Exercise Physiology- Part 6

Dr. Andrew Klein

OK, now we're going to get in a little bit into the muscle physiology. And we'll go through some of this and hopefully approach it from a clinical point of view a little bit. The ultrastructure of skeletal fibers, I'm sure all of you are familiar with this already. And we don't need a review, but we'll review it anyway. OK?

OK, everyone remembers the basic building blocks, the myofilaments, the filaments in here. And I really want to bring it right down after we do the single muscle fiber, break it down, the sarcomere because this is the basic functional unit of the muscle cell, the sarcomere, right in there, from Z line to Z line.

Our thick filaments, the myosin-- our thin filaments are the actin. We have our cross-bridging, the calcium cross-bridging. This is what leads to the contraction. This is the sliding filament theory, which has not changed much in the last 50 or 60 years. This still is the theory that we rely on for muscle contraction.

And let's look at the physiology of the muscle for a second. Here is our Z line to Z line. Here is our sarcomere. So the first thing I want to look at when we look at the sarcomere is this would be right in here. I'm going to put this on here. Resting length, this is lengthened and shortened as in a contraction.

When we look at the muscle physiology as to where can you develop the most tension, the most contraction, it's based on the amount of cross-bridging. The more cross-bridging you have there, the greater potential for energy. So if we look at resting length, this is where we have the most overlap of the myosin and actin filaments. So the resting length, you would think, is where you can develop the most muscle tension.

Of course, in the lengthened position, you can see we've lost all this space for cross-bridging. And now in the shorter position, they've already gone past each other. So you've lost the ability to develop tension there in the shortened position. So based on this, theoretically, the greatest tension developed is at rest, but we know that's not true.

The greatest tension is actually developed here in the lengthened position. The reason why is because in the lengthened position, even though you lose some of the crosshatching, you make up with it with the elasticity of the surrounding connective tissue and with the stretch reflex. Now, I bring that up because when we talk about training and conditioning, this is one of the basic components of plyometrics. That's our ability to develop greater power from this stretched position using the elasticity of the tissue and the stretch reflex.

Intuitively, we can see this. Because if you're going to watch someone take a jump, if they're going to do a vertical jump-- so here I am at resting length for the quadriceps. Does anyone jump from this position? No. We all use a countermovement, what we call a countermove, where we drop down. What am I doing? I'm actually stretching the quads in here. So this is the countermove we talk about. The quicker I can do this, the quicker I can do and reverse it, the more force I can produce.

All right, and we'll get into plyometrics in greater detail. But you can see from the muscle physiology one of the reasons why this works. And we'll also talk about the stretch reflex as part of this.

Here's our Z line. Here's our Z line. This is the sarcomere. Now, you know about actin. You know about myosin. All through here, through the Z lines, are what we call intermediate filaments which help keep everything together. When we talk about getting stronger and increasing the cross-sectional area of the muscle, this is where it occurs. When you talk about exercise, you actually will disrupt the Z line, and this is how you can incorporate more sarcomeres, more protein into the muscle fiber.

This is sometimes, if you see this disrupted, what we call Z-disk streaming. So we're not going to increase the actual number of fibers in the muscle. What do we increase? We increase the cross-sectional area of the fiber. This is where we put in more protein. So that basic functioning of the sarcomere, we increase the cross-sectional area. That is where it comes.

How long a process does this take? If you're exercising, how long a process does this take to start remodeling this muscle? Six to eight weeks, six to eight weeks is the minimum. So when you're dealing with patients, and working with patients, and putting them on an exercise program, they have to understand they're not going to see changes in strength for six to eight weeks. That'll be the minimum.

Now, why do people feel stronger before that when they work out? We'll get to that in a little bit. A lot of people will work out for a week or two and already feel stronger. But it's not because of the actual structural changes in the muscle.

Now, if we go down into the intracellular tubular system, which is in here now-- really can't see it that well. But this is where the calcium is secreted or released, and then the calcium absorbs. So that's how we get these contractions-- intertubular system, calcium is released.

We have the sliding filament theory. Everybody can see that in the notes. The sliding filament theory cross bridges the [? actin, ?] myosin, ATP. You can see the action potential by the motor nerve, the depolarization. So you know the whole process. I'm not going to ask you to read the whole thing and memorize the whole thing. I want it there for you.

But if you go down to the next page, let's go to H. When muscle stimulation seizes, calcium ion concentration decreases as the ions move back into the lateral sacs of the sarcoplasmic reticulum. The removal of calcium restores the inhibitory function of the troponin-tropomyosin complex. Actin and myosin will remain in the relaxed dissociated state.

