muscles and tendons of the hand and forearm for robotics project at northglenn high school
preliminary teacher's guide 9-24-2014

## GENERAL BACKGROUND AND PERSPECTIVE

The human hand and arm developed to reach out into space and grab. To do this, the arm had to be able to reach in a wide range of motion at the shoulder, extend at the elbow, bend at the wrist, and flex within the fingers.

The shoulder represents a joint with three degrees of freedom: side to side, up and down, and transversely. The elbow moves in only one degree of freedom, along a single plane. The wrist allow movement in two degrees of freedom, back and forth and in and out. Within the hand, different joints have different potential.

The three extensions of the fingers beyond the palm (each is called a phalanx) have a combination of movement: the top two joints have one degree of freedom (similar to the elbow) but at the base, a ball-and-socket type of structure that allows two degrees of freedom. Within the base of the hand, three different rows of bones – tied together with ligaments, tendons, and muscles – add to the overall flexibility with small movement capabilities that allow "cupping" and contribute to the hand's grasp.

Gripping is a collated action, a combinations of the various degrees of freedom of the fingers, base of the hand, wrist, and forearm.

GENERAL RULES ABOUT MUSCLES AND TENDONS

● Muscle fibers can only pull – to pull, they contract.

● Muscles occur in pairs. Because muscles can only pull, therefore in order to reverse the movement produced by one muscle, there must be an opposing muscle that can pull in the other direction. These opposing muscles – agonists and antagonists – can work in tandem to slow down movement, stabilize a joint, and in muscles that cross two joints, allow movement at one joint while the other joint is stable.

● Muscles must cross at least one joint. There are exceptions: the heart, and some muscles in the head.

● Muscles fibers can only contract completely – its all the way or not at all.

● When muscle fibers contract, they shorten by half.

● Varying degrees of movement in a joint are produced by the body's ability to recruit select muscle fibers or fiber bundles – the amount of movement is determined by how many muscles fibers or bundles are recruited.

● A muscle that crosses one joint provides strength, but is slow. It is also more predictable and controllable.

● A muscle that crosses two joints provides speed, but is unpredictable (unstable). Stability is provided by tension – opposing pairs of muscles provide the tension. The opposing muscle resists the flexion of the first muscle. It is the tension that modulates the joint.

● Flexion pulls two ventral surfaces of the body together. Extension pulls two dorsal surfaces of the body together.

● Tendons are collected strands of tissue that connect muscle bellies to attachment sites.

● Muscles are covered with a thin, tough membrane called fascia.

● Crests, knobs, and other physical features on bones represent prime attachment sites for muscles.

● Muscles do not attach directly to bone, but to periosteum, a thin, tough fabric that covers the surface of bones. Ligaments and tendons also attach to periosteum, not directly to bone.

● Some muscles attach to other muscles (by the fascia that covers them), cartilage (fiberous structures around joints), and interosseus membranes.

● Tendons on the back of the hand are close to the surface of the body and are slightly flattened. Tendons on the palm side of the hand are rounded and deep beneath the surface.

BUILDING

The first stage of building involves muscles that move the fingers within the hand.

Individual fingers have one degree of freedom when they move from side to side. This movement is called ABDUCTION (moving apart) and ADDUCTION (moving toward). In use, some people say "a-d duction" and "a-b duction" to stress the difference in similar sounding terms.

The main ray of the hand is the middle finger. Everything on the hand is abducting (away) or adducting (to) to middle ray.

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## **BUILD** *palmar interossei muscles*

"Interosseus" means *between the bones*. Palmar means *palm*. Ventral means *front*.

Attachment sites:

1. The tubercle on the base of the proximal phalanx.

2. From the base and along the inside surface of the metacarpals.

Construct these muscles one at a time from small tubes of clay. Each is round and slightly tapered. There are four units in total, each placed on the palm (ventral) side of the hand.

DISCUSSION

Each of these small muscles crosses the joint between the metacarpal and the proximal phalanx. The middle finger does not have this muscle. For each of the other fingers and the thumb, the muscle is on the inside facing surface of the bone. These muscles are **adductors**, pulling the fingers toward one another.

After you bild the muscle on the inside of the first finger, hold up your hand and demonstrate how this muscle will work when it contracts. (The finger will pull toward the main ray).

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## **BUILD** *dorsal interossei muscles*

Dorsal means *back*. Interossie means *between bones*.

