Lesson 5: Birth, Growth, and Reproduction

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Learning objective for lesson 5: Students will learn a generalized life history of a dinosaur, from birth through adulthood, including reproduction, and will be able to describe major techniques used to evaluate growth stages and growth rates in dinosaurs

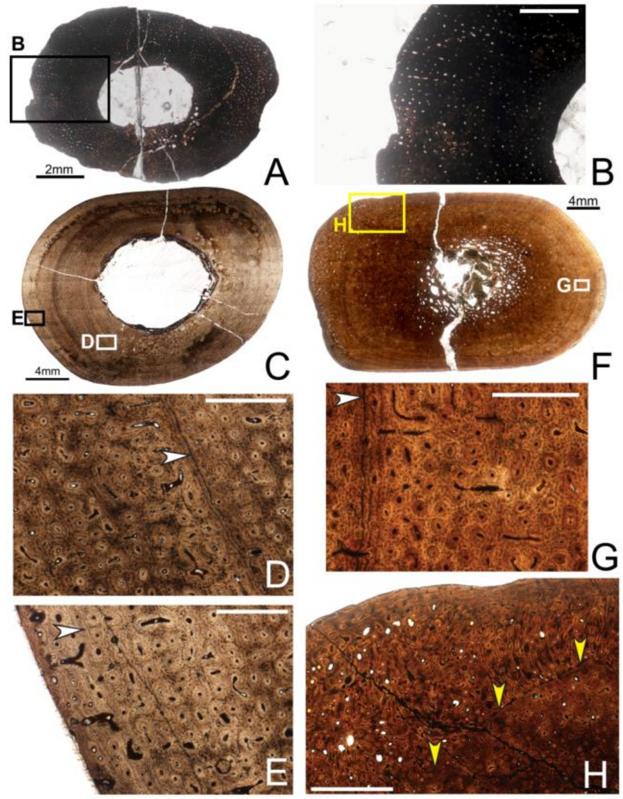
Learning objective 5.1: Describe the characteristics of a dinosaur egg.

A little over 312 million years ago (long before the evolution of dinosaurs or mammals), a major milestone in tetrapod evolution was reached: the **amniotic egg**. Prior to this adaptation, all tetropods laid eggs that were similar to those of modern frogs and salamanders and could not retain water. Such eggs would dry out and die if not laid in a wet, humid place. Amniotic eggs are different. They have encapsulating membranes that are watertight. Animals that lay amniotic eggs are called **amniotes**. Being able to hold in their own water, amniotic eggs can be laid in dry habitats. This allowed amniotes to colonize new terrestrial environments. The membranes of amniotic eggs also became adapted to form tough leathery or hard shells. Shells improved amniotic eggs' ability to hold in water and also made the eggs more durable and less vulnerable to small predators. Mammals, birds, dinosaurs, and reptiles are all amniotes. Although most extant mammals do not lay eggs, mammalian embryos still have membranes that cover them while in the uterus.

Although amniotic eggs are watertight, they are not airtight. If they were, the eggs would suffocate. As the living cells inside an egg grow and develop, they consume oxygen and produce carbon dioxide waste (just as all animal cells do). This carbon dioxide waste needs to go somewhere, and fresh oxygen needs to be constantly supplied. Even hard eggshells are covered with tiny holes that permit gasses to be exchanged between the inside of the egg and the outside world. This need to breath places a limit on how big eggs can be.

Recall the cube-square law -- as any shape increases in size, its surface area increases more slowly than its volume. Although truly enormous dinosaur eggs are often depicted in cartoons and poorly-researched science fiction, the largest known dinosaur egg is only half a meter long and most are much smaller. Eggs that are much larger than this are not possible, because the amount of oxygen that a dinosaur developing inside an egg requires is a function of its volume, while the rate at which oxygen can be exchanged is a function of the eggshell's surface area. Giant eggs would have a low ratio of surface area to volume and would die.

Learning objective 5.2: Define terms related to the gross anatomy and histology of bones.