When you work out, when you fatigue the muscle enough, you don't get all this calcium to go back in. Not all the calcium is reabsorbed. And if this calcium that's left in the space, that will trigger an inflammatory reaction. So with an injury to the muscle or with fatigue, you will have calcium that will not go all the way back and all of it be absorbed. This will trigger an inflammatory reaction. It will trigger endogenous proteases to come to the area. You will have an inflammatory reaction.

This is good. This inflammation is good because this is an inflammation from the exercise. This is what's going to trigger the repair. This is what's going to trigger the incorporation of more protein.

Now, in your diet, if you have enough protein or they're supplementing, they've done their work out. They've fatigued the muscle. The calcium has started this inflammatory reaction. They have extra protein in the area now that the body is demanding it, and that's how you make the muscle stronger.

So once again, it's a case of inflammation being good. Inflammation is not that much different than rehabilitation. Uncontrolled inflammation is always the problem we have. Uncontrolled inflammation will be a problem. Inflammation triggers a nice response in terms of rehabilitation.

So now you have this person with the injury. And the calcium is still within the muscle. It's still intramuscular. What will happen around this calcium? I've had some classes in this. We'll see if some of my former students remember what we call this. What happens is a phenomenon which some people have referred to as ultrastructural capping.

Ultrastructural, what happens is you have calcium in the area. And what the body will do is the filaments, the contractile filaments, will actually tighten and contract to sequester the calcium, though, so the calcium can't spread too far and cause damage up and down the muscle fiber. So you'll actually have a tightening of the contraction, a tightening of the muscle fiber. That's what the contraction is.

Now, if you have a contraction or a muscle that stays tight for 24 to 48 hours, what is the general response? What will happen? It will generally stay shortened. So now you have an area of the muscle that's going to be a little bit shorter. Can you stretch it out with exercise? Maybe. You might be able to just release it that way with exercise, with stretching, but maybe not, especially if you have a chronic problem.

Let's say it was more of an injury and a strain than it was an exercise-induced injury. What will happen is, over a period of time, that will become tighter. They will not have full function. It's like having a rubber band. All right, if the rubber band is the muscle and you stretch it, that's the flexibility of the muscle.

Now what happens if you have an adhesion in the connective tissue in the muscle in the middle? Can you still stretch that rubber band? Yes. You end up with more stress on the areas that still have their elasticity. But you put a lot more stress on it, it can lead to damage further down the line into a chronic problem.

So if you can't release it with exercise or stretching, what are you going to have to do? You're going to have to go in and do some sort of soft tissue technique. This might be one of the factors that makes soft tissue techniques so important and so valuable, the ability to break up some of these adhesions.

OK, if we go through the healing process of muscles now, this is something I always talk about. Early mobilization versus immobilization-- and this should be a review for some of you. What's better, early mobilization or immobilization? Initial immobilization followed by mobilization is probably your best bet, and here's why.

OK, when you have an injury, very rarely do you have just a muscle injury. Usually, there's a muscle injury in connective tissue with it. You don't have an isolated muscle injury very-- I mean, that just doesn't seem to happen. Connective tissue is most likely to form-- if you want a good, strong connective tissue, generally the quicker you can mobilize, the better that connective tissue is. The fibroblasts will produce collagen that will align along the lines of stress. So if you want a nice, elastic, dense connective tissue, you want to mobilize it as quickly as possible.

However, muscle, if the muscle is torn, that's held together usually by almost like a fibrin clot-- kind of fragile. If you mobilize too quickly, you'll end up-- you'll keep tearing that, and the muscle will not regenerate as well. The other problem you have is if you mobilize right away, if you'd end up creating a really good, strong connective tissue, like very dense, you may inhibit the ability for the muscle fiber to actually regenerate through that.

So you have two different processes which are at odds with each other. The muscle would probably work better with some immobilization. The connective tissue works better with mobilization, early mobilization. So probably your best bet is mobilizing with immobilization-- simple enough.

Now what does that mean? OK, because it makes no sense. What you're trying to do is you're trying to mobilize as quickly as possible without reinjuring the area. So if we're talking about a low back now, they've hurt their back. They have strain. They probably have-- it's a combination sprain-strain.

So for the ligamentous tissue and the [? capsule ?] tissue that might be strained, we really want to get that repairing very well. So you want movement without too much movement. This is a case they're if they're working, they probably should be off for a couple of days so they don't put as much stress on it if it's an acute injury. A back brace is probably very good at this point because it limits movement, but you can still have some.

