Lesson 18

◊ **Lesson Outline:**

- ♦ General Features of Muscle
- ♦ Muscle Form and Function
  - Muscle Fibers
  - Bone-Muscle Lever Systems
  - Muscle Actions
- ♦ Ontogeny (Embryonic Origin) of Muscle

◊ **Objectives:**

At the end of this lesson you should be able to:

- ♦ Describe the different ways of classifying muscle
- ♦ Describe the structure of skeletal muscle
- ♦ Describe the properties of muscles
- ♦ Describe how muscles work together with bones to produce lever systems with different functional characteristics
- ♦ Describe basic muscle actions
- ♦ Describe the embryonic origins of postcranial (appendicular and axial) and cranial (jaw, pharyngeal, and eye) muscles

◊ **References:**

Chapter 11: 233-264

◊ **Reading for Next Lesson:**

Chapter 11: 233-264

Muscular System
General Features of Muscle

The primary role of the skeleton is to support the body, to provide protection to nerves, blood vessels and other vital organs, and, to provide structures on which muscle can act to produce movement.

The primary role of muscles is to provide force for movement.

Classification of Muscle:

Muscles are classified in different ways by different groups of researchers.

Striated versus cardiac versus smooth muscle

This classification scheme is based on the cellular structure of the muscle. The differences are in the arrangement of organelles and sub cellular structures as well as in the properties of the membranes. These differences, however, give each type of muscle unique properties that are of critical importance for their functions (structure-function). Study of structure/function at this level is the realm of physiology and you will study this next year in your physiology course.

Somatic (voluntary) versus visceral (involuntary)

Muscles are also often classified according to location. The somatic muscles insert on bones or cartilage while visceral muscles are associated with organs, blood vessels and ducts. The former tend to be striated muscle while the latter tend to be smooth muscle.

Muscles have been classified based on the ways in which they are controlled – as voluntary or involuntary muscles – those that we can volitionally control or not.

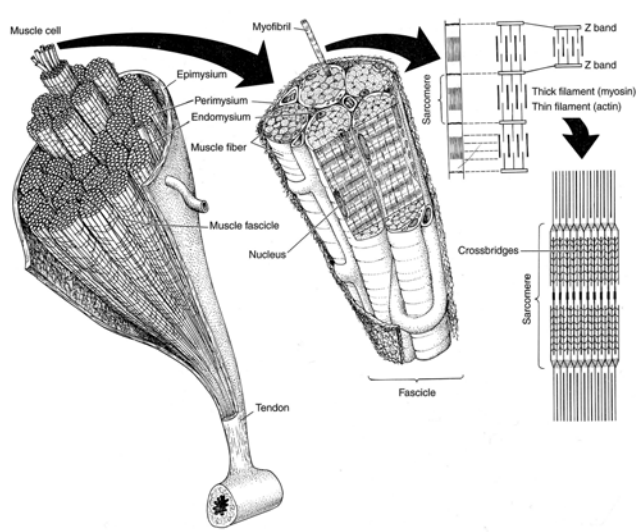
Red and white (or fast/slow twitch or oxidative/glycolytic)

Some muscles are designed for sustained activity while others are designed for very short but rapid bursts of activity. Over the years several different classification schemes have been put forward to distinguish between them. In general, the slow, fatigue resistant fibres are oxidative and red in colour (high myoglobin content) while the fast fibres are less resistant to fatigue and tend to be glycolytic and white in colour. There are also fibres that are intermediate in fatigue resistance, fuel type and colour leading to complexities in all of the classification schemes.

Muscle Characteristics - Striated vs Smooth vs Cardiac Muscle

Striated Muscle

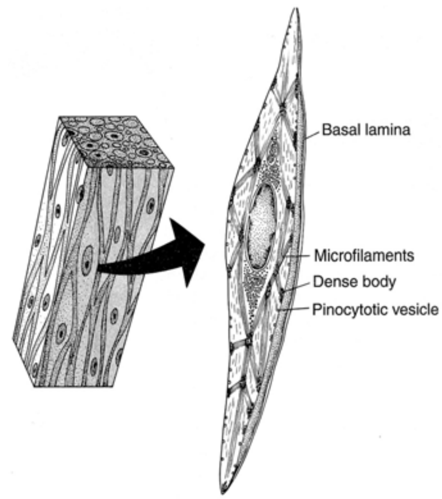
Skeletal muscle is composed of multi-nucleated cells (muscle fibres), is usually under voluntary control and is generally somatic (associated with bones and ligaments). Cells are joined end to end to form longer composite strands.



