>> March 9th, 2015. Got a little more daylight now because it's Daylight Savings Time. Doesn't help you in the morning when you're trying to get up. But does help you in the evening. Today our eighth lecture in this particular unit. It's a topic that we've already visited. So we are, in fact, revisiting and examining muscle tissue on a little more close, or detailed inspection. Classes and characteristics of muscle tissue. What common behavior -- what common capacity does all muscle demonstrate? It contracts. So it's not contraction, it's the speed of contraction. The duration of contraction. And the location and the effect of that contraction that distinguishes the three types of muscle tissue. What's the most abundant by weight? What's the most common muscle tissue? Skeletal muscle. Makes up most of your body weight -- we'd like to think. And there are over 600 different skeletal muscles in your body. Astounding. All of these are said to be voluntary. What's that mean? You decide whether, or when, or if you want to engage them. And the function of skeletal muscle is self explanatory. What do skeletal muscles attach to? Therefore, their involvement is not just the stability, but the movement of the skeleton. Usually across diarthrotic, or freely moveable joints. Bringing about motility. That means moving you from point A to point B. But also some subtle things, like breathing, is that skeletal muscle activity. Laughing. Facial expression. All of these are also actions of skeletal muscle. And even if you're not visibly moving, are skeletal muscles always busy, or engaged in some degree of contraction? Yes. You all are sitting pretty upright on your desk. And so that's a function of support. Anti-gravitational effort of posture. So needless to say, without skeletal muscle, we'd be dead. If only for one simple reason. What's that muscle that divides the chest from the abdominal cavity. And of course, that's involved in breathing. So respiratory arrest would certainly occur without skeletal muscle. But let's look at the more typical design, or anatomy of skeletal muscle. Knowing that, of course, they are of different shapes; different sizes. But as we look at a skeletal muscle diagrammed here on the whiteboard, typically certain things are seen. That is, there's going to be points of attachment to the skeleton. And what do you call that connective tissue that joins muscle to bone? Tendons. So typically there would be two tendons. One would attach at one location. The other, beyond a diarthrotic joint on another part of the skeleton. So these are tendons. Made of what? Dense, regular, connective tissue. Which essentially connect the muscle to the periosteum of the bone. And then, on the surface of the muscle, a very glossy and tough outer covering, called the superficial fascia. This is also known as the epimysium. A term that you'll learn and read about. But essentially this is like, well, a tortilla around a burrito. What's the function of the tortilla around a burrito? Well, it keeps all the goodies inside. So the function of the superficial fascia is to bind. To surround. To enclose. To encase the individual cells of the muscle. And this superficial fascia is continuous with the tendon. Even though it's made of dense, irregular connective tissue, it's basically the same type of tissue as the tendon. And do skeletal muscles have a blood supply? Do they have arteries going in? And veins coming out. Is there a nerve supply? Of course. So we could show, or otherwise assume that those soft tissues also permeate a muscle mass. But let's look down at the cellular level. When you looked at skeletal muscle in the lab, you were looking at fibers. Individual cells. And so what are some of the features you recall about skeletal muscle fibers? They were multi-nucleated. And that's on the list of characteristics. And all cells -- certainly skeletal muscle cells no exception, have a cell membrane. That membrane is very hard to see with a light microscope. But nevertheless, it has a name. It's called a sarcolemma. That last word, L-E-M-M-A. Sarcolemma. The cell membrane around a single skeletal muscle cell. So if this is a diagram of a single cell, what is this dark line meant to be on the outside? Sarcolemma. And what are these dark organelles that are just underneath the sarcolemma? Those are the nuclei. And you've already mentioned that those are many per cell. Often flattened, and typically up against the sarcolemma. Also, every single skeletal muscle cell receives a branch from one motor nerve. When a nerve supplies a cell, it's called being innervated. So every single skeletal muscle cell is innervated -- that means receives a motor nerve. Indeed, if that were not the case, skeletal muscle would fail. In other words, that motor nerve is what stimulates, and makes possible the