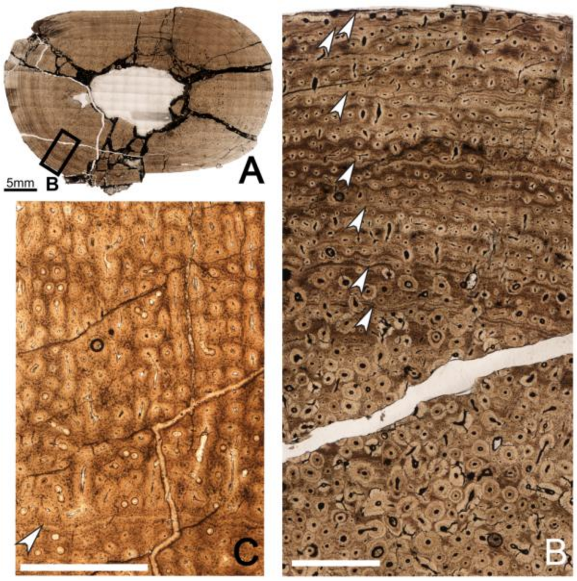


Cross-sections through the ulnae of different individuals of the iguanodontian ornithopod *Tenontosaurus*. A and B are cross sections through a juvenile's ulna, and have lots of holes representing blood vessels. C-H are from subadults. You can see the dark circular LAGs in C, and an arrow points to a LAG in D. Figure 3 in Werning S (2012). The ontogenetic osteohistology of *Tenontosaurus tilletti*. PLOS ONE 7:e33539.

Hatching from relatively small eggs meant that baby dinosaurs had a lot of growing up to do. Bone histology has helped paleontologists to better understand dinosaur growth rates. Recall that bone cells are called osteons. As animals grow their bones, they add osteons to their bones' outer walls. But the rate at which osteons are added is not always the same and varies with changes in growth rates. During seasonal periods, when resources needed for growth are scares, such as during winter or the dry season, growth may slow down. This creates rings inside the bones, analogous to those of a tree trunk. These rings are called **lines of arrested growth**, or **LAGs** for short. By studying LAGs in young and old dinosaurs, we can determine how long it took a dinosaur to grow to a particular size and at what speed a dinosaur grew. It turns out that dinosaurs grew fast. It is estimated that a *Tyrannosaurs rex* grew to its adult size in only 20 years. Even large sauropods only took 30 years to fully mature, and they are estimated to have gained an average of one to two pounds every day!

The bones of younger dinosaurs are characterized by having **high vascularity** (many blood vessels) and a texture we call **lamellar bone**. LAGs formed later, as dinosaurs grew.

More mature dinosaur bone then underwent a process called **remodeling**, where the old bone cells were replaced by newer bone cells. This kind of bone is called **Haversian**, or **secondary bone**, and a picture of Haversian bone texture is in the study guide for lesson 3. Finally, as growth slows and then finally stops, a closely spaced series of LAGs is formed, which is called the **external fundamental system (EFS)**. The presence of an EFS indicates that the dinosaur is skeletally mature and has stopped growing.



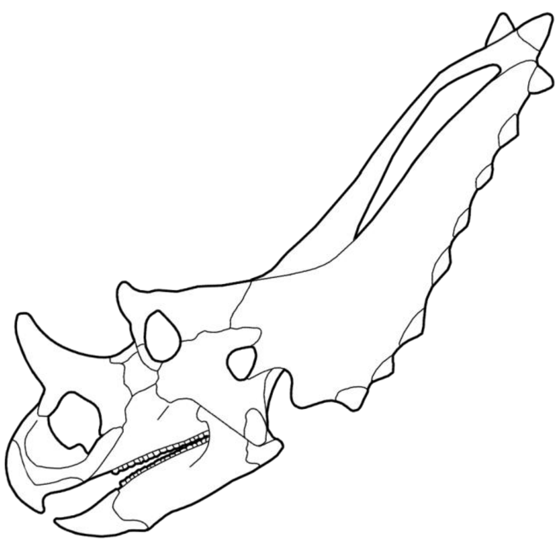
Cross sections through the ulna of two adult *Tenontosaurus*, showing remodeled bone. Many LAGs are visible in A. In B, the LAGs get closer and closer together, towards the top, indicating that growth is slowly in this dinosaur and an EFS is forming Figure 4 in Werning S (2012). The ontogenetic osteohistology of *Tenontosaurus tilletti*. PLOS ONE 7:e33539.

Learning objective 5.3: Evaluate the evidence for identifying individual dinosaurs as juveniles or adults.

Some newborn or newly hatched animals look like tiny versions of their parents, and others look different in a few particular ways. For instance, new born human babies have heads that are large relative to the overall size of their bodies and eyes that are large relative to the overall size of their heads. As humans grow up, the relative proportions of our bodies, heads, and eyes gradually approach those of their parents. Changes in the form of an organism that occur as it matures are called ontogenetic changes.

Big heads and big eyes are common traits of young animals. Baby dinosaurs also had relatively large heads and eyes. Some dinosaur ontogenetic changes were more dramatic. For instance, the crests of many hadrosaurs were not present in very young individuals, but grew gradually as the dinosaurs reached maturity. Some ontogenetic changes involve the growth of entirely new structures. It seems that many baby ankylosaurs hatched with little or no armor and with no tail cubs. Ankylosaur body armor and tail clubs did not grow until later in life.