This muscle type is often referred to as striated muscle because of the microscopic appearance of striations in the cell due to the ordered alignment of protein filaments within the cell. Each cell receives innervation from one branch of a single nerve cell. Cells can be excited individually and hence only small parts of an entire muscle can be recruited at one time.

Smooth Muscle

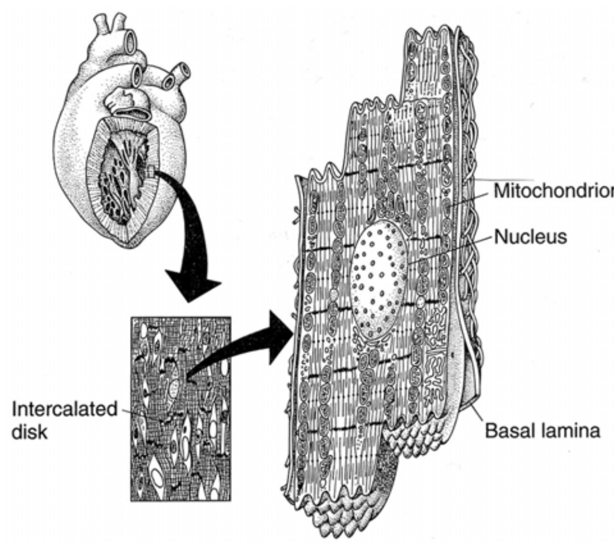
Smooth muscle is composed of mono-nucleated cells, is usually not under voluntary control and is generally visceral. Contraction of this muscle is usually slow and prolonged.



The cells are not striated but are smooth in appearance, and individual cells join together in sheets, and are electrically coupled. Nervous innervation spreads easily throughout the sheet. The mechanism of contraction is believed to be through the same sliding filament mechanism that has been well described for skeletal muscle but these filaments are not organized in the same fashion as in skeletal muscle.

Cardiac Muscle

Cardiac muscle occurs only in the heart. It is composed of mono-nucleated cells, which are also striated in appearance. Like smooth muscle, the cells are electrically coupled but unlike all other muscle, cardiac muscle cells are capable of spontaneously initiating contraction – they are autorhythmic.



Structure of Skeletal Muscle

Each muscle cell (muscle fibre) is internally composed of myofibrils, each myofibril is a chain of sarcomeres, and each sarcomere is composed at the molecular level of myofilaments; specifically, overlapping thick (myosin) and thin (actin) filaments. The underlying arrangement of these filaments produces the pattern of striations within a myofibril. Because bundles of myofibrils are aligned together within the muscle cell, they produce a visible striated pattern superficially on the muscle cell.

Individual muscle cells are wrapped in connective tissue (endomysium).

Groups of cells are bundled by more wrappings (perimysium) and are referred to as a muscle fascicle.

The entire muscle is covered by an outer sheet of fibrous connective tissue (epimysium).

These layers of connective tissue extend beyond the ends of the muscle cells to form tendons that connect muscle to bone. The tendons connect to the periosteum or connective covering of the bone.

Muscle is an organ, and hence a muscle is in fact more than just the muscle cells and their connective tissue sheaths. It also consists of nerves and blood vessels and blood.

Tendons and Ligaments

Muscle are not attached to bone by the individual contractile muscle cells but instead, the connective tissue sheets that bind the muscle cells together extend beyond the muscle fibres to attach to the bone.

These extensions are the tendons. Tendons can be of varying length. Muscles tend to be only as big as need be to produce the forces required. The rest of their length is made up of tendon. Thus, some muscles extend from their origin to their insertion and the tendons are very short while other muscle are quite compact and the tendons extend very long distances (wings of birds, muscles in the forearm that control finger movement). This permits muscle mass to be localized optimally while still allowing force to be applied some distance away.

Tendons are metabolically economical and hence their vascular supply is modest. They require little maintenance and consume little energy (unlike muscle). This allows energetically expensive muscle fibres to be only as long as is necessary to produce the required amount of shortening or force.

Ligaments, on the other hand, attach bone to bone and act to stabilize joints. There is no muscle involved.

Muscle Form and Function

Each muscle fibre (cell) contracts in an all or none fashion. Muscle, which are composed of a large number of muscle cells, however, can contract with:

different degrees of force for
different periods of time at
different speeds.

