Lesson 12

◊ **Lesson Outline:**

- Function of the Appendicular Skeleton
- Appendicular Skeleton in Fish
- Evolution of Fins
- Phylogenetic Trends in the Fishes
- Evolution of Limbs from Fins

◊ **Objectives:**

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

- Describe the structure and function of fins in fish
- Describe the evolution of fins and the phylogenetic trends seen in the development of the different types of fins and girdles in fish
- Describe the evolution of limbs from fins and the changes in the roles of the pectoral and pelvic girdles

◊ **References:**

Chapter 10: 200-232

◊ **Reading for Next Lesson:**

Chapter 10: 200-232

Appendicular Skeleton

Overview: function of the appendicular skeleton

The appendicular skeleton is not used *so much* for protection (as the skull and vertebral column are)

It *primarily* subserves the roles of:

- support
- provision of attachment sites for muscles
- provision of levers for locomotion

The biggest differences are between aquatic and terrestrial animals since both the means of support and the style of locomotion differ tremendously.

Within each group, however, there are tremendous differences

Fishes:	Tetrapods:
lift for cruising	running
paddling, sculling	digging
some thrust but most from the tail	swimming
maneuvering	flight
	gliding, parachuting

Note: the emphasis in lectures will be on the trends we see in the form of the appendicular skeleton, and the relationship between form and function. You will learn the names of the various elements in lab! You should be able to link the two sources of information.

Evolution from Fins to Limbs

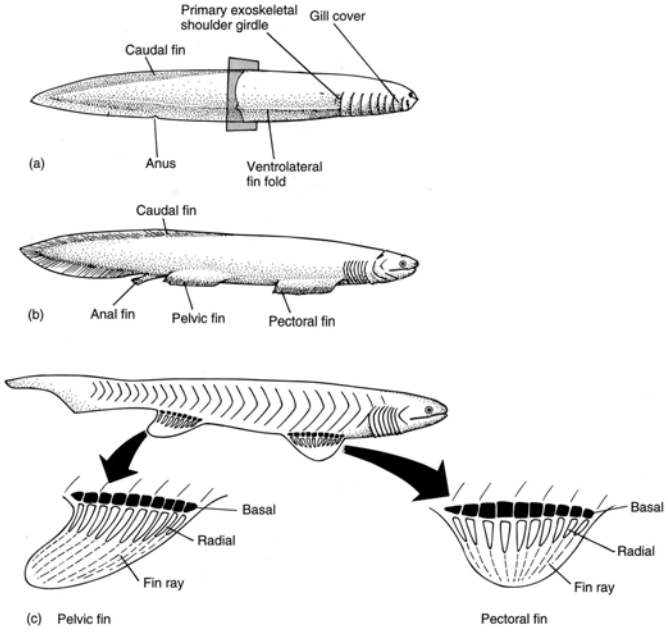
There are three theories of the origins of paired fins:

- the Gill arch Theory
- the Finfold Theory
- the Fin Spine Theory

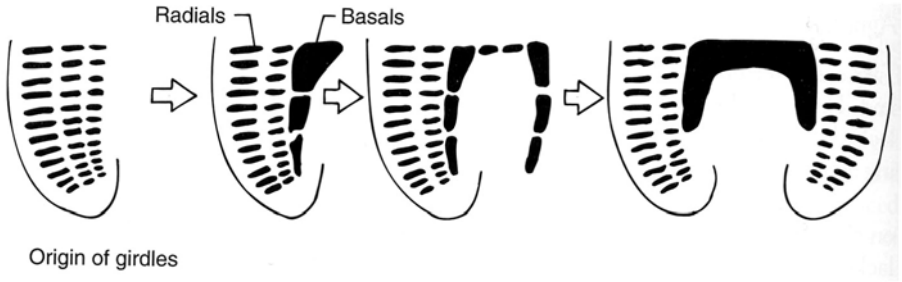
The gill arch theory maintains that paired fins and their girdles arose from gill arches.

The gill arch theory was not very satisfying and most researchers currently adhere to the finfold theory.

The finfold theory maintains that paired fins arose within bilateral ventrolateral folds in the body wall.



