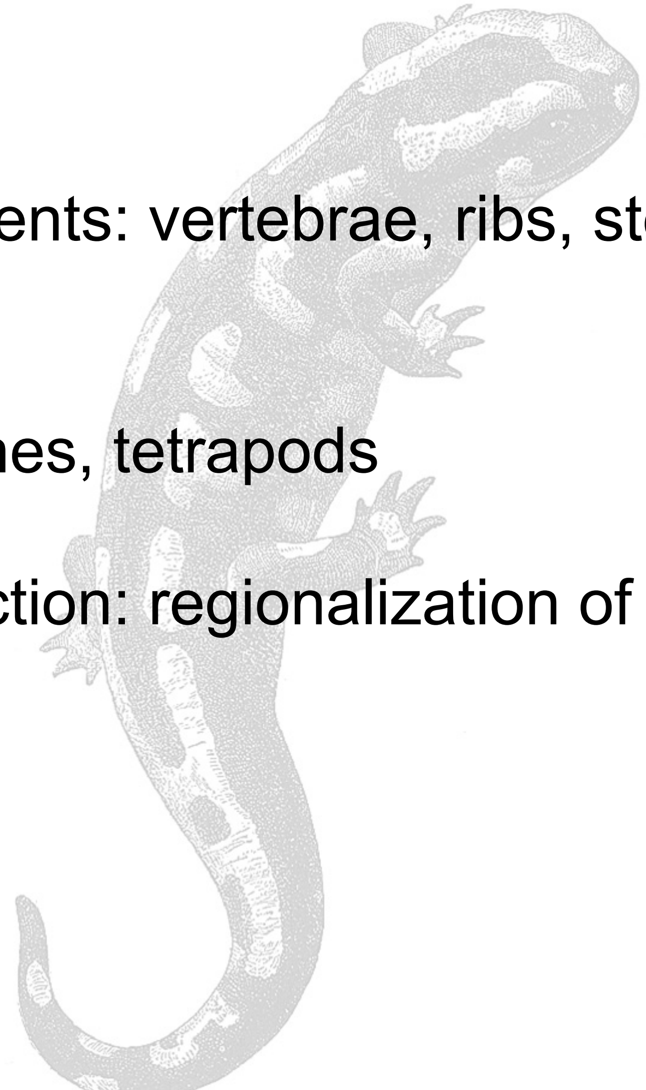
Skeletal System
Axial Skeleton



Introduction

Basic Components: vertebrae, ribs, sternum, gastralia

Phylogeny: fishes, tetrapods

Form and Function: regionalization of the verterbrae

Overview

The **notochord** and **vertebral column** define the long axis of the vertebral body. Offer sites for muscle attachements, prevent the body to slide inward or outward, and support much of the weight

The **notochord** is a long, continuos rod of fibrous connective tissue wrapping a core of fluid or fluid filled cells.

The **verterbral column** consists of a discrete but repeating series of cartilaginous or bony elements.

The **notochord** is phylogenetically the oldest of the two structural components, but it tends to give way to the vertebral column, which assumes the role of body support in most vertebrates.

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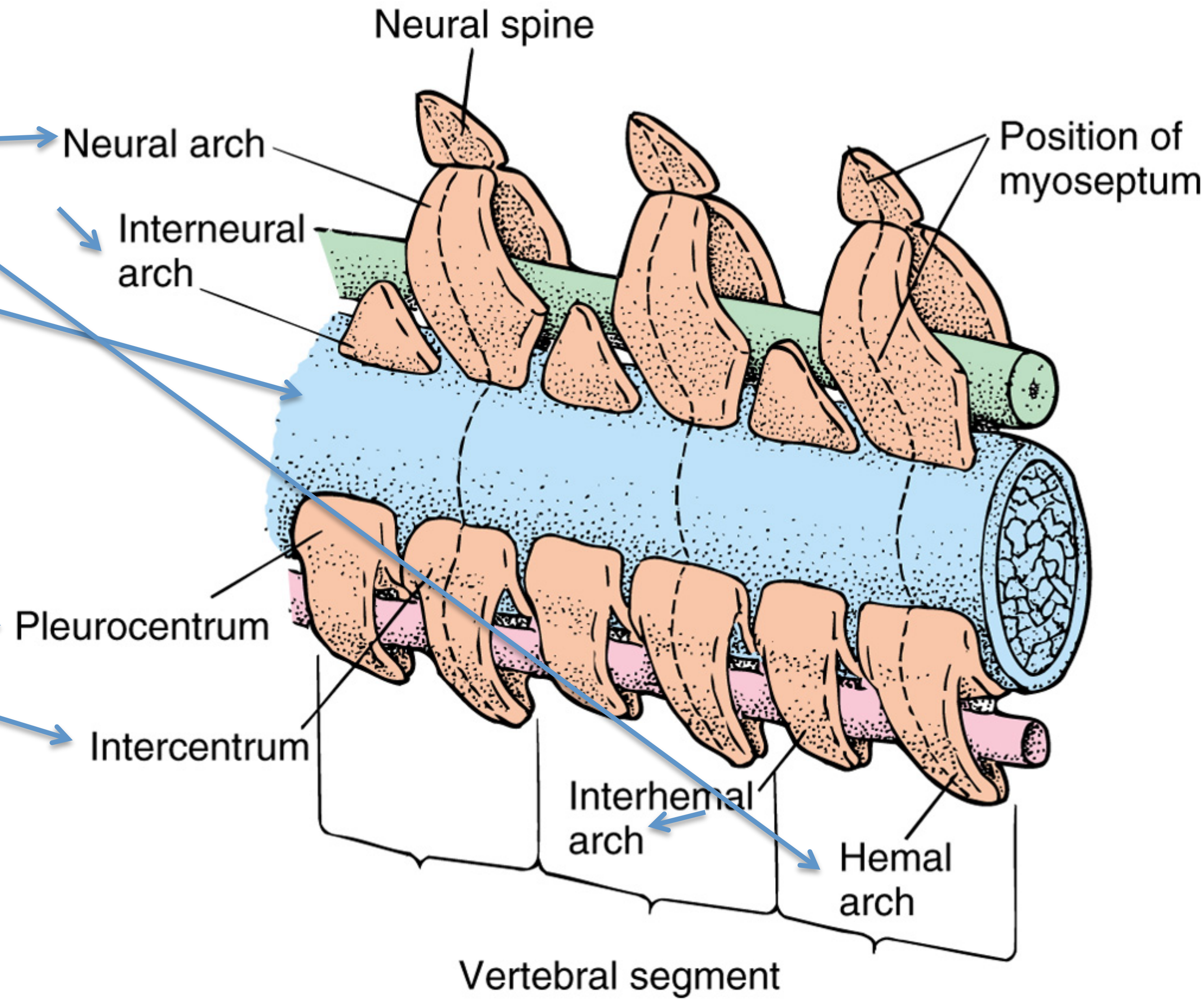
VERTEBRAE

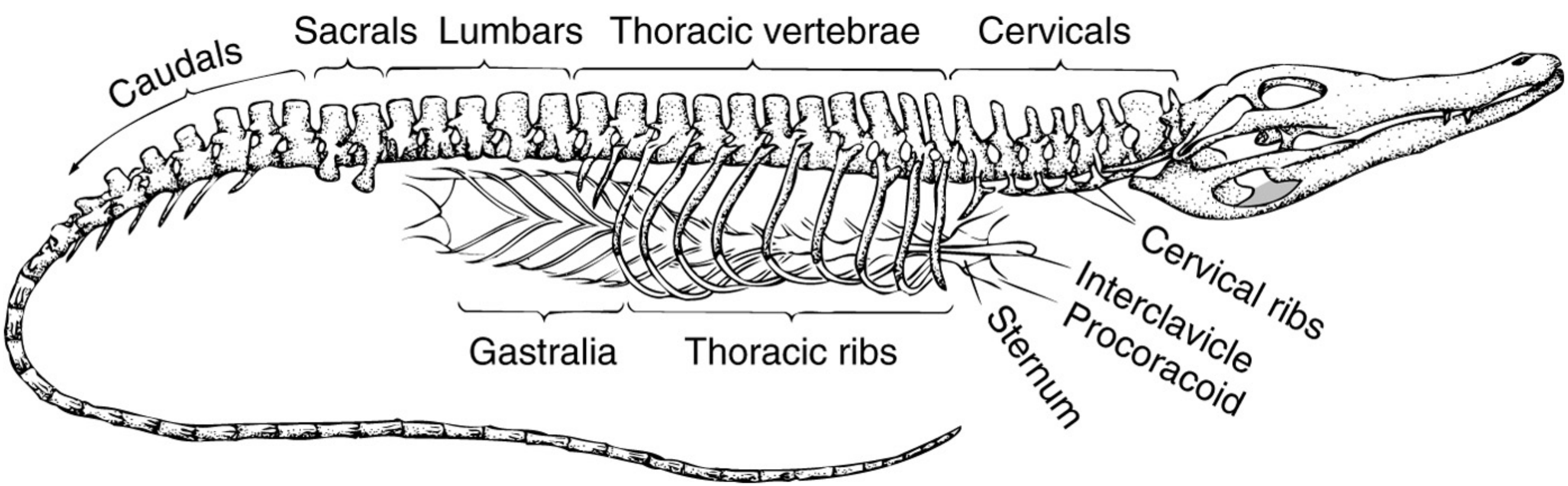
The first vertebral components to appear were the dorsal and ventral arches that rested upon the notochord. The next stage was the formation of two centra.
The bases of the central arches expand to form these centra
where they meet the notochor. The centra served to anchor and support these arches



Regions of the vertebral column

In fishes: trunk and caudal.

In amniotes: cervical, thoracic, lumbar, sacral, and caudal.



Each vertebral segment consist of arches and central.

Great variation in the **structure of the centra**, in the realtive importance of the pleurocentrum compared with the intercentrum, in the extent of the ossification, and in the degree to which centra supplement replace the notochord as mechanical elements of the axial column
Each centrum constitues the body of the vertebra.

-**aspondyly** : absence of centra

-**monospondyly**: one centra

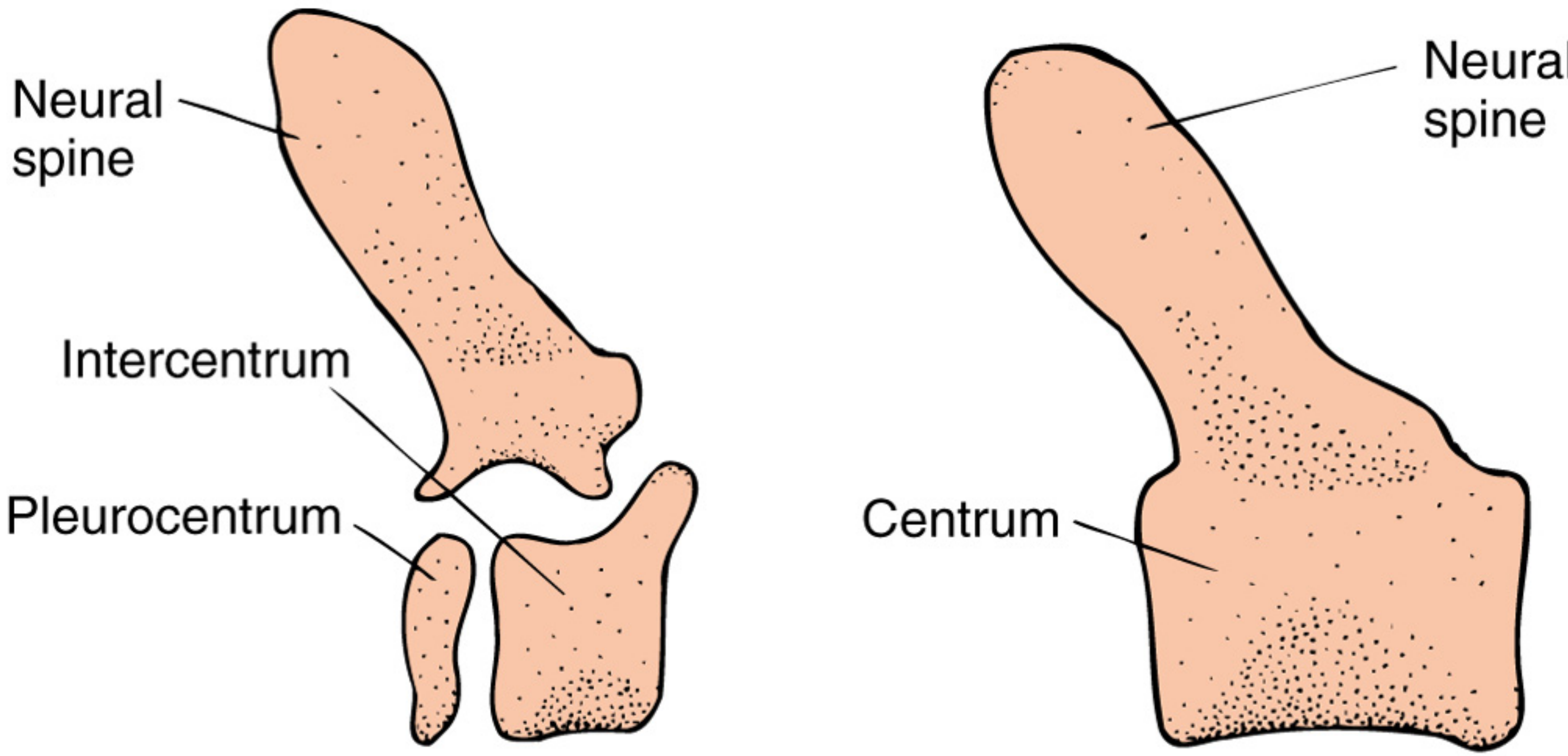
-**diplospondyly**: two centra per segment

In amniotes, the pleurocentrum predominates and becomes the body of each vertebral segment. The intercentrum usually becomes the intervertebral cartilage (disk) of the anmiote vertebral column.

