while they swim. But instead of the swimmers (myosin) moving towards the bulkhead (Z-line), they actually move the bulkhead towards themselves, constantly shortening the pool as they swim. Impressive!

That's how muscle works, and now that you understand that, I can start explaining why it matters to you.

Myosin Heads: The Movers

When a sarcomere is activated it's an "**all or nothing**" event. All of the myosin heads start pumping along and crawl their way to the end of the actin, bringing the Z-lines closer together.

BUT, **not all myosin heads are created equal.** When myosin heads are activated, it costs energy. Some myosin heads use up a lot of energy and they crawl real fast, and others spend only a little energy and move slowly. We will call these different myosin head types fast and slow myosin heads. These myosin heads play a **big role is what we call fast twitch and slow twitch muscle fibers** (more in the Muscle Types section).



As you can imagine if you have a muscle fiber with 100% fast twitch myosin heads, that muscle fiber is going to spend a lot of energy, move itself quickly down the actin, and generate a lot of force. Versus a slow twitch fiber which will have mostly slow twitch myosin heads. They will eat up energy slowly, generate much less force, but can make those energy reserves last much longer (energy in the cell is stored as ATP, a molecule we will talk about in the next chapter). Along with giving the muscle fiber a better maximum power ability, **fast myosin heads (as the name implies) also reach that peak power more quickly.**

Tangent: Myosin head type (slow vs. fast) is only one factor that plays into whether a muscle fiber (the entire muscle cell) is slow or fast twitch.

To complicate things further, **a single muscle fiber can have any combination of fast and slow myosin heads making up its power producing ability**. This gives any muscle in the body a wide range of abilities as far as power production and endurance. Some muscles are specifically engineered to have a dominant type of myosin heads. The soleus, one of your calf muscles, is almost all slow twitch myosin heads (good for walking miles). While the outer quad muscle, called the vastus lateralis, is almost all fast twitch (good for jumping a few times). Most muscles in the body of a normal person start with a relative equal amount of slow and fast muscle fibers.

