GLOBAL EDITION

Visual Anatomy and Physiology

THIRD EDITION

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Module 9.9

Tension is greatest when muscle fibers are stimulated at optimal length

There is no mechanism to regulate the amount of tension produced in a contraction by changing the number of contracting sarcomeres. When calcium ions are released, they are released from all triads in the muscle fiber. Thus, a muscle fiber is either "on" (producing tension) or "off" (relaxed). Tension produced at the individual muscle fiber does vary, however, depending on the fiber's resting length at the time of stimulation.

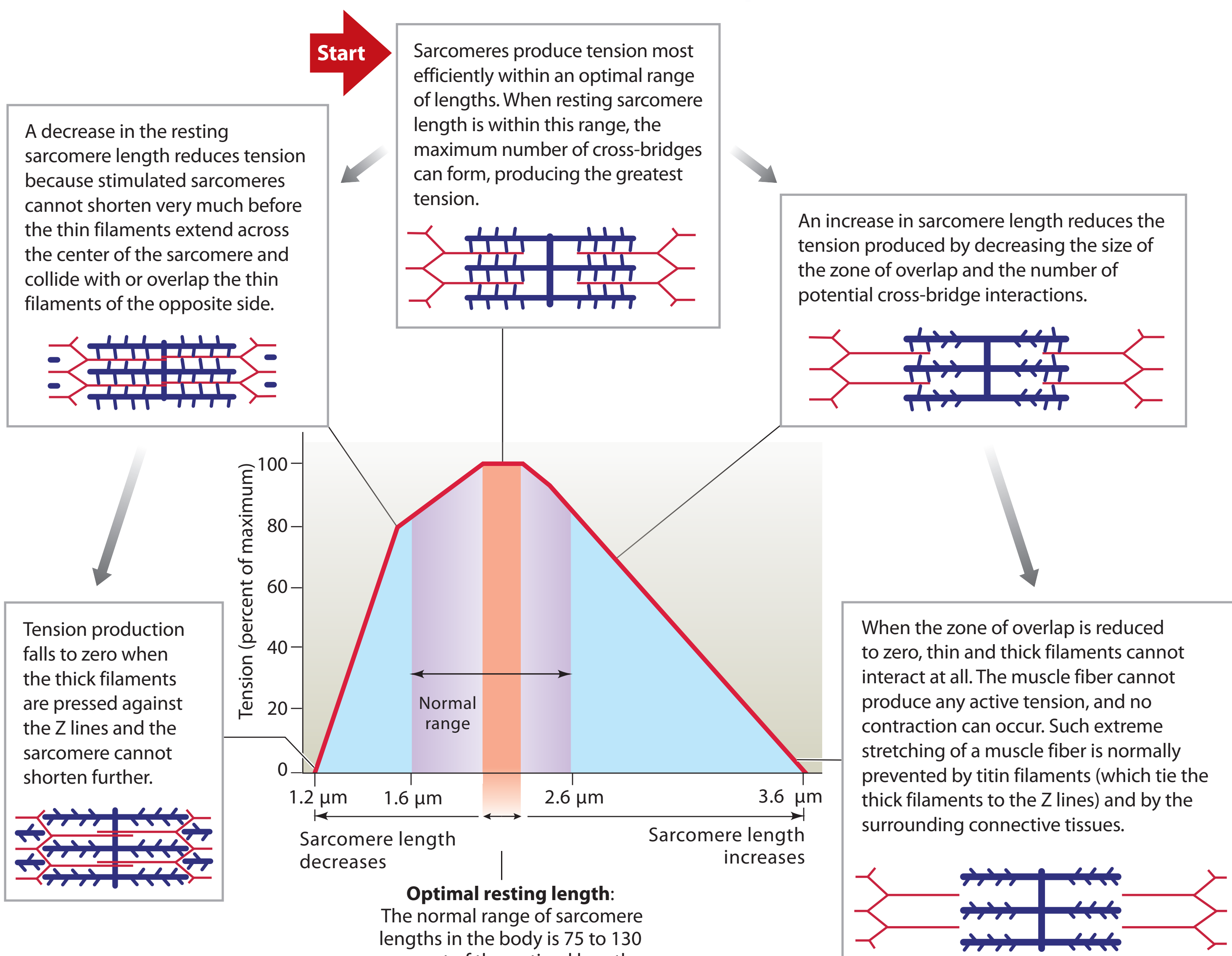
The Sarcomere Length–Tension Relationship

1 The tension a muscle fiber produces is related to sarcomere length. When sarcomeres are either stretched or compressed compared to optimal resting length, tension production declines. The arrangement of skeletal muscles, connective tissues, and bones normally prevents too much compression or stretching. During walking, for example, leg muscle fibers are stretched very close to "ideal length" before contractions occur.