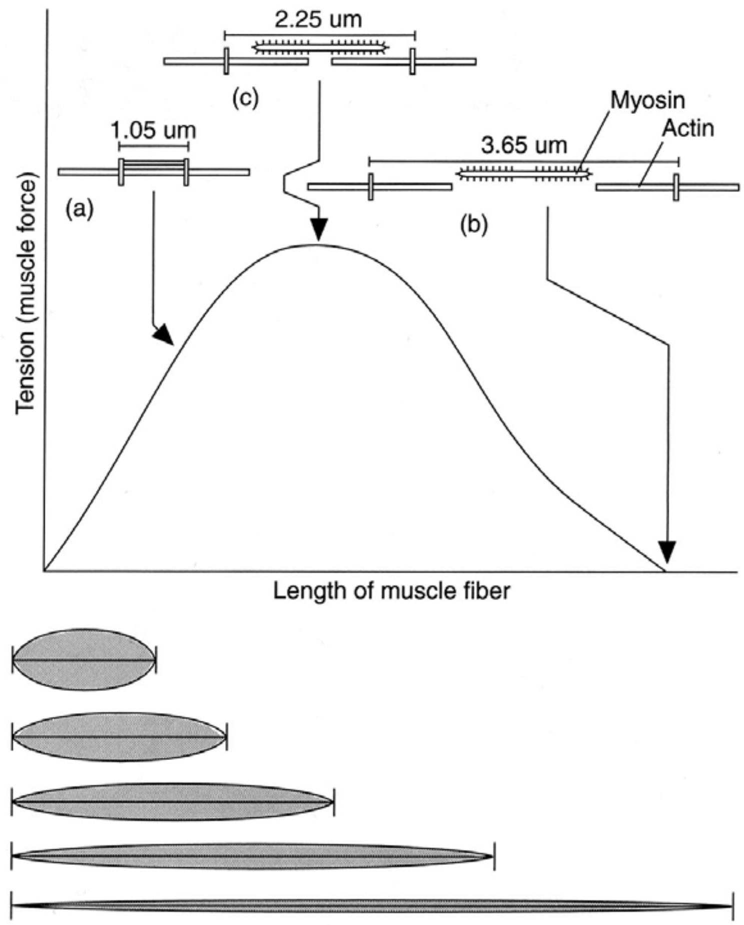
How does this occur?

Properties of Muscle Fibres

Optimal Length: Length-Tension Curves for a single muscle fibre

One of the factors that determine the tension that a particular muscle cell (fibre) can produce is its resting length.

Muscles can generate greater force when they are partially stretched. The ideal resting length for a muscle is one where the actin and myosin filaments just overlap. If a muscle is stretched to the point where the thick and thin filaments no longer overlap, it can no longer generate any force. If the filaments overlap too much, the thin filaments from both sides of the sarcomere interfere with one another, the thick filament runs into the Z line and the sarcomere cannot shorten any further.



Metabolic and Structural Properties: Colour, Speed Endurance and Resistance to Fatigue

Another group of factors that determine the strength and speed of muscles are their biochemical properties. (The book separates out colour versus tonic and twitch fibres. These properties are inter-related and we will treat them together).

Birds that only fly for short distances but rapidly tend to have white breast muscle while those that are long-range migrators tend to have darker breast muscle.

In fish, the majority of axial musculature is white for short rapid bursts of swimming. The muscles used for slow sustained swimming are red and small and occur along the lateral line.

The fastest twitch fibres can be very rapid indeed.

Human Occulomotor	30/sec
Finch Flight	25/sec
Hummingbird flight	45/sec
Bat Cricothyroid	200/sec
Toadfish Sonicator	300/sec

	Red. Slow Twitch Fatigue Resistant	White, Fast Twitch Fatiguable	Intermediate, Fast Twitch Fatigue Resistant
Metabolic Characteristics			
Twitch Rate	Slow	Fast	Fast
Myosin ATPase	Slow	Fast	Fast
Source of ATP	Lipid Aerobic	Glycogen Anaerobic	Glucose Aerobic
Myoglobin	High	Low	High
Glycogen Stores	Low	High	Intermediate
Rate of Fatigue	Slow	Fast	Intermediate
Structural Characteristics			
Colour	Red	White	Pink
Mitochondria	Many	Few	Many
Capillaries	Many	Few	Many
Fibre Diameter	Small	Large	Intermediate

