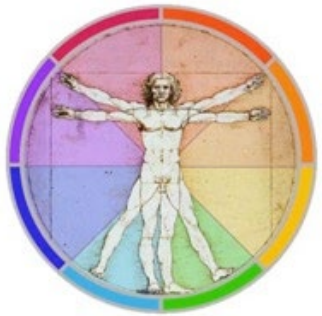
HUBS 191 Lecture Material

This pre-lecture material is to help you prepare for the lecture and to assist your note-taking within the lecture,
it is NOT a substitute for the lecture !



Please note that although every effort is made to ensure this pre-lecture material corresponds to the live-lecture there may be differences / additions.

HUBS 191

Jeff Erickson – Department of Physiology

Lecture 9
Skeletal Muscle: Contraction, Tension, and Fibre Types

Example exam question

Which of the following events during EC-coupling would contribute to relaxation of a muscle cell?

A. A signal arrives at the cell through the t-tubules.
B. The SERCA pump moves calcium into the SR.
C. The voltage-gated channel (DHPR) is activated.
D. The ryanodine receptor (RyR) releases calcium from the SR.

Objectives and Study Guide

After this lecture you should be able to:

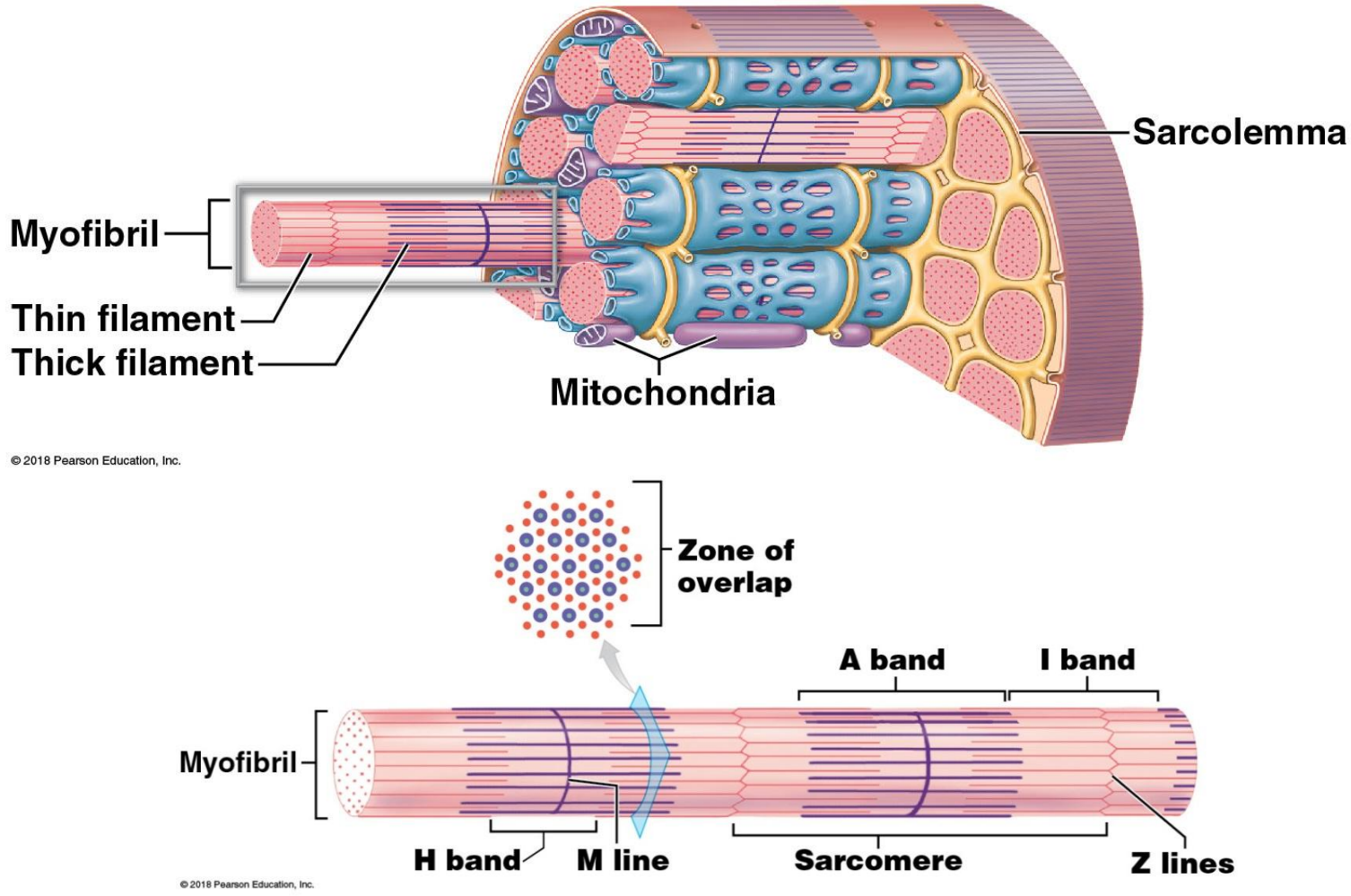
- Describe the sequence of events that occur during a cross-bridge cycle
- Explain the two determinants of skeletal muscle force generation
- Describe the key differences between fast and slow muscle fibres

Related reading: Martini et al. Modules **9.7** (p. 368-69), **9.10** (p. 374-75), and **9.14** (p. 382-83)

The myofilament is primarily composed of actin and myosin

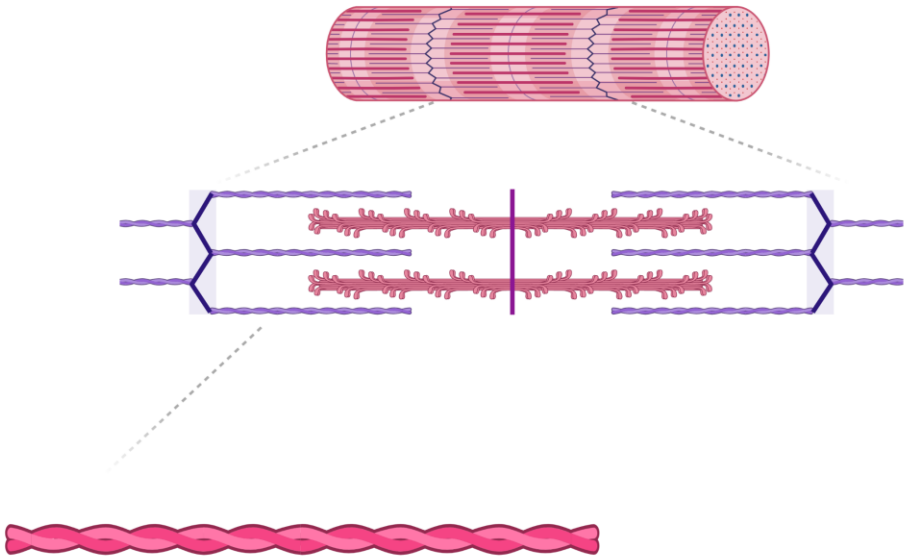
Actin

Myosin



Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.3, pg 360.