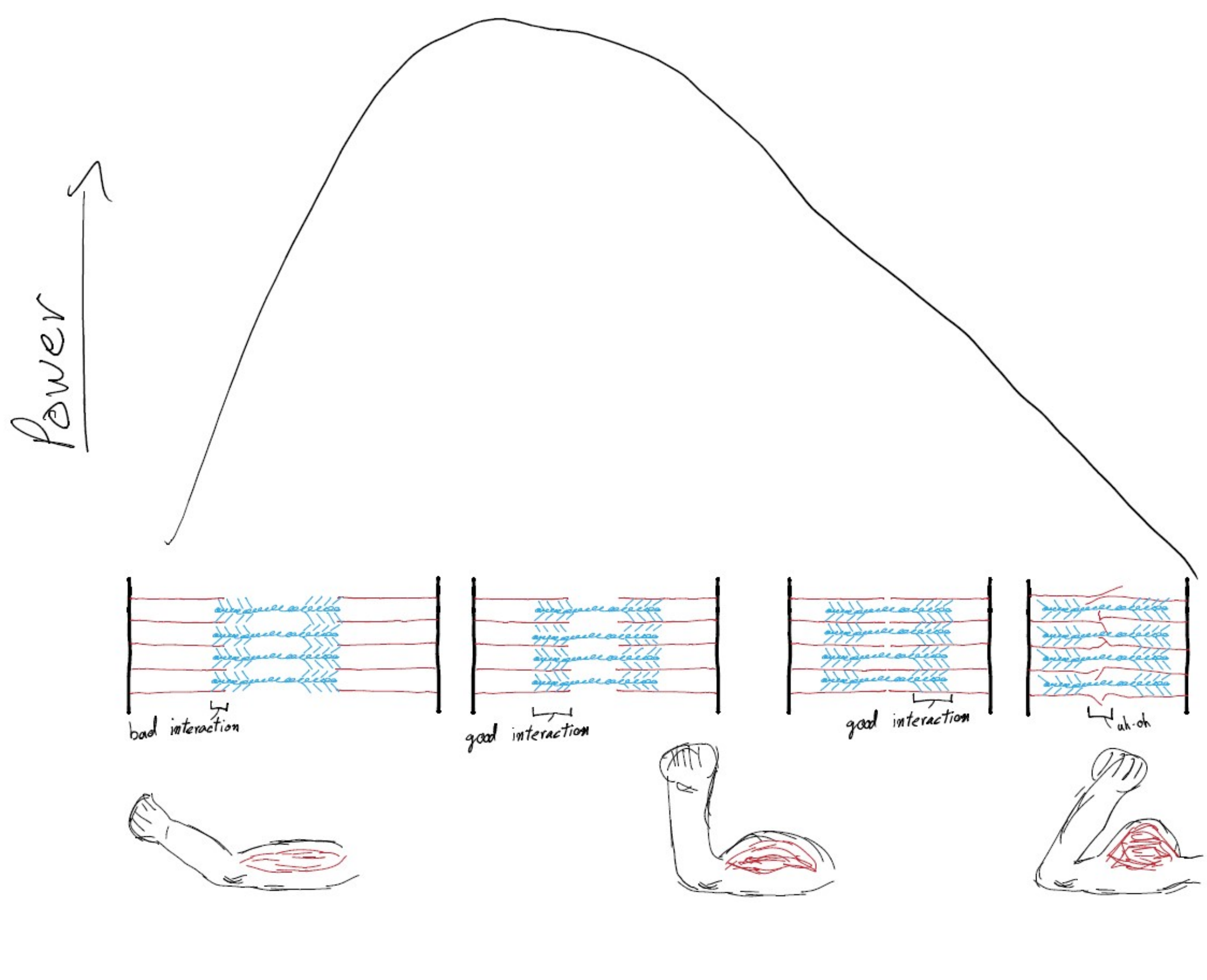
What initially determines which muscles get what type of myosin heads? Genetics. Not the way you work out (sprint vs. distance), not what you eat or how much you lift but genetics is the biggest factor.

Your baseline muscle fiber composition is based on genetics. This is part of the reason some people are naturally good at the 100 meter dash, and others are great at marathon running. The difference isn't as obvious in swimming since our events are not as extreme as running. To understand the complicated differences that go into explaining each person's natural ability, **we will compare Sprinters and Milers as we learn about each component of the swimming machine.** By looking at these extremes in our sport, we can more easily understand how the machine works and adapts.

Swimming Long is Against Biology, that's why it Hard!

Do an experiment for me. Flex your arm at 90° and have a friend try to pull your arm away. Tough isn't it. You could probably hold them off pretty well. Now, open your arm until it's almost straight and repeat. Repeat with your arm all the way flexed. At the extreme two points, your bicep is much weaker and your friend should be able to out-muscle you, if only for an inch or two. **Every muscle in the body encounters this phenomenon**, including the ones you swim with (which is all of them pretty much). The question is why?

What applies to the microscopic is what occurs at the macroscopic, so let's get back to our sarcomere. Here is a series of sarcomeres with the muscle stretched at different lengths, from **super stretched to super flexed.**