Bed rest is not good for this. This is not-- when I talk about immobilization, I am not talking about bed rest. I'm talking about relative restrictions. So they can still move around. They can still get motion in there, which will help stimulate the fibroblasts to produce the proper linkages, so you get a good glycogen, good connective tissue buildup there but, at the same time, not enough motion where you're going to constantly be reinjuring the muscle.

Now when I talk about braces, remember, you don't put a brace on without a plan to take it off. So whereas a back brace might be good for two or three days, then what do you do? Well, then they take it off, and they take it with them. And maybe they can go an hour or two before they feel fatigue, and then they have to strap it on. And gradually, they can go longer.

If we take the same concept to an extremity for an ankle injury, should they be on crutches? Well, probably just to help with the load but not to take all the load off. Because if they're limping on the ankle like that and it's hurting, they're probably constantly reinjuring it. If they have a cane, something where they can keep as much normal motion as possible without the pain, that's probably where you're going to get the best healing going on. So you can actually stimulate the fibroblasts, stimulate the fibroblasts and the glycogen linkages, without injuring the muscle. The muscle seems to be more vulnerable in the early stages than the connective tissue at that point.

We're going to get more into the motor unit, a little bit of the neurology in here. This is under the muscle physiology. I want to get to some of the neural aspects. First of all, with the motor unit, as a refresher, we know that it's an all-or-none principle. The motor unit is fired, or it's not fired. OK, we understand that.

Gradation of force-- how do we actually increase force? All right, there are two different ways that it's done. One is with recruitment. One is with rate coding. Recruitment is you recruit more motor units. Rate coding is you increase the frequency of the motor units that are firing.

Now, it appears that our muscle fiber types, type I and type II muscle fibers-- everyone's familiar with that? I have it later in the notes, so we will review that. But type I are generally the ones that are used for endurance events. Type I muscles generally are the slower, more anaerobic fibers that we use for endurance.

When type I muscle fibers are stimulated, it appears to be that their initial stimulation comes from recruitment. And as you use the muscle and you increase the force, you increase the recruitment. Until you hit about at about 50% of the maximum contraction of these muscles, you have almost 100% recruitment of the motor unit. Anything after that becomes rate coating.

Now, with the type II muscle, which tend to be more of the explosive strength muscles, what we find is for the first 10% of your contraction, that tends to be rate coating. Just for the first 10% is rate coating. So you have a couple of motor units firing, and they fire quicker.

From about 10% to 90% of the contraction is recruitment. And then the last 10% is rate coating again. All the units are firing. 90% of all the units are firing. And the last 10%, they fire a little quicker.

So what might this mean in terms of exercise? OK, type I fibers, for us, we can start thinking about some of the spinal muscles, the endurance fibers. They're postural. We're not talking about explosive movements. We're talking about the local muscles connecting into the vertebra, postural muscles. They're a lot of endurance. If we want to get all of those motor units to fire, we only have to have 50% of a contraction.

You don't have to do huge strength moves to get all of these motor units to fire, which makes sense because we usually don't use them that way. So you can take an exercise and not need a lot of weight. A lot of our exercises that revolve just around body weight work very well-- back extension-type exercises, working on a Swiss ball and just doing back extensions, maybe holding a light weight.

But if we look at the type II muscles, which are generally more explosive, we can't get all those motor units to fire until we go about 90% of their maximum contraction. And this might be why we have our athletes working out and telling us-- and all our trainers, we know this-- that if you really want true strength and power, you have to go almost to max lifting. If you're looking at really increasing strength and power for a lot of theses muscles, you have to go to 80% to 90%.

So you have two different populations. If you talk about your regular patient population, just some general strengthening, back, things like that, they don't have to lift very heavy at all. If you're talking about some of your athletes, they will never reach those true powerful levels without going near max. OK, and that's neurology behind it.

Now, the firing principle, the firing pattern, one of the things that determines firing pattern-- I'm talking about motor units. I'm not talking about patterns like Janda and Levett right now. I'm talking about the motor unit itself is almost a size-- what we call the size principle, which means with increasing stimulation, you start the smaller axons, and the motors units with the small axons start firing first. And gradually, the larger ones start firing. And the smaller ones are usually more of the type I muscle. The larger ones are more of the type II muscle. So it's the kind of the size principle behind which ones fire first.