contraction of each and every cell. So real quick, if this is a skeletal muscle cell now, we would show these organelles that are flattened and multiple -- what are those? Nuclei. The membrane itself -- "S" word. And then we'd show this -- which is an attempt to show that motor nerve, which stimulates and makes possible the contraction of that cell. And certainly in lab you notice that these cells are banded. They have striations. And we'll see why. And also that feature is not unique. Because cardiac muscle is also striated -- I guess you know. One thing you learned from the lab though, is that these cells are all parallel. They're very long. And the word here is uni what? Meaning all running in the same direction. So very long. Very straight. Very parallel arrangement. Which allows this to be a rather strongly contracting muscle. That is this unidirectional pattern improves the force that these muscles can generate and carry across these tendons. So I'm sure all of these things are features that you've seen, and learned to recognize already through the laboratory experience. But now let's go where you haven't been before. Let's look inside a single, skeletal muscle cell. Up here I have a test tube -- an ordinary glass test tube -- that I've filled with a bunch of applicator sticks. All right? So this glass tube represents the membrane we've given a name to. What's that membrane that surrounds the cell? Sarcolemma. And these black things that I drew on there with a sharpie, must represent the nuclei. So now we're teasing out from the interior of this cell, one of many subcellular components identified by name here as a myofibril. Subcellular means under, or otherwise smaller than the cell. Now in this particular model, there are only a handful. But typically in an ordinary cell, there might be hundreds, or even thousands of these stuffed into a single sarcolemma. And one of these is drawn here, diagrammatically. And magnified further in the view below. But as you look to a single myofibril, you'll see a repetitive design. In other words, we see these dark areas. Then light areas. Then dark areas. Then so on. And these repetitive units, which are described and defined between what are called Z lines, are known as sarcomeres. So the sarcomere is the working unit of the muscle cell. This is where the contraction actually occurs. So it might seem silly, but if you've seen on sarcomere, you've seen them all. That is, they're all designed along this pattern. So let's look at a single sarcomere. Which is exaggerated and diagrammed here, in two very different states. The relaxed state, versus the contracted state. And our goal here is to understand how actually the skeletal muscle shortens. And we're going to find out that the actual explanation is not that anything is actually telescoping in, but rather that proteins are sliding past each other in a design which we'll design as the Sliding Filament Theory. So let's back up. This was the skeletal muscle cell. This component, one of thousands, is a myofibril. And along the length of the myofibril, there are many hundreds of basic repetitive units called sarcomeres. Which can be examined under an electron microscope to reveal this pattern. The molecular level. The protein level. Way beyond the instruments that you're using in our lab. Those are called light microscopes. This requires something called an electron microscope, where you can actually see the molecules -- in this case, the proteins -- that make up the myofilaments. And therefore the myofibrils. So you should be able, at some point, to understand/explain diagram, the molecular design. The so-called myofilament design. Which essentially makes possible contraction. And is the result of two proteins, thick and thin. The thick are called myosin. The thinner ones, actin -- A-C-T-I-N. And these are said to be interdigitated. A word which is fancy. But when you take your fingers from opposite hands, and lace them together, that's something called interdigitation. That is, you're allowing for the sliding of one set of fingers along the other. And as you look to this diagram, you see that that, in effect, is what's going on. The actin are seen here in blue. The myosin is seen in red. Which one is physically thicker? Hm. The thicker ones are the myosin. The thinner ones are actin. And notice that the thin ones, are actually anchored to, or part of something we mentioned previously called a Z-line. Something that now actually is called a Z-disc. Because it turns out it's not a line at all, it's a circular plate upon which these actin are anchored. So this is the molecular level. The so-called sarcomere. Which is the result of the innerdigitation of the actin and the myosin. Incidentally every myosin is surrounded by six actin. Which creates a tunnel or a passageway through which the myosin can glide or slide. And this notion is captivated by this expression, the Sliding Filament Concept. The

