Evolution of the Skeleton

Reading Benton Chapter 5

The Vertebrate Archetype (Richard Owen)
Next week

Tuesday (17 Sept): Paper Discussion


Wednesday (18 Sept): No formal lab

You may visit the Zooarchaeology Collection during lab hours. Let Ryan Kennedy know as a courtesy if you plan on going (jonrkenn@umail.iu.edu).

Thursday (19 Sept): No lecture

Tuesday (24 Sept): Midterm I, Project proposal due

- be able to fully label diagrams of dermatocranium and amniote skeleton
- be familiar with terms listed in Lab 1 handout
- be familiar with modern tetrapod groups and their phylogenetic relationships
- be familiar with the Carboniferous Crisis and its relevance to vertebrate evolution (first lecture, see reference by Sahney et al if you want to read more)
- be familiar with the homology and evolution material from today’s lecture
- be familiar with chordate characters and early fossil chordates
Schematic view of two aspects of evolution

Aspect 1: evolutionary change. involves change in a species’ (populations’) average morphology and variation around that mean over time. Results in morphological change.

Aspect 2: speciation. involves splitting of a species from one population into more than one. Results in increased diversity (where diversity means number of species).
Two definitions of species

**Biological species definition:** “Species is a population of interbreeding individuals reproductively isolated from other such populations” (after Mayr, 1942)

- emphasizes the fact that there is variation within species
- emphasizes that the only way for species to become different is when they are reproductively isolated
- emphasizes that speciation requires the breakdown of gene flow for two isolated populations to emerge

**Evolutionary species definition:** “Species is a lineage (ancestor-descendant sequence of populations) evolving separately from others with its own tendencies” (after Simpson, 1961)

- emphasizes role of reproductive isolation in speciation
- emphasizes evolutionary change within a species, separate from speciation itself
- A biological species is essentially one population in the set of ancestor-descendant populations in the evolutionary species
Two definitions of evolution

“Descent with modification”. (after Darwin, 1859)

• recognizes that descendant is a modified form of ancestor
• homologies are modified features inherited from ancestor

“Control of development by ecology”. (after Van Valen, 1974)

• recognizes that the phenotype of an organism is produced by developmental processes that are only partly genetic
• by “ecology” refers to the ability of an organism to function in its environment and in relation to other species with the phenotype it possesses
Two kinds of evolutionary change

Modification of ancestral features

involves the inheritance of homologous structures with modification in their size, shape, position, or function.

Examples: enlargement of openings between existing bones, reduction in the size of bones, incorporation of bones of mandible into bones of middle ear, modification of branchial arches into mandibular and hyoid arches, fusion of metatarsal bones into a single tarsometatarsus

Origin of novel features

involves origin of a new feature that wasn’t present in ancestor.

Examples: origin of new bones in fins or limbs. increase in the number of vertebrae or digits.
Homology and “analogy”

The bones of the forelimbs of pterosaurs, bats, and birds are homologous, shared from their common amniote ancestor (humerus, radius and ulna, carpals, phalanges).

The wing structure is not homologous because it evolved independently in the three groups (wings are termed “analogous”, or non-homologous).
Formal definitions of homology

Corresponding structures in different organisms

[homology is] “the same organ in different animals under every variety of form and function” - Richard Owen, 1843

“a feature in two or more organisms is homologous when it is derived from the same (or corresponding) feature in their common ancestor” - Ernst Mayr, 1982

Homology is a key concept for the interpretation of fossil organisms, for phylogeny reconstruction, and for understanding of mechanisms of evolution

Criteria for homology include similarity of structure and position, the documentation of transitional forms in the fossil record, the study of development (or ontogeny).
Richard Owen and the vertebrate archetype

Owen (1804-1892) was the pre-eminent paleontologist and anatomist in London

Contemporary of Queen Victoria, Charles Darwin, and Thomas Huxley

Described many fossils, including the first *Archaeopteryx* and the fossils Darwin collected in South America

Interested in reconciling the apparent contradictions between functional adaptation and the structural continuity represented by homology

Developed the idea of the vertebrate archetype, a common structural plan from which all vertebrates are derived
Types of homology

**Homology** - the same structure in different organisms under every variety of form and function inherited from the common ancestor of those organisms.

**Serial homology** - repetition of the same structure within an organism, such as vertebrae, ribs, legs in arthropods, gills in fish, etc.

**Deep homology** - similar structures derived from the same underlying patterns of gene expression, even if the structures have different evolutionary origins and losses.

**Primary homology** - a homology recognized based on structural similarity, but whose inheritance from a common ancestor has not been tested by phylogenetic analysis.

**Secondary homology** - a homology whose evolution from a common ancestor has been confirmed by phylogenetic analysis.
Example 1: tetrapod limb

Transformation of early tetrapod limb involves modification of bones, loss of some bones, addition of other bones.

Formation and growth of these bones is regulated by gene expression during development. Changes in the regulation result in evolutionary changes in the adult.

In earliest development, the precursors of the bones are similar in tetrapods and their closest relatives.

Developmental biology (ontogeny) is an important aid to paleontologists for identifying or confirming homologies in radically transformed groups.

Example 2: HOX genes and regionalization

HOX (homeobox) genes control the boundaries of morphological regions.

They are shared by all bilateral organisms, maybe all animals in general.

HOX genes are expressed in different areas of the developing embryo in the same order as they are found on chromosomes.

Expression of these genes create boundaries inside which structures develop differently, such as cervical versus thoracic regions.
Mutation in HOX gene doubles the axis bone (C2)

Figure 9.3  Schematic of a lateral view of a mouse skeleton; anterior to the right. Axial elements are shaded black. Colored lines in back of the elements denote regions patterned by respective Hox genes based on genetic loss of paralogous function experiments. Note the significant regions of phenotypic overlap between adjacent paralogous groups.

Evolution of cervical-dorsal boundary in amniotes
Evidence for shifts in HOX expression
Example 3: vertebral evolution

Developing thoracic vertebra and rib in a dog

Blue = cartilage
Red = bone ossification center

Early vertebral development

Vertebrae are modeled around notochord from somite tissue

Each vertebra develops between somites, receiving tissue from one in front and one behind

Directly related to evolutionary transformations in vertebrae of early tetrapods

Early development of the centrum in the chick (from Patten, 1958. Foundations of Embryology.)
Vertebral evolution in early tetrapods
Lissamphibians retain intercentrum, amniotes retain pleurocentrum
Scientific papers for further reading