Now, with firing patterns, there are ways of bypassing some of the smaller axons. One way that they've seen before is electrical stimulation. Sometimes with electrical stimulation to the muscle, it almost blocks type I, and you go right into type II. They've also found that with some of the very quick, powerful strength-training movements, that seems to bypass type I, and you can get right into the type II fibers there, the large axon fibers also. So there seem to be ways of bypassing it. And this may all feed into the concept of power and strength is done with very large weights, very quick movements for very short periods of time, and a very small amount of repetitions.

Now if we look at neuromuscular fatigue, let's see where we can get the neuromuscular fatigue. First of all, with neuromuscular fatigue-- and I would define this as a decrease in muscle tension with repeated stimulation. You can have central nervous system fatigue. You can have it in the peripheral nervous system. You can have it at the motor unit. And you can have it at the muscle fiber.

Now, this has not been kind of extrapolated as much in terms of exercise. But what we do know is that with training, you'll actually train the central nervous system. You train the peripheral nervous system. It's not all taking place just at the motor unit in the muscle, that the nervous system itself can be trained.

And when we talk about it, we can talk about a field that's a lot of work has been done in neuroplasticity, that you can change the way a nerve fiber fires. You can change the size of the nerve, what muscle fibers it may stimulate. And they've done animal studies. And one of the things they found about neuroplasticity is it's easier to get a change as you increase the complexity of the task.

A lot of this is animal studies. But instead of asking-- when they do some of the rats studies, to do just get on the wheel and just run around the wheel, they may have them do the wheel and push something to the side, things like that. It appears that the more complex the task, the greater the neuroplasticity.

Anecdotally, we probably see this with all the proprioceptive changes and all proprioceptive exercise, that it's no longer enough just to throw a medicine ball, but you have to be standing on a Swiss ball when you throw it. OK? And we've seen this kind of training, people who swear by it. And this may be a change in the way the central nervous system is firing when you increase the complexity of the task.

Now the question is, because you may have seen-- I mean, you may see exercises now where they involve a rocker board, Swiss balls, asymmetrical dumbbells. They're changing everything. We have no idea whether that works or not. How complex do you have to get? We don't know this.

Generally, what happens is you have someone who does an exercise, and people are, basically, just keep trying to top themselves. All right? So now you have someone standing one foot on each ball with the medicine ball and the flaming juggling clubs while they're working. How much more benefit does that give? We don't know. All right? I'm sure there's probably a law of diminishing returns on this stuff.

Now if we go to the next page, let's talk about the muscle proprioceptors. OK, now real quick is a review. The proprioceptive is the muscle spindle which is in parallel with the extrafusal fibers. It will detect length and tension changes.

When you have a quick lengthening of the muscle spindle, it will respond with an increased contraction and a shortening of the muscle. So once again, we see the spindle being part of the plyometric response for exercise. That's the stretch reflex. Just stretch it very quickly with tension, and the muscle will respond with a stretch reflex and contract with more tension.

Now, the Golgi tendon organ is slightly different because it's in series. It detects tension without the change in length. Now, it will detect tension with passive stretching. So if you're stretching out someone very easy, it will detect that kind of tension and let the muscle relax. If there's too much tension in the muscle as it's contracting, the Golgi tendon organ will get the muscle to relax.

This is probably the reason, the difference, between ballistic stretching and static stretching, why you have patients who you can put on a table, and you can stretch them out, do very well. And then the athlete gets off the table, and they run around the track, and they say it feels like it's going to pull even though you just did a great stretch. When you do your passive stretching, what are you resetting? You're working the Golgi tendon organ. You're not working the spindle reflex, the stretch reflex in the spindle.

So when we talk about flexibility, there's a lot of research on flexibility being what we call stretch tolerance, a dynamic ability to stretch. Really, static stretches, not what's important to the athlete. It's dynamic stretch, what can they control, how much force they can control.

Ballistic stretching probably helps reset the stretch reflex. And we've been told by peop-- well, we haven't been told. But we tell our patients, don't bounce when you stretch. Why shouldn't they bounce when they stretch? What is the problem with bouncing when they stretch.

Muscle [INAUDIBLE].

Muscles-- possible injury. The problem is, they bounce too much, they can certainly tear. They can go too much, and they can hurt themselves. But for the athlete, they need this dynamic stretch. So the benefit to balli-- and when I talk about ballistic stretching, I don't think this is a problem for most people, just an easy up and down like that. That should not be a problem. I think they're talking about a more violent bouncing up and down, which is more likely to get the injury.

But most of all, the athletes intuitively know. If you watch a track athlete when they loosen up, they're doing this kind of stuff. And it's pretty dynamic in there. Why? They're probably setting the stretch reflex at that point so they can handle more of the dynamic stretch. I don't think you can get a really good response without some sort of ballistic or dynamic stretching for the athlete.