In tetrapods, two anatomic relationships between centra and their neural arches:

Aspidospondyl: all elements are separated (different types: rhachitomus, embolomerous, stereospondylous verterbrae)

Holospondyl: all vertebral elements in a segment are fused into a single piece.



(a) Rhachitomous vertebra

(aspidospondyl)

(b) Lepospondyl vertebra

(holospondyl)

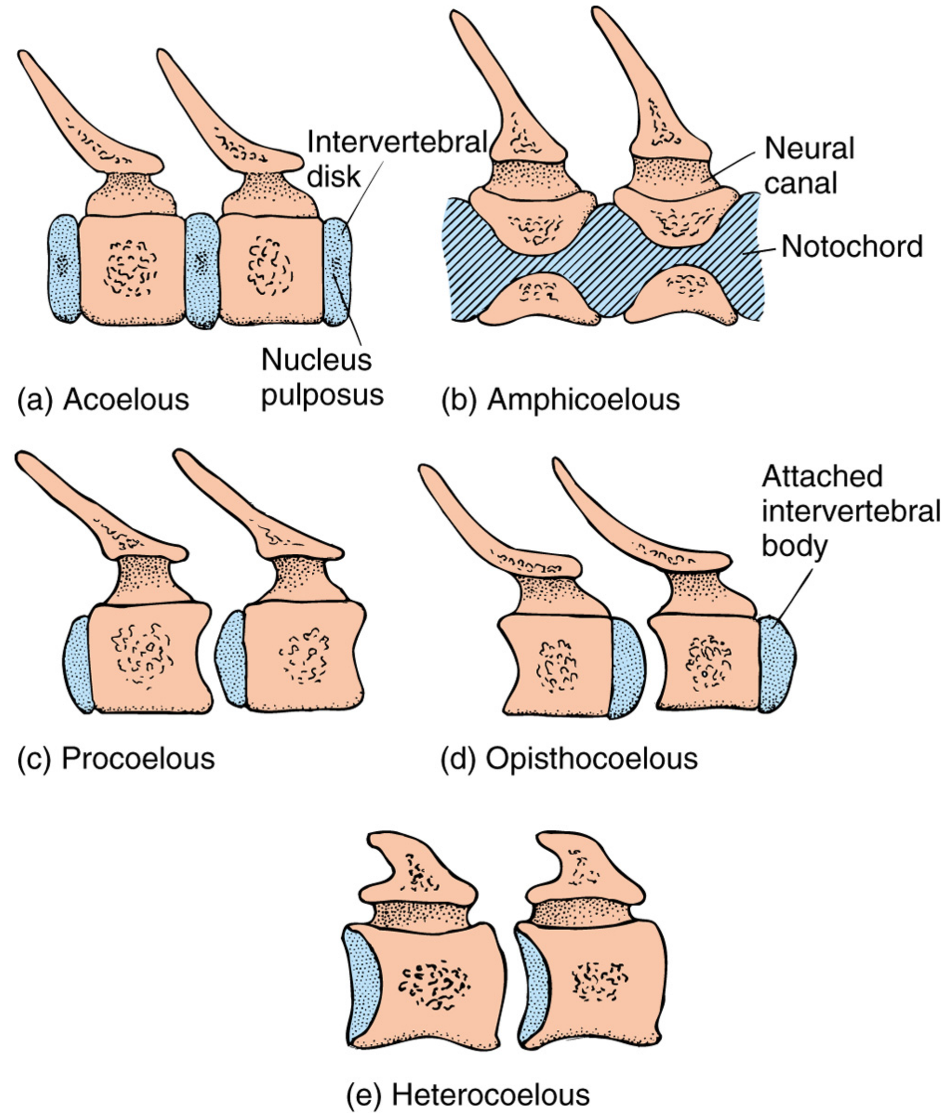
Centra with flat ends are **acoelus**, designed to receive and distribute compressive forces within the column.(humans)

If each surface is concave, the centrum is **amphicoeulous**, a design to allow limited motion in most directions. (fish)

Centra that are concave anteriorly and convex posteriorly are **procoelus**. Centra that convex posteriorly and concave anteriorly are **opisthocoelus (**extensive motion in both directions, frogs**)**

Central that bear saddle-shaped articular surfaces at both ends are **hetercoelus** (lateral and vertical motion but no rotation, bird necks)

The centra are linked into a chain of verterbrae, **the axial column.**

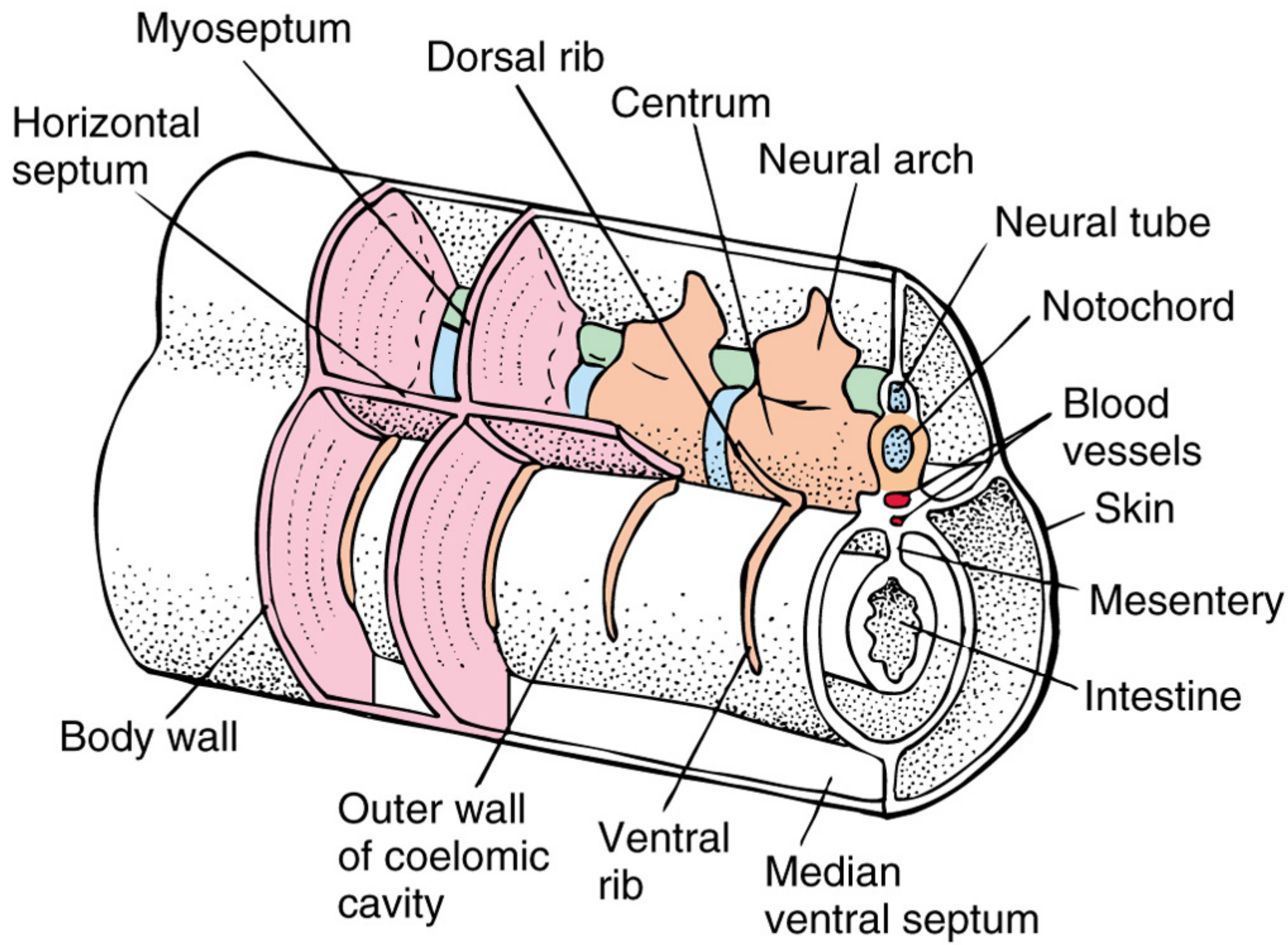


RIBS

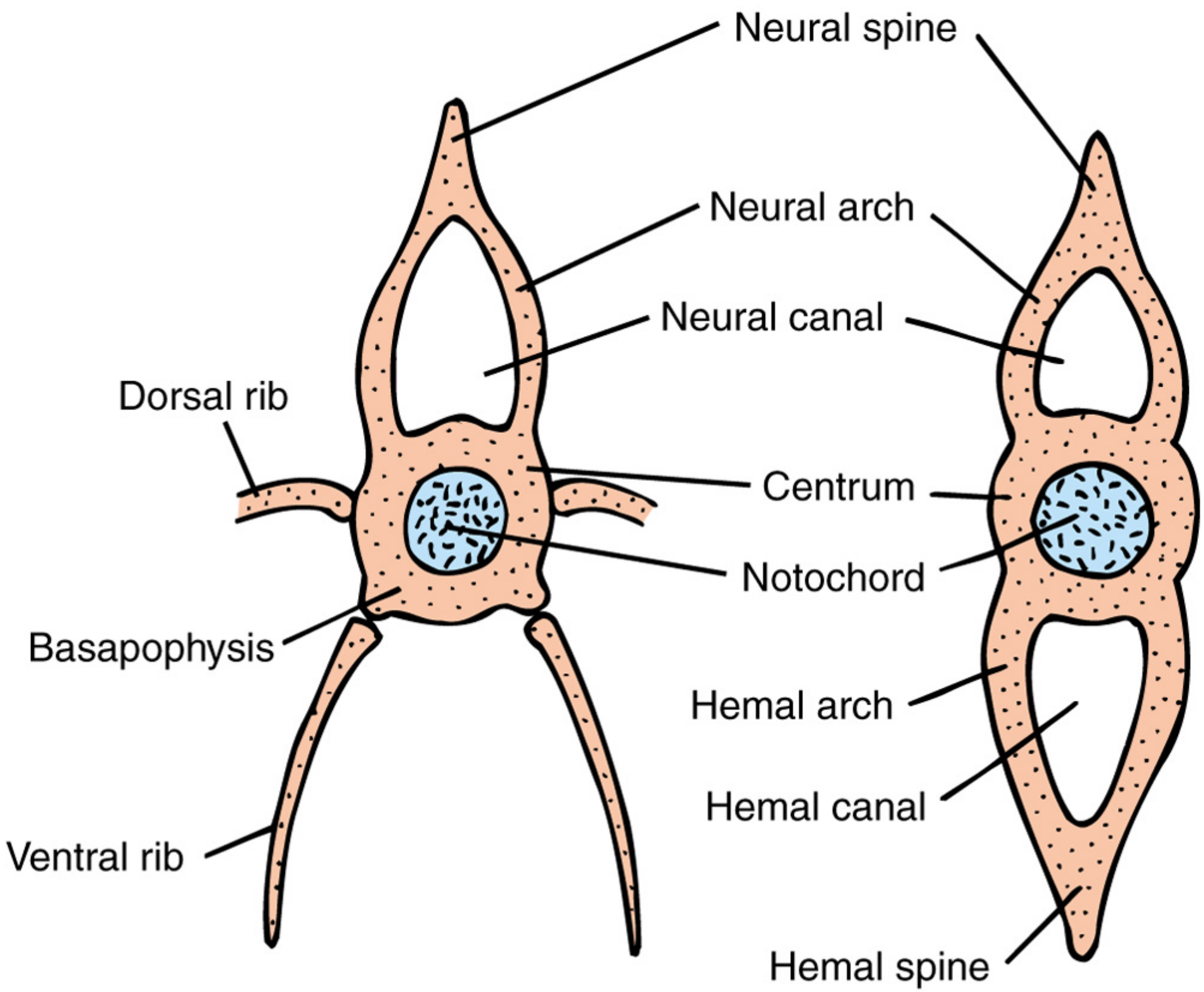
provide for secure muscle attachment,
help suspend the body,
form a protective case around viscera (rib cage),
and sometime serve as accessory breathing devise.