Changes in the relative proportions of an animal as it grows, that are not simply changes resulting from a general increase in size, are called **non-isometric** ontogenetic changes. The changes in the relative lengths of the horns and frills of ceratopsians are examples of non-isometric changes. Take a look at the skull of "Baby" the *Chasmosaurus*, and compare it to the skull of a fully-grown *Chasmosaurus*. The frill on the adult *Chasmosaurus* is proportionately much longer compared to the juvenile. The frill in *Chasmosaurus* grows at a faster rate than the rest of the skull, resulting in a longer frill in the adult. If the frill grew at the same rate as the rest of the skull, then the proportions would be the same in juveniles and adults. "Baby" also lacks a nasal horn, which is present in the adult, which shows that the nasal horn only appears later during growth.



Above: The skull of "Baby" the *Chasmosaurus* alongside the jaw of an adult ceratopsian. This little *Chasmosaurus* still had a lot of growing to do! Photo by J. Ulan.

Left: The skull of an adult *Chasmosaurus*. Note how much longer the frill is relative to overall skull size. Illustration by S. Hartman.

Another example can be seen in the legs of dinosaurs like *Tyrannosaurus*, where the tibia was much longer than the femur in juveniles, while in adults the tibia and femur were close to the same length. **Isometric** ontogenetic changes are changes in absolute size but not proportions. For instance, unlike in *Tyrannosaurus*, the length of ceratopsian hind legs changed proportionally as the animal grew. That is, the length of the tibia relative to the length of the femur of a baby ceratopsian was nearly the same as the length of the tibia relative to the length of the femur of a full-grown adult.

Learning objective 5.4: Evaluate the evidence for determining whether or not a dinosaur was male or female.

Males and females of the same species are different – this is called **sexual dimorphism**. Sexually dimorphic features of the skeleton are usually subtle but can be extreme. Consider the massive antlers of a bull moose, which are entirely absent on females. As with the antlers of moose, it is common for sexually dimorphic features to be ontogenetic changes (after all, an animal usually does not reproduce immediately after it is born or hatches). Sexual dimorphism is difficult to identify in dinosaurs. For example, some palaeontologists have suggested that the ceratopsian Protoceratops was sexually dimorphic, because some specimens have wider frills than others even though their heads and bodies are about the same size. However, it is hard to be certain that the wider-frilled Protoceratops are not simply older individuals, or that they represent a different species (a problem we will come back to in lesson 7), and not all palaeontologists agree with the sexual dimorphism interpretation. Another example is the ancient bird *Confuciusornis;* some specimens possessed extra-long tail feathers.

Sometimes, adult dinosaur bones are associated with nests and eggs. If a dinosaur skeleton was found with eggs preserved inside its body cavity, this would probably be pretty good evidence that the dinosaur was a female. However, we would have to rule out that the eggs are there because of other reasons – perhaps the dinosaur had eaten them, or they had washed in after death and the association is just a coincidence.

In some very rare and spectacular cases, dinosaurs have been fossilized while sitting on, ('brooding' or incubating) a nest of eggs. We often think that female birds do all of the brooding, but in fact many male birds spend a lot of time looking after eggs, and so a dinosaur sitting on a nest of eggs could be a male or a female.

