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Notes

Evolution of Vertebrates

The process of evolution

The process of evolution involves a series of natural changes that cause species (populations of different organisms) to arise, adapt to the environment, and become extinct. All species or organisms have originated through the process of biological evolution. In animals that reproduce sexually, including humans, the term species refers to a group whose adult members regularly interbreed, resulting in fertile offspring- that is, offspring themselves capable of reproducing.

Origin of Vertebrates

Early in the Cambrian period, some 530 million years ago, an immense variety of invertebrate animals inhabited Earth's oceans. Predators used sharp claws and mandibles to skewer their prey. Many animals had protective spikes or armour as well as modified mouthparts that enabled their bearers to filter food from the water.

Mylokonungia fengjiao, although lacking armour and appendages, this ancient species was closely related to one of the most successful groups of

animals ever to swim, walk, slither, or fly: the vertebrates, which derive their name from vertebrae, the series of bones that make up the vertebral column, or backbone.

For more than 150 million years, vertebrates were restricted to the oceans, but about 365 million years ago, the evolution of limbs in one lineage of vertebrates set the stage for these vertebrates to colonize land. There they diversified into amphibians, reptiles (including birds), and mammals. Vertebrates are members of the phylum Chordata, the chordates. Chordates are bilaterian (bilaterally symmetrical) animals, and within Bilateria, they belong to the clade of animals known as Deuterostomia. The best known deuterostomes, aside from vertebrates, are the echinoderms, the group that includes sea stars and sea urchins. The cephalochordates and the urochordates are two groups of invertebrate deuterostomes that are more closely related to vertebrates than to other invertebrates. Along with the hagfishes and the vertebrates, they make up the chordates.

Derived Characters of Chordates

All chordates share a set of derived characters, though many species possess some of these traits only during embryonic development. Four key characters of chordates are: a notochord; a dorsal, hollow nerve cord; pharyngeal slits or clefts; and a muscular, post-anal tail.

Notochord

Chordates are named for a skeletal structure, the notochord, present in all chordate embryos as well as in some adult chordates. The notochord is a longitudinal, flexible rod located between the digestive tube and the nerve cord. It is composed of large, fluid-filled cells encased in fairly stiff, fibrous tissue. The notochord provides skeletal support throughout most of the length of a chordate, and in larvae or adults that retain it, it also provides a firm but flexible structure against which muscles can work during swimming.

Dorsal, Hollow Nerve Cord

The nerve cord of a chordate embryo develops from a plate of ectoderm that rolls into a tube located dorsal to the notochord. The resulting dorsal, hollow nerve cord is unique to chordates. Other animal phyla have solid nerve cords, and in most cases they are ventrally located. The nerve cord of a chordate embryo develops into the central nervous system: the brain and spinal cord.

Pharyngeal Slits or Clefts

The digestive tube of chordates extends from the mouth to the anus. The region just posterior to the mouth is the pharynx. In all chordate embryos, a series of pouches separated by grooves forms along the sides of the pharynx. In most chordates, these grooves (known as pharyngeal clefts) develop into slits that open to the outside of the body. These pharyngeal slits allow water entering the mouth to exit the body without passing through the entire digestive tract. Pharyngeal slits function as suspension-feeding devices in many invertebrate chordates.

In vertebrates (with the exception of vertebrates with limbs, the tetrapods), these slits and the structures that support them have been modified for gas exchange and are known as gill slits. In tetrapods, the pharyngeal clefts do not develop into slits. Instead, they play an important role in the development of parts of the ear and other structures in the head and neck.

Muscular, Post-Anal Tail

Chordates have a tail that extends posterior to the anus, although in many species it is greatly reduced during embryonic development. In contrast, most nonchordates have a digestive tract that extends nearly the whole length of the body. The chordate tail contains skeletal elements and muscles, and it helps propel many aquatic species in the water.

Lancelets

The most basal (earliest diverging) group of living chordates are animals called lancelets (Cephalochordata), which get their name from their bladelike shape. As larvae, lancelets develop a notochord, a dorsal, hollow nerve cord, numerous pharyngeal slits, and a post-anal tail.

Tunicates

Contrary to what was formerly thought, recent molecular studies suggest that the tunicates (Urochordata) are more closely related to other chordates than are lancelets. The chordate characters of tunicates are most apparent during their larval stage, which may be as brief as a few minutes.

Early Chordate Evolution

Although lancelets and tunicates are relatively obscure animals, they occupy key positions in the history of life and can provide clues about the evolutionary

origin of vertebrates. Lancelets display key chordate characters as adults, and their lineage branches from the base of the chordate phylogenetic tree. These findings suggest that the ancestral chordate may have looked something like a lancelet—that is, it had an anterior end with a mouth; a notochord; a dorsal, hollow nerved cord; pharyngeal slits; and a post-anal tail.

After the evolution of the basic chordate body plan, that seen in lancelets and tunicate larvae, the next major transition in chordate evolution was the appearance of a head. Chordates with a head are known as craniates (from the word cranium, skull). The origin of a head—consisting of a brain at the anterior end of the dorsal nerve cord, eyes and other sensory organs, and a skull—enabled chordates to coordinate more complex movement and feeding behaviours.