Attachment sites:

1. The tubercle on the base of the proximal phalanx, opposite to the site where the palmar interossei muscle was attached.

2. From the base and along the sides of the metarcapals.

Construct these muscles one at a time as fan-shaped, flattened shapes. Each is narrower and thinner toward the top and wider and thicker toward the bottom. There are four units in total, all placed on the dorsal (back) side of the hand.

DISCUSSION

The tapered tip of each of these muscles is a tendon. These muscles **abduct** the three main fingers (not including the little finger). The main ray has two of these muscles, so that it can be abducted to either side.

Hold up your hand and demonstrate what happens when these muscles contract. (The fingers pull apart). There are other muscles needed to allow the little finger and thumb to abduct.

With the palmar and dorsal interossei muscles built so far, the fingers have no limits to how far they can abduct – pull apart. This unbounded movement has to be limited but without restricting the necessary flexibility of the palm and fingers. How can this potentially damaging movement be controlled?

The answer is found in the next step.

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**BUILD** *transverse metacarpal ligament*

Transverse means *across* or *at right angles to the long axis of the body*. Metacarpal literally means *beyond the wrist* and refers to bones of the fingers that are within the palm.

This is a ligament, not a muscle, and the attachment sites are the same on each of the four fingers (not including the thumb).

1. The proximal side of the condyle of the metacarpal.

2. The base of the condyle on the proximal phalanx.

Construct this element from a tube of clay, flattened into a strap. This strap attaches on the palmar side, running from the little finger to the index finger, but not connecting to the thumb. It bridges the joint between the metacarpal and its proximal phalanx, just covering the base of the condyles on each bone.

DISCUSSION

This ligament is made up of fibers similar to those in tendons – they are flexible but do not contract like muscle fibers. The fingers are tied together within the palm by this strap of ligament, limiting extreme movement to the sides. But it also allows the hand to form an arch, a necessary form for strength and dexterity. The thumb is not part of this bundle, allowing it independent freedom of movement.

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**BUILD** a*bductor digiti minimi muscle*

Construct this muscle as a flat strap of clay in the shape of a boat. It is wider at the base, tapering to a narrow tendon at the top.

Attachment sites:

1. The full length of the edge of the crest of the 5th metacarpal (little finger).

2. The top of the pisiform bone.

DISCUSSION

Because of the position of the little finger at the extreme end of the hand, its base has more room for movement than the fingers next to it. Like the thumb, it can span a greater distance than the other fingers.

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**BUILD** *abductor pollicis brevis muscle*

Pollicis means *of the thumb* (the root word for thumb in Latin is pollex). Brevis is Latin for *small.* The different terms used to name muscles and ligaments are like name tags – each part of the name is necessary to differentiate the structure, just as a different first names refer to different people with the same last name. Here, *abductor* suggests there must be an *adductor* as well, and *brevis* suggest there must also be a *longus.*

Construct this muscle as a flattened stra, in the shape of a boat – like a larger version of the previous muscle on the little finger.

Attachment sites:

1. The lateral base of the first phalanx of the thumb on the dorsal side, and along the lateral (outer) edge of the metacarpal.

2. The proximal tier of carpals. In reality, this attachment site is not directly on the bones, but an underlying strap of muscle that is not built in this exercise.

DISCUSSION

This muscle is part of a group of muscles that pull the thumb out and away from the center of the palm. Not all of these muscles will be included in this exercise.

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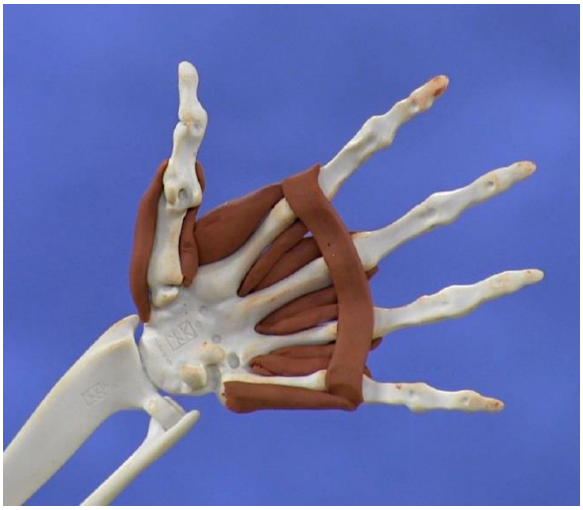