REVIEW

A. What sarcomere characteristic affects the amount of tension produced when a skeletal muscle fiber contracts?

B. Explain two key concepts of the sarcomere length–tension relationship.



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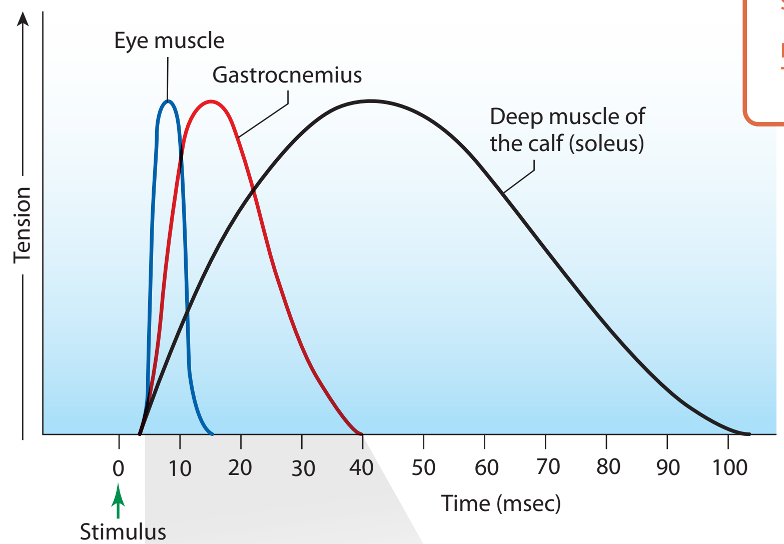
PhysioEx 9.1

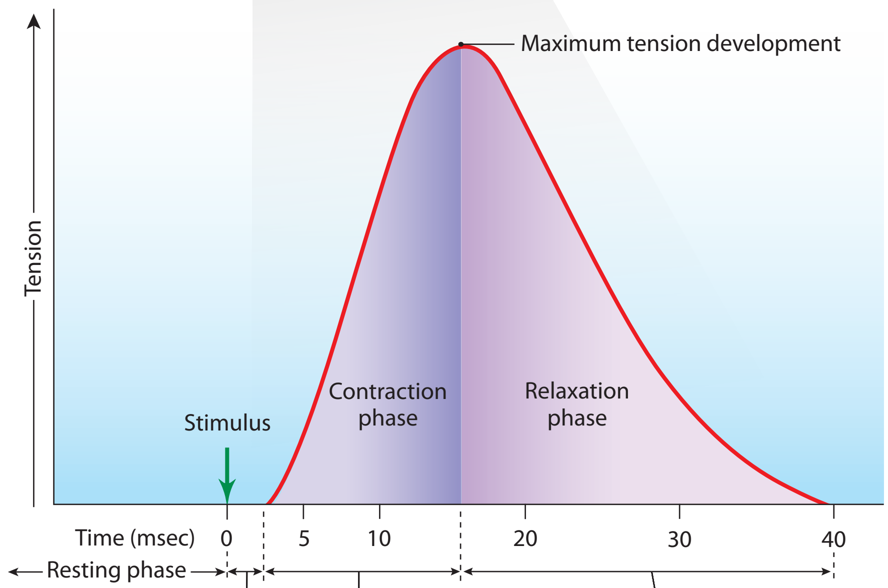
Skeletal Muscle Length-Tension (Ex 2,6)

Measuring Muscle Fiber Tension

2 A **myogram** is a graphical representation of tension development in muscle fibers. This myogram shows three examples of a **twitch**, a single stimulus-contraction-relaxation sequence in a muscle fiber. Twitches vary in duration, depending on muscle type and location, internal and external environmental conditions, and other factors. We have all probably seen or felt an involuntary "muscle twitch" under the skin. Such a muscle twitch is called a **fasciculation** (fa-sik-yū-LĀ-shun). A fasciculation involves more than one muscle fiber. It is the synchronous contraction of a *motor unit*, that is, a group of skeletal muscle fibers all controlled by a single motor neuron (see Module 9.10).