Actin forms the thin filament, a structural scaffold that runs along the myofilament

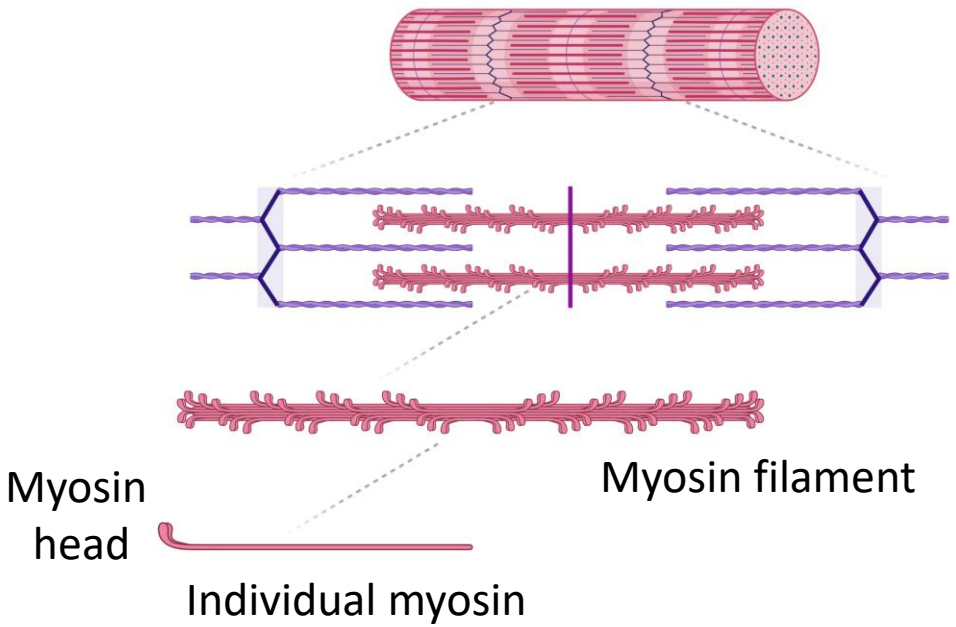


Actin filament

dreamstime.com

In this example, the rope is like the actin filament…

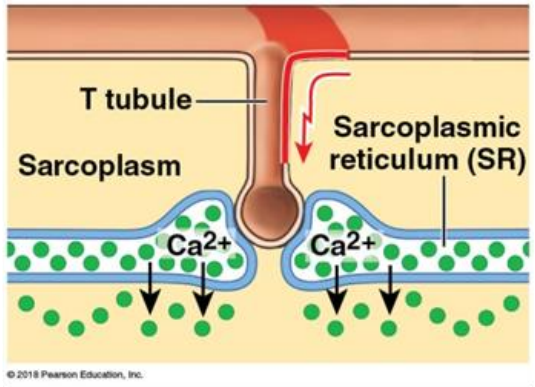
Myosin forms the thick filament and acts a motor molecule, attaching to actin and generating force to pull

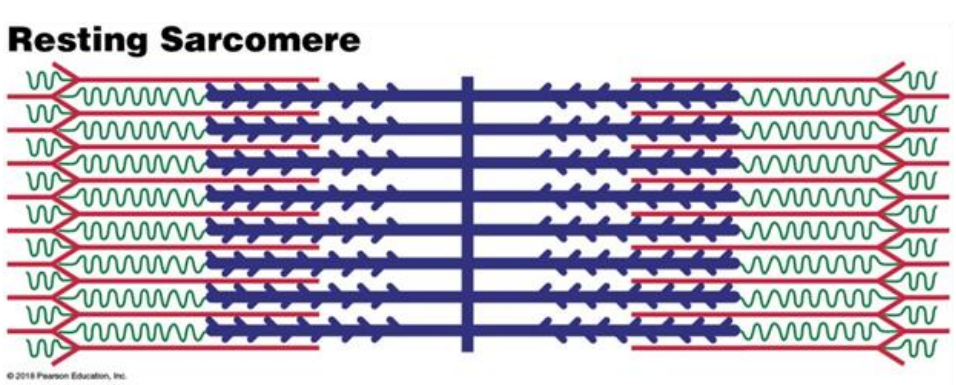


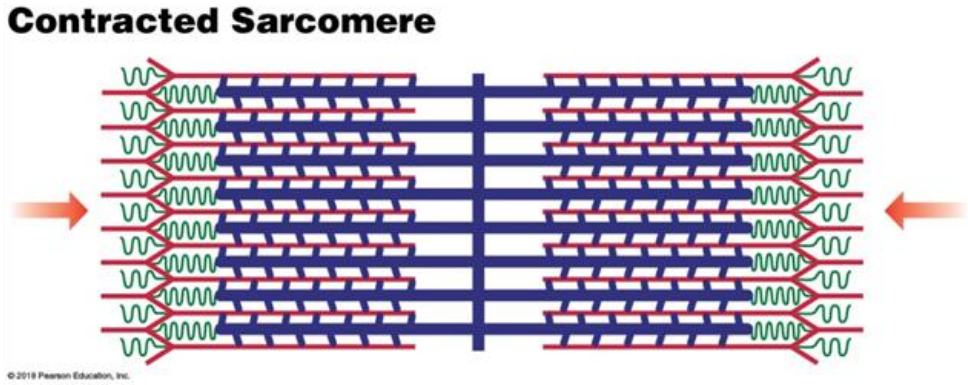
dreamstime.com

…and the people are like the myosin, complete with hands that act like myosin heads!

Actin and myosin bind together when calcium is present, forming cross-bridges and allowing contraction to occur