**BUILD** *flexor carpi radialis tendon*

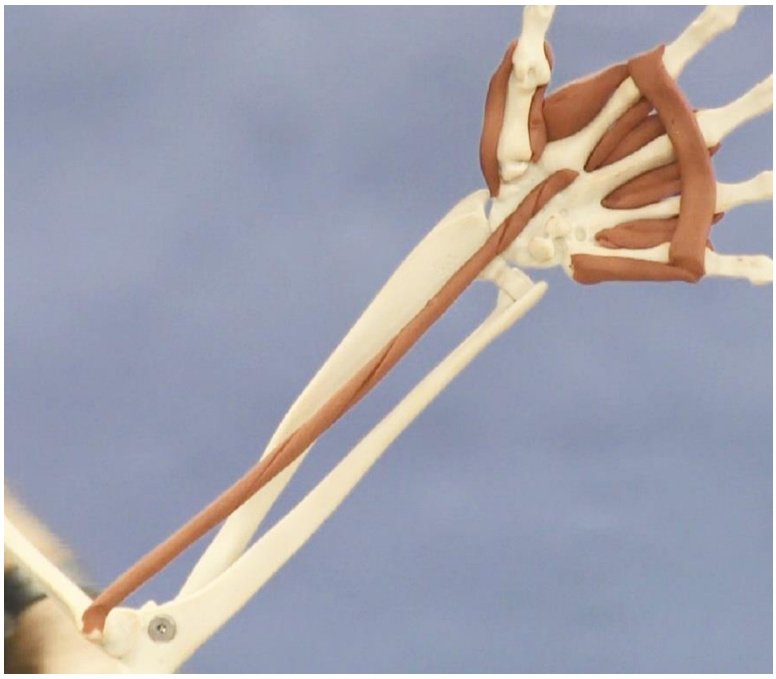
Flexors of the hand all start at the medial epicondyle of the humerus.

Attachment sites:

1. The palmar base of the metacarpals on the index and middle fingers, forming a forked tendon.

2. The medial epicondyle of the humerus.

In the first step, construct the tendon of this muscle as a long tube of clay about 1/8 inch in diameter. The tube runs from the bases of the metacarpals of the index and middle fingers, down across the wrist, along the inside of the radius and into the epicondyle of the humerus. As the tendon runs across the palm at the base of the thumb, feel for a deep groove at the base of the trapezium. The tendon should fit snuggly into this groove. The completed tube should be taut, running in a straight line. The muscle belly will be constructed in a later step.



DISCUSSION

Raise your forearm so that it is in about the same position as the model (the elbow bent at about 90 degrees. Ask for this tendon/muscle to shorten in your body, watching as the fingers on your hand flex, moving toward the upper arm as they are pulled together.

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**BUILD** *extensor carpi radialis tendon*

The extensor muscles of the hand and fingers come from the lateral epicondyle of the humerus, opposite from the medial epicondyle. The muscle belly of this tendon will be constructed in a later step.

Attachment sites:

1. The dorsal base of the metacarpals on the index and middle fingers, forming a forked tendon. The opposing muscle – *flexor carpi radialis* – attaches at the same spots on the opposite side of the hand.

2. The lateral epicondyle of the humerus.

Construct the tendon of this muscle as a long tube of clay about 1/8 inch in diameter, similar to the tendon of the *flexor carpi radialis muscle.* The tube runs in a straight line, across the back of the hand, crosses the wrist along a large groove in the ventral side of the radius, and directly to its attachment site on the humerus. In the model with the upper arm and forearm bent at the elbow, this straight line leaves a large gap between the elbow and the tendon.

DISCUSSION

Use your hand and forearm to demonstrate the opposing forces of the extensor and flexor muscles just constructed. By moving your hand foreward and back (toward the forearm and away from it), visualize how these two muscles work as agonist and antagonist, pulling the hand in opposite directions. The contractions of the muscles themselves can be felt by placing the fingers of the other hand on one side of the humerus, just above the elbow, as your hand is moved back and forth.

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## **BUILD** muscle bellies of *extensor carpi radialis* and *flexor carpi radialis muscles*

Construct the muscle belly of *extensor carpi radialis* as a carrot-shaped slug of clay and then flatten it. The piece is placed on top of the *extensor carpi radialis tendon* (the long tube on the back of the hand), with the narrow tip at the top (the base of the humerus). The larger end should extend across the elbow and down the radius about one quarter of the distance to the wrist. This piece is pushed down into the tube, merging the two pieces and forming a tight bond with the bone.

