Lesson 10

◊ **Lesson Outline:**

- ♦ Form and Function of the Axial Skeleton
  - o Regionalization of the Vertebral Column
  - o Bridging
  - o Design of Vertebrae
    - Angle of the Neural Spines
    - Height of Neural Spines
  - o Ribs and their Derivatives
  - o Sternum

◊ **Objectives:**

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

- ♦ Discuss the major design features of vertebrae listing the major forces involved in producing change and the biological significance of the solutions.

◊ **References:**

Chapter 8: 148 - 161

◊ **Reading for Next Lesson:**

Chapter 8: 143 - 161
Chapter 7: 133 - 142

Form and Function

Regionalization of the Vertebral Column

In fishes the vertebral column is differentiated into two regions, the trunk and the tail. The centra are undifferentiated reflecting the fact that the column is not used for support. The only differentiation is whether the vertebrae receive ribs or hemal arches. No movement is possible between the first vertebra and the skull.

In tetrapods, the column supports the body and receives and transmits the forces from the limbs that generate locomotion. Since diverse forces are placed on different parts of the column, not surprisingly we see differentiation of specialized regions.

The first two regions to specialize in early vertebrates are the cervical region allowing some freedom for the head to turn independently of the body, and the sacral region for the attachment of the pelvic girdle and the hindlimbs.

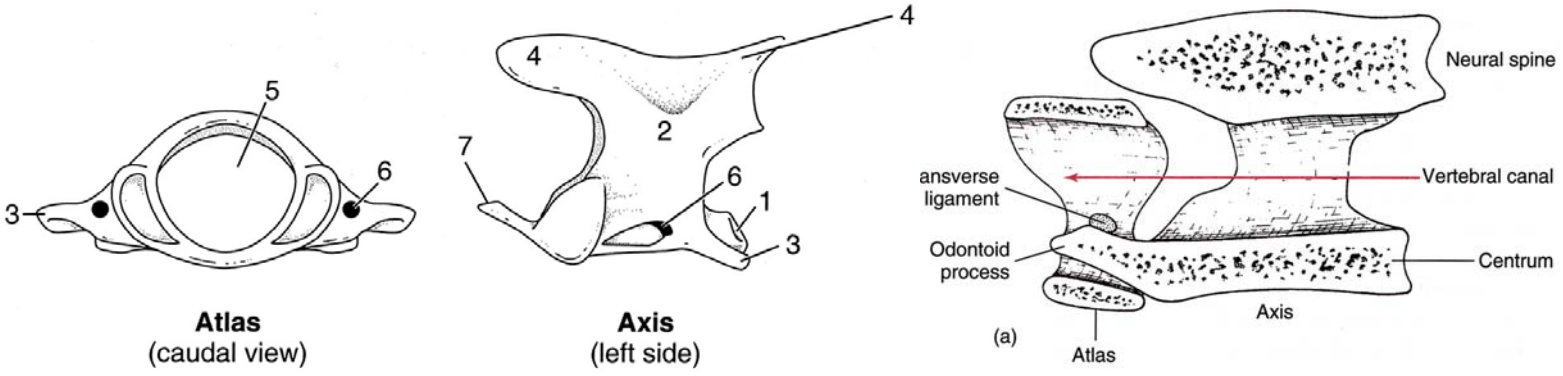
The Cranio-Vertebral Junction

Flexibility between the skull and vertebral column was achieved by development of a more mobile joint, and eliminating ribs in this area.

The first vertebra, or atlas, is highly modified in all vertebrates. It is missing a centrum making it ring-like. It has one or two concavities at the cranial end for articulation with the occipital condyle(s) of the skull. This allows the skull to rock in a nodding motion only.

The second vertebra, the axis, has a cranial extension, the odontoid process which is believed to be the centrum of the atlas. It projects forward and inserts into the floor of the atlas. There is usually a reduction in zygapophyses and ribs on which the skull and atlas rock.