3 This myogram shows the phases of a 40-msec twitch in a muscle fiber from the gastrocnemius muscle, a prominent superficial muscle of the calf. Remember that a millisecond is one thousandth of a second! So these events happen rapidly—in less time than a finger snap.



The **latent period** begins at stimulation and typically lasts about 2 msec. During this period, an action potential sweeps across the sarcolemma, and the SR releases calcium ions. The muscle fiber does not produce tension during the latent period, because the contraction cycle has yet to begin.

In the **contraction phase**, tension rises to a peak. For about 15 msec, calcium ions are binding to troponin, active sites on thin filaments are being exposed, and cross-bridge interactions are occurring.

The **relaxation phase** lasts about 25 msec. During this period, calcium levels are falling, active sites are being covered by tropomyosin, and the number of active cross-bridges is declining as they detach. As a result, tension returns to resting levels.

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REVIEW

C. Describe the events that occur during each phase of a twitch in a stimulated muscle fiber.

LEARNING OUTCOME

Describe the mechanism responsible for tension production in a muscle fiber, and discuss the factors that determine the peak tension developed during a contraction.

Module 9.10

The peak tension developed by a skeletal muscle depends on the frequency of stimulation and the number of muscle fibers stimulated

Two factors determine the amount of tension produced by a skeletal muscle: (1) the amount of tension produced by each stimulated muscle fiber and (2) the total number of muscle fibers stimulated at a given moment.

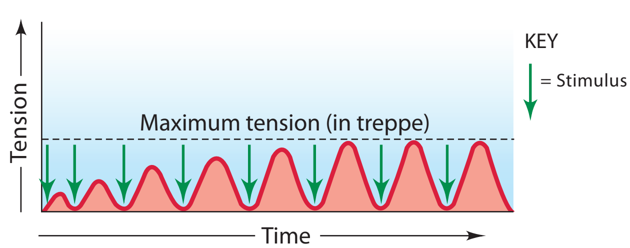
REVIEW

A. Compare incomplete tetanus with wave summation.

Frequency of Stimulation and Muscle Fiber Tension

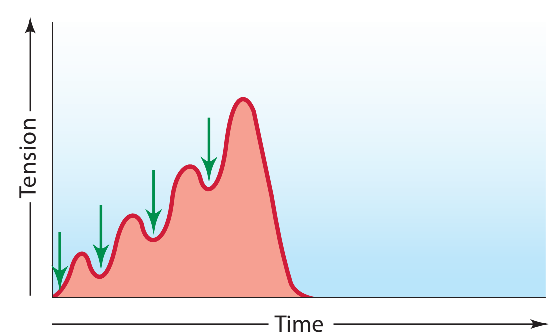
Treppe

1 Each time a skeletal muscle fiber is stimulated immediately after the relaxation phase has ended, the subsequent contraction will develop a slightly higher maximum tension than did the previous contraction. The increase in peak tension will continue over the first 30–50 stimulations. Because the tension rises like the steps in a staircase, this phenomenon is called **treppe** (TREP-eh, German for *staircase*). Most skeletal muscles do not demonstrate treppe. (However, treppe occurs in cardiac muscle tissue if stimuli of the same intensity are sent to the muscle fiber after a latent period.)



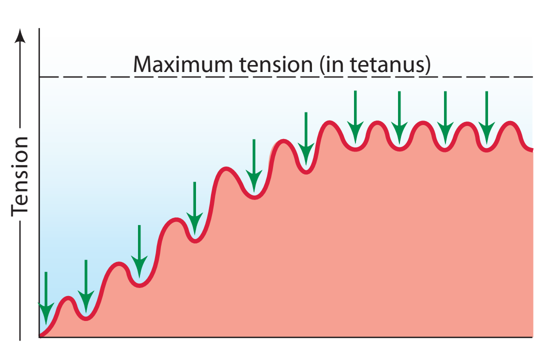
Wave summation

2 If a second stimulus arrives before the relaxation phase has ended, a second, more powerful contraction occurs. The addition of one twitch to another in this way is called **wave summation**. The duration of a single twitch determines the maximum time available to produce wave summation. For example, if a twitch lasts 20 msec (1/50 sec), a stimulus frequency of greater than 50 per second produces wave summation, whereas a stimulus frequency of less than 50 per second will produce individual twitches and treppe.