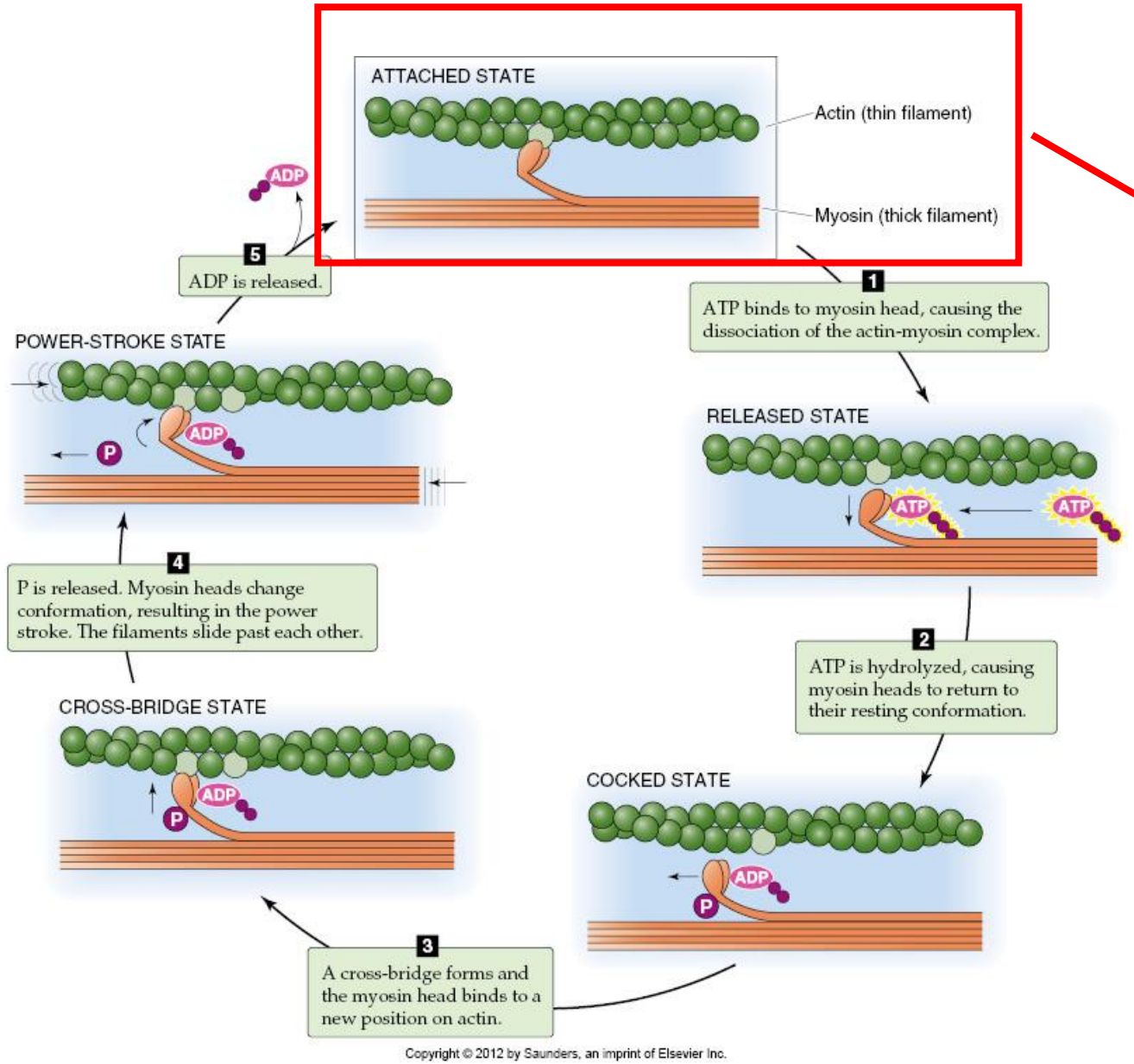






Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.8, pg 371.

Cross-Bridge Cycling

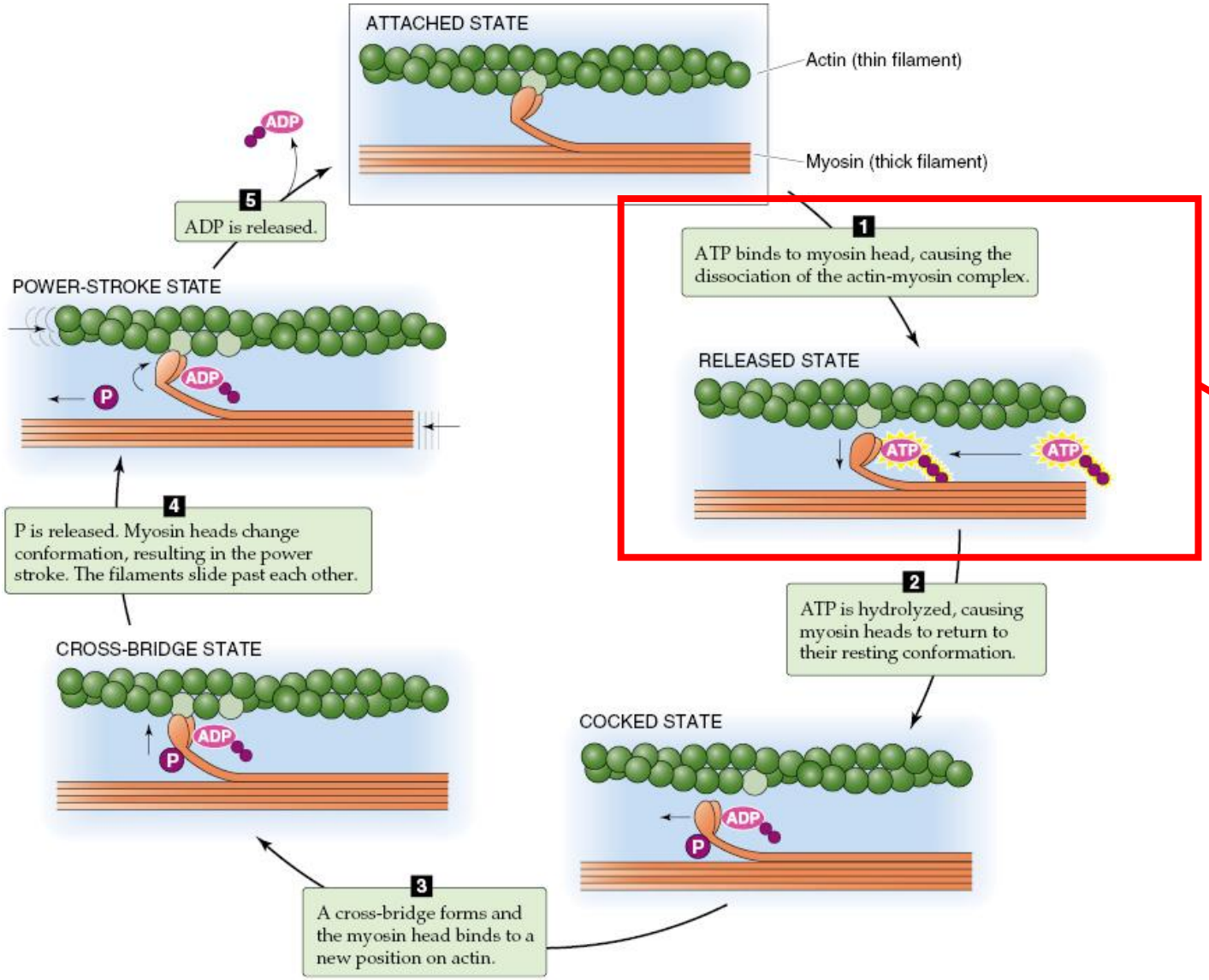


The myofilament has just finished a power stroke (pulling on actin).

Actin/myosin cross-bridges are still present.

Boron, W. F., & Boulpaep, E. L. (2009). Medical physiology (2nd ed).