Bone-Muscle Lever Systems

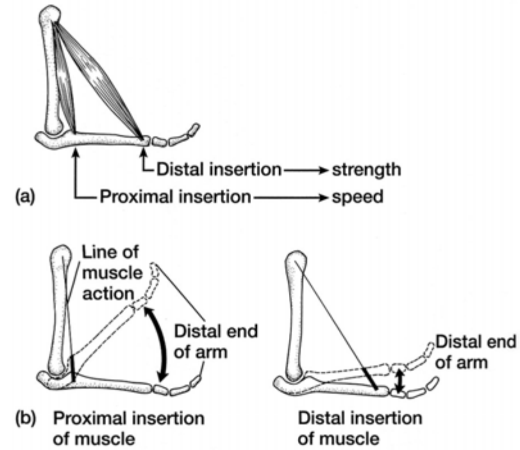
Origins and Insertions

The two points of attachment of a muscle are its origin and insertion. The origin is the relatively fixed point of attachment and the insertion is the relatively movable point of attachment. Each site of origin is a head and each site of insertion is a slip. Muscles are not attached to structures at any other point along their length, which is essential if they are to be able to contract and shorten.

Sites of Insertion and Strength versus Speed

Muscles inserted at different points on a lever system produce different mechanical advantage and this changes the properties of the movement produced by an identical muscle. If inserted near the point of rotation, the muscle favours speed but can not develop as much force or strength as a muscle inserted more distally.

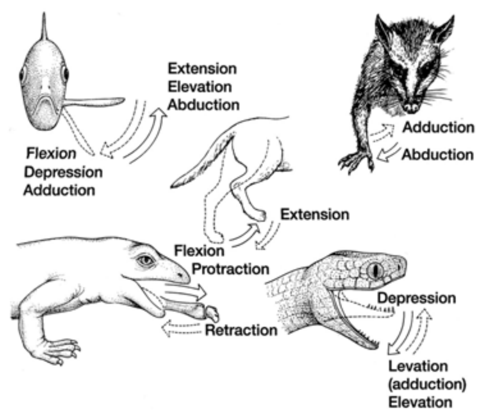
Proximal insertion will also produce a greater excursion for the same degree of shortening (This, of course, is why the movement it produces is faster).



Movements of Muscles – Muscle Actions

There are several terms used to describe muscle actions. These include:

Flexion - to bend one part relative to another about a joint.
Extensors - to straighten one part relative to another about a joint.
Adduction - to draw a limb towards the body.
Abduction - to move the limb away from the midline of the body.
Levators - (special form of adduction) to close (such as the jaw, or the oral cavity).
Depressors - (special form of abduction) to open.
Protractors - projection of a part (such as the tongue).
Retractors - withdrawl of a part.
Rotators - rotate a part.
Supinators - rotate a part up.
Pronators - rotate a part down.
Constrictors reduce the diameter of a tube, vessel, or opening.
Dilators increase the diameter of a tube, vessel, or opening.



Embryonic Origin (Ontogeny) of Muscle

Muscles arise from three embryonic sources:

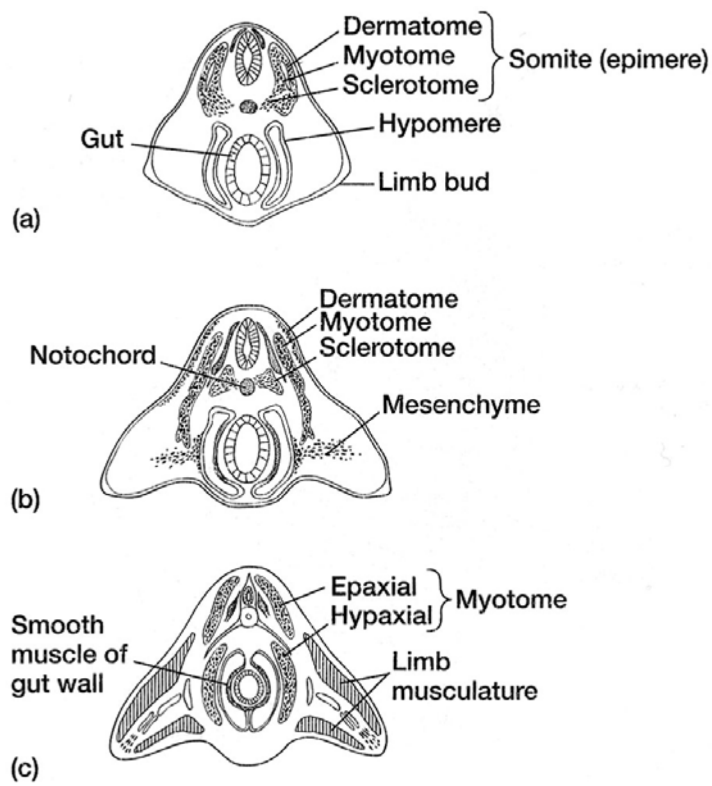
1) Mesenchyme is a loose dispersed layer of mesoderm found throughout the embryonic body. It can arise from the epimere or the hypomere. Smooth muscle within the walls of blood vessels and some viscera arise from this source.