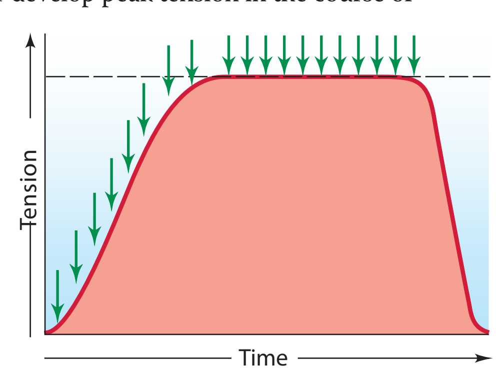
Incomplete tetanus

3 A muscle producing almost peak tension during rapid cycles of contraction and relaxation is said to be in **incomplete tetanus** (*tetanos*, convulsive tension).



Complete tetanus

4 **Complete tetanus** occurs when a higher stimulation frequency eliminates the relaxation phase. During complete tetanus, action potentials arrive so rapidly that the SR cannot reclaim calcium ions. The high cytosolic levels of Ca^{2+} prolong the contraction, making it continuous. Tension plateaus at a maximum level. Although muscles can be forced into tetanus in the laboratory, they seldom if ever develop peak tension in the course of normal activities. In part, this is because normal movements require precise control over, and continuous variation in, the amount of tension produced.



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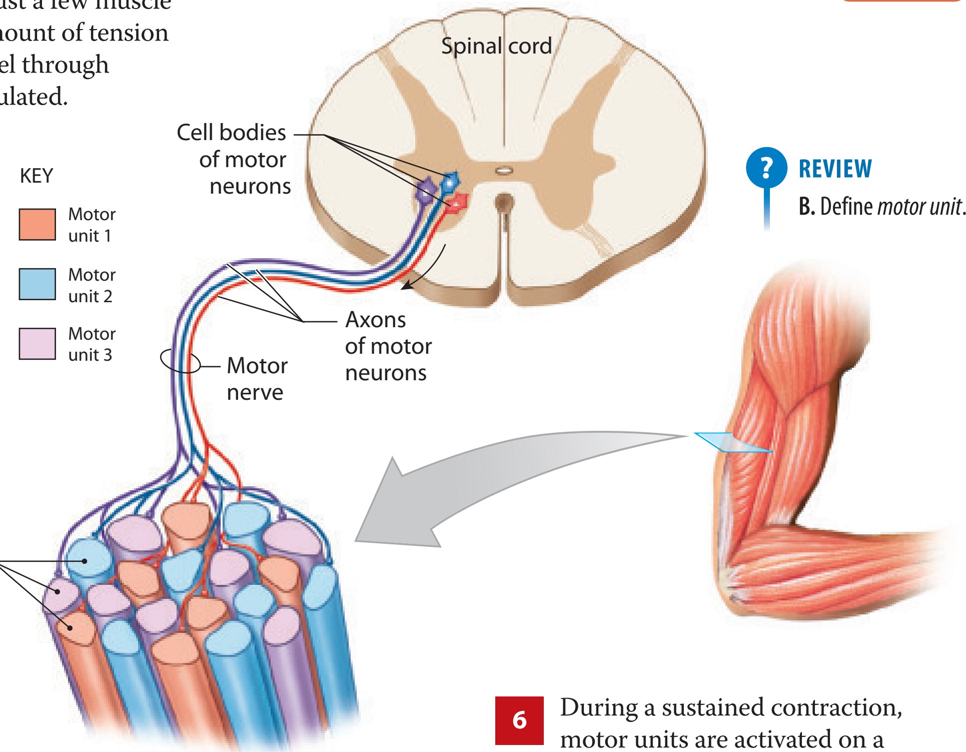
Motor Units and Recruitment

5 A typical skeletal muscle contains thousands of muscle fibers. Although some motor neurons control just a few muscle fibers, most control hundreds of them. The amount of tension produced is controlled at the subconscious level through variations in the number of muscle fibers stimulated.