Subsequent cervical vertebrae also have more mobile articulations giving rise to a highly flexible neck, which reaches its greatest in birds and turtles. The combination of 1) the atlas-axis complex, 2) a mobile articulation between cervical vertebrae and 3) a large number of cervical vertebrae -give rise to a very flexible neck.



Atlas
(caudal view)

Axis
(left side)

The Sacrum and Synsacrum

In many vertebrates the sacral vertebrae have become fused into a single sacrum. This increases the strength of the complex to withstand the thrust of the pelvic girdle and hind limbs during locomotion.

In birds, the demands of flight lead to fusions and flexions of different parts of the column. The synsacrum forms (sacrum and adjacent vertebrae fuse with the inominate (ilium, ishium, pelvis) to produce a stable platform while the head and cervical spine are quite flexible to compensate.

In tetrapods, the column supports the body and receives and transmits the forces from the limbs that generate locomotion. Since diverse forces are placed on different parts of the column, not surprisingly we see differentiation of specialized regions.

The trunk region subsequently differentiates into the thoracolumbar region, which ultimately becomes the thorax and lumbar regions. The thorax has ribs and the lumbar region does not.

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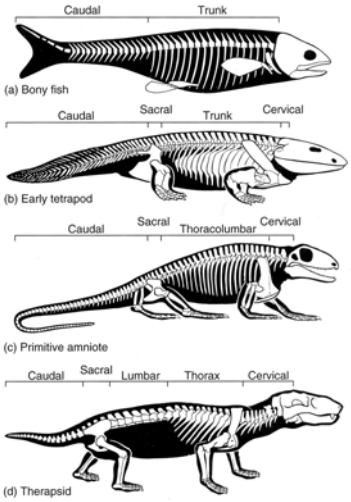
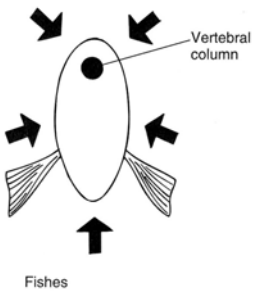


The origin of a separate, ribless lumbar region is believed to reflect increasing speed of locomotion on land. The presacral region is the region that experiences the greatest lateral flexion during terrestrial locomotion in quadrapeds and it is thought that the ribs interfered with rapid movement and thus they were subsequently lost.

Thus, in mammals, there are five distinct regions to the vertebral column, cervical, thoracic, lumbar, sacral and caudal.

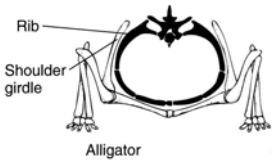
Fluid Environment

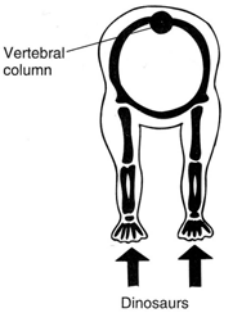
For aquatic organisms, the endoskeleton does not play much of a role in support. Most animals are close to being neutrally buoyant and their weight is supported by the water all around them.



Terrestrial Environment

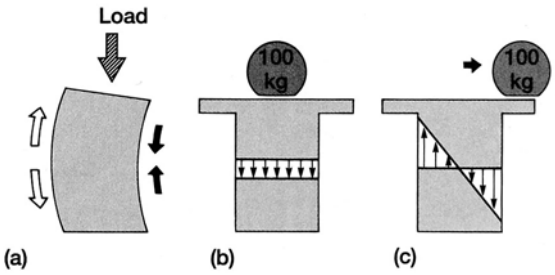
The transition from water to land was accompanied by the mechanical demands placed on the axial skeleton.



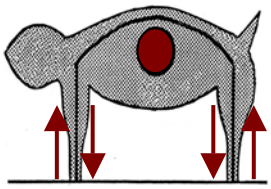


For terrestrial animals, gravity becomes a problem. They must either rest fully on the ground or be supported by legs.