Embryologically, ribs preform in cartilage within myosepta, that is within the dorsoventral sheets of connective tissue that partition succesive blocks of segmental body musculature.

Many **fishes** have 2 sets of ribs: **dorsal and ventral ribs**
In tetrapods, ventral ribs are lost, dorsal ribs become the trunk ribs of terrestrial vertebrates


Myoseptum
Dorsal rib
Centrum
Horizontal septum
Neural arch
Neural tube
Notochord
Blood vessels
Skin
Mesentery
Intestine
Body wall
Outer wall of coelomic cavity
Ventral rib
Median ventral septum

(a) Fish ribs



(b) Trunk vertebra

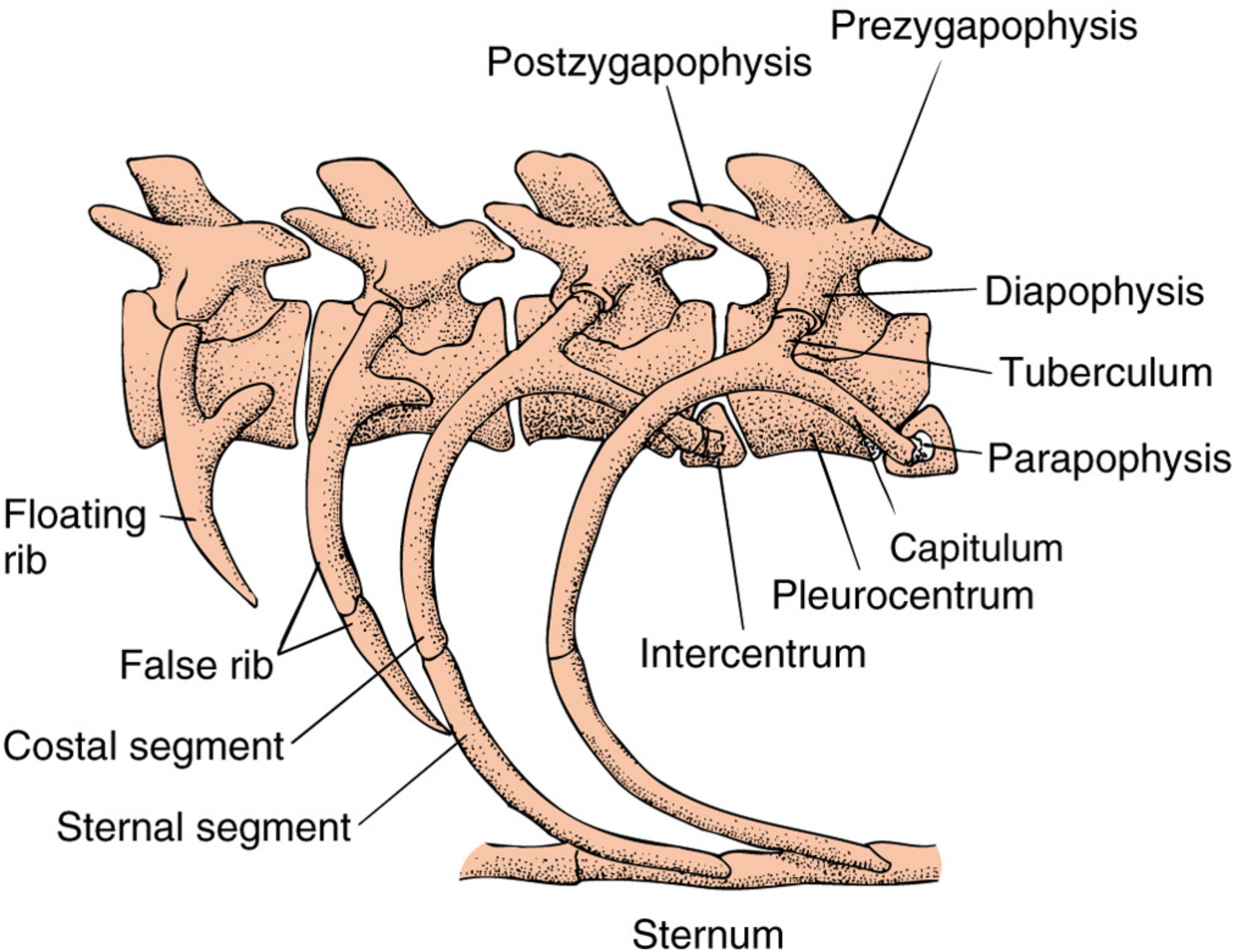
(c) Caudal vertebra

Ribs of primitive tetrapods are **bicipital** (two head articulate with the verterbrae)

Capitulum (ventral rib head) articulates with the paraphophysis (ventral process)

Tuberculum (dorsal head) articulates with the diapophysis (process on the neural arch).

If these verterbral process fail to develop, the articular surface persits, forming a small concavity or **facet**, to receive the rib.


Prezygapophysis
Postzygapophysis
Diapophysis
Tuberculum
Parapophysis
Floating rib
Capitulum
Pleurocentrum
False rib
Intercentrum
Costal segment
Sternal segment
Sternum

In **birds**, cervical ribs are reduced and fused to the vertebrae. In the thoracic region, the first several ribs are floating ribs followed by true ribs that articulate with the sternum. Some floating and most true ribs bear uncinate processes, projections that extend posteriorly from proximal rib segments. These processes act as lever arms for inhalatory muscles that flare the rib cage.

Similar rib projections are found in some living and fossil **reptiles**, as well as in some early **labyrinthodonts**.

In **mammals**, ribs are present on all throracic vertebrae. Some are floating (posterior) and others are false. Most are true ribs and they meet the sternum through cartilaginous sternal rib segments. Within cervical and lumbar regions, ribs exist only as remnants fused with transverse processes (pelurapophyses)

Sternum

It’s a midventral structure that is endochondral in embrionic origin and arises within the ventral connective tissueseptum and adjacent myosepta.
It offers a site of origin for chest muscles. It secures the ventral tips of true ribs to complete the ossified rib cage.

The **rib cage** consists of ribs and sternal elements that embrace the viscera.

Size and shape changes in the rib cage act to compress and expand the lungs, promoting ventilation.
The sternum may consist of a single bony plate or several elements in a serie.

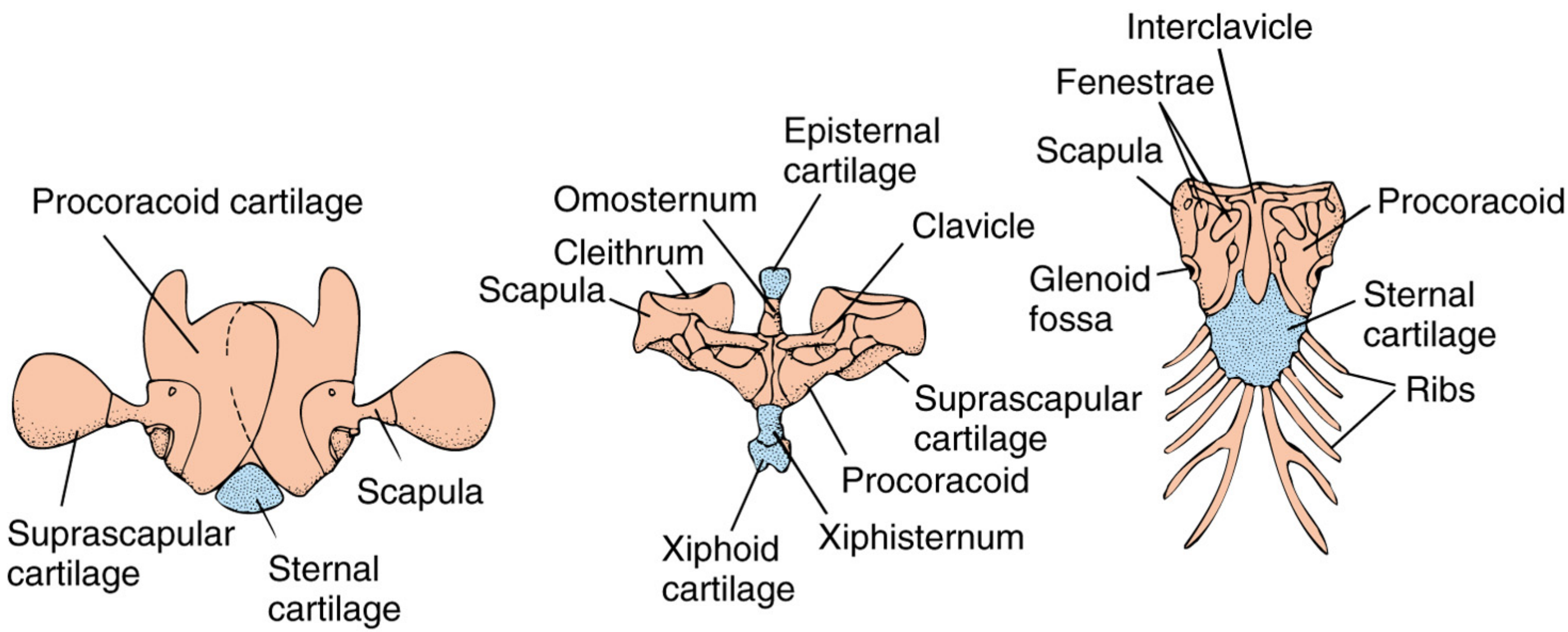
Fish lack sternum. When it appears in tetrapods, the sternum is not a phylogenetic derivative of either ribs or the pectoral girdle. A sternum is absent in the first tetrapods, but it is present in modern amphibians. In many urodeles, the sternum is a single sternal plate (fig 8.8a).

In **anurans**, a single element, the siphisternum, lies posterior to the pectoral girdle. (fig 8.8b)

In **turtles, snakes, and many limbless lizards**, the sternum is absent.

In **other reptiles**, the sternum is common and it consists of a single midventral element associated with the shoulder girdle. (fig 8.8.c). During locomotion, the reptilian sternum provides stability on weight-bearing girdle elements.

In **flying birds**, the massive flight muscles arise from a large sternum that bears a prominent ventral keel, the carina (8.8d).