A **motor unit** is a motor neuron and all the muscle fibers that it controls. The size of a motor unit indicates how fine, or precise, a movement can be. In the muscles of the eye, where precise control is extremely important, a motor neuron may control 4–6 muscle fibers. We have much less precise control over our leg muscles, where a single motor neuron may control 1000–2000 muscle fibers.



The muscle fibers of each motor unit are intermingled with those of other motor units. As a result, the direction of pull exerted on the tendon does not change when the number of activated motor units changes. When you decide to perform a specific movement, the contraction begins with the activation of the smallest motor units in the stimulated muscle. As the movement continues, larger motor units containing faster and more powerful muscle fibers are activated, and tension rises steeply. The smooth but steady increase in muscular tension produced by increasing the number of active motor units is called **recruitment**.

REVIEW

B. Define *motor unit*.

REVIEW

C. Describe the relationship between the number of fibers in a motor unit and the precision of body movements.

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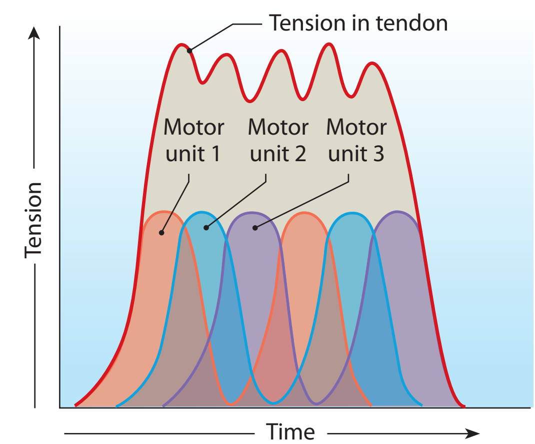
6 During a sustained contraction, motor units are activated on a rotating basis, allowing some to rest and recover while others are actively contracting. In this "relay team" approach, called **asynchronous motor unit summation**, each motor unit can recover somewhat before it is stimulated again. As a result, when your muscles contract for sustained periods, they produce slightly less than maximal tension.



Everyday Physiology

What Is Muscle Tone?

A variable number of motor units is always active, even when the entire muscle is not contracting. Their contractions do not produce enough tension to cause movement, but they do tense and firm the muscle. This resting tension in a skeletal muscle is called **muscle tone**, and it is regulated at the subconscious level. The activity level of each motor neuron changes constantly, and individual muscle fibers can relax while a constant tension is maintained in the attached tendon. Activated muscle fibers use energy, so the greater the muscle tone, the higher the "resting" rate of metabolism. Elevated muscle tone increases resting energy consumption by a small amount, but the effects are cumulative, and they continue 24 hours per day.

LEARNING OUTCOME

Discuss the factors that affect peak tension production during the contraction of an entire skeletal muscle, and explain the significance of the motor unit in this process.

Module 9.11

Muscle contractions may be isotonic or isometric; isotonic contractions may be concentric or eccentric

We can classify muscle contractions as *isotonic* or *isometric* on the basis of their pattern of tension production.

Isotonic Contractions

In an **isotonic contraction** (*iso-*, equal + *tonos*, tension), tension rises to a constant level, and the skeletal muscle's length changes. Lifting an object off a desk, walking, and running involve isotonic contractions. There are two types of isotonic contractions: *concentric* and *eccentric*.