Sliding Filament Concept indicates that on the ends of the myosin, there are extensions, projections, called crossbridges. Which literally grab onto the actin and pull the actin across the myosin. And that results in an overall shortening of the sarcomere. In other words, the Z-lines come closer together. So if this is baffling to you, let's make it clear. What are these zones here and here marked as what? Z-lines. And those serve as anchor points for the actin. Which project a parallel as seen. And the myosin more or less floats. Or is otherwise travelling among the actin proteins of which there are six. Six actin around every what? Six actin around every myosin. At the ends of the myosin molecules, we have these extensions called crossbridges. They grip onto the actin. Pull the actin. And therefore bring the Z-lines closer together. What does that do to the overall length of the sarcomere? Brings it closer together. So when you draw this at home, as you practice it, notice that the relaxed state, the Z-lines are far apart. And in the contracted state, the Z-lines are closer together. Now this model that I made years ago, is kind of decrepit at this point. But it still works. And even from way back there, you can distinguish two basic pieces to it. There's the glass or clear pieces, and the red ones, right? And so the red ones would be which of these proteins? The myosin. And the glass rods would represent the actin. To get a chance to look at this in lab, and it'll be on display, you should do so from the end. Because that way you'll see that every red piece -- every myosin is surrounded by six actin, which allows for the myosin to slide or glide, or move among those six actin molecules. And these plates here -- this plastic plate -- one, two, three -- those are actually known as the Z-lines, now called the Z-discs. They were called Z-lines at first, because under the microscope they look kind of fuzzy. But actually, as you can see they're circular plates. With all that said, how many sarcomeres are in this model? How many sarcomeres? Multiple choice. One, two, ten, a hundred? Well, okay. This is a Z-line. This is a Z-line. And what is the name of this structure between one Z-line and another? A sarcomere. With that said, how many sarcomeres here? Two. This is one sarcomere here, and that's another sarcomere. And there'd be another one here. And another one here. And here. And here. And here. And here. And here all the way out the door. So as I said, if you see and know one sarcomere, you've seen them all. Now what's missing from this model are the extensions. The little grabbing units at the tip of the myosin. And those are called crossbridges. But still, what we want to get from this model, because it does work in a kind of jerky way. Is the actual contraction. And are these sarcomeres -- as far as you can tell -- are they in a relaxed state or a contracted state at this time? Because as I shine some light here, you can see there's light. Then dark. Then light. Then dark. Then light. See that? And in fact, that explains something you've known for a long time. What's a characteristic of skeletal muscle? What's that S word? Striations. So striations are not painted on the surface. The striations are the result of the light and dark arrangement of these molecules at the molecular level. So to repeat, are these sarcomeres in a contracted or a relaxed state right now? And is there room for these myosin molecules to slide? And if so, what would that do to the length of the sarcomere? All right. So I'll do this, because I can only do it once. That is, this thing is just not up to multiple repeats. But do you see there's a light area here. Then dark. Then what? Light, then dark? What are these again? Z-lines, also known as Z-discs? So this is how many sarcomeres? And they're in what state? All right. Now they're in what? A contracted state. Is the dimension between any two Z-lines now shorter? And if you multiple that hundreds of times, would the muscle physically reduce its length considerably? Yes. So that's the explanation. In fact, that's called the Sliding Filament Theory. So how do we know this? Because we photographed sarcomeres in two states. And the sarcomeres, when they're relaxed, have a visible gap or light zone here -- the so called I-band. Which disappears when the muscle is in a contracted state. So you need to practice this. Be able to draw a sarcomere in a relaxed, as well as a contracted state. And also identify and label these proteins, which we've given names to, actin and myosin. So this is the sub-cellular, the molecular anatomy of skeletal muscle. It applies also to cardiac muscle. And even to smooth muscle. So it's no simple thing that is unique to skeletal muscle. As we leave this category, let's summarize some of the properties that are typical, or essentially valuable for skeletal muscle. First, each fiber; each cell contracts in an all or none fashion. Now that idea is

easy enough to memorize. It is even easy to understand. That means a cell, like this one, that cell when it contracts, will contract how? All or nothing. The problem, the confusion, is that some students say, I don't know what you mean by that, because my muscles don't have to contract all or none, all or none all the time. That's confusing the whole muscle bundle with the individual cells. Do all the cells in a muscle bundle contract together, fully, all the time? No. But at a cellular level, it's all or none contraction. In other words, these actin and these myosin slide completely, or not at all. And we also know from experience that skeletal muscle is pretty energy-hungry. That is, it takes a lot of cellular energy to keep muscles going. And from our own experience, we know that they can tire easily. And what's