Cross-Bridge Cycling

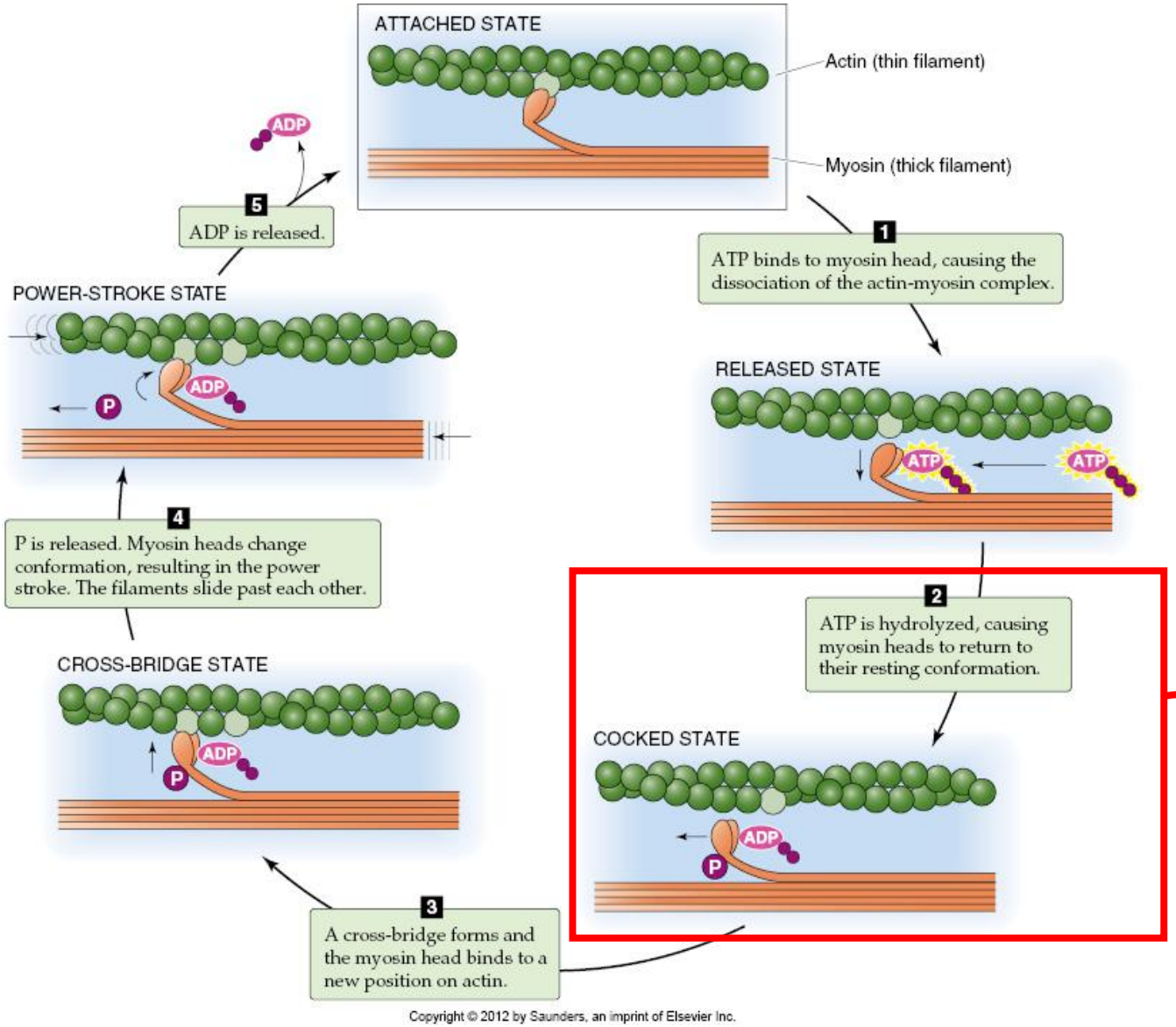


A molecule of ATP binds to the myosin, in preparation for releasing some energy to prime the myosin head.

The binding of ATP causes the myosin head to release actin…no more cross-bridge!

Boron, W. F., & Boulpaep, E. L. (2009). Medical physiology (2nd ed).

Cross-Bridge Cycling

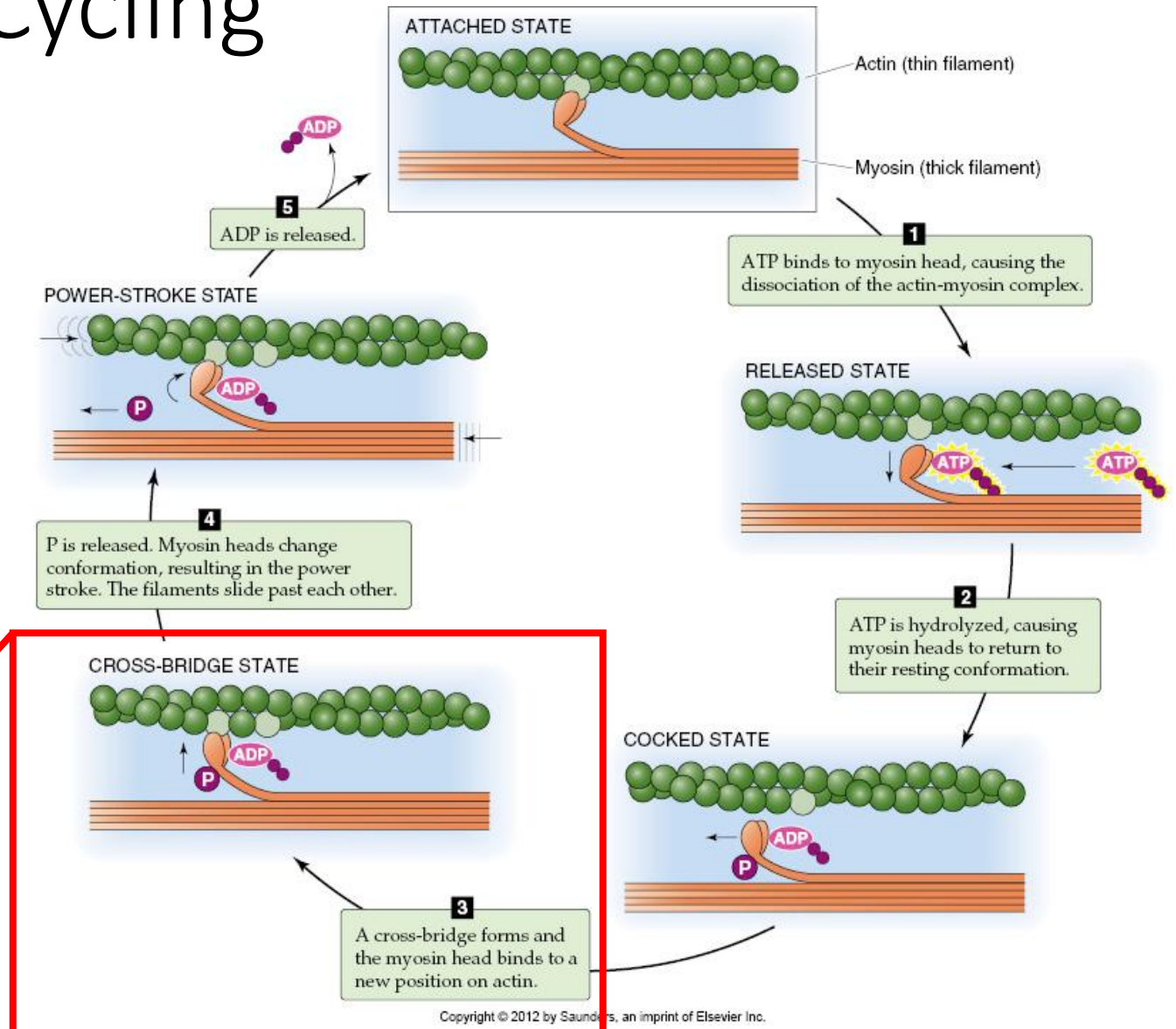


The myosin head burns the ATP to make energy (and some ADP waste).