Concentric Contractions

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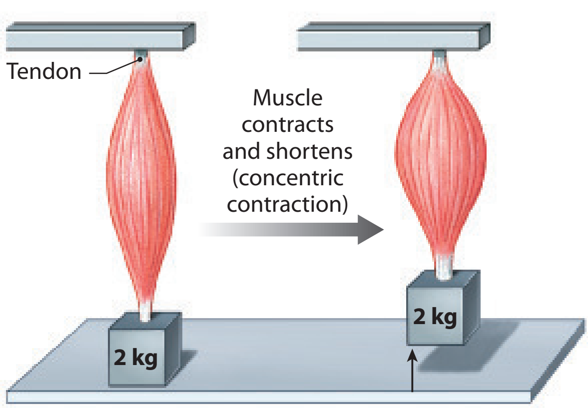
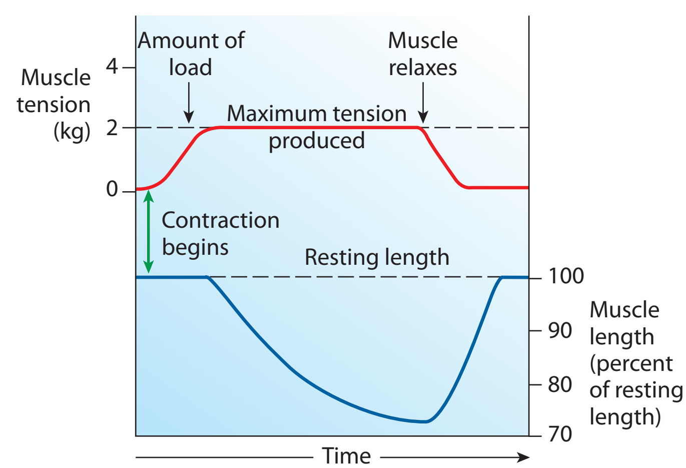
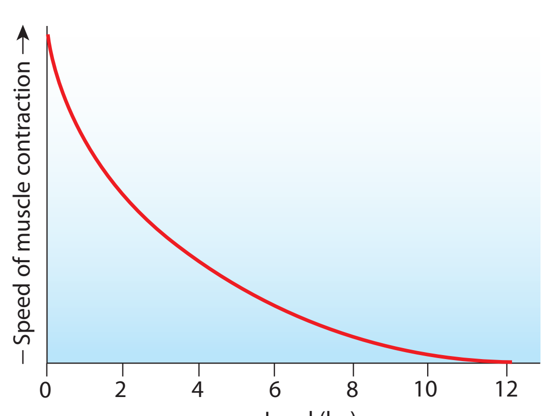
1 In a **concentric contraction**, the muscle tension *exceeds* the load, and the muscle *shortens*. Consider an experiment with a skeletal muscle that is 1 cm^2 in cross-sectional area and can produce 4 kg (8.8 lb) of tension in complete tetanus. If we hang a load of 2 kg (4.4 lb) from that muscle and stimulate it, the muscle will shorten. An example of a concentric contraction is flexing the elbow joint from an extended position while holding a dumbbell. To lift the weight, the muscle must recruit enough motor units to overcome gravity and actively shorten.



2 Before the muscle can shorten, the cross-bridges must produce enough tension to overcome the load—in this case, the 2-kg weight. At first, tension in the muscle rises until the tension in the tendon exceeds the load. Then, as the muscle shortens, its tension remains constant at a value that just exceeds the load. The term i*sotonic* arose from this type of experiment.



3 The speed, or rate, of muscle contraction varies inversely with the load on the muscle. If the load is relatively light, the muscle will contract quickly; if the load is heavy, the muscle will contract slowly or not at all. The speed of muscle contraction is fastest when the load equals zero.



? REVIEW

A. Explain the relationship between load and speed of muscle contraction.

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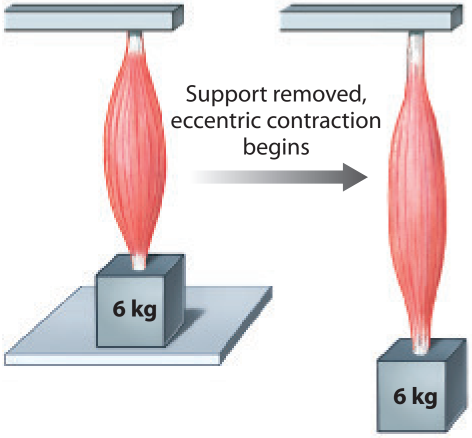
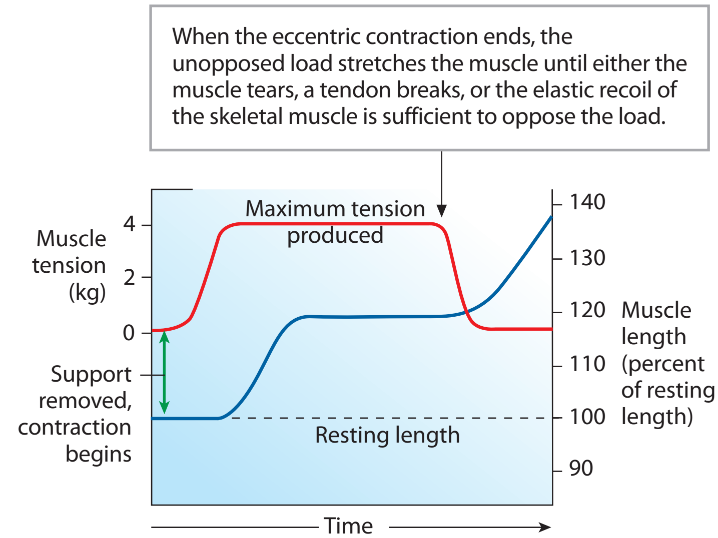
PhysioEx 9.1
Isotonic Contractions (Ex 2,7)