The muscle belly of *flexor carpi radialis* is made with the same shape, but slightly larger. The narrow end attaches at the end of the humerus and the larger end extends across the eblow and about two thirds along the length of the forearm, angling in from the ulnar edge at the top to between the two bones at its lowest end. This piece is pressed down onto the clay tendon.

DISCUSSION

The muscles bellies of *flexor* and *extensor carpi radialis* provide an advantage to the body by being placed so far away from the hand. As they are involved in gripping and holding objects, the weight of these muscles would be a disadvantage if the hand had to lift them as well as what it was holding. Farther up the arm, they shift this weight away from the hand, improving its weight-carrying capability.

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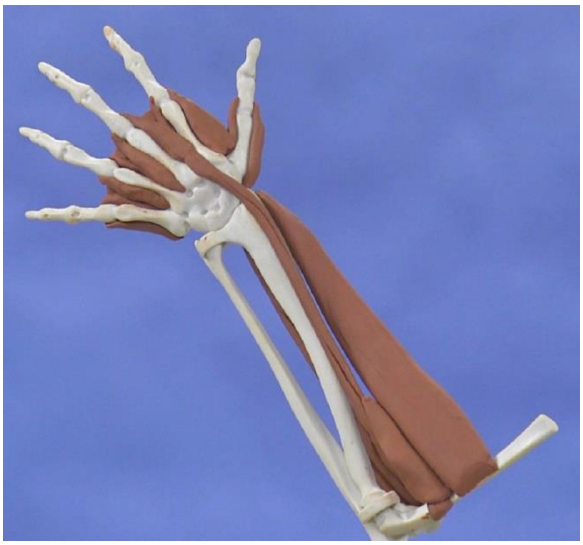
## **BUILD** *brachioradialis muscle*



Brachio means *arm* (or, in its original Latin, *branch*), and radialis is the adjective form of *radius*, referring to the bone in the forearm. By combining brachio- and –radialis, the name of the muscle describes where it lies in the body.

Attachment sites:

1. Most of the lateral supracondylar ridge and continuing about one third of the distance up the humerus. Although not built in this exercise, this muscle attachment also includes the lateral intermuscular septum.

2. A point at the lateral, distal end of the radius (called the styloid process).

Construct this muscle as a long, flat sheet of clay, tapering at one end. In the body, it is one of the longest one-joint muscles in the body. Using the wire loop tool, etch a line into the clay perpendicular to its length and about 1 ½ inches down from the wrist. This line represents the approximate area where the muscle's tendon joins the muscle belly (the two pieces can also be constructed separately, to emphasize this division).

DISCUSSION

Because of the extreme length of this muscle, if the fibers in the muscle belly constracted to their fullest extent – 50 percent – the effects could produce an extremely negative effect on the arm. How does the body modulate this negative effect? This and other muscles have a combination of short and long muscle fibers. By recruiting these in varying combinations, not only can movement be fine tuned, but redunancy is available for insurance. Body movements large and small are governed by a network of sensors and nerves within the muscles, called the **proprioceptive** system. This system is mostly independent of the brain and extremely fast – your arms and legs must be able to move faster than your brain can think in order to survive.

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**BUILD** *extensor carpi ulnaris muscle*

This muscle is involved with movement of the wrist. In Latin, carpus means *wrist.*

Attachment sites:

1. The lateral epicondyle on the humerus.

2. The medial side of the base of the 5th metacarpal..

Construct the tendon of this muscle first, building a long tube of clay about 1/8 inch in diameter. The clay tendon has to run up and over the joint at the base of the radius, then runs along the dorsal side of the ulna for about two thirds of its length before crossing the wrist. The muscle belly can be constructed of an additional flattened strap, pressed into the tendon beginning just beyond the wrist and ending at the attachment site on the humerus. This muscle belly is relatively small.