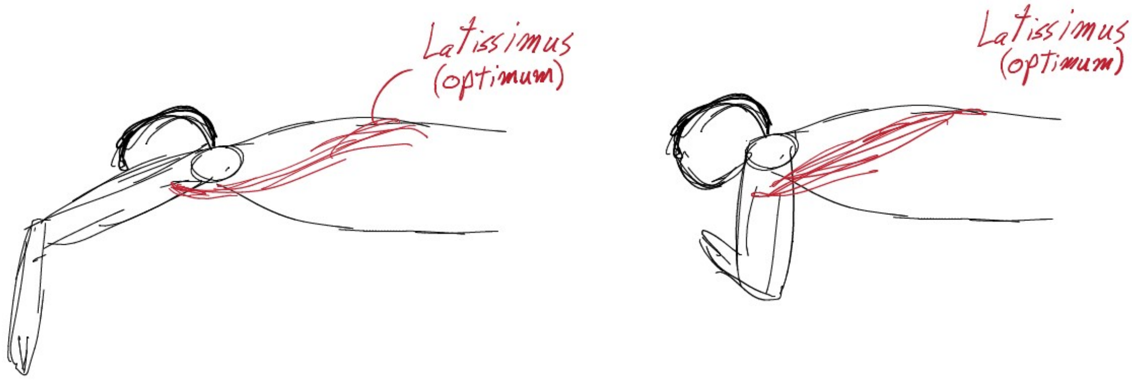
Notice anything special about the actin and myosin? In the middle, the actin and myosin are well overlapped and there is maximum "interaction" between the myosin heads and the actin proteins. This means the **sarcomere is at its strongest because all the myosin heads have a chance to "crawl"**. At the extreme stretch however, the myosin and actin barley overlap, and so only a few myosin heads can crawl along the actin, explaining the weakness at this point. When fully flexed, the actin from either end of the Z-lines get too close and overlap, causing too much congestion and weakness.

This is a big reason why swimmers get short when they get tired!! This is why swimmers get short when training with paddles! You have seen and felt all this happen when you swim, and this is the reason why: **your mind says "go faster, more power!!" and your body says "use the best sarcomere length," so it chooses to get short to maintain power when you're tired.**

Let's try to draw it out.

When your arm is fully stretched, it's **at its weakest point**. This is for multiple reasons (angle of the muscle pulling on the bones, the length of your arm….) but also because the sarcomeres in those muscles (the lats mostly) are fully stretched, and **there is little actin and myosin interaction**.

Tangent: This is the same reason the toughest part of a pullup is the start, when your just hanging there all stretched out.

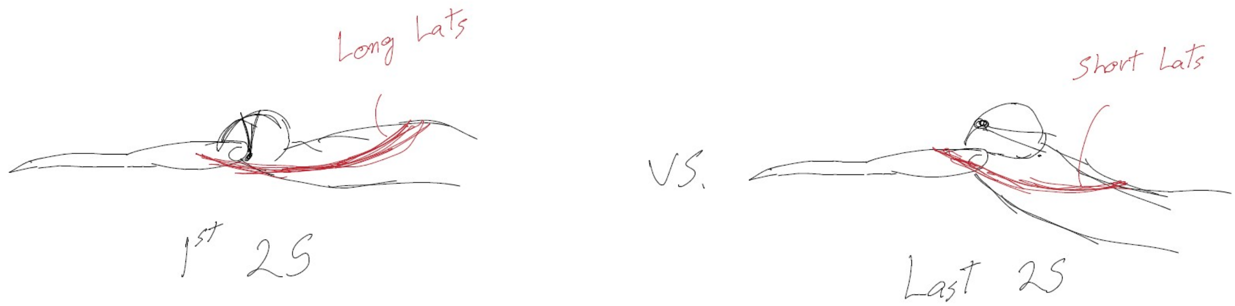


By the time the arm has started pulling a few inches, the **actin and myosin are fully overlapped and all the myosin heads** are crawling along the actin, producing **maximum power**. This is where the greatest acceleration in your stroke occurs (if your forearm is pointing in the right place of course).