Vertebrate Evolution

The earliest vertebrates were jawless fish, similar to living hagfish. They lived between 500 and 600 million years ago. They had a cranium but no vertebral column. As more data become available, new ideas about vertebrate evolution emerge.

Hagfishes

The most basal group of craniates is Myxini, the hagfishes. Hagfishes have a skull made of cartilage, but they lack jaws and vertebrae. Hagfishes have a small brain, eyes, ears, and a nasal opening that connects with the pharynx. Their mouths contain tooth like formations made of the protein keratin. During the Cambrian period, a lineage of craniates gave rise to vertebrates. With a more complex nervous system and a more elaborate skeleton than those of their ancestors, vertebrates became more efficient at two essential tasks: capturing food and avoiding being eaten.

Lampreys

Lampreys (Petromyzontida) are the most basal lineage of living vertebrates. Like hagfishes, lampreys may offer clues to early chordate evolution.

Fossils of Early Vertebrates

Conodonts were slender, soft-bodied vertebrates with prominent eyes controlled by numerous muscles. Most conodonts were 3–10 cm in length,

although some may have been as long as 30 cm. They probably hunted with the help of their large eyes, impaling prey on a set of barbed hooks at the anterior end of their mouth. These hooks were made of dental tissues that were mineralized—composed of minerals such as calcium that provide rigidity. Conodonts were extremely abundant for over 300 million years. Their fossilized dental elements are so plentiful that they have been used for decades by petroleum geologists as guides to the age of rock layers in which they search for oil. These elements also gave conodonts their name, which means “cone teeth.”

What initiated the process of mineralization in vertebrates?

One hypothesis is that mineralization was associated with a transition in feeding mechanisms. Early chordates probably were suspension feeders, like lancelets, but over time they became larger and were able to ingest larger particles, including some small animals.

The earliest known mineralized structures in vertebrates—conodont dental elements—were an adaptation that may have allowed these animals to become scavengers and predators. In addition, when the bony armor of later jawless vertebrates was examined under the microscope, scientists found that it was composed of small tooth-like structures. These findings suggest that mineralization of the vertebrate body may have begun in the mouth and later was incorporated into protective armour.

Not too long after hagfish first appeared, fish similar to lampreys evolved a partial vertebral column. The first fish with a complete vertebral column evolved about 450 million years ago. These fish also had jaws and may have been similar to living sharks. Up to this point, all early vertebrates had an endoskeleton made of cartilage rather than bone. About 400 million years ago, the first bony fish appeared. A bony skeleton could support a larger body. Early bony fish evolved into modern ray finned and lobe-finned fish.

One of the most significant events in vertebrate history took place about 365 million years ago, when the fins of some lobe-fins evolved into the limbs and feet of tetrapods. Until then, all vertebrates had shared the same basic fishlike anatomy. After tetrapods moved onto land, they took on many new forms, from leaping frogs to flying eagles to bipedal humans.

Derived Characters of Tetrapods

- The most significant character of tetrapods gives the group its name, which means “four feet” in Greek.
- In place of pectoral and pelvic fins, tetrapods have limbs with digits.
- Limbs support a tetrapod’s weight on land, while feet with digits efficiently transmit muscle-generated forces to the ground when it walks.

The Origin of Tetrapods

The Devonian coastal wetlands were home to a wide range of lobe-fins. Those that entered particularly shallow, oxygen-poor water could use their lungs to breathe air.

Some species probably used their stout fins to help them move across logs or the muddy bottom. Thus, the tetrapod body plan did not evolve “out of nowhere” but was simply a modification of a pre-existing body plan. The recent discovery of a fossil called Tiktaalik has provided new details on how this process occurred.

Like a fish, this species had fins, gills, and lungs, and its body was covered in scales. But unlike a fish, Tiktaalik had a full set of ribs that would have helped it breathe air and support its body. Also unlike a fish, Tiktaalik had a neck and shoulders, allowing it to move its head about.

Tiktaalik and other extraordinary fossil discoveries have allowed paleontologists to reconstruct how fins became progressively more limb-like over time, culminating in the appearance of the first tetrapods 365 million years ago. Over the next 60 million years, a great diversity of tetrapods arose.

Judging from the morphology and locations of their fossils, most of these early tetrapods probably remained tied to water, a characteristic they share with some members of a group of living tetrapods called amphibians.

The amniotes are a group of tetrapods whose extant members are the reptiles (including birds) and mammals. During their evolution, amniotes acquired a number of new adaptations to life on land. Amniotes are named for the major derived character of the clade, the amniotic egg. In contrast to the shell-less egg of amphibians, the amniotic eggs of most reptiles and some mammals have a shell.

The shells of bird eggs are calcareous (made of calcium carbonate) and inflexible, while the eggshells of many other reptiles are leathery and flexible. Either kind of shell significantly slows dehydration of the egg in air, an adaptation that helped amniotes to occupy a wider range of terrestrial habitats than amphibians, their closest living relatives.