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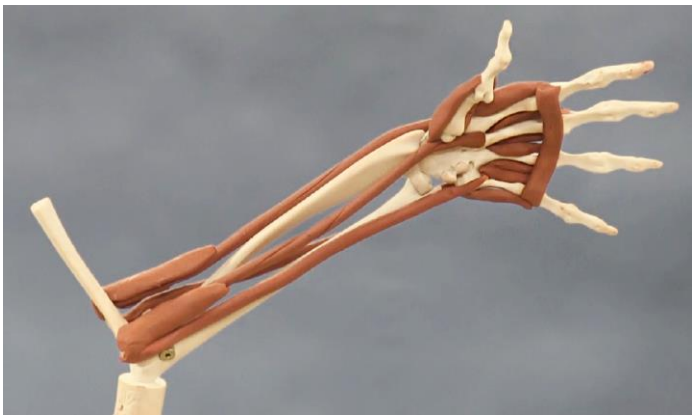
**BUILD** *flexor carpi ulnaris muscle*



This muscle lies on the palmar side of the hand, like all of the flexors of the hand, but it is positioned along the ulnar edge of the forearm and hand.

Attachment sites:

1. The medial epicondyle of the humerus plus the medial olecranon and dorsomedial margin of the shaft of the ulna.

2. The base of the 5th metacarpal plus the ulnar (outer) side of the pisiform bone.

Construct the tendon of this muscle as a long tube about 1/8 inch in diameter. It runs in a straight line along its length, including across the gap formed between the end of the ulna and the base of the wrist. Note that the end that attaches to the humerus shares an attachment point with muscles built previously. This attachment site also extends along the medial (outside edge) of the ulna. Press the tendon into the ulna along its length to represent this attachment.

Construct the belly of this muscle from as a narrow, flattened strap, and press it into the clay tendon, with the widest end toward the humerus. Use the wire loop tool to draw lines on the surface to represent the direction and length of the muscle fibers.

DISCUSSION

Long muscles benefit from having a mix of long and short fibers because these can be recruited in various combinations to produce different ranges of movement. Here, the muscle belly has more short fibers at its narrow end, and the fibers get progressively larger farther up. This represents one pattern in which short and long fibers are distributed along the length of a muscle.

Another pattern is common in short, wide muscles. Here, the pattern resembles the fibers in a bird feather, radiating out along the length of one side. These muscles are called pennate, which means *feather-like* in Latin. Because these fibers run diagonally, when they shorten by half, the long edge of the muscle shortens by a lesser distance (demontrated by the ratio of lengths in the sides of a triangle).

When a muscle needs to produce smaller, delicate movements, the shortest fibers are recruited. When a muscle needs to produce larger, more dramatic movements, the longest fibers are recruited. Why? Because muscles can only contract, and when muscle fibers contract, they can only contract with one outcome – shortening to half of their full length.

You can observe what muscle fibers look like by looking closely at packages of meat in the grocery store. In many types of meat that are cut lengthwise – beef, pork, chicken – lines can be seen along the surface, which are the muscle fibers and fiber bundles.

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## **BUILD** *adductor pollicis transversus* and *adductor pollicis obliquus muscles*

The thumb is called the pollex in Latin; pollicis is the adjective form of the word. These are sometimes considered a single muscle but here, the two units are combined for simplicity. This combined muscle pulls the thumb into the palm, which is why it is called an adductor – it "adds" the two parts together. Because it is on the ventral (palmar) side of the body, it is a flexor muscle.

Attachment sites:

1. The palmar ridge of the metacarpal ridge of the main ray (middle finger) and the proximal carpals.

2. The medial base of the proximal phalanx of the thumb .

Construct this combined muscle from a flattened triangular sheet of clay. The pointed end of the triangle attaches to the thumb; the wide end of the triangle is pressed down into the palm along its most stable zone, the metacarpals and carpal bones at the center of the hand.

DISCUSSION

Thumbs are one of the important digits for some mammals, but in humans, monkeys, and great apes, they are especially important. Thumbs in humans provide the major linking power for grasping and holding objects because they can cross over and reinforce the fingers.

The joint at the base of the thumb is called a double saddle – roughly described, two U-shaped structures that nestle together. The more range of movement – and degrees of freedom – in a joint, the more muscles that are required to control it. Why? Because muscles can only pull, and it takes a separate muscle for every direction of movement.

The great apes have the same opposable thumb engineering as in the hand, a necessity for effective movement in trees. Humans lost this structural capability long ago as the big toe evolved to become a stablizing part of the foot. This gave humans much more mobility when standing and running.

Each finger has three phalanges, or segments (the metacarpals are inside the palm and are considered separate segments), but the thumb has only two. This provides greater leverage and strength when it is flexed because the muscles pulling on it have fewer joints to cross.