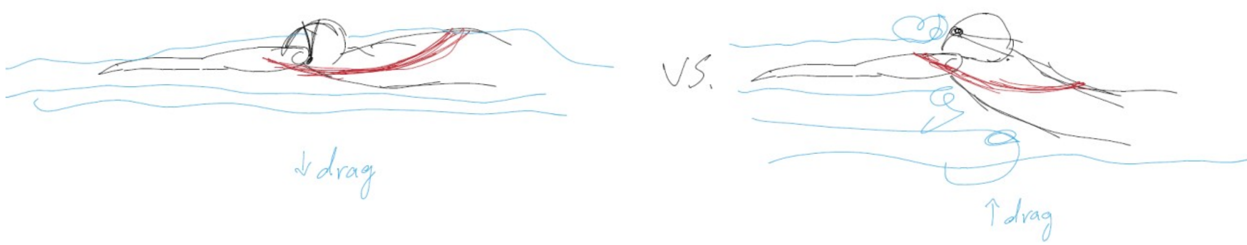
If you have not-so-good technique and you let your arm swing all the way back to your hips, you are now on the other side of the graph, where the **sarcomeres are squished together too much** to create any more force. That's why coach says "don't pull back all the way, get your elbow out of the water when you're at your hips."

This begs the question, "why am I always working on staying long and out in front with my arms if being short is so much more powerful? Why don't I just stick my arm straight down where I get the most leverage?" **The biggest reason for staying long is to reduce drag** and increase efficiency. Any shortening of the stroke will almost always mean an increase in drag. In swimming, if you choose to increase your power instead of decreasing your drag…the water will always win. At least now we understand why your body is fighting your mind.

This brings us to a phenomenon of "going vertical" at the end of a race. That first 25 is great, you feel strong, long and relaxed. But **by the end of the race you look and feel like you're swimming up** instead of forward. Here is an illustration:



The first 25, your muscles are full of energy and without much lactic acid in them (more on lactic acid in Energy Systems), so your muscles are pretty strong throughout the full range of motion. By the last 25, you are neck and neck with your greatest rival, your muscles are not working well and burn like the sun, and **your brain is shouting "GO FASTER, GO FASTER, GO FASTER**." Naturally, your body responds to those commands, but not in the way you want. Because your muscles are tired, they can no longer maintain the same tempo or strength throughout the entire range of motion. So, **your body does the "smart" thing, and sacrifices the length of the stroke in order to maintain tempo and power**. By lifting the head and body up vertically in the water, your body shortens the muscle (even with your arms at full extension) and keeps the actin and myosin fully overlapped. You can see how the angle of your armpit gets smaller, this means the muscle is shortening a little even if the arm is straight.



That's all fine and dandy to maintain power, but your body gave up the battle against drag. That's why you got out touched! That's why you work on head position so much. That's why you practice your finishes with your head down. That is also why some swimmers finish their races with straight arms and heads down, so they can force their body position.

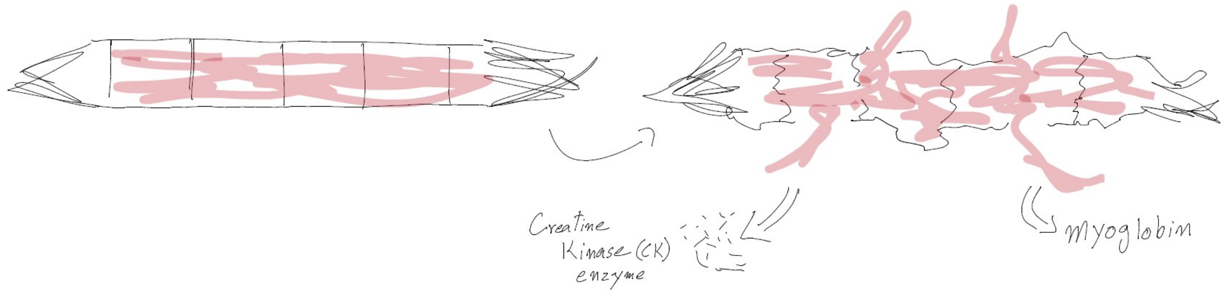
Tangent: In Part II we will look closer at how the Swimming Machine adapts, but for now you should know that training the muscle in a stretched out position will improve its ability in that position. So don't give up the details.