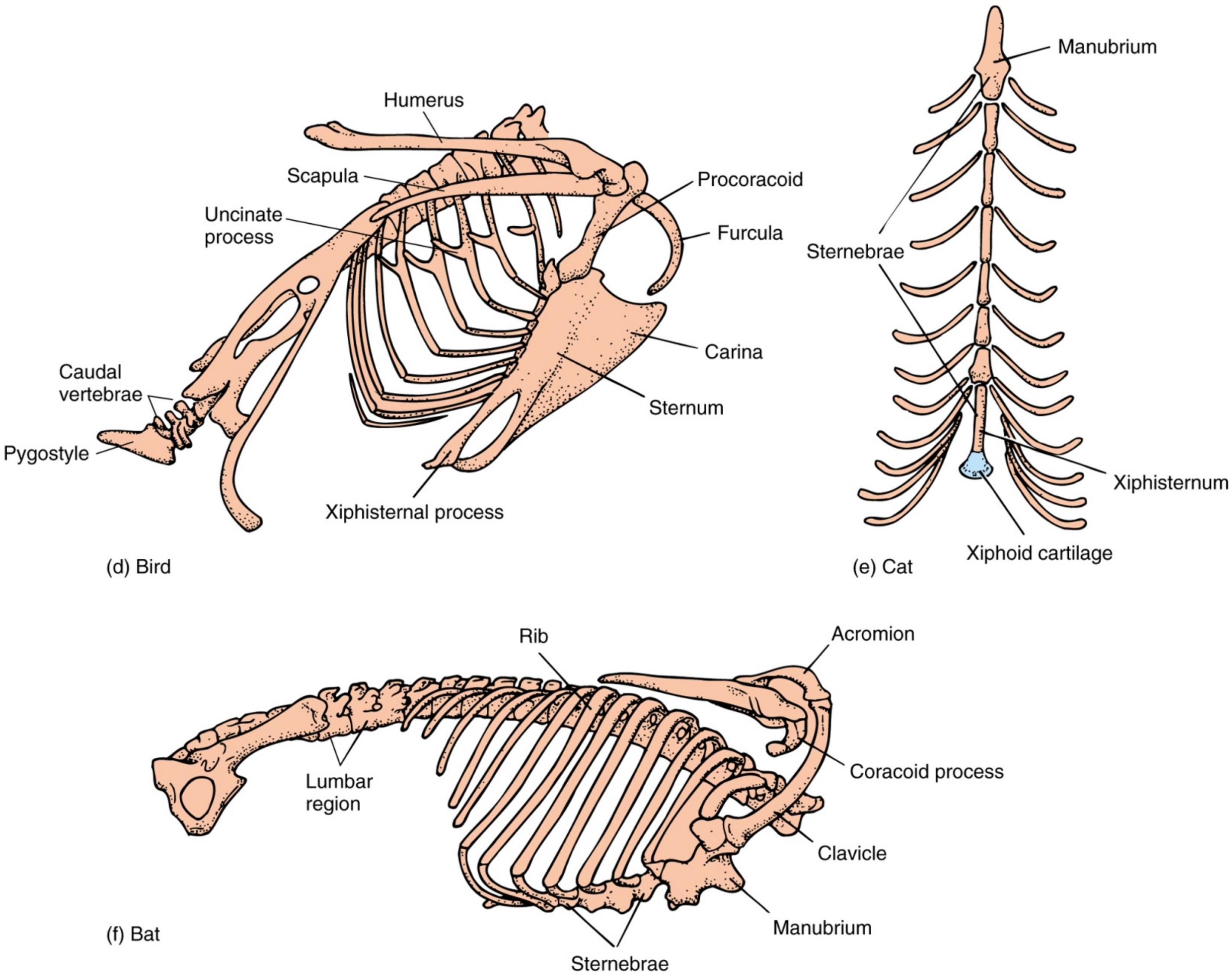
(a) Urodele sternum

(b) Anuran sternum

(c) Lizard sternum

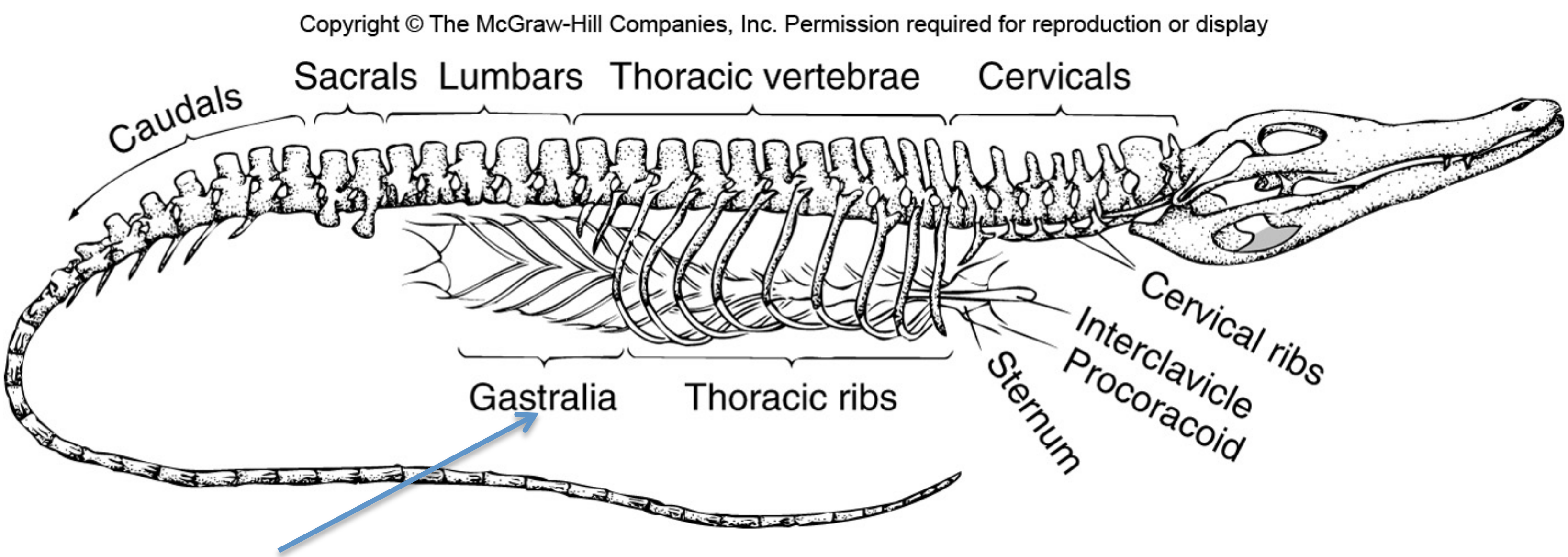
In most mammals, the sternum consists of a chain of ossified elements in series, the sternebrae (fig 8.8e,f). The first and last of these sternebrae are modified and are called the manubrium and xiphisternum.

Thus, a sternum occurs in some modern amphibians and most amniotes.


Humerus
Scapula
Uncinate process
Procoracoid
Furcula
Carina
Sternum
Caudal vertebrae
Pygostyle
Xiphisternal process
(d) Bird
Manubrium
Sternebrae
Xiphisternum
Xiphoid cartilage
(e) Cat
Rib
Acromion
Lumbar region
Coracoid process
Clavicle
Manubrium
Sternebrae
(f) Bat

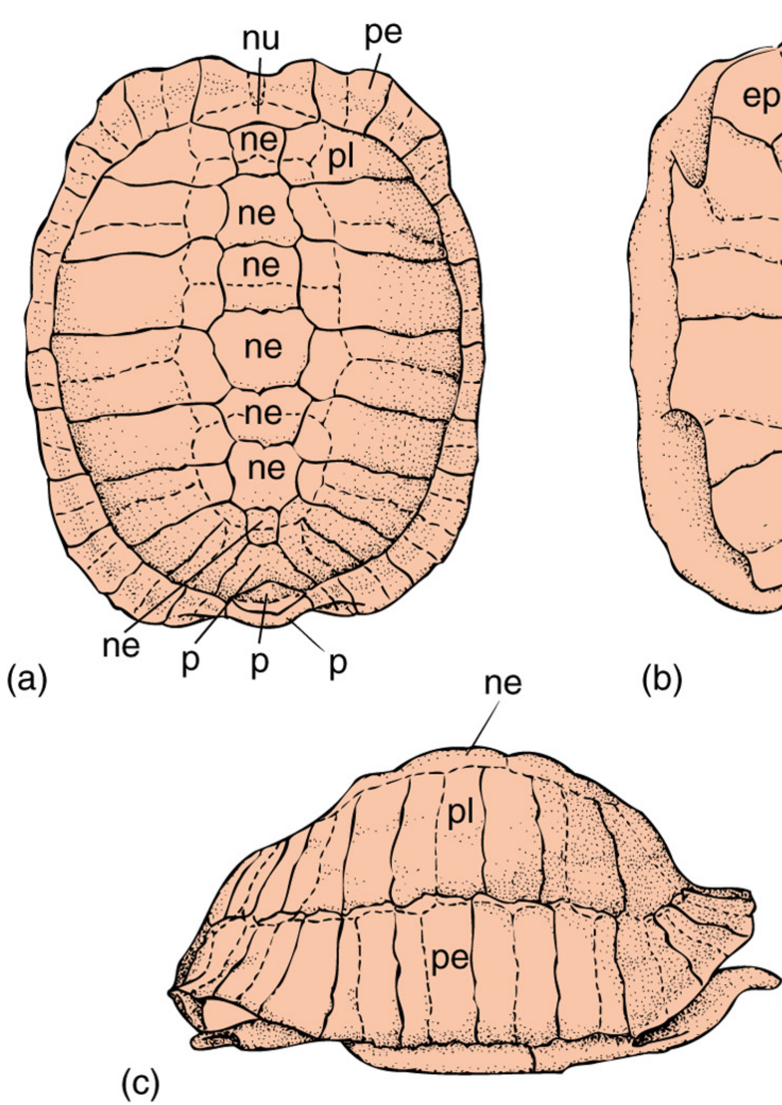
Gastralia

In some vertebrates, posterior to the sternum is another set of skeletal elements, the gastralia, or abdominal ribs. Unlike the sternum or ribs, the gastralia are of dermal origin. They are restricted to the sides of the ventral body wall between sternum and pelvis and do not articulate with vertebrae



Gastralia are common in some lizards and crocodiles. The serve as accessory skeletal system that provides sites for muscle attachment and support for abdomen.

Within turtles, the plastron is a composite bony plate forming the floor of the shell. It consists of a fused group of ventral dermal elements, including contributions from the clavicles (epiplastrons), and interclavicle (entoplastron) as well as dermal elements from the abdominal region (possibly the gastralia). Such ventral dermal bones are usually absent in birds and mammals, but in many fishes bones form within the dermis of the belly region .



Shell of the tortoise.

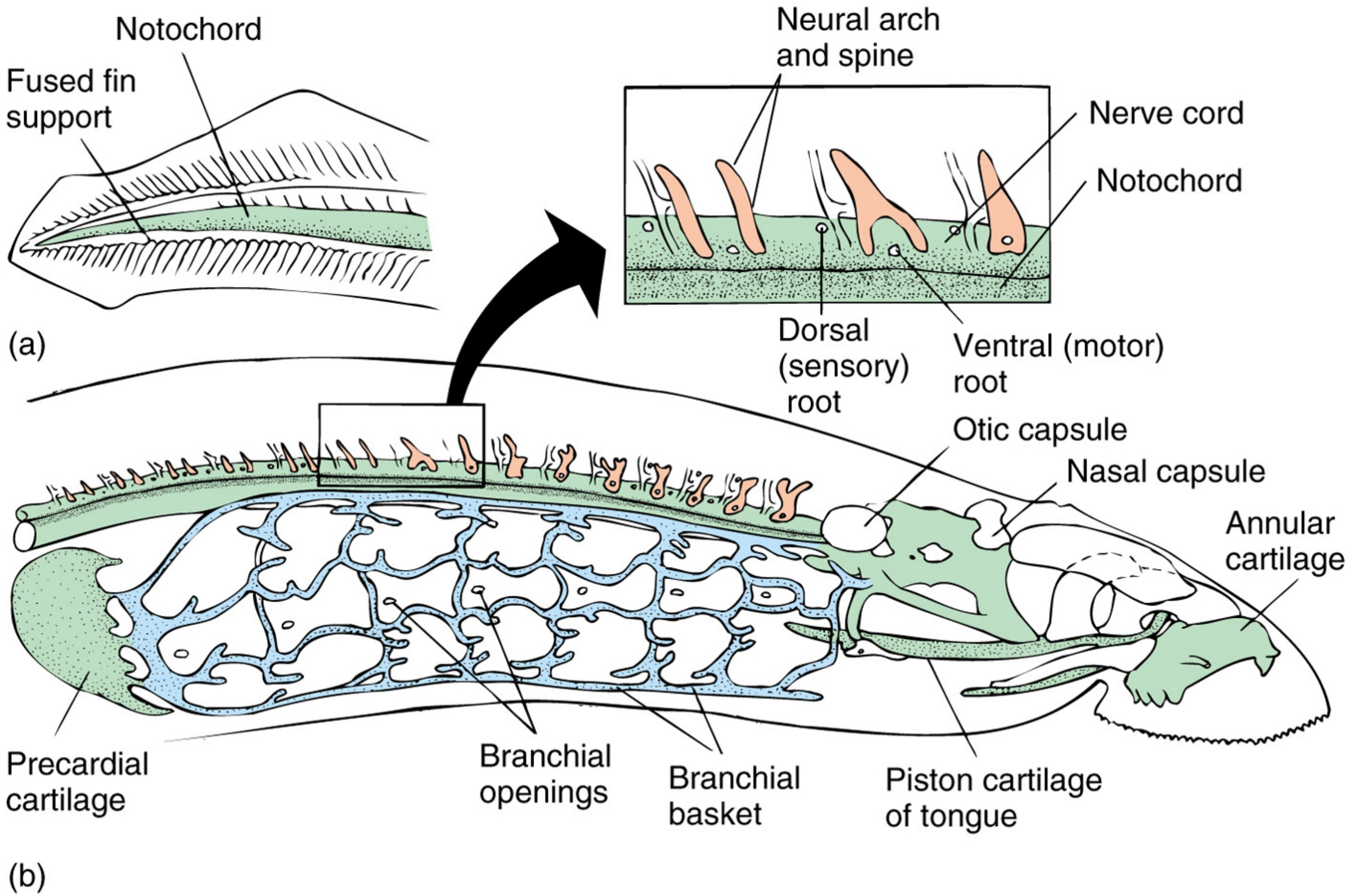
a) Dorsal view of carapace
b) ventral view of flat plastron
c) lateral view of whole shell.

Phylogeny

Among ostracoderms, the notochord is large and prominent, a major contributor to functional axial skeleton. They may have had verterbrae but were not preserved, probably small and unossfied pieces resting upon the notochord.

Living hagfishes posses a prominent notochord but lack verterbral elements.