Reptiles

Fossil evidence indicates that the earliest reptiles lived about 310 million years ago and resembled lizards. Reptiles have diverged greatly since that time, but as a group they share several derived characters that distinguish them from other tetrapods. For example, unlike amphibians, reptiles have scales that contain the protein keratin (as does a human nail). Scales help protect the animal's skin from desiccation and abrasion.

Reptiles freed themselves from aquatic habitats where amphibians had not. Reptiles developed larger and more powerful legs than those of amphibians. The placement of the reptilian legs beneath the body (instead of at the side as with amphibians) enabled them greater mobility. In addition, most reptiles lay their shelled eggs on land.

Evolution of Endothermy & Ectothermy

Until mammals and birds evolved, all vertebrates were ectothermic. Ectothermy means regulating body temperature from the outside through behavioral changes. For example, an ectotherm might stay under a rock in the shade in order to keep cool on a hot, sunny day. Almost all living fish, amphibians, and reptiles are ectothermic. Their metabolic rate and level of activity depend mainly on the outside temperature.

They can raise or lower their own temperature only slightly through behavior alone. Both mammals and birds evolved endothermy. Endothermy means regulating body temperature from the inside through metabolic or other physical changes. On a cold day, for example, an endotherm may produce more heat by raising its metabolic rate.

On a hot day, it may give off more heat by increasing blood flow to the surface of the body. Keeping body temperature stable allows cells to function at peak efficiency at all times. The metabolic rate and activity level can also remain high regardless of the outside temperature. On the other hand, maintaining a stable body temperature requires more energy—and more food.

Birds

Sometime during the early Jurassic period, two groups of reptiles gained the ability to fly; one of these groups later gave rise to the birds, almost every feature of their anatomy has been modified in their adaptation to flight.

Derived Characters of Birds

- Many of the characters of birds are adaptations that facilitate flight, including weight-saving modifications that make flying more efficient.
- For example, birds lack a urinary bladder, and the females of most species have only one ovary.
- Living birds are also toothless, an adaptation that trims the weight of the head. A bird's most obvious adaptations for flight are its wings and feathers.
- Feathers are made of the protein β -keratin, which is also found in the scales of other reptiles.
- Flight provides numerous benefits. It enhances hunting and scavenging; many birds consume flying insects, an abundant, highly nutritious food resource.
- Flight also provides ready escape from earthbound predators and enables some birds to migrate great distances to exploit different food resources and seasonal breeding areas.

The Origin of Birds Cladistic analyses of birds and reptilian fossils indicate that birds belong to the group of bipedal saurischian dinosaurs called theropods. Since the late 1990s, Chinese paleontologists have unearthed a spectacular trove of feathered theropod fossils that are shedding light on the origin of birds.

Several species of dinosaurs closely related to birds had feathers with vanes, and a wider range of species had filamentous feathers. Such findings imply that feathers evolved long before powered flight. Among the possible functions of these early feathers were insulation, camouflage, and courtship display.

How did flight evolve in the theropods?

1. In one scenario, feathers may have enabled small, running dinosaurs chasing prey or escaping predators to gain extra lift as they jumped into the air.

2. Or small dinosaurs could have gained traction as they ran up hills by flapping their feathered forelimbs—a behavior seen in some birds today.

3. In a third scenario, some dinosaurs could have climbed trees and glided, aided by feathers.

By 150 million years ago, feathered theropods had evolved into birds. Archaeopteryx, which was discovered in a German limestone quarry in 1861, remains the earliest known bird. It had feathered wings but retained ancestral characters such as teeth, clawed digits in its wings, and a long tail. Archaeopteryx flew well at high speeds, but unlike a present-day bird, it could not take off from a standing position.

Fossils of later birds from the Cretaceous show a gradual loss of certain ancestral dinosaur features, such as teeth and clawed forelimbs, as well as the acquisition of innovations found in extant birds, including a short tail covered by a fan of feathers. During the course of avian evolution their beaks have taken on a variety of shapes suited to different diets.

Mammals

Mammals are amniotes that have hair and produce milk. The reptiles we have been discussing represent one of the two living lineages of amniotes. The other amniote lineage is our own, the mammals (class Mammalia). Today, there are more than 5,300 known species of mammals on Earth.

Derived Characters of Mammals

- The distinctive character from which mammals derive their name is their mammary glands, which produce milk for offspring.
- Hair, another mammalian characteristic, and a fat layer under the skin help the body retain heat. Like birds, mammals are endothermic, and most have a high metabolic rate.
- Like birds, mammals generally have a larger brain than other vertebrates of equivalent size, and many species are capable learners.
- Differentiated teeth are another important mammalian trait. Whereas the teeth of reptiles are generally uniform in size and shape, the jaws of mammals bear a variety of teeth with sizes and shapes adapted for chewing many kinds of foods.
- Humans, like most mammals, have teeth modified for shearing (incisors and canine teeth) and for crushing and grinding (premolars and molars).

During the Jurassic (200–145 million years ago), the first true mammals arose and diversified into many short-lived lineages. A diverse set of mammal species coexisted with dinosaurs in Jurassic and Cretaceous periods, but these species were not abundant or dominant members of their community, and most measured less than 1m.