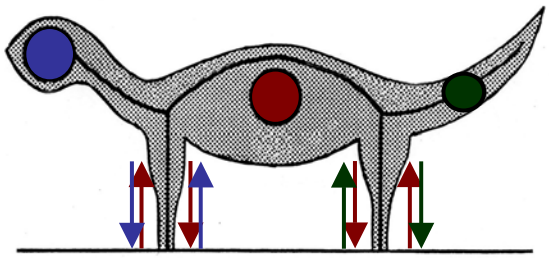
Bridging



Forces acting on pillars: a) When a material bends under a load, compressive forces develop along the concave side and tensile forces along the convex side. b) When the supportive column is loaded symmetrically the only type of force experienced is compressive force. c) Asymmetrical loading of the same mass causes the column to bend. The column experiences compressive forces and tensile forces that are greater near the surface and diminish towards the centre of the column.



Forces acting of the spinal column: Since the weight of the viscera hangs from the vertebral column between the two pair of legs, the load will tend to compress the bones on one side of the legs and stretch the bones on the other side (put them under tension).



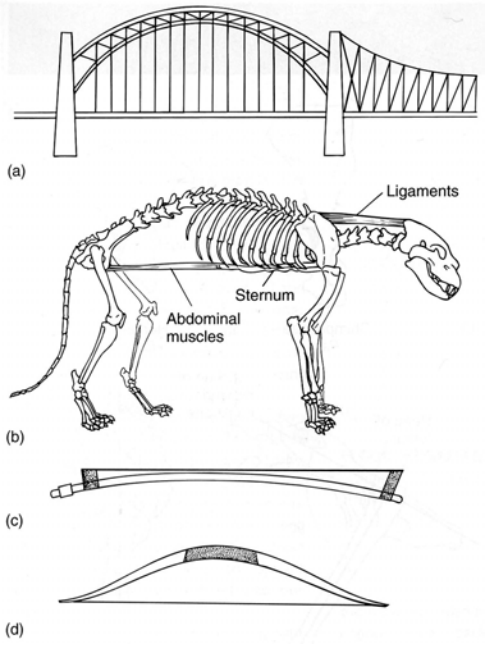
These compressive and tensile forces can be offset if equal, and opposite forces are applied from the other direction. This is a form of cantilevering. In the case of tetrapods, the tail acts as a cantilever at one end and the head at the other.

Note, the vertebral column itself will have forces acting to cause it to bend, placing the column under compression on one side. The ligaments that join the vertebrae together will oppose this tendency by being placed under tension.

In the case illustrated here, the cervical vertebrae are place under compression on the bottom and the ligaments running from the back of the skull down the column oppose this force and are placed under tension (as in the case of the violin bow).

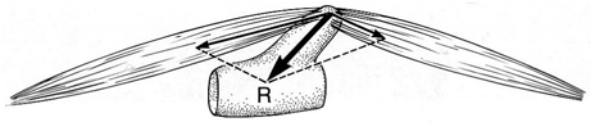
The thoracic and lumbar vertebrae are also placed under compression on the bottom (note the direction of the arc) and the ligaments running from the sternum to the pelvic girdle oppose this force and are placed under tension.

As long as the forces are equal and opposite, the structure is solid and stable.



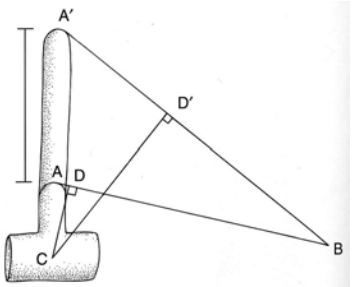
Design of Vertebrae

Angle of the Neural Spines



The angle that the neural spine makes with its centrum usually reflects the forces being placed upon it. The tensile ligaments, and the axial muscles attach to the spines and exert forces on them. Muscles will attach from both the front and the back. The resultant force placed upon the spine will be the net sum of these forces acting from both directions.