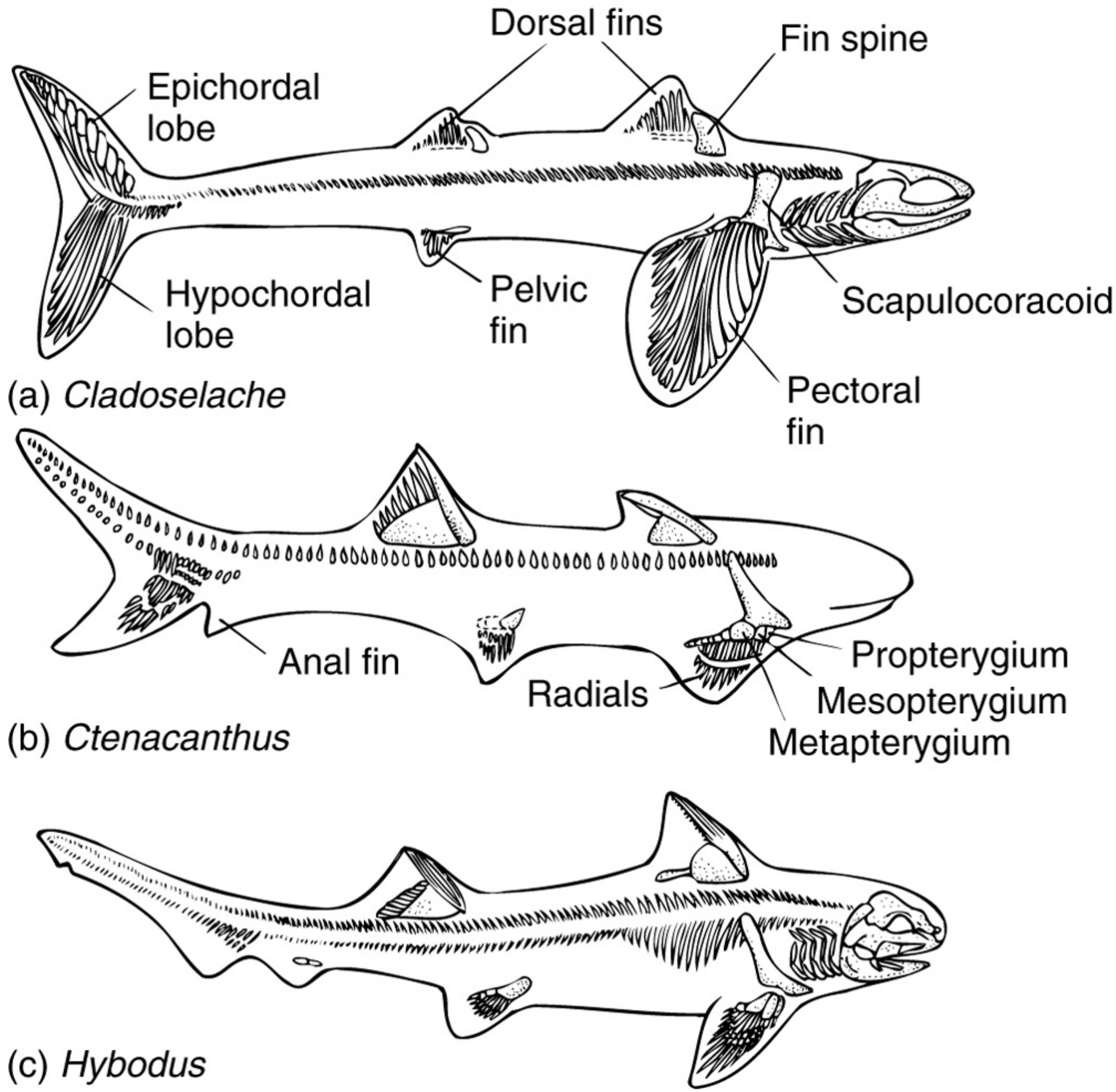
Lampreys have vertebral elements but they are small, cartilaginous elements resting dorsally upon a very prominent notochord that gives axial support for the body,



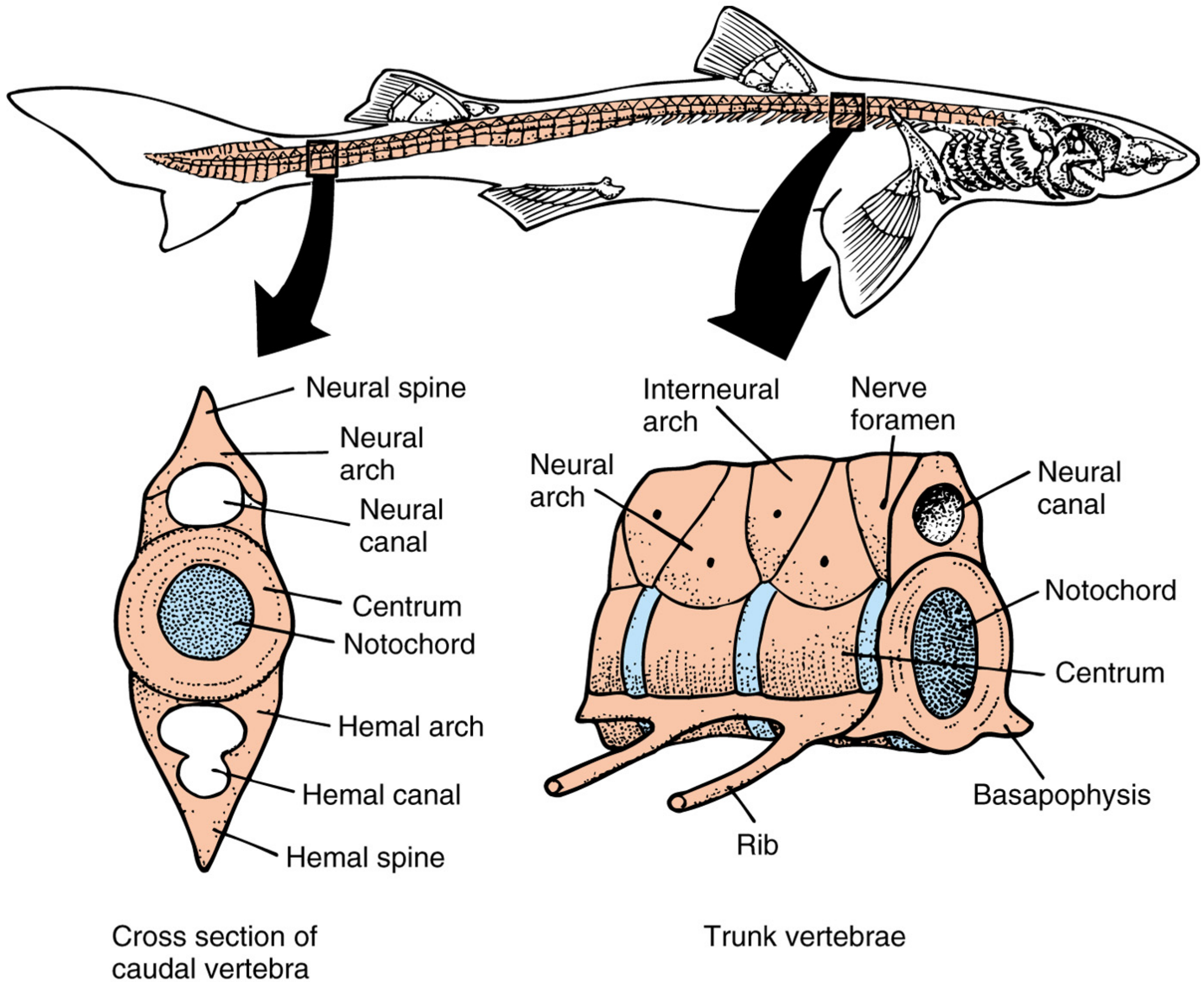
Lamprey skeleton

In most primitive fishes, the axial column consisted of a prominent notochord. There is no evidence of vertebral centra, although dorsal and ventral arches were usually present.

In advance sharks, these vertebral elements enlarge to become the predominant structural element of the body axis, although the constricted notochord enclosed within the vertebral central persists



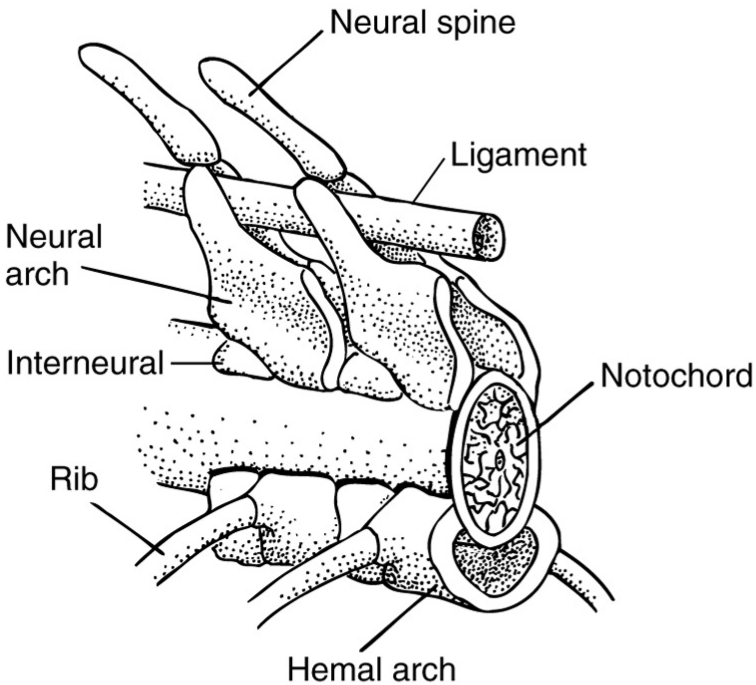
Shark ancestors



(d) *Squalus*

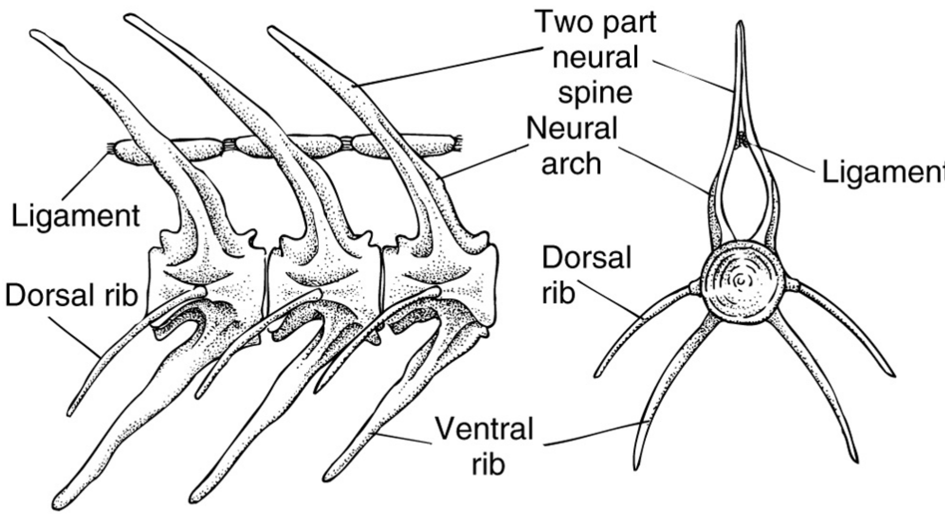
Modern shark

Among living primitive bony fishes (sturgeons, paddlefishes), the vertebra column is unossified but several elements of the vertebrae are present in each segment



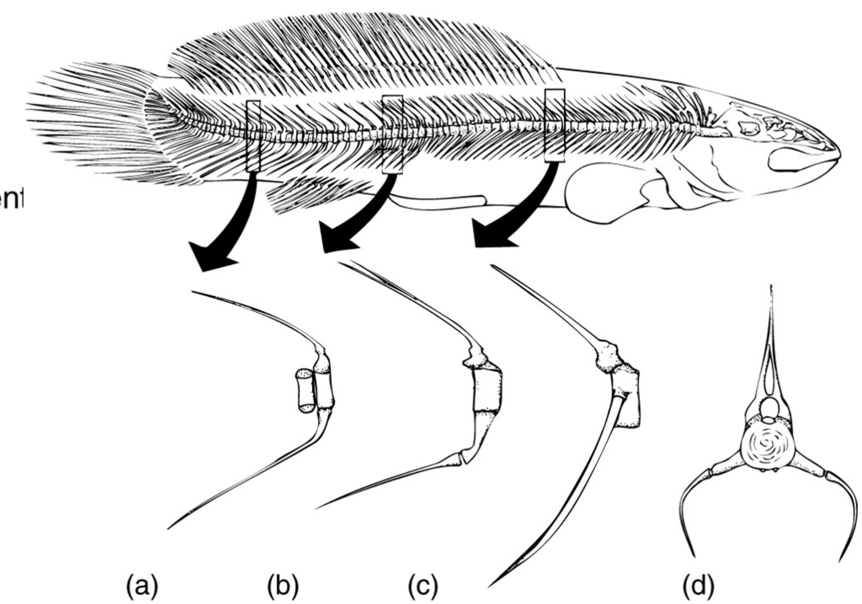
(a) Sturgeon vertebrae (lateral)

In more derived bony fishes, such as the teleost and bowfin, the vertebral column is ossified and its centra more prominent to replace the notochord as the major mechanical support for the body. Neural spines and ribs become more developed, as do accessory bony elements that help internally stabilize some of the unpaired fins.