Muscle Damage: Explaining Soreness

What happens the next day after using paddles or fins for the first time, or training breastroke kick after months of not swimming breastroke, or any time you do something new in training? You get sore! Where is this pain coming from: **muscle damage** (or at least is starts with muscle damage). Yup, your muscle cells actually break when you train. We can even detect how much damage you caused by measuring certain muscle enzymes in your blood (creatine kinase if you're interested).

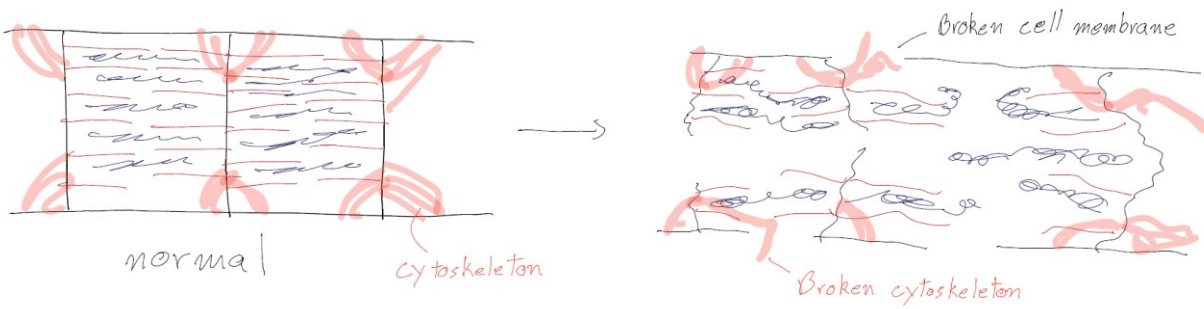
Tangent: Troponins are another protein found in muscle and leak out if the muscle is damaged or dies. In medicine, we measure these troponins during a heart attack.

And if you damage too much muscle and don't stay hydrated, certain muscle proteins which are toxic to your kidneys can cause a disease called **rhabdomyolysis** (rhabdo= rod, myo= muscle, lysis= breaking) explaining the "peeing blood" phenomenon when you work out too hard (not actually blood BTW).

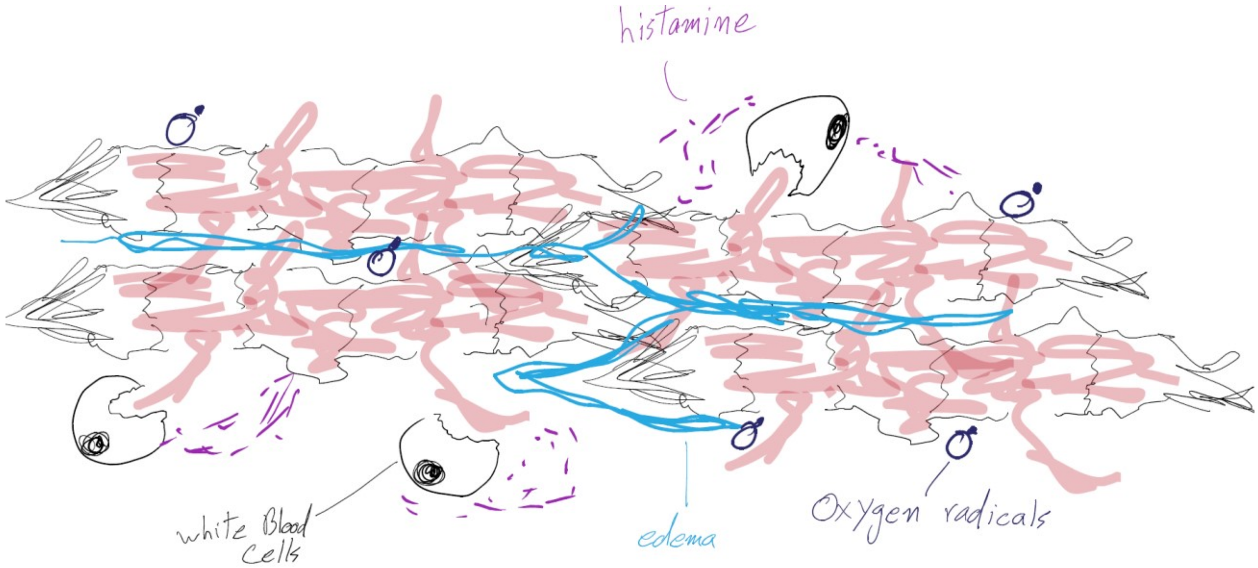


Tangent: No…you don't get to take this book to your coach and say "See! We can't work hard otherwise we will die of rhabdo!"