It stores the energy by changing the shape of the myosin, getting it ready to pull on actin again.

Boron, W. F., & Boulpaep, E. L. (2009). Medical physiology (2nd ed).

Cross-Bridge Cycling



If calcium is present and bound to the myofilament, then it's time for the next contraction!

The energized myosin head can now bind to actin, forming a cross-bridge.

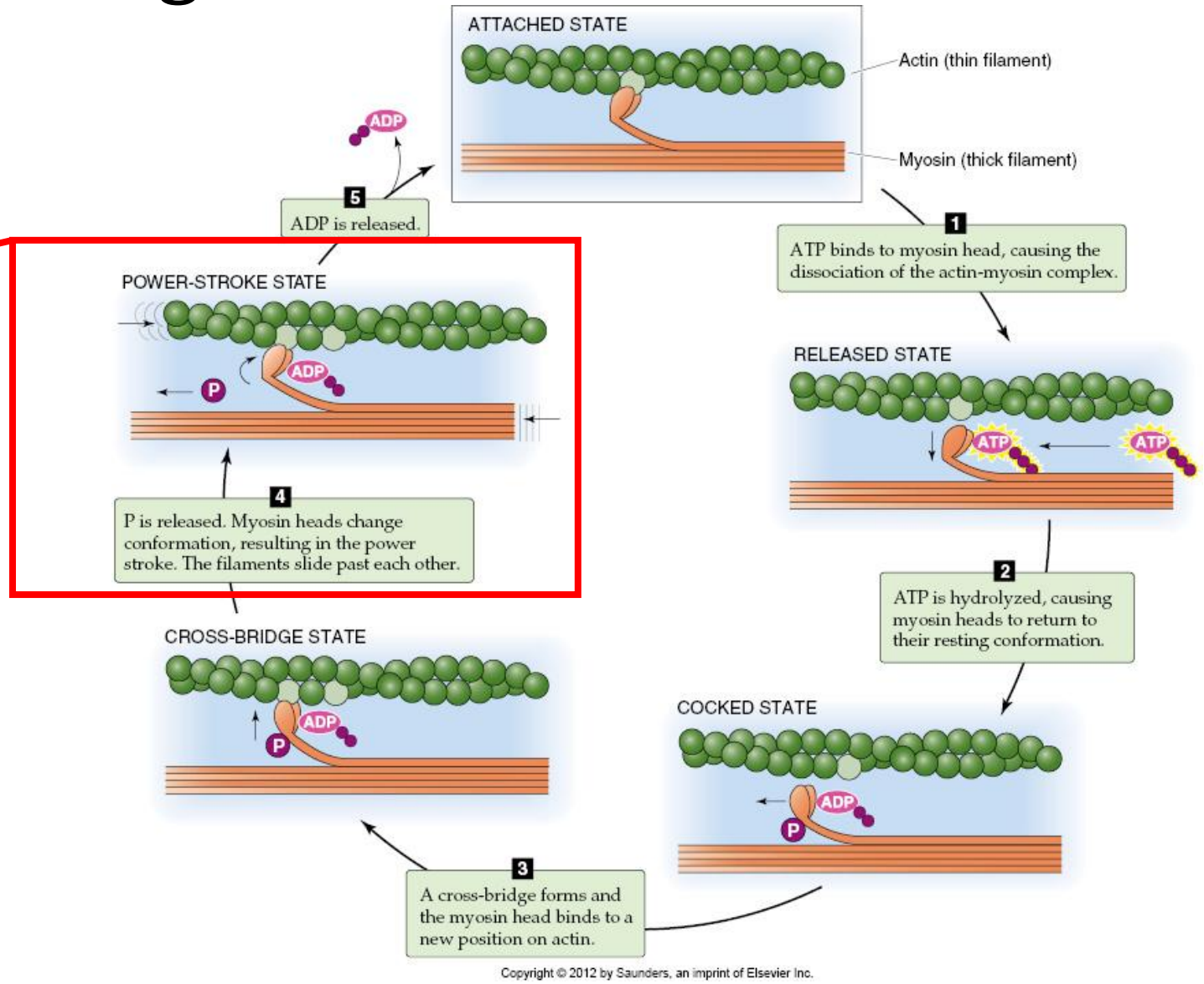
Boron, W. F., & Boulpaep, E. L. (2009). Medical physiology (2nd ed).

Cross-Bridge Cycling

We now have a cross-bridge with an energized myosin head attached to actin.

The myosin uses its stored energy to pull, causing the actin filament to slide.

The sarcomere shortens…contraction has occurred!



Boron, W. F., & Boulpaep, E. L. (2009). Medical physiology (2nd ed).

Did you catch it?

NZ Herald

- What are the two key proteins that make up the myofilament?
- What is the order of the five states within the cross-bridge cycle? At what point in the cross-bridge cycle does the myofilament slide?
- What event has to happen for a cross-bridge to form? What event has to happen for the cross-bridge to be released?

Example exam question

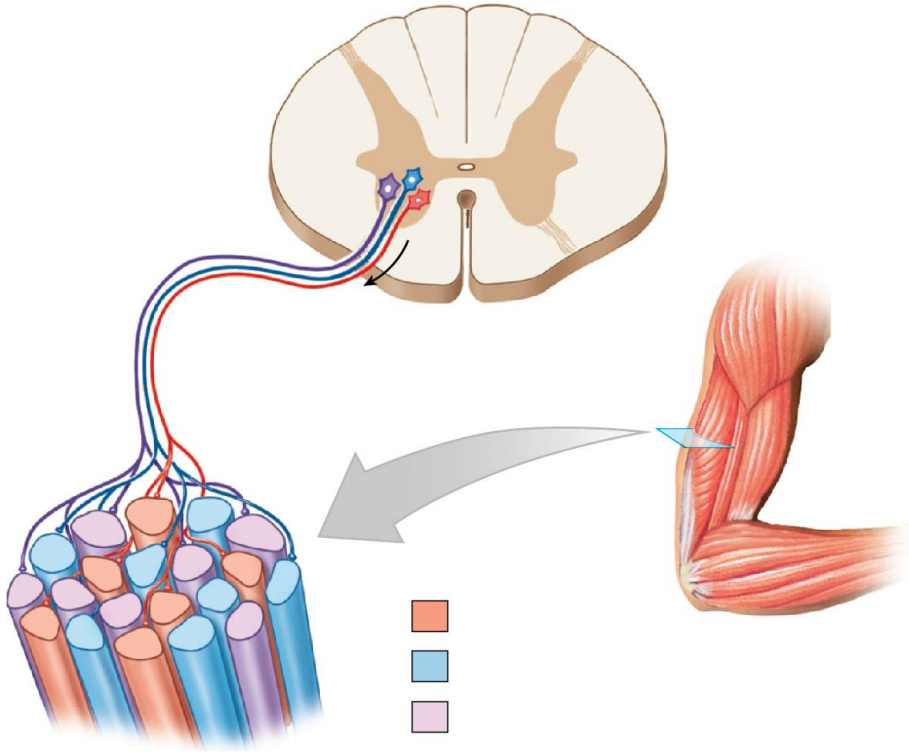
If calcium is present in a muscle cell and myosin binds to the actin filament, which of the following events would typically occur NEXT?