For our regular patient population, because they're not as aware-- they may be a little older. They're not used to stretching. Just because of the risk, then you would have them do the static stretching because it's safer for them. Remember, static stretching, ballistic stretching, what's the advantage? What's the disadvantage? You do that risk-benefit measurement. For our athletes, the benefit is great. Even though there's some risk, the benefit is great. For a regular patient population, we probably keep them more to that static-type structure.

What about an injured athlete?

An injured athlete, once again, with an injured athlete, the question is, when they do that stretch, are they going to reinjure the area? You can overstretch. I think this is one of the biggest things I see in patients with reinjury, that they overstretch. A person should not be stretching to pain. Patients should not be stretching to pain. They should feel maybe a discomfort, a little discomfort. They should feel a little pull.

The most radical example of stretching I know-- I had a friend who was training in a dojo in Japan and couldn't get the full split. So what did they do? They had him go, and they jump on the hips to drive him down to the ground. What does it do? It tears everything.

Now, at that point, all right, first of all, you've got to be very dedicated to getting a full split if you want, if you go through that type of thing. What would happen now if every day he gets up, and he limps around, and he doesn't restretch it? It'll just shorten up. So if you're going to go through something like that, it's got to heal in the stretch position also. So that's the problem. We don't want our patients to go through that. There are much easier ways. OK? Plus, most of our patients don't need a full split.

The Pacinian corpuscles, now these are just to provide more sensory information to help balance out the effect of the muscle spindle versus the Golgi tendon organ. They are bodies that are right by the Golgi tendon organs. They respond to deep pressure very well. So some of the muscle techniques we may do, if we're getting pressure on the Pacinian corpuscles, this may lead to some of that relaxation we get with the deep pressure we put in the muscle.

Is that where myofascial release techniques, and maybe Graston, or just doing some--

A question about myofascial techniques and Graston, is that where they get some of the benefit? I would guess so. Most of the research around myofascial technique and Graston technique probably is around the stimulus of fibroblasts, that when you put a certain pressure, a mechanical pressure on, fibroblasts will actually increase synthesis, collagen synthesis. So I think that's where most of it-- but I think it probably does have an effect when you do that kind of soft tissue

Or Jeff Spencer, he'll use the stick [INAUDIBLE] and roll all the muscles, just to create stretching

OK, I didn't know Jeff Spencer's using a stick. I haven't seen it. Is anyone else using a stick?

I've seen it. You've seen it. You've seen a stick-- which would make sense. When you look at all the soft tissue techniques, they have the same principles behind them. The question is, are you using an implement, or are you using your hands? And how deep are you going, how much pressure you're going?

I always recommend when you are doing any kind of a soft tissue technique, the key is light pressure to begin with. Because light pressure-- and you can add pressure gradually. If you put too much pressure in right away, you can't take it back. But the body can slowly adapt. You're putting pressure, and the body can adapt, and you can go deeper. But if you go to deep right away, the body kind of just starts fighting it. Everything will tighten up.

Muscle fiber types-- slow twitch. This is what we talked about-- slow twitch, type I, fast twitch, type II. OK, fast twitch, you have type IIa, type IIb. The difference is type IIa has some endurance to it. Type IIb does not. Type IIb is easily fatigued and seems to be the muscle fiber that's damaged most of the time when we talk about muscle soreness. It's especially susceptible to eccentric actions.

Type IIc-- there's a type IIc. There's a type IIab. There's a type IIxac. If you really want to get into great detail, there are a ton of different fiber types. And a lot of it is based on what the protein content is and the ratio of heavy chains versus light chains. And I think that's really out of the scope of this right now.

So we can see the different muscle fiber types. And there are the fiber type variables, which are pretty straightforward. So if you look at the fast twitch fiber versus the slow twitch fiber, the variable, the fast twitch fiber has a high fast speed. The slow twitch fiber has a slow speed. That is pretty self-explanatory.

If you want to remember the actual fiber types, remember type I is generally darker in nature, more myoglobin. Type II is the white. It's the white fiber. So if you think of the chicken, all right, if you remember the chicken-- the chicken, the dark meat is in the legs because he walks around all day. And he really doesn't do much. All right, it's just a very slow, nice easy movement. That's the dark meat.

The type II fiber in the chicken is the white meat, the breast, OK, the wings. Because every once in a while, he'll flap his wings. He'll have a convulsion and flap. So if you can remember the chicken, you can remember whether it's type I or type II fibers. OK, where we're going to pick up now--