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**BUILD** *flexor pollicis longus muscle*

The thumb has several different muscles that control its flexion, all located on the palm side.

Attachment sites:

1. The distal two-thirds of the anterior (ventral, or inside) surface of the radius plus the interosseus membrane next to it.

2. The ventral base of the distal phalanx (last segment) of the thumb.

Construct this muscle tendon from a long tube of clay. Fasten one end to the base of the last joint of the thumb and following a direct line, press the other end into the inside surface of the radius about halfway along its length.

DISCUSSION

Most tendons and muscles follow straight lines between their attachment points, as illustrated here. In a later step, this straight line will be adjusted.

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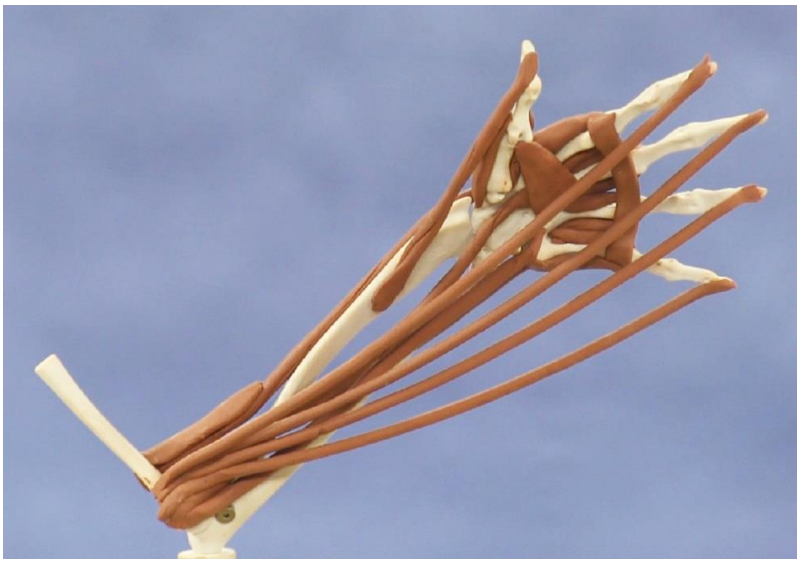
## **BUILD** *flexor digitorum profundus muscle*



The fingers and wrist are flexed with a strong muscle that is located high up on the forearm. The tendon of this muscle divides into four strands, one going to each of the fingers. The thumb is controlled with a different muscle.

Attachment sites:

1. About two-thirds of the proximal length of the ulna on the ventral side, plus the interosseus membrane next to it.

2. The bases of the distal phalanges of fingers 2 through 5 (not including the thumb). This includes all of the segments of the digits.

Construct the tendons of this muscle from four long strands of clay. Attach each to the inside tip of four of the fingers (not including the thumb) and the other end to the medial epicondyle of the humerus (the large protrusion on the ventral side). Press the ends attached to the humerus together – they actually form one common tendon at the end.

DISCUSSION

The four straight strands of tendon – plus the previous strand on the thumb – create a web of strings that cannot function effectively as they are now constructed. With their muscle bellies, these strings pull directly on the digits to produce the critical function of grasp. In this configuration, as they contract to pull on the digits they could not form a curved inside surface of the palm that is necessary to form the foundation of a strong grasp. Plus, if they were pulled tight and unrestricted, the act of gripping could damage them.

How can the straight-line function of the tendons be restricted? The answer: redirection.

The four strands of clay leading to the fingers are gathered together at about the mid-palm. Press the massed tendon into the palm at this point to produce a tendon bundle.

The strand of clay leading to the thumb is also pulled in toward this massed group of tendons at the same point. The point were this convergence occurs is between two protrusions of bone on the palm – the trapezium (at the base of the thumb) and the hamate (at the base of the little finger). The space between the two protrusions forms a channel for redirecting these tendons down into the wrist and forearm. Covered with a ligament, this channel becomes a tunnel. It is called the carpal tunnel.

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**BUILD** *transverse carpal ligament*

The tendons that control flexion in the fingers and thumb need to be held in place as they are redirected through the carpal tunnel. This function is provided by this ligament, a flat band of tissue that spans the two "hooks" on the palm of the hand.