A. The myosin head goes through a power stroke, pulling on the actin filament.
B. ATP binds to the myosin head.
C. ATP is converted into ADP, energizing the myosin head.
D. The myosin head detaches from actin.

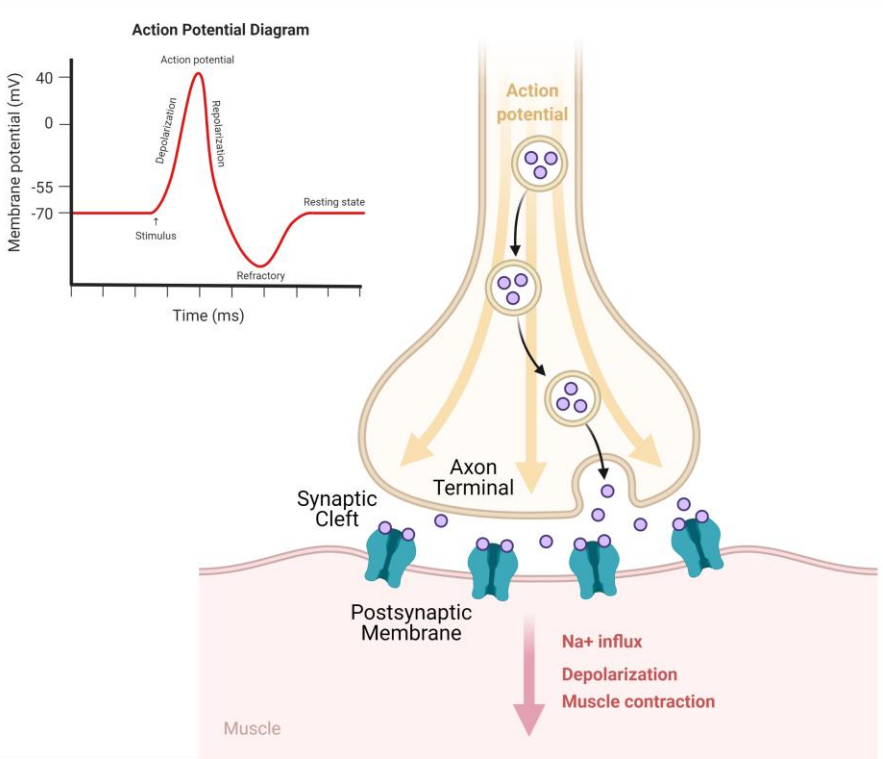
Muscle Tension

Tension (or force) depends on two things:

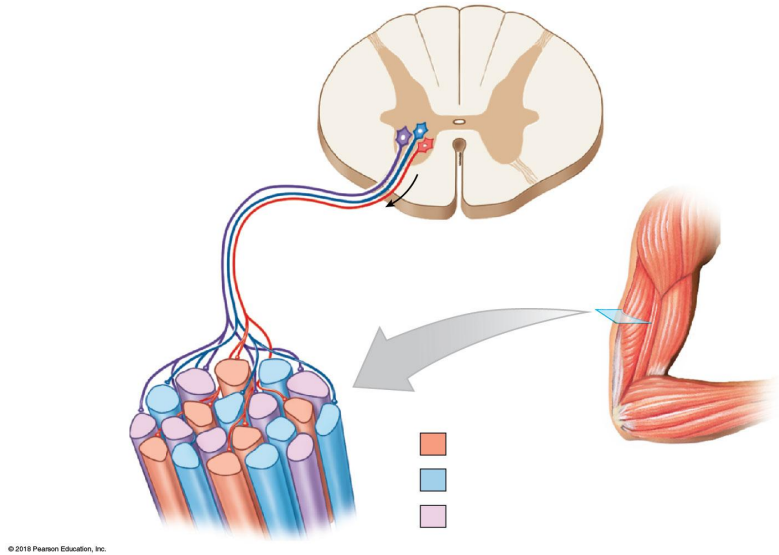
1. The number of muscle fibres recruited