The spines are strongest when the net sum produces a force that acts along the spine towards the centrum (it is under compression). Also, bones tend to grow as a result of the forces placed on them. The net result is that the direction of the spine reflects the direction of the resultant force imposed upon it by all axial muscles inserted on it.



The height of the neural spine is proportional to the mechanical leverage the muscles must exert to move or stabilize the spinal column.

To counter increasing forces acting on a neural spine, you could either use larger and larger muscles, or use a longer lever (or both).

(Analogy: try to use a lever to open something and think about how much easier it is to use a longer lever.)

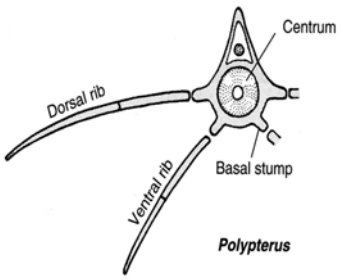
Vertebral designs incorporate modifications to meet mechanical problems. In many animals the height and direction of the spines within the same vertebral column indicate the specialized functions served by different sections of the vertebral column.

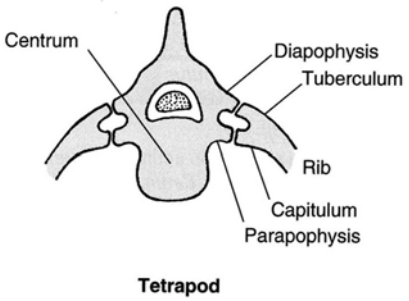
Ribs and their Derivatives

Agnatha have no ribs.

Ribs develop in other vertebrates as struts that can either fuse with the vertebrae or articulate with them (one or two heads). They provide sites for muscle attachment, and form a protective case around the viscera.

In some fishes, there are two sets of ribs with each vertebral segment in the trunk region. The dorsal ribs separate the epaxial and hypaxial musculature of each segment and grow out in the horizontal septum. The ventral ribs form along the lining of the coelomic cavity. They are serially homologous with the hemal arches of the caudal region. In some they only occur in the dorsal position while in others they only occur in the ventral position.



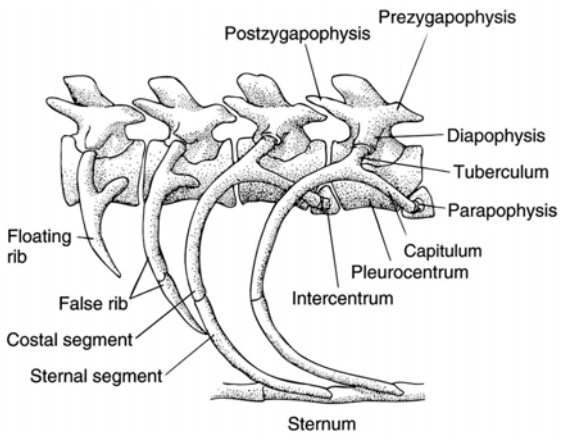


In tetrapods, the ventral ribs are lost and the dorsal ribs persist but take up the position of protecting the body cavity.

While they play a role in locomotion in tetrapods, they become important for producing respiration.

They are bicipital, having two heads, the tuberculum and the capitulum.

In amniotes, in the thorax, the ribs consist of two parts, a costal rib that articulates with the vertebrae, and a sternal rib that often articulates with the sternum. The latter may remain cartilagenous. This combination of vertebrae, costal and sternal ribs and sternum, forms a basket that protects the thoracic viscera.



Sternum

This structure is absent in fish and first appears in tetrapods. It is derived from either the ribs or the pectoral girdle and becomes associated with both.

It has evolved independently several times and confers stability to weight bearing girdle elements.

Its size is a function of the extent to which the forlimbs are used for locomotion. It serves for flight muscle attachment in birds.