Attachment sites:

1. The lateral surface of the trapezium.

2. The hamate bone and the pissiform bone.

Construct this lagment from a small, flat strap of clay. It is just long and wide enough to span the three protrusions on the palm of the hand.

DISCUSSION

Capping the channel between the protrusions on the palm of the hand forms a natural tunnel. Tendons are held into place within this tunnel as they redirect force from muscles high up on the forearm and the fingers and thumb. The carpal tunnel is also bridged by a second layer of ligament called the *flexor retinaculum ligament*. In reality, the tendons running to the fingers are separated from the tendons running to the thumb by these separate layers of ligament.

DISCUSSION

The three rows of carpal bones in the palm of the hand are not symmetrical but form an arch -- the metacarpal bones radiate out from this arch instead of being parallel. If this were not the case, as the fingers closed into the palm they would rotate down in four parallel tracks – similar to the shape formed when waving goodbye. This shape does not provide much flexibility – such as needed when holding irregularly shaped objects – because the tips of the fingers cannot come together.

Instead, the joint between the metacarpal and each digit allows each finger to angle inward as it closes. As they close, the ends of the fingers converge, allowing for more effective control over grasped objects. In addition, the rows of carpal bones themselves form a shallow arch, further directing the fingers to converge. This arch of carpal bones also adds to the strength generated by the hand.

Test this feature by holding up your own hand and closing each finger separately into the palm, beginning with the index finger. You can control each of the other fingers as it closes, touching the same spot (or close to it) as the index finger. This features is a significant feature for dexterity. Added to this converging capability, the mobility of the thumb allows it to lock over the clasped fingers, magnifying grip strength.

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## **BUILD** *extensor digitorum muscle* and *extensor pollicis longus muscle*

Attachment sites:

1. The length of the dorsal surface of each finger and the base of the distal phalanx of the thumb. In reality, these attachments are not to the bone itself, but dorsal hoods, which are thin layers of tissue running along the dorsal surfaces.

2. The lateral epicondyle of the humerus. This site on the humerus is a shared attachment site for several muscles. The muscle for the thumb actually attaches on the dorsal side of the ulna about two thirds of the distance toward the elbow, plus the interosseum membrane next to it. The thumb's extensor tendon runs in a straight line down the thumb and along the extreme right side of the back of the hand.

Contruct the tendons of these muscles as four long tubes of clay and flatten them slightly with the spatula or roller. The tendons reach from the top phalanx of each finger (but not the thumb) down to a common attachment site on the humerus. The finger tendons run through a channel formed between the ulna and the crest of the radius on the back of the hand. The thumb tendon crosses the wrist and is redirected through a groove on the left (ulnar) side of the radius, and then down into the ulna.

Construct the muscle belly for *extensor digitorum muscle* from a carrot-shaped piece of clay, with the widest part facing toward the humerus end. The tendons run into this muscle an inch or so below the wrist. For the thumb's tendon, the muscle is a smaller version of the one just built, and attaches to it, ending just below the elbow.

DISCUSSION

Two sets of tendons provide the connections that open and close the fingers. The most critical of these are on the palm side, the flexor tendons that control grasp. Because these tendons are the most important in survival, they are the most protected of the two sets, with thick layers of tissue between them and the skin of the palm. The extensor tendons on the back of the hand are less critical to survival. They are also much closer to the surface of the body. To minimize their profile in this exposed position, the extensor digitorum muscle tendons are slightly flattened.

Most people can see their own *extensor digitorum* tendons – hold up your hand with the back side toward you and pull your fingers as far back as you can. You should be able to see – or feel – four rigid strings converging from the knuckles toward the wrist. These visible tendons also showcase the concept of the strings on a puppet – the puppeteer pulls on the strings to make the puppet move, just as a muscle pulls on the tendons to make the fingers move.

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## BUILD digital tendon sheaths

Along the inside surface of the phalanges, the tendons built so far run in a straight line down into the palm. As they now exist, they would form a “bowstring” shape as the fingers flex down into the palm. This would be an ineffective situation because the protruding lines of tendons would interfere with gripping.

The body’s solution to this problem is to hold the shifting tendons down and onto the inside surfaces of the fingers as they flex by creating closed channels that redirect their movement. These channels are called digital tendon sheathes.

There are two digital sheaths on each finger and one on the thumb.

Contruct each as a small flat rectangle of clay. Press each piece onto individual segments of the digits in the center of each segment. The edges connect to the segments on both sides – the lateral and medial edges.