(b) Teleost vertebrae (lateral)

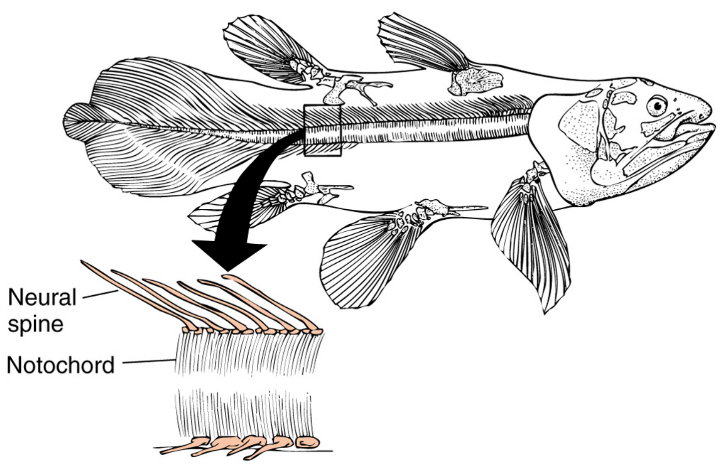
(c) Teleost vertebra (cross section)



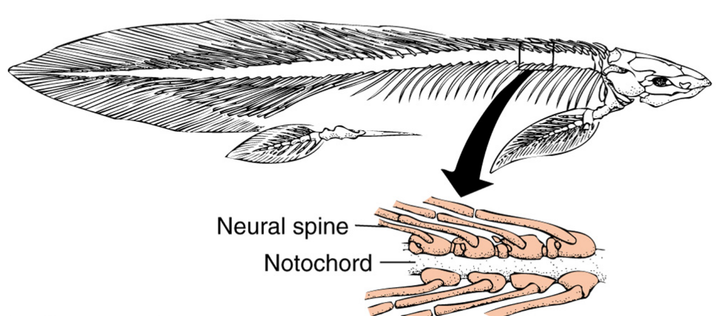
Bowfin Amiacalva

Sarcopterygians

The notochord continues to serve as the major supportive element within the axial skeleton. In living sarcopterygians, the vertebral column can be rudimentary and cartilaginous

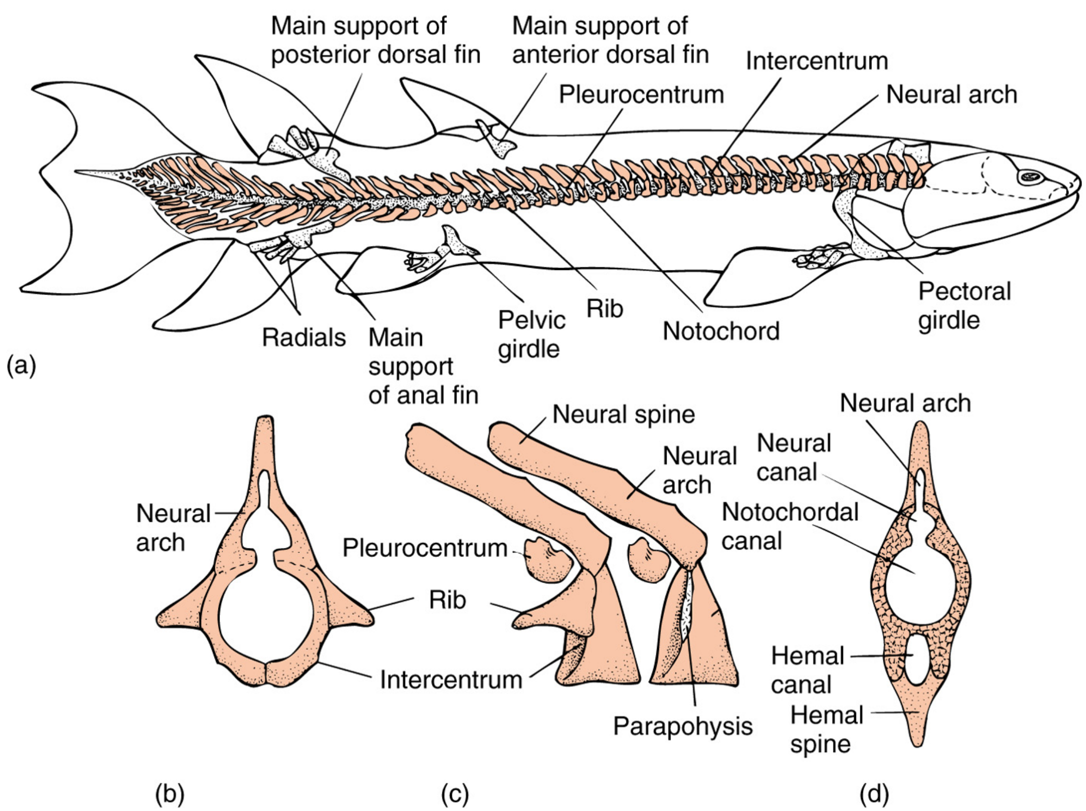


(a) *Latimeria*



(b) *Neoceratodus*

However, in many early species, such as the rhipidistians, vertebral elements were usually ossified and exhibited a rachitmous type of aspidospondyly in which each vertebra consisted of three separate elements: a neural arch, a hoop- or-crescent-shaped intercentrum, and paired pleurocentra



Tetrapods

The vertebral transition to land brough considerable changes. As animals evolved from water to air, their bodies went from buoyant support design to a design in which bodies were suspended between limbs.
All systems, including respiration, excretion, and body support, were affected. Changes in the axial skeleton are especially indicative of these new mechanical demands

-Labyrinthodons evolved directly from rhipidistians, taking over their aspidospondylous type of verterbrae as well.

-The characteristic mode of fish progression in which locomotion depends on lateral waves of undulation in the vertebral column (VC) has been retained in modern salamanders and was probably present in early amphibians as well.

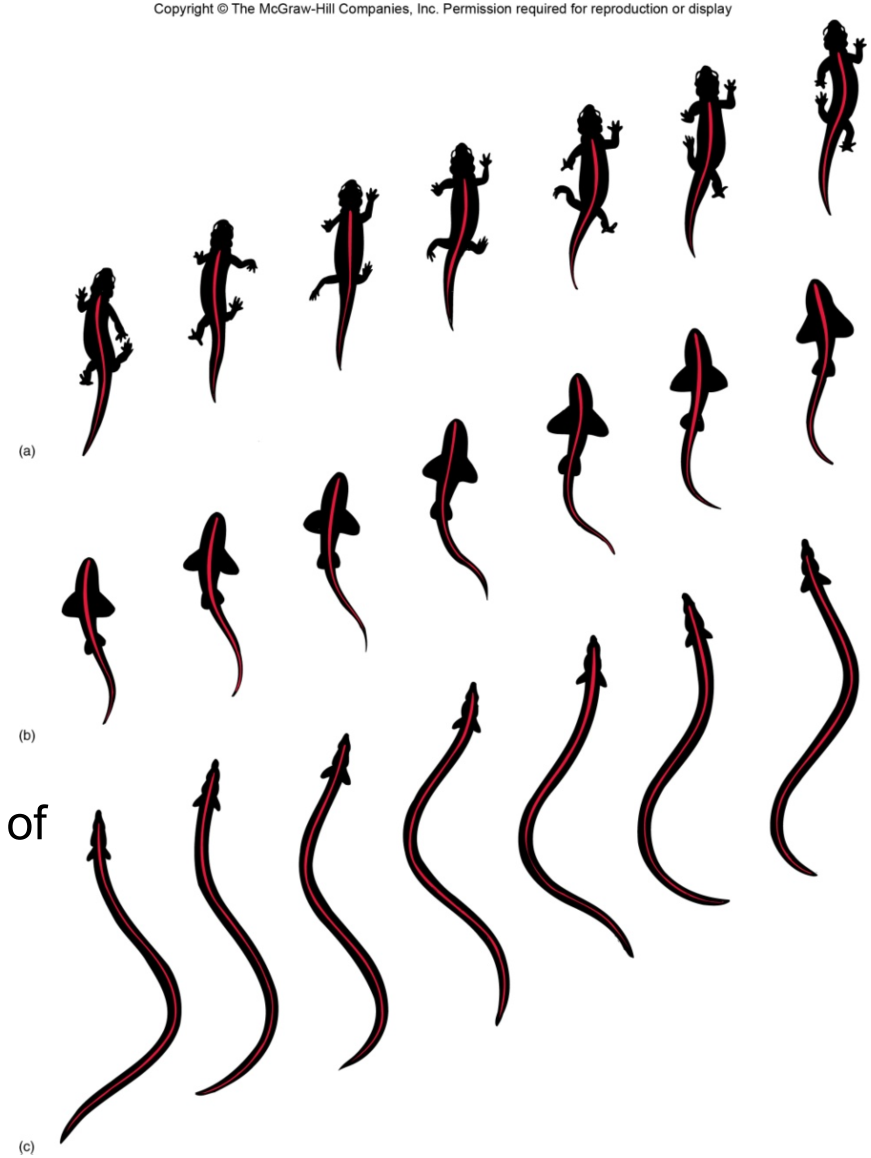
-What was new was the tendency to twist the VC. Without surrounding water to support the body and with planted feet establishing pivot points, walking on land placed new torsional stresses on the verterbrae

Lateral undulatory locomotion
From fishes to tetrapods.

a) Lateral undulations of a salamanders serve to advance each foot forward, plant it, and then rotate the body about this point of pivot for locomotion

b) Similar lateral undulations of a shark's body push against the water and drive the fish forward

c) Side-to-side sweeps of the body of an eel exert a force against the surrounding water s the fish travels forward.



Vertebral innovations in tetrapods

-**Zygapophyses** or articular processes to resist twisting.
In fishes, the axial skeleton continuous support along its length, whereas in tetrapods only two pairs of points, the forelimbs and hindlimbs, provide support.

As opposite feet plant themselves on a surface to establish points of support during locomotion, the VC is twisted, placing stress on the fibrous connection between successive vertebrae.

Zygaposhyses reach across these joints to interlock gliding articulations. They are oriented to allow bendingi n horizontal or vertical plane, but they resist twisting.

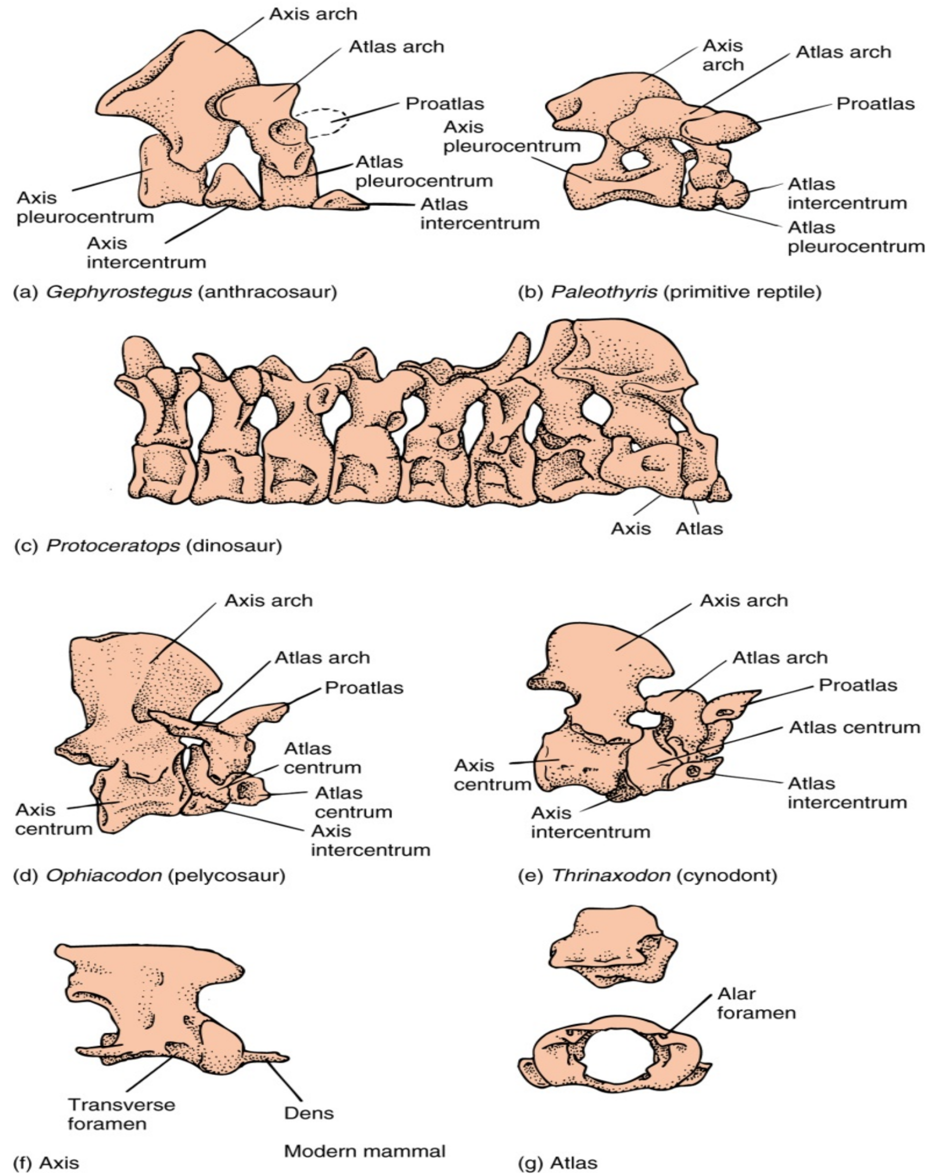
-**Sacral Region** (site of attachment of pelvic girdle to VC)
Shown in earliest labyrinthodonts
Presence of sacral region is taken as evidence that direct transfer of propulsive forces in the hindlimbs to the axial skeleton became an important component of terrestrial locomotor system very early in tetrapod evolution.