2. The rate at which the muscle is stimulated



Muscle Tension – Recruitment

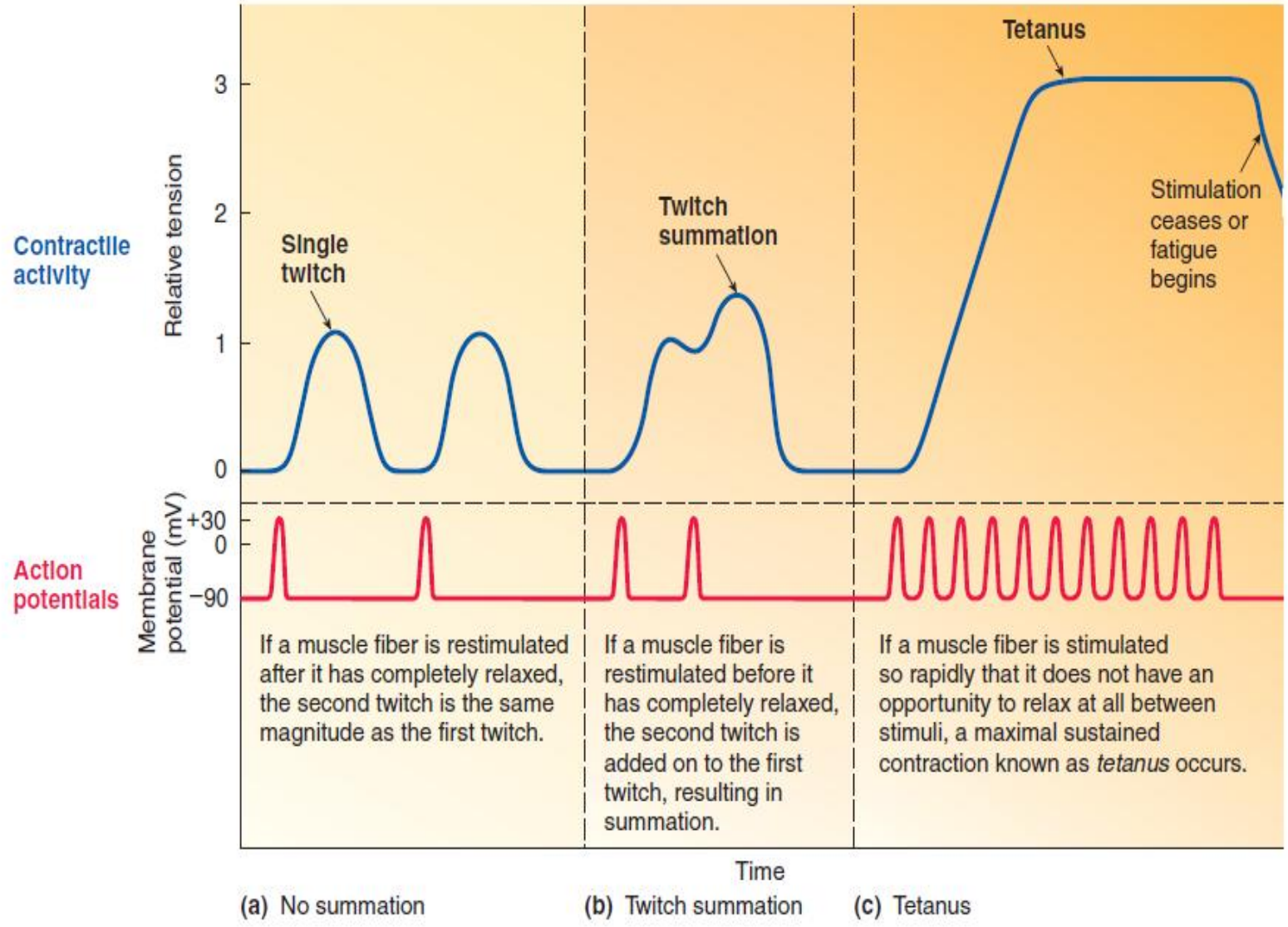


- The *number* of fibres activated is regulated by how many neurons are active at one time.
- A small number of active neurons tends to produce low force from the muscle, with the amount of force generally increasing as more neurons are activated.
- This process of activating more fibres to make more force is called *recruitment.*

Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.10, pg 375.

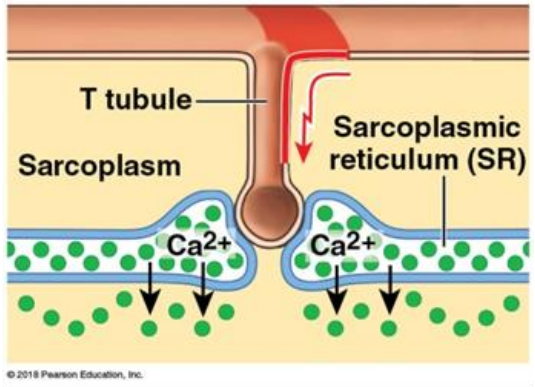
Muscle Tension – Frequency of stimulation

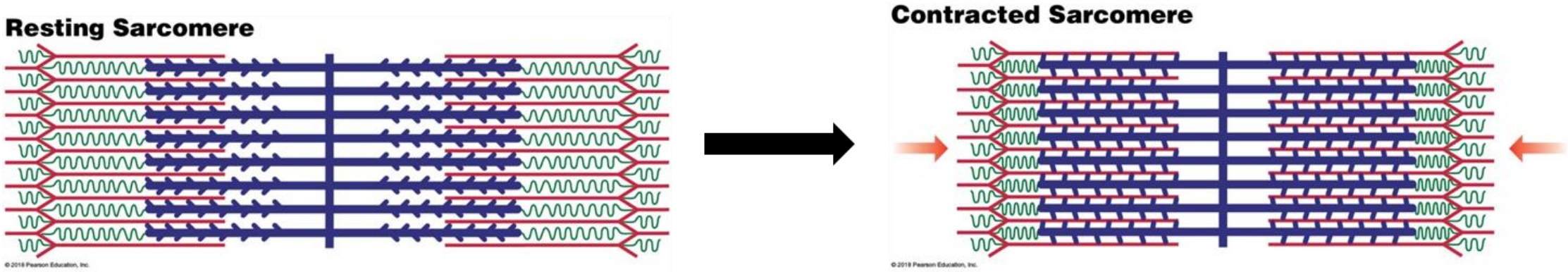
- A SINGLE action potential will result in a pulse of Ca^{2+} release into the cytoplasm, and a short period of tension development, called a *twitch*.
- Many action potentials fired in rapid sequence results in a sustained release of Ca^{2+} from the SR, a sustained period of actin-myosin interaction, and a sustained period of contraction (summation).
- Eventually we reach maximal signaling and contraction capability of the muscle, at which point the force will plateau. This is called *tetanus*.



Sherwood, Lauralee. (2013). Human physiology : from cells to systems. Belmont, CA :Brooks/Cole

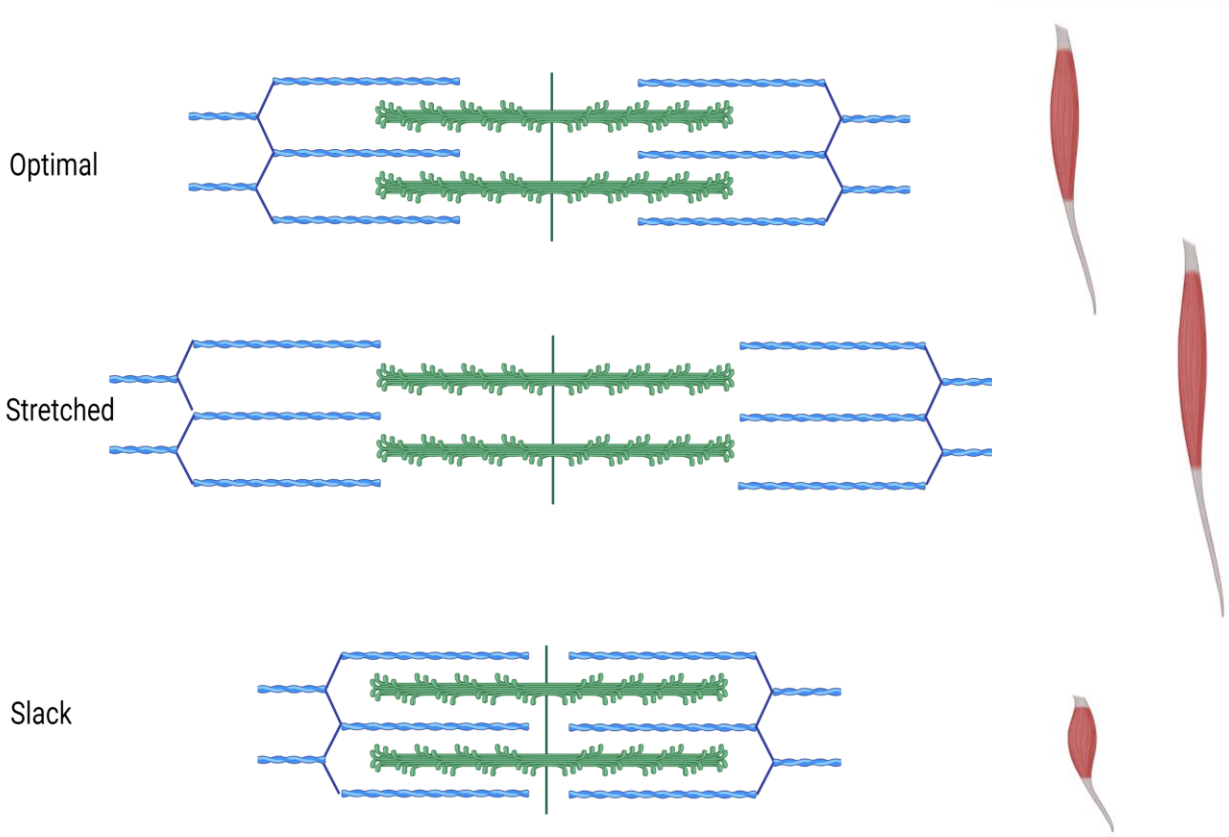
Actin and myosin bind together when calcium is present, forming cross-bridges and allowing contraction to occur





Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.8, pg 371.

Length-Tension Relationship



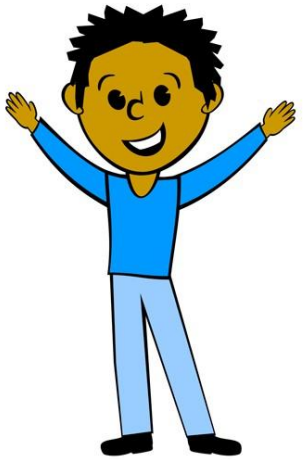
- Each muscle has an optimal length where it will be strongest, and when either longer or shorter than that length, it will be weaker
- This is a result of the changing overlap between the actin and myosin filaments
- Not enough overlap and you don't get many cross-bridges…too much and there's no space left to contract!

Think about how we make use of the length-tension principle when designing human-powered machines, such as bicycles.
Why can you ride faster on a bike that is the “right size”?

https://www.thesoleclinic.com/blogs/bike-fitting-myths/

https://velo-orange.blogspot.com/2010/06/that-frame-doesnt-fit.html

Muscle fibre types: Fast fibres vs. Slow fibres



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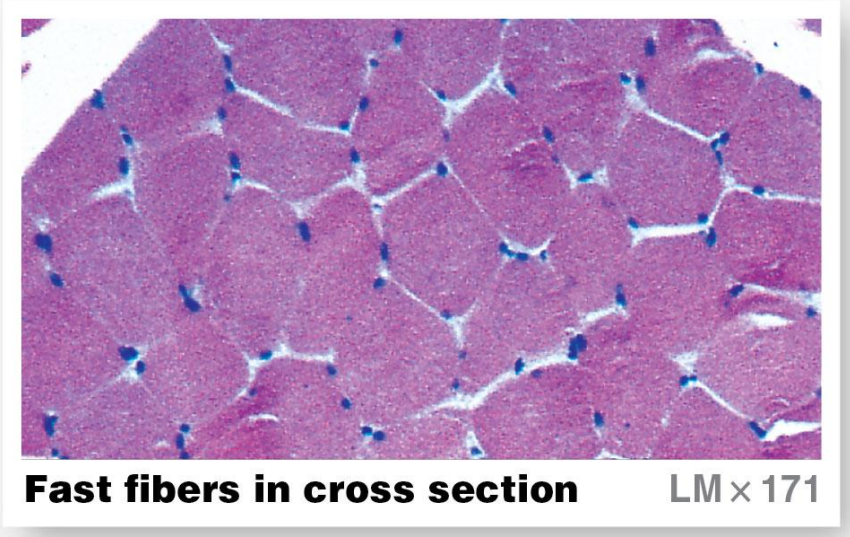
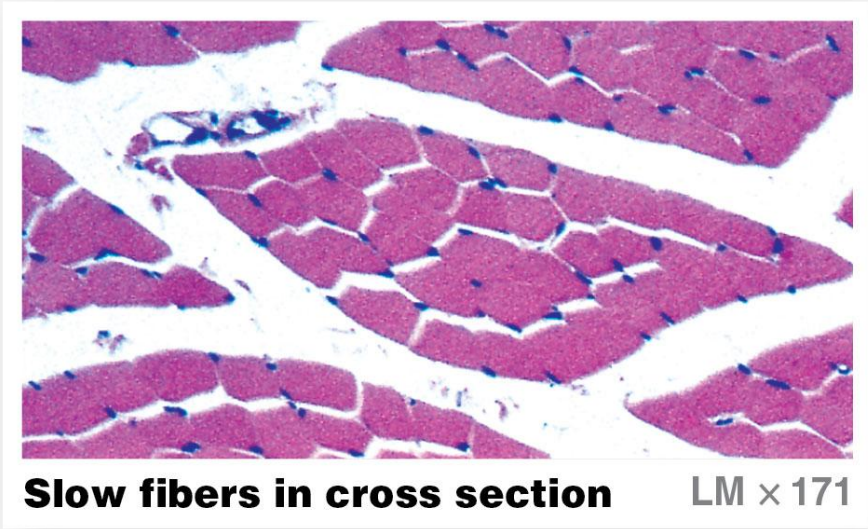
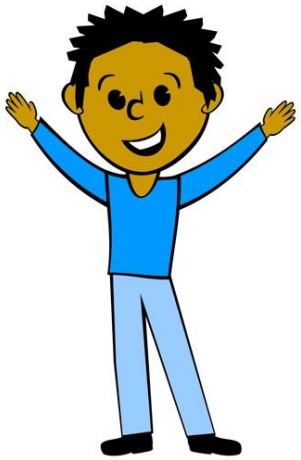




Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.14, pg 382.

Fast fibres are mighty but fatigue quickly, while slow fibres supply steady force and are slow to tire



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Fibre diameter	Large	Small
Capillary supply	Few	Many
Mitochondria supply	Few	Many
Colour	White	Red
Fatigue resistance	Low	High
Time to peak tension	Fast!	Slow…

Martini et al., Visual Anatomy and Physiology (3rd ed), Module 9.14, pg 382.

Summary

- The myofilament proteins actin and myosin bind together when cellular calcium is high, creating cross-bridges. Myosin then uses the energy liberated from ATP to pull on the actin filament, causing a contraction.

- Skeletal muscle force generation depends on the number of fibres that contract (recruitment) and the frequency of stimulation, up to a maximum possible force (tetanus).

- Muscles rich in fast fibres produce lots of force quickly thanks to their energy reserves, but they tire out quickly too! Slow fibres are able to generate a lot of energy even while working, so they are difficult to fatigue.

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