the F word for tiring? Fatiguing. So some of us fatigue sooner than others. We also know from experience that skeletal muscle's very rapid in its contraction. And there are many examples that you can think of. One that might not be on your mind, but what about the blinking of an eyelid? Is that pretty quick? In fact, it's so quick that you don't even notice any darkness. That is, your lids go down and up and it doesn't look like anything's happened. So very rapid contraction. Those are some of the features of skeletal muscle. And we'll compare those to the other categories as we move now to Roman Numeral 2. If skeletal muscle's the most abundant, what's the least abundant in your body? Cardiac. That doesn't mean it's the least important. Because obviously, without cardiac muscle you wouldn't move blood. And you would be, well, dead. What's the word involuntary mean? You cannot start or stop it. If you can, that'd be great. Come on down. We'll put you onto a monitor. We'll have you demonstrate that. How you can start and stop your heart. And then we'll get you on YouTube. Then we'll get you on Jimmy Fallon. And then, you know, Maybe David Letterman. You'll make a career of that; it'll be wonderful. But as far as I know, no one's been able to do that. So it's involuntary. Its function is, well, self-explanatory. Cardiac muscle is involved in contraction of the heart. And that moves blood around the circulatory system. And that's about all we need to say. The structure of cardiac muscle. The structure of the entire organ, is really a description of the heart itself. Which will differ -- we'll postpone -- until we get to the circulatory system. So for now, we'll through out some vague words here. And it is common knowledge that your heart has how many chambers? Four. And these are involved in moving blood through the heart, and eventually to the lungs and throughout the body. So the actual details of that anatomy will reverse, or I should say reserve, for later. But certainly one thing's self-evident. Does cardiac muscle have tendons? That is, are there tendons connecting the heart to the skeleton? No. Because clearly, it's not attached to the skeleton. And therefore we don't have tendons as we do in skeletal muscle. The actual cell's familiar to you. And so these are the things you already know. These cells are not multi, but what? Mononucleated. Usually a rather large and dominant, visible nucleus. And the cells have a curious manner of connection. That is, their ends are not just blunt. Their ends are sort serrated. Like two pairs of knuckles that are interlocked. And that creates what under the microscope? What can we see? What's a characteristic feature? What are these dark bands here, they're called intercalated disks. These have a number of functions. They help reinforce, or connect one cell to another. Therefore, transmit the force of one to the cell next to it. But mainly they allow the electrical signals from one cell to spread quickly, instantaneously, to the next. So as a description they're called cell bridges. Because literally they bridge or weld -- W-E-L-D -- weld together these cells, and allow for electrical communication between the cells. Is cardiac muscle striated? And that makes it similar to what? Skeletal muscle. What makes it different is that these cells are shorter. They're highly branched. And multi-directional. That means not long and parallel, but short and splintered, as you've come to recognize in the lab. So all of you can, and have already, mastered the ability to identify cardiac tissue under the microscope. Now remember, this tissue's striated, yes? And remember, striations are the result of the molecular anatomy, that is actin and myosin. So are there myofibrils? The answer is yes. And these myofibrils are not much different than in skeletal muscle. In fact, the myofibrils in one cell are linked in the myofibrils in the adjacent cell, actually passing through these cell bridges, known as the intercalated discs. And if there are myofibrils, would you expect there to be myofilaments? Yes. Is there actin? Is there myosin? And does this

perform or contract in the same way as skeletal muscle? The answer is yes. So the manner of contraction and the molecular anatomy is identical to skeletal muscle. The difference here is that cardiac muscle contracts slower than skeletal muscle. But it still contracts, although it achieves a different net result, namely, circulation of the blood. So with that said, what are some properties of cardiac muscle that distinguish it, or set it apart from the other two types of muscle? Well, all or none contraction. But wait a minute, that's not unique. Because what did we say already about skeletal muscle? All or none. The only thing unique about this is that because these cells are bonded, or welded together through the intercalated disc, when one cell contracts, they all will contract eventually. That is, that contraction will spread, and eventually reach and cause the contraction of the entire heart. So this all or none rule, it applies to the cell. But it also applies to the entire heart. That is, the contraction of the heart is pretty much all or none. That