2) Muscle also arises from the splanchnic hypomere. This gives rise to the smooth muscle of the digestive tract and its derivatives, as well as the heart.

3) Most skeletal muscle is derived from the epimere – or paraxial mesoderm. This tissue forms shortly after neurulation next to the neural tube along the axis of the embryonic body. Hence the name paraxial mesoderm.

Postcranial Musculature

In the trunk, the paraxial mesoderm becomes segmentally arranged into anatomically separate somites.



Axial Musculature

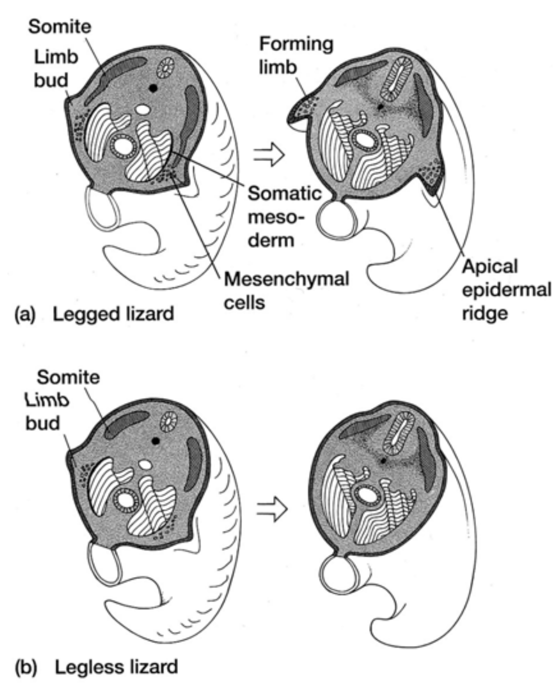
Along the general body axis, the musculature that arises from the myotomes grows down and expands along the sides of the body forming the musculature associated with the vertebral column, the ribs and the lateral body wall. The sheet becomes divided by a horizontal septum that divides the myotomes into dorsal and ventral regions that become separated by the ribs into the epaxial and hypaxial musculature. At the same time, the developing muscles from adjacent somites fuse to form muscle sheets.

Appendicular Musculature

In the regions where the limbs arise, the ventral tips of adjacent myotomes (several segments) grow downward into the emerging limb bud. In fish, they differentiate directly into the fin musculature. In tetrapods, the ventral tip interacts with the mesenchymal cells of the somatic hypomere that grow out to become the appendicular skeleton, along with the tensons, ligaments and vessels. The myotome tissue becomes the muscle of the limbs.

The role of interaction between the mesoderm and the mesenchyme in the production of the limbs is well illustrated in the case of the limbless lizards:

In limbed lizards, mesenchymal cells normally leave from the somatic hypomere and enter the forming limb bud and become the appendicular skeleton. The ventral processes from the local somites reach into this area and become the muscles associated with the limbs.



In limbless lizards, early limb buds begin to form but the ventral tips of the somites do not grow down into this viscinity and do not interact with the migrating hypomeric mesenchyme. Without the interaction between the two cell groups, the apical epidermal ridge (developing limb bud) regresses, the limb bud recedes and no limbs develop.

Cranial Musculature

In the head, the paraxial mesoderm does not differentiate into discrete somites but forms clusters of mesoderm called somitomeres.

Extrinsic Eye Muscles

The anterior portion of this group of cells separates and gives rise to the ocular muscles of the eye (somitomeres 1,2,3 and perhaps 5). These are the muscles that rotate the eyeball. It is still debated how many somitomere are involved in this process.

Branchiomeric Muscle

The posterior somitomeres, (4, 6, and 7) grow down and become the muscles of the jaws and the first two visceral arches (innervated by cranial nerves V, VII and IX. These are the branchiomeric muscles.

Behind this region, the epimere form somites just as they do along the remaining length of the body. The anterior somites grow down to become the branchiomeric muscles of the gill arches (visceral/gill arches 4 to 7, innervated by cranial nerve X).

Hypobranchial Muscle

Finally, the next group of somites behind the gill arches not only grow down to become the axial muscles of the body wall, they also extend forward below the branchial region (hence the name hypobranchial muscles) to form the muscles of the floor of the pharynx as well as the tongue in tetrapods.