- the fins then became stiffened by a series of endoskeletal pterygiophores (the basals and the radials, developing from mesenchyme within the folds).
- additional stability came from the inward extension of the basals until they eventually fused in the midline to produce the supportive girdles.
- the girdles are believed to have developed to stabilize the fins.



The fin spine theory maintains that lateral hollow spiny appendages developed along the entire length of the trunk supported by fleshy membranes and that the pectoral and pelvic fins were the largest of these.

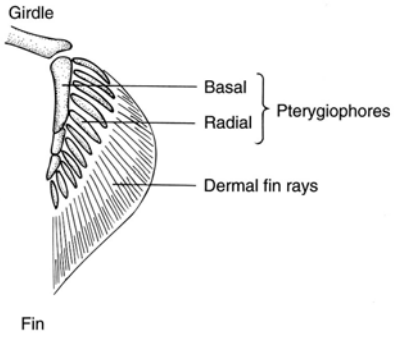
There is no strong evidence for any of the theories but the balance of what evidence there is tends to support the fin fold theory.

Appendicular Skeleton in Fish

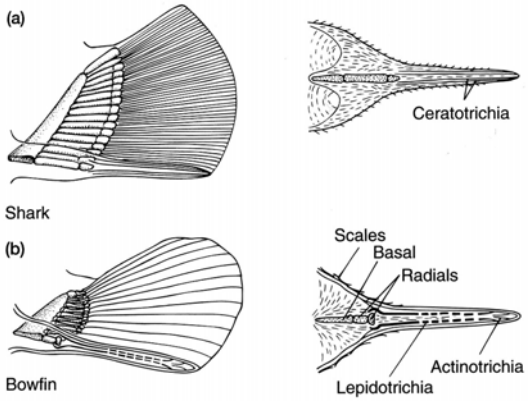
The appendicular skeleton in fish includes the paired fins and their girdles (not the dorsal and ventral fins or the tail)

They are derived from mesodermal cells from the somatic hypomere.

Fins are made up of basal and radial elements.



The tips of the fins are strengthened internally by fin rays
- slender keratinized rods that form from the dermis (ceratotrichia) in Chondrichthyes
- slender cartilagenous rods or ossified supports form from the dermis (lepidotrichia) in bony fishes (Osteichthyes)



Phylogenetic Trends in the Fishes

The living agnathans lack paired fins

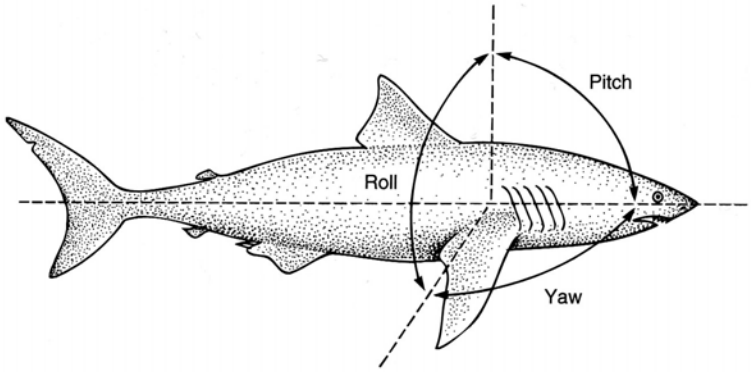
The first of the living vertebrates to exhibit fins are the Chondrichtyes.

In modern sharks, the paired basal components of the pectoral and pelvic girdles become extended and fuse in the midline of the body

They are embedded in body wall muscle and are not attached to the vertebral column

In the sharks, the girdles serve to anchor the fins and the fins are relatively immovable. That is, they do no "flap" or contribute to propulsion. Propulsion is produced by the tail.

While sharks do have a high concentration of oil in their livers that lightens the body, they do not have a swim bladder and, in general, are about 5% heavier than water. As a result they must swim constantly to keep from sinking



The action of the tail tends to push the fish forward but also
-pushes the head downward (pitch)
-wags the head from side to side yaw)
-causes the animal to roll.

The paired fins act to prevent this. As such they provide stability.
They do rotate slightly and can change angle and act to produce lift and support in the water.