Let's go through this step by step. You're just starting a new season and you work out for a couple hours in the pool. During workout, the **first thing to break are the Z-lines** we talked about earlier. They are damaged through overstretching, repetitive motions, overloading and even lactic acid (some think so at least). Once enough sarcomeres are broken, the entire muscle cell loses its structural strength (maintained by a cytoskeleton made of more actin proteins) and the **muscle cell membrane breaks open**. This does not kill the cell. But it won't function anymore until it is repaired.

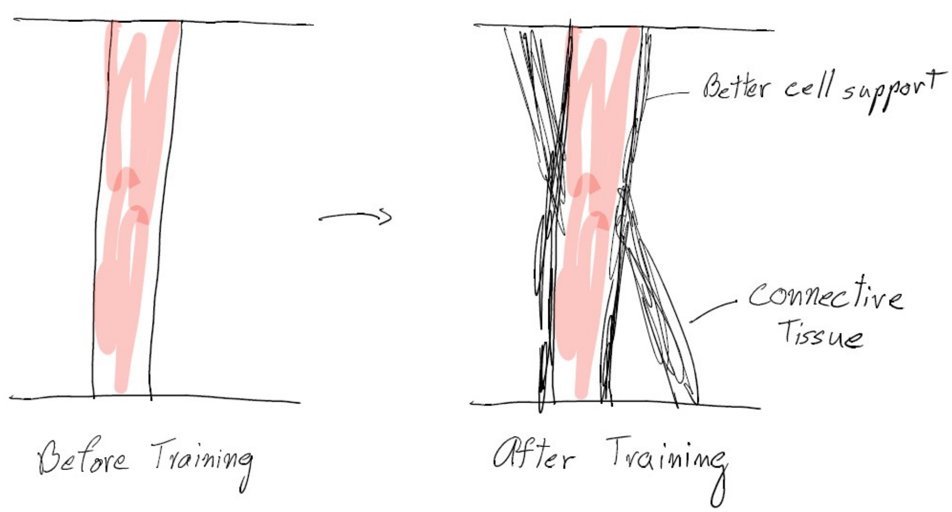


By this time you are getting out of the water. You're not in much pain though. That's because **muscle cells are not nerve cells, and they don't transmit pain to your brain**. When you get a deep cut through muscle, it hurts because you cut adjacent nerves, but the muscle itself does not feel pain. After about a day the pain starts to set in. That's because while you were sleeping your body was busy fixing what you broke. To do that, it had to recruit a whole lot of **inflammatory cells who clean up the mess of broken proteins by eating them up**. This also causes edema, or the buildup of fluid, and oxygen radicles to form (bad versions of oxygen molecules that cause more damage). These place tension on the swollen, broken muscle and also release certain chemicals that cause pain just by themselves (like histamine). **This also causes the muscle to spasm and contract involuntarily, which may explain why muscle is "tight" when sore**. This may also explain why stretching and rolling helps.



One day after your first workout of the season, you are in maximum pain. Remember, your body is a machine that takes care of itself, and **the best way for it to protect itself from further damage is by telling you to stop breaking things through the message of pain**. BUT…in your infinite knowledge, you decided to go back to the pool. By the time warmup is over however, you feel pretty good. That's because the extra movement has worked out some of the swelling and chemicals causing the pain. Also, warming the muscle helps it relax instead of spasm (just like a hot pack).