-**Cervical vertebra**. Redesign of the first vertebra
Connection between the pectoral girdle and back of the skull is lost in labyrinthodonts.
First vertebra became a cervical vertebra, allowing greater freedom of head rotation.
Uncoupled from the pectoral girdle, head can be lifted w/o restraint from the shoulder.
First cervical vertebra allowed the tetrapod to rotate head w/o reorienting the rest of its body

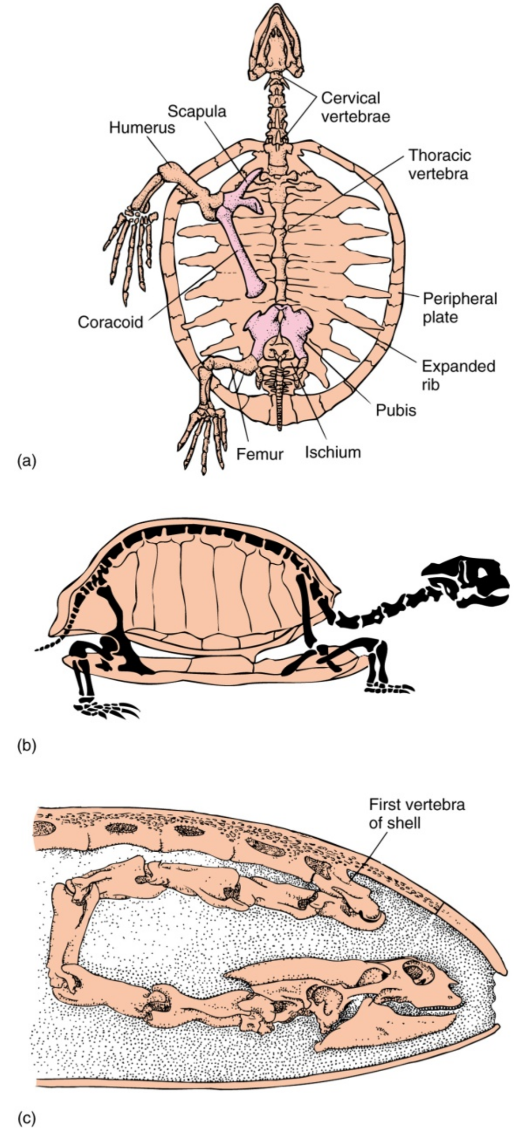
Amniotes

-**Atlas and axis**: Head rotates primarly on two anterior cervical vertebrae specialized to the function. Vertical and horizontal movements of the head are largely limited to the skull-atlas joint, whereas twisting movements occurs within the atlas-axis joint.

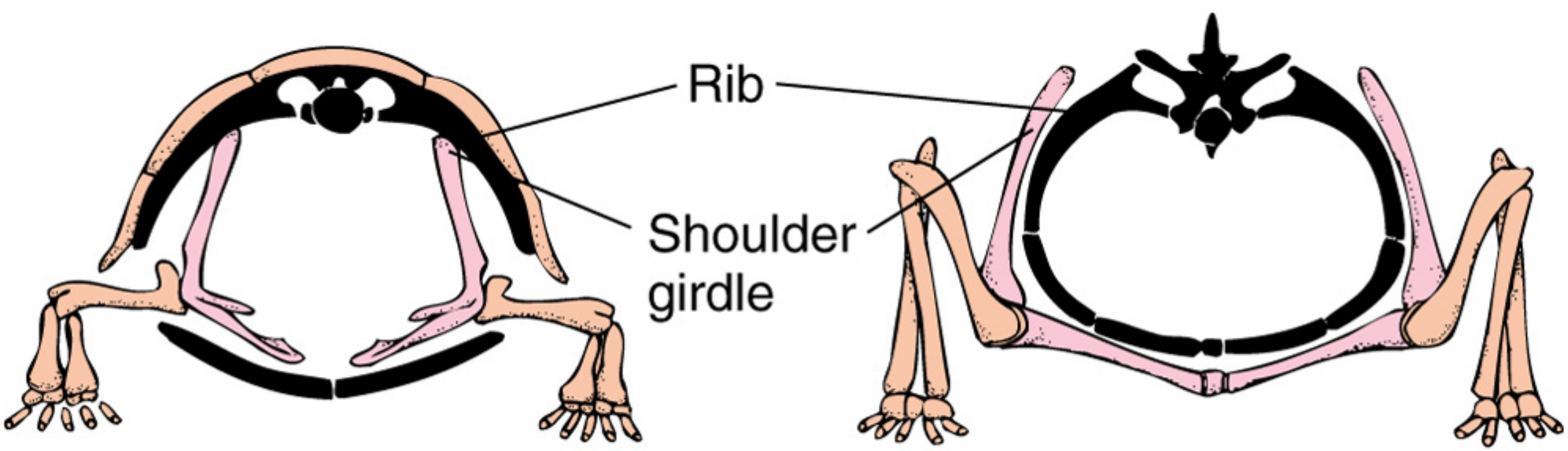
Fusions and reductions in the first few vertebrae produce the distinctive cervical vertebrae



In turtles, the shell into which the limbs and head retreat is a unit made of ribs, vertebrae, and dermal bones of the integument that fuse into a protective bony box that harbors the soft viscera.



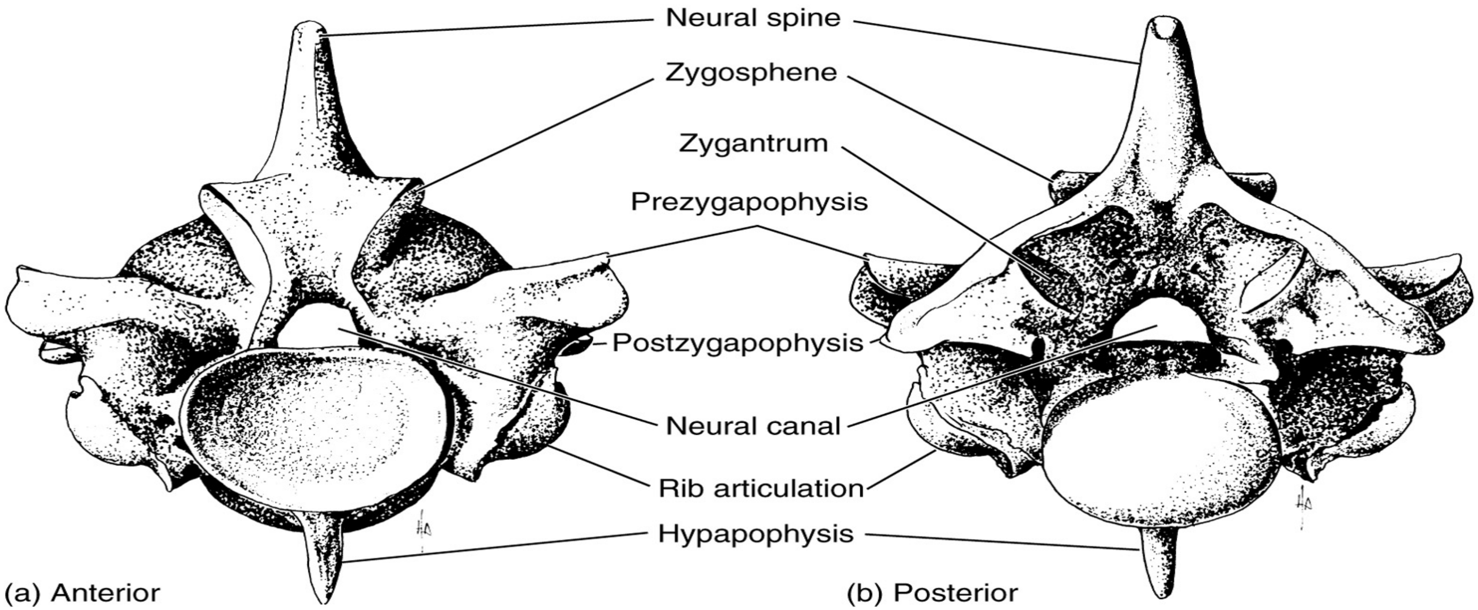
Turtles are unique in that the appendicular skeleton lies *within* the rib cage rather than on the outside as in all other vertebrates



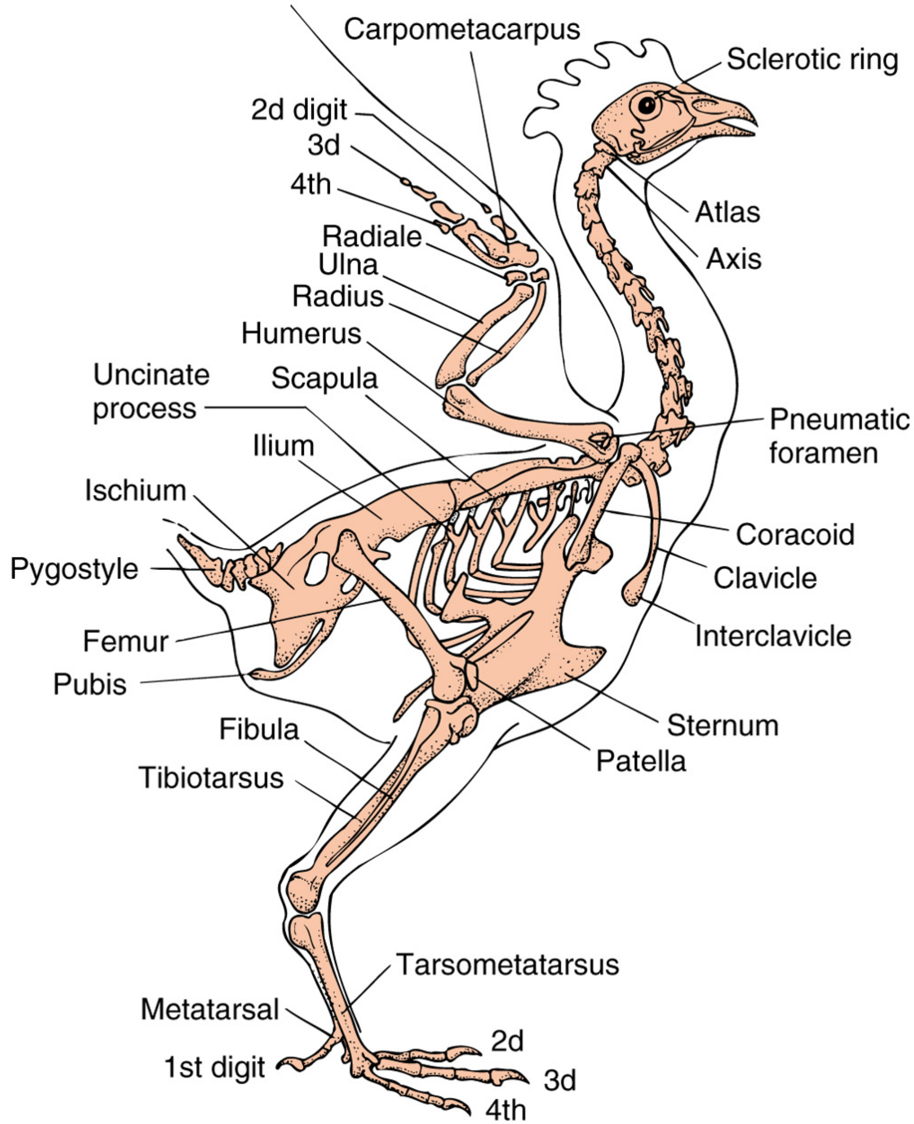
(a) Turtle (b) Alligator

-VC in amniotes is often specialized.