In males, the pelvic fins move and also act as copulatory organs.

In the Actinopterygians (ray finned fishes) - the fins serve mainly for stabilization and for close maneuvering, adjusting body position or braking.

These animals have air bladders and do not need fins for lift.

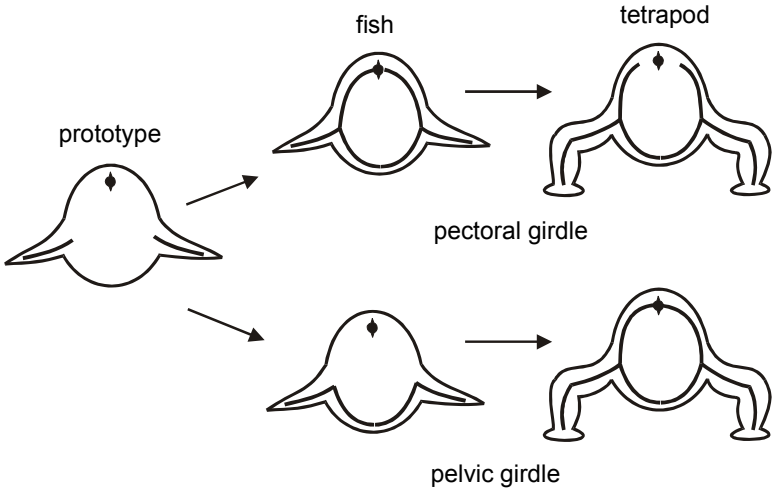
The pectoral girdle is well developed and now consists of both endoskeletal and dermal bones. The elements from each side meet ventrally in the midline and dorsally, the dermal elements are attached to the back of the skull producing a strong platform for muscle attachment and support of the fins.

A Word About Girdles

The primary purpose of girdles is to serve as attachment sites for the muscles of the appendages and to brace the appendages against the body to reduce counterforces. For instance, when you contract your deltoid muscles, the muscle will not only pull on the upper arm to raise it, they will also pull on the scapula and act to pull it down. The force is transmitted to both attachment sites. By bracing the scapula, the force is more

effectively transmitted to the arm and the movement is more efficient. To further stabilize the appendages, girdles are generally braced to either the axial skeleton or to themselves.

Thus the pectoral girdle is usually braced dorsally to either the vertebral column, the back of the skull or both, in fishes. It looses this connection in tetrapods. It is braced ventrally to either the sternum or to itself where elements of the girdle meet in the ventral midline in all vertebrates.



The pelvic girdles tend to be braced only to themselves in the ventral midline in fishes but also to the vertebral column in tetrapods.

Remember that bone tends to grow as a function of the forces that are placed on it. There is tremendous variation in the extend of the development of the various bones of fins and limbs and of the bones of the pectoral and pelvic girdles. All these variations tell a story about the life styles of the animals and the various uses for which the appendages are adapted. (Think about differences you might see in animals adapted for digging, swimming, climbing, running)

Dual Origin of the Pectoral Girdle

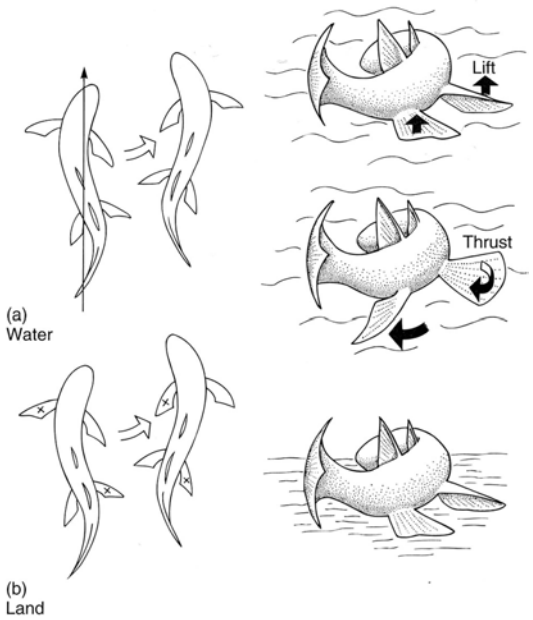
It is believed that the dermal component of the pectoral girdle first evolved, at the transition between the head and trunk in fishes, as a consolidations of dermal bones (from dermal armour) as an attachment site for the body wall muscles of the trunk, to form the posterior wall of the buccal cavity, to protect the heart, and as an attachment site for jaw and branchial arch muscles.