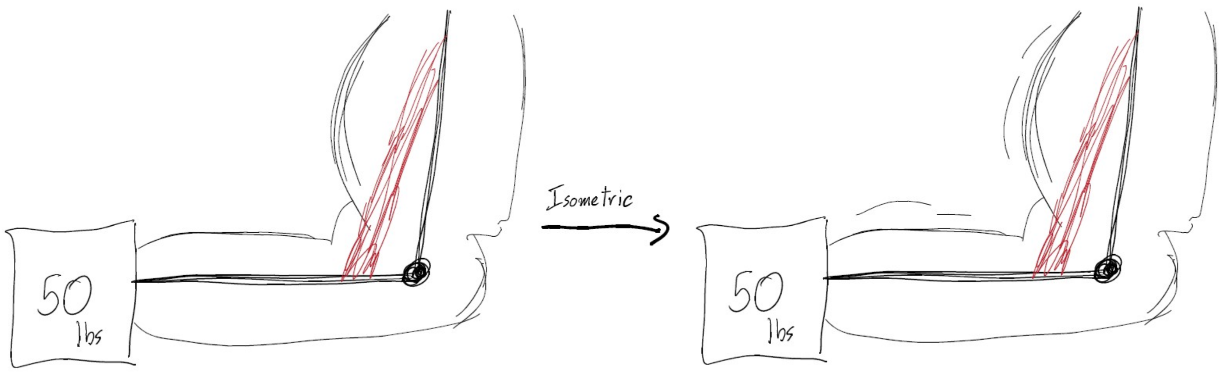
After a few days of this, you notice you don't get sore anymore, even from a two hour butterfly work out (yucky...). What changed to make your muscles not break as much? A few things, but they all have to do with **decreasing the amount of breakdown that occurs**. First, you're in better shape, so you don't make as much lactic acid (or at least, you can get rid of it faster, Lactate Threshold chapter). Second, the cytoskeleton of the muscle improves, giving muscle cells more structural integrity. And lastly, outside the muscle cell, connective tissue develops to further stabilize the muscle.



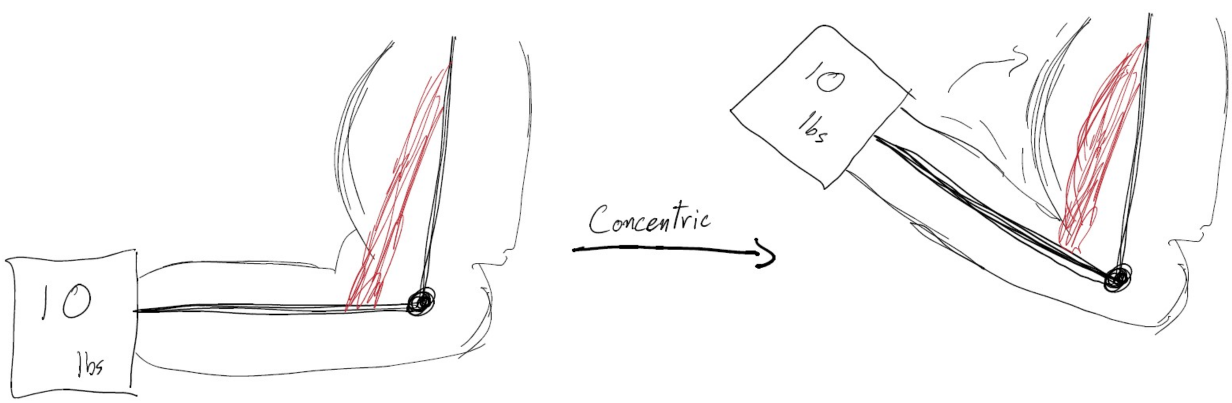
Your half way through the season now, and coach decides it's a good time to start running for dryland. Great…now you're sore again, and it's even worse than before! Why? You're in good shape, you kick a lot in practice, but a couple work outs with gravity and you're shot again. The big thing to note here is that **muscle adapts according to the challenge**, and nothing else! Your body is lazy, and conserves resources above all else. When muscle adapts, it only adapts to the stimulus it is given (swimming, not running). **This means every new challenge (running, paddles, fins, weights...) causes the muscle to break in a new way and you get sore all over again**.