Eccentric Contractions

4 In an **eccentric contraction**, the peak tension developed is *less than* the load, and the muscle *elongates* because of the contraction of another muscle or the pull of gravity. This figure shows what happens if we attach a 6-kg weight to the muscle and then stimulate the muscle (6 kg is 2 kg greater than the 4-kg maximum tension potential). To continue our example, think of lowering the dumbbell by extending your flexed elbow joint. To lower the weight, the muscle will decrease motor unit recruitment, the dumbbell will overcome the tension generated by the muscle, and the muscle will lengthen. In the example shown below, the muscle is still actively contracting, but not enough to lift the weight.



5 The rate of elongation during an eccentric contraction depends on the difference between the tension developed by the active muscle fibers and the size of the load. By varying the tension in an eccentric contraction, you can control the rate of elongation.



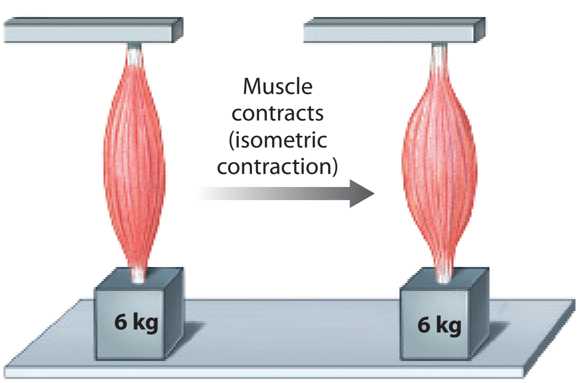
REVIEW

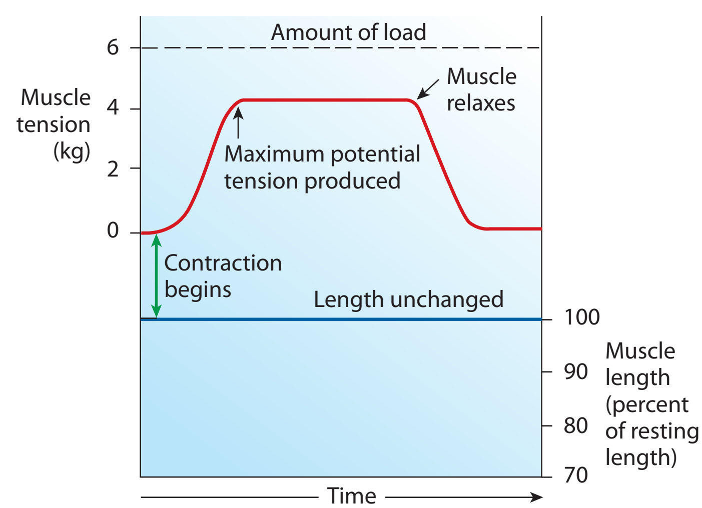
B. Compare concentric and eccentric contractions.

Isometric Contractions

In an **isometric contraction** (*metric*, measure), the muscle as a whole does not change length, and the tension produced never exceeds the load. Many of the reflexive muscle contractions that keep your body upright when you stand or sit involve isometric contractions.

6 If the load equals the peak tension, the load won't move when the muscle contracts. The contracting muscle bulges, but not as much as it does during an isotonic contraction. In an isometric contraction, although the muscle as a whole does not shorten, the individual muscle fibers shorten as connective tissues stretch. The muscle fibers cannot shorten further, because the tension does not exceed the load.





INTEGRATION

C. Can a skeletal muscle contract without shortening? Why or why not?

LEARNING OUTCOME

Compare the different types of muscle contractions.

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