It may then, secondarily, have grown inwards and joined with endoskeletal elements to support the fins.

No similar selection forces would be acting posteriorly which might explain why there are no dermal elements associated with the pelvic girdle.

The Sarcopterygian fishes (lobe finned fishes), possess fin features that approach the limb features of early tetrapods. These are most advanced in latimeria, the coelocanth.

Now there are extra internal bony elements in the fin as well as muscles external to the body wall, projecting along the limb itself.



Adaptive Advantage of Lobe Fins
Lobe fins developed in the ancestors of the tetrapods while they were still fully aquatic,
- **not** after they had started to venture out onto land.
Thus while they were necessary preadaptations for the evolution of tetrapod limbs, they arose for a different reason.

It is believed that they evolved for pivoting and maneuvering through aquatic vegetation in shallow waters, as well as for working on bottom habitats in deeper waters.

Thus the trend was:

-fins to stabilize the body
-girdles to stabilize the fins
-addition of dermal bone in the pectoral region and connection to the skull for extra stability
-addition of extra internal elements in the fin and muscles external to the body wall projecting along the fin for more maneuverability

The overall trend is one of an increasing role in maneuvering

Evolution of Limbs from Fins - Onto Land
The shift from an aquatic to a terrestrial habitat was a challenging one. Several theories have been put forward to explain why fishes with lobed fins may have first ventured out on land.

In earlier lectures I mentioned that at the time tetrapods evolved, there appear to have been long periods of persistent drought that may have given rise to stagnant pools which would warm up, become hypoxic, become salty and deprived of food. If droughts were severe and ponds dried up, fish with larger fins that could "crawl" along river channels could find another pond. This presumes that these fish not only had lobed fins that could be used for locomotion but that they also had lungs.

Two facts argue against this, however. The first is that modern lungfishes do not do this. Instead they estivate by burrowing into the mud, forming a protective cocoon, lowering their metabolic rate and waiting until water returns. The second is that it seems unlikely that the limbs would have been strong enough to allow long trips. They would have been too weak initially

Thus, it has also been suggested that fish first ventured onto land for other reasons:

- to escape predation. Young fish commonly hide in vegetation in very shallow water to avoid predation by larger fish. This is a habitat where lobed fins would have been useful and the first trips onto land may have been to avoid being eaten. These would be short trips but an incentive for further development of a limb suitable for use on land.

- to find food. Insects would have invaded land by this point offering a food source that may have encouraged short trips onto the beach initially that could serve as the basis for later development.

Tetrapods

The earliest tetrapods already displayed changes correlated with locomotion on land.

First, the pectoral girdle looses its attachment to the skull. This increases cranial mobility.

Girdles and limbs become stronger and more robust, and more completely ossified

- for support and locomotion.

The fins are replaced with digits.

In the pectoral girdle, the dermal bones become reduced (or lost completely). In many the clavicles and interclavicle persist. The endochondral bones tend to become larger and more prominent.

The pelvic girdle is composed only of endochondral bone. It arose from the pterygiophores just like the pectoral girdle. In most fishes it is a single element but in tetrapods, it consists of three bones (pubis, ilium, ischium) and through the ilium, the pelvic girdle becomes attached to the vertebral column defining the sacral region. In birds, all three bones become fused into the inominate bone.

(pectoral girdle now free, pelvic girdle now fused)

Throughout the tetrapods, we see tremendous variation in the shape and general pattern of the two girdles. Given the role of the girdles as sites for muscle attachment and for transmission of propulsive forces to the body, these clearly reflect differences in locomotor function.

Read this section in your text (pgs 204-207) and just use common sense in trying to understand differences in form relative to differences in function. Try applying your ideas to what you see in the lab.