Tangent: This is why you do NOT do new things during taper time! Even if it is "easy" or not a lot. The newness of the activity will make you sore. Bad bad bad.

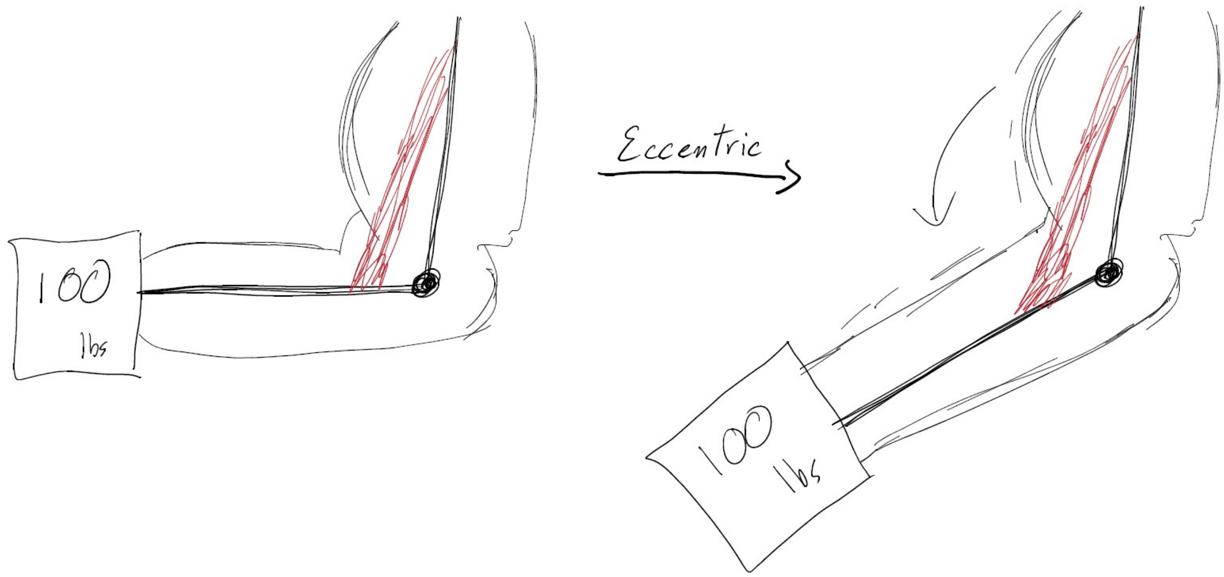
One more thing, **different types of motions can cause more muscle damage than others**. Isometric (iso=same, metric=length) exercises are motions where the muscle is **contracting, but not moving**. Like pushing against a solid wall, your muscles are working, but nothing is happening.



Concentric (con=together/shortening) motions are where the muscle is **contracting and getting shorter**. Like curling a weight that is light.



Eccentric (ek=out of/lengthening) motions are where the muscle is **contracting and getting longer**. Like curling a weight that is too heavy and overcomes your muscle strength.



In an untrained person (or if done for long enough), all these motions will cause muscle damage and soreness. However, **eccentric motions cause the most damage, and lead to the most soreness.** Can you think of any motions in swimming that are eccentric? Nope, neither can we. This right here is the limiting factor in almost every other sport. Marathon runners, powerlifters and ball sports are all limited in how much they can train because eventually their muscles breakdown too much from the eccentric motions and they have to wait until they heal. Trained swimmers don't have that limit. That is also why swimmers don't deal with rhabdomyolysis much either, so no excuses swimmers.

Tangent: Eccentric exercise and muscle damage is a big factor in stimulating muscle growth, which is why these exercises are heavily targeted in bodybuilding.