is, there's no such thing as a small contraction. And also, here's an interesting and in fact unique property of cardiac muscle. It's self excitatory. What does that even mean? The equivalent name is autorhythmic. Auto meaning self, and rhythmic meaning rhythm. If we take a skeletal muscle cell out of a skeletal muscle bundle, to do so would cut its motor nerve, wouldn't it? And would that skeletal muscle cell contract spontaneously by itself in that situation? No. But if you take a cell out of a heart and put it in a nutrient petri dish, it will do what all by itself? It will contact. In other words, it contracts in a spontaneous, autorhythmic fashion. Indeed, if we could rip your heart out of your chest and put it on the desk, what would you see until you lost consciousness? [Laughter] you would see it contract. And maybe, just possibly, with your rat experience, that might have been something. Many of you, when you removed the heart from the animal, noticed very tiny contractions that still continued, even though the heart was removed from the so-called dead animal. So autorhythmicity. And also, this contraction, even though it's all or none, it's subject to outside influences. Isn't it common knowledge that your heart can speed up or slow down? And what are the factors? Well we know stress or sleep might raise or lower heart rate. But what are the actual, anatomical explanations for that? Do we have hormones; chemicals, that circulate through the circulatory system that cause the heart rate to go up? And indeed, what's one you know by name? Adrenaline. Also known as epinephrine. And aside from that, we have something you'll learn quite a bit about, called the ANS. An acronym for? Autonomic Nervous System. Maybe already from biology you've heard of the parasympathetic versus the sympathetic. And that these tend to serve as accelerators and brakes for -- among other things -- cardiac muscle. So sympathetic -- sympathetic fibers tend to speed up the heart. Parasympathetics slow it down. These are all branches or components of the autonomic nervous system. So, of course, does your heart rate have a fixed number? Is it always 70 beats a minute? No. Can it double that? Can it go down quite a bit lower? It does. It does in response to circulating hormones. And the affects of the autonomic nervous system. Another interesting thing to say about cardiac muscle, and which also applies to skeletal muscle. And that is, if you destroy a cardiac muscle cell, or if you destroy a skeletal muscle cell, will another one take its place tomorrow? Are these tissues able to replace destroyed cells? The answer is, no. So someone who has survived a heart attack, they might say, well the doc says I'm as good as new. Well no [laughter] you're never as good as new. Because if you have sustained a heart attack, have you lost; have you destroyed some cardiac muscle? Of course. Are you able to live? Yeah, maybe. But are you as good as new? Sorry, no. And so that idea applies not just to cardiac muscle, but also to skeletal muscle. Once it's destroyed, it's not going to be replaced. Let's finish off with smooth muscle. It's said to be involuntary. Matching the cardiac description. That means it contracts on its own without your intervention. It also means that it requires no outside stimulus. It's not dependant on motor nerves. Its functions are known to you in examples. If you think about where smooth muscle is, you realize that it's often found around hollow, tubular, sac-like organs. Like those found in the GI tract, the urinary tract, and so forth. So here's just a cardboard tube which I've wrapped some paper around. And here we see that paper's wrapped in a circular fashion. And here I have it laid out in a longitudinal fashion. This represents how smooth muscle is normally organized. Some of it runs circularly. Some of it runs longitudinally. And what

happens to this tube if this circular muscle contracts? If the circular muscle contracts, the tube is squashed. If the longitudinal muscle contracts, the tube tends to flatten out in a sort of series of wavic contractions. And the net result is just like taking your hands around a garden hose -- got that image? Garden hose has water in it. What happens if you take your hands around a garden hose, squeeze, and then run it forward? What happens to the water? It spurts out. That process, as it occurs in the GI tract -- P word -- peristalsis. So whether it's blood or urine, that's exemplified in this type of activity. Not to forget childbirth. How do children get delivered out into the world? Do they just drop out onto the floor? Wouldn't that be great? Spread your legs. Kid goes down. Walk away. Yeah [laughter] yeah. It would be. We like to keep it difficult and painful. I'm being facetious, but clearly this requires a severe amount of effort. And what is the organ made of smooth muscle, which delivers children into this world? Uterus. Assisted by the vagina to some extent. And then every vessel that's an artery or a vein is surrounded by smooth muscle. And that smooth muscle helps to maintain blood pressure. Also direct or steers blood pathways. Therefore controls the route and the flow of blood. With