Snakes: additional set of zygapophyses provide additional checks on torsion where twisting forces might be even greater because they are legless



Birds: Numerous cervical vertebrae have highly mobile heterocoelus articulations, giving the skull great freedom of movement

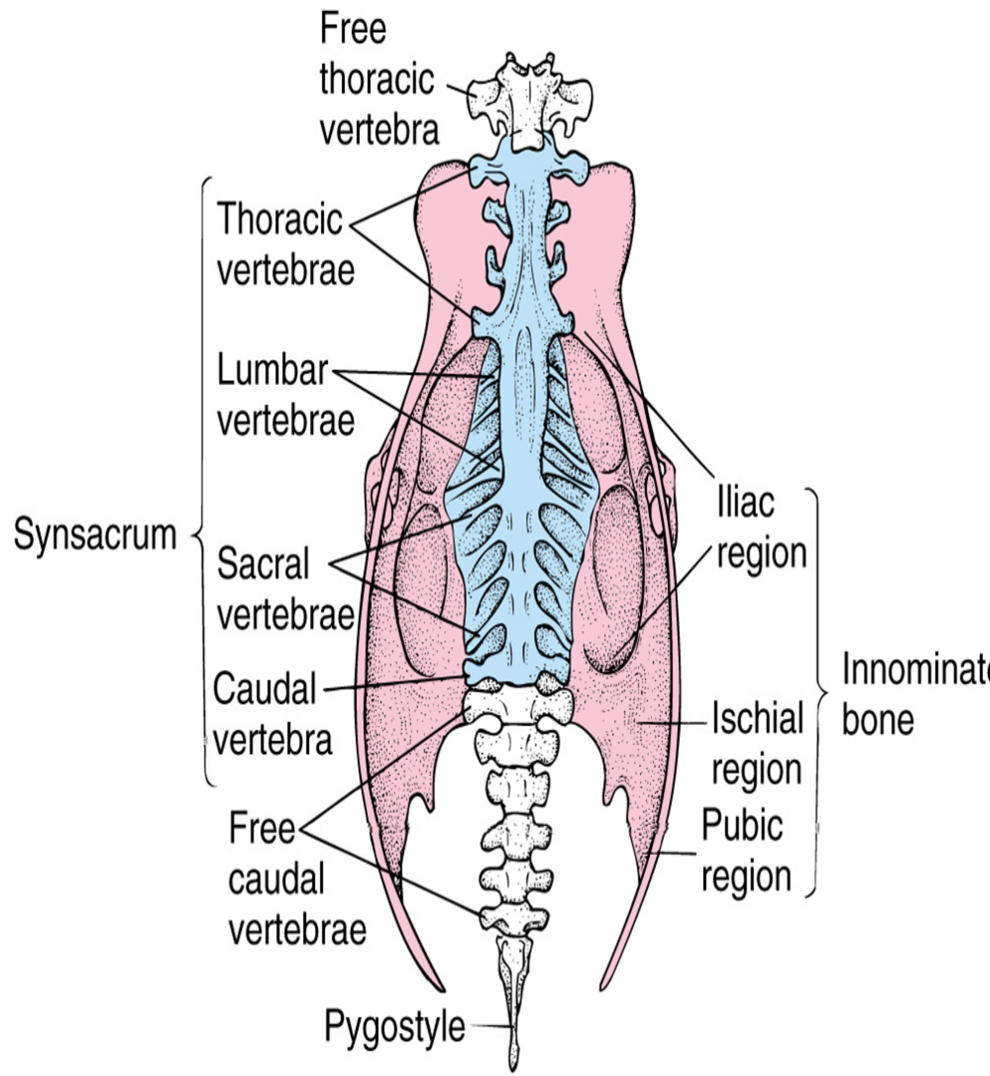


-Posterior thoracic, lumbar, sacral, and occasional caudal fuse into a unit, the **synsacrum**.

-Adjacent bones of the pelvic girdle fuse into the **innominate bone**, which in turn fuses with the synsacrum.

-The union of the pelvic and vertebral bones results in a sturdy but light structure supporting the body during flight.

Birds



Mammals

Differentiated VC into regions:

-cervical vertebrae (7)

-thoracic vertebrae

-lumbar verterbrae

-sacral vertebrae

-caudal vertebra. Less massive than the reptilian tail. Most caudal vertebrae near the end consist of only the centra

Form and Function: Regionalization of the VC

-Fishes: VC is differentiated into two regions, caudal and trunk
Zygapophyses and similar interlocking projections are generally absent
VC is not used to support the body. Support comes from the buoyancy of the water. The VC only offers sites of attachment for the swimming musculature.

-Tetrapods: VC supports the body against gravity and receives and transmits the propulsive forces that limbs generates during locomotion.

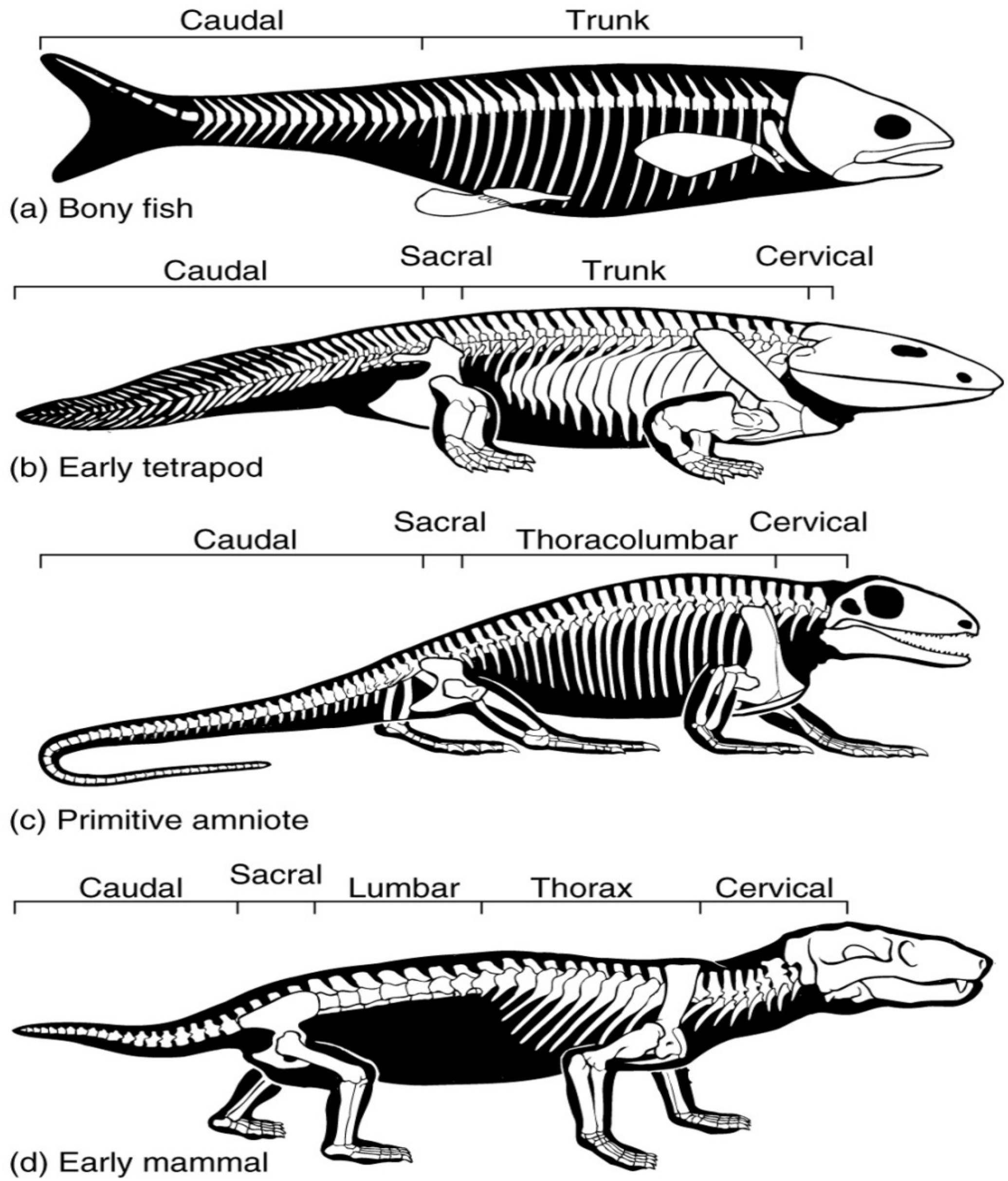
Early tetrapods: caudal, sacral, trunk, and modest cervical regions are delineated. Much of the musculature and axial skeleton still retains similarities to their fish ancestors.

-Amniotes

Primitive amniotes: cervical , dorsal, sacral and caudal regions. Designed to support more existence on land

Mammals:

VC: cervical, thorax, lumbar, sacral, and caudal

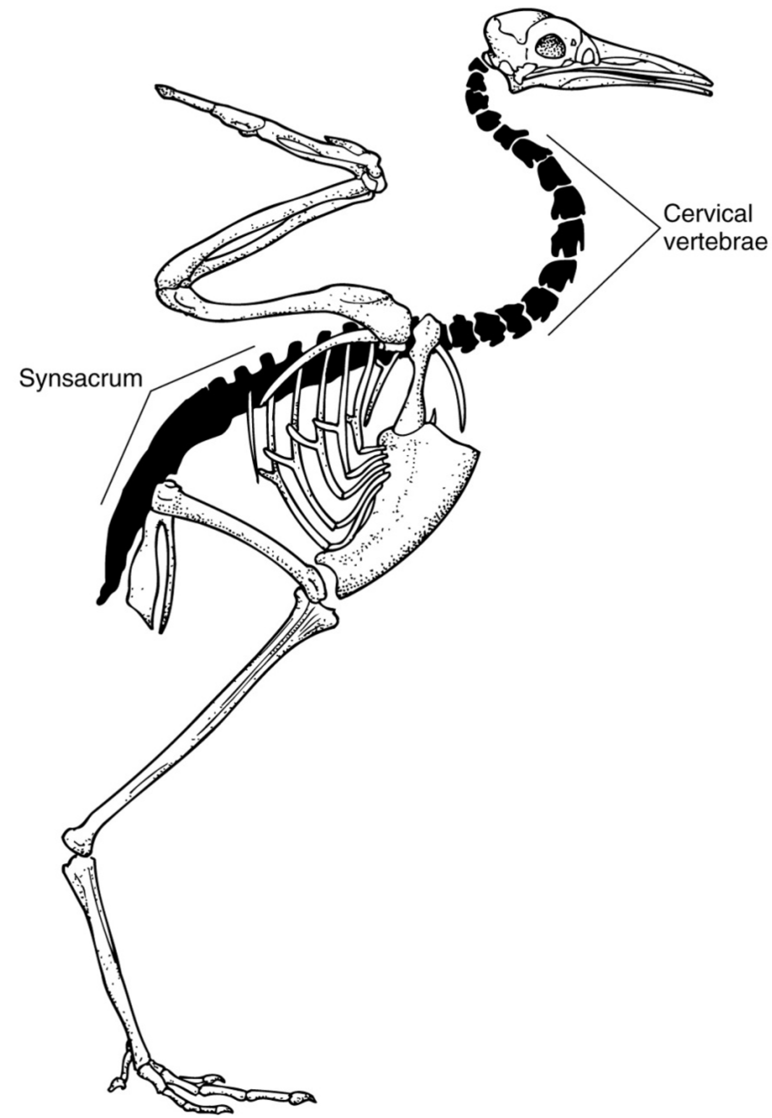

Caudal
Trunk
(a) Bony fish
Caudal
Sacral
Trunk
Cervical
(b) Early tetrapod
Caudal
Sacral
Thoracolumbar
Cervical
(c) Primitive amniote
Caudal
Sacral
Lumbar
Thorax
Cervical
(d) Early mammal

Close match of form and function in birds VC:

-Cerv vert are flexible articulated to give the head great freedom of movement.

-Most middle and posterior vertebrae are fused toe ach other and to the pelvic girdle resulting in rigidity and a stable axis for flight.

-Fusion decreases weight because less muscle is required to control individual vertebrae.



Overview

-Axial skeleton includes: notochord and VC.

-Notochord is a slender rod developed from mesoderm. Composed of a core of fluid cells wrapped in a fibrous shealth.

-Notochord predominates into derived fishes, serving as the major means of locomotion
-Even when replaced by VC, it appears as an embryonic structure

-VC: chains of articulated vertebrae (cartilaginous or bony)

-Each vertebra is composed of a centrum, supports a neural arch and spine, and often associated with processes including ribs.

-Intervertebral bodies or disks occur between successive vertebrae. They resist tension and shear forces

-Ribs protect viscera and contribute to respiratory movements in tetrapods.

-In the buoyancy of water, axial column serves primarly as a compression girdle, resisting telescoping of the body during locomotion and translating axial muscle into lateral swimming undulations.

-In terrestrial environments, the axial column has the function of suspending the weight of the body. The tetrapod VC incorporates anti-twisting features such as the zygopophyses.

-VC is regionalized reflecting functional demands. In fishes: vc is undifferentiated, only trunck and caudal regions and it lacks zygopophyses. In tetrapods, vc is used to support the body proper, limbs provide the propulsive force of locomotion and these forces are transmitted through the vc. A cervical region differentiated in tetrapods for cranial mobility

-In mammals, locomotion based on flexions of the vc vertically is accompanied by the appearance of a distinct lumbar region. Mammals have 5 regions: cervical, thorax, lumbar, sacral, and caudal.

-In birds, locomotion is accompanied by fusion and flexion of vc: fusion of synsacrum with the innominate produces a stable and firm platform while flight; multiple, heterocoelus cv give head flexibility