all that said, what about the structure of smooth muscle? Again, tends to form the walls of tubular, or circular, or hollow structures. Multi-layered. Typically in a circular, or a longitudinal pattern. Multi-layered. Multi-directional sheets of smooth muscle. And you've seen this in the lab. And typically, smooth muscle is seen when you cut cross section or a long section through some tubular structure. Whether it's, let's say the esophagus or other portions of the GI tract. And the cells you've come to recognize are not cylindrical, but rather tapered at both ends. And so whereas this might be a drawing of a skeletal muscle cell, how would a smooth muscle cell look in comparison? It would tend to be sharply pointed at both ends. Something called a muscle spindle. What about the nucleus? What's the story there? How many? One mononucleated. A remember, why are these cells called smooth? What's the idea? Hm. They're non-striated. Which is interesting, and begs a question. Why are skeletal muscles striated? What was the molecular explanation for their banding? Well it was the light/dark pattern of the molecules. And so if this is not banded, you might expect that maybe this pattern doesn't exist in smooth muscle. It actually does. But the myofibrils are not as orderly. They're disorderly. In other words, instead of all being parallel, they are running at different angles. And therefore, any pattern of light and dark tends to get muddied or grayed out. But there are myofibrils. And there are myofilaments. And so at least on a molecular level, the means of contraction is the same. Same as what? Same as skeletal muscle. Same as cardiac muscle. But remember, it's not that these contract differently, it has to do with the speed of their contraction. So let's back up. Which of the muscle types that we've named so far has the fastest rate of contraction? Skeletal. And then we mentioned cardiac being faster or slower? And what do you think about smooth muscle from your own experience? Smooth muscle is really slow. Just think about that ice cube that you've swallowed. And it moves gently down to the stomach. Taking maybe 20 seconds to get there. So that's rather slow. And if that doesn't ring a bell, than what about defecation? What about delivering a child? Is that fast or slow? Well, it can be fast, but it's typically slow. So what have I said? Skeletal muscle is the fastest. Cardiac is somewhere in between. Smooth muscle is slow. Now don't confuse that. We're not saying skeletal muscle is better; it's just faster. And smooth muscle is doing just fine, considering what it's designed to do. So slow. Definitely slow, prolonged, oh yeah, wavic contraction. So anybody that's given birth, you can relate to those words. Anybody that's every had a bowel movement, you can relate to those words. And I guess that covers everybody in the room [background laughter]. And are these muscles susceptible to change? Can their rate of contraction be increased or decreased? And the answer is, yes. And incidentally, if you folks need to leave the room, what's the most proper way to exit? That door back there. Why is that the courteous, most etiquettely correct way to go? Less distracting. Thanks. So circulating hormones do influence as do ANS. What's that? Autonomic Nervous System. We're going to find a kind of interesting turn of events here. Sympathetic, as you'll recall, does what to the heart rate? But actually here in the smooth muscle, it decreases it. So that's just a fact that we'll discover and explain later. Autorhythmic? In fact this is something you can relate to. When you looked at the rat, the heart

may have stopped. But if you really were looking, you saw that the GI tract was still in motion. And is it in motion all the time? If we put a stethoscope on your belly, would you hear something? You'd better hear something. And what's that called? Bowel sounds. If you don't have bowel sounds, then well, you've got a problem. Things aren't moving. So autorhythmic -- 24/7, 365, smooth muscle is contracting. At least in the GI tract. Ooh, and I just recalled though, remember, smooth muscle is not always or only found around tubular structures. What's that little, microscopic piece of smooth muscle in the skin? The electrophile, yeah, which causes the goosebumps. But that's a really weird exception. And finally, in this category, smooth muscle can be stretched without what? Without damage. What's an obvious example of that? If you're a female, you have a uterus about the size of a pear. Does it stay that way in pregnancy? Gets to watermelon size. Does that stretch the uterus? Does that diminish its capacity to contract? No. On the other hand, if you stretch skeletal muscle, will that be a good thing for it? If you stretch skeletal muscle, you can tear it and cause permanent damage. So that's unique. What's unique? Smooth muscle can be what? Stretched without damage. And if you can't relate to the uterus, do you all have bladders out there? And does that bladder stretch? And does that diminish or otherwise paralyze it? Nope. So there you go. Smooth muscle. Very unique from the other types. Have a great afternoon. Enjoy the daylight savings.