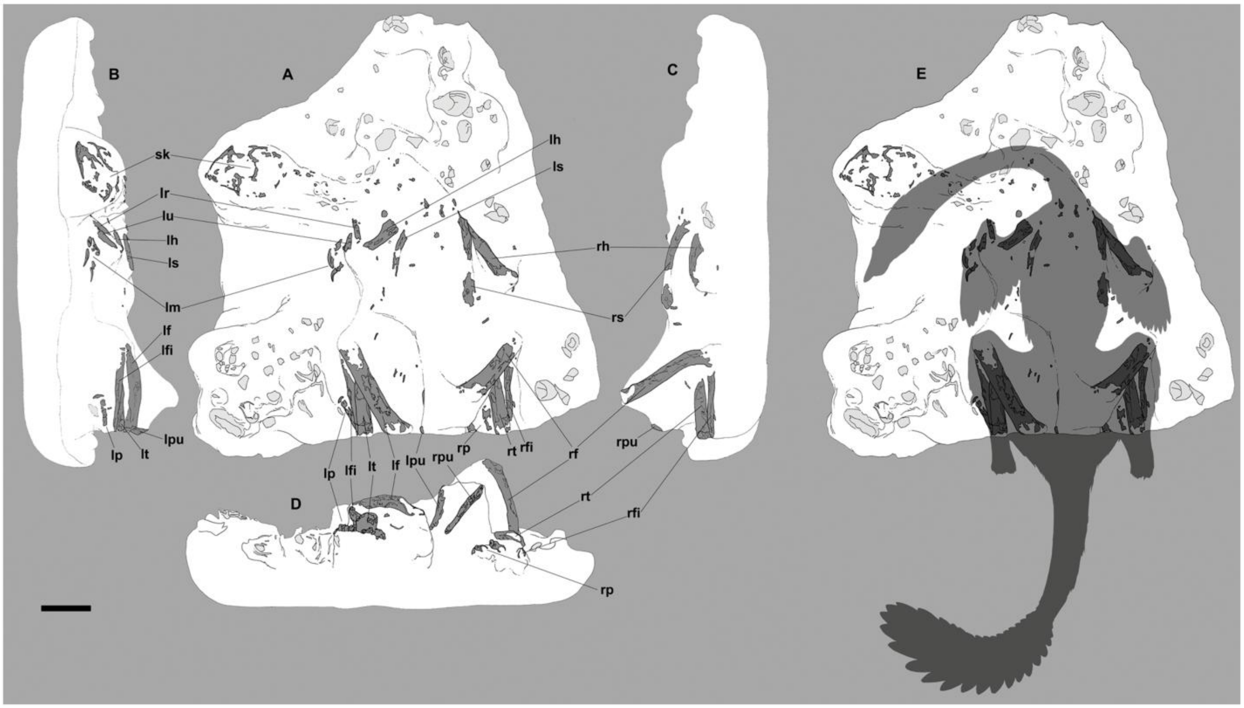
A recent new approach seems to have solved the problem of identifying a dinosaur's sex, at least for some specimens. Laying eggs with hard shells requires a female to donate a large quantity of calcium. In preparation for this donation, female birds grow medullary bone. **Medullary bone** contains concentrations of calcium that are stored prior to eggshell development. Studies of bone histology work can identify medullary bone, and, because only female birds produce eggs, the presence of medullary bone shows that a particular specimen is a female. The application of this technique is limited, because medullary bone is only grown by females prior to egg production and is not present at other times. Theropod bones without medullary bone therefore could be from a male, or from a female that was not getting ready to lay eggs.

Learning objective 5.5: Evaluate the evidence for or against parental care in different groups of dinosaurs.

Were dinosaurs devoted parents that spent large amounts of time and energy caring for their young, or did they simply lay their eggs and leave their offspring to fend for themselves? Understanding dinosaur parental care is hard, because fossil evidence usually provides few clues about an animal's family values. As the closest living relatives of dinosaurs, modern birds and crocodilians may offer some insights. Many birds, not only care for their eggs but also feed and protect their young after they hatch. Crocodilians also tend to be good parents. Female crocodiles guard their nests and, although they do not provide their hatchlings with food, also protect their young for an extended period of time after they hatch.

Skeletons have been found of oviraptorosaurs (a kind of herbivorous theropod) positioned over top of their egg-filled nests. It appears that these dinosaurs were fossilized in the processes of incubating their eggs and it seems likely that they were also guarding their nests. Often, the skeletons of young dinosaurs are found alongside the skeletons of adult dinosaurs, and this suggests that these dinosaurs lived together as a family group. So, many dinosaurs do appear to have devoted considerable time and effort to parental care.

In this scene, representing the fossil finds at Devil's Coulee in southern Alberta, *Hypacrosaurus* tend their hatchlings in shallow nests and protect them from marauding *Troodon*. Hadrosaurs hatched with flat heads and did not develop crests until they became much larger. By Jan Sovak



This specimen of the oviraptorosaur *Nemegtomaia* was found sitting on top of its nest of eggs! From Fanti F, Currie PJ, Badamgarav D. 2012. New specimens of *Nemegtomaia* from the Baruungoyot and Nemegt Formations (Late Cretaceous) of Mongolia. PLOS ONE 7:e31330.

However, other lines of evidence indicate that some dinosaurs had adaptations that allowed them to avoid parental care completely. Return to our thinking about the cube-square law and the limitation that it imposes on the potential size of dinosaur eggs. Now, recall that sauropods include the largest of all dinosaurs. Some giant sauropods weighed more than ten adult elephants but laid eggs no bigger than a basketball. Although mother sauropods could not lay big eggs, they were able to lay a great many eggs. Fossil nests of sauropods from Argentina show that herds of sauropods also laid their eggs all at the same time and at the same place. These mass sauropod nesting grounds have the individual nests too close together for a mother sauropod to have attended to her eggs without stepping on the nest of a neighbor. It seems likely that sauropods were using a strategy called **predator satiation**. To produce a new generation of sauropods, only a tiny fraction of the eggs that were laid needed to hatch and grow into adults. Rather than investing time into guarding and rearing their young. Sauropods simply produced so many offspring at one time that predators would not have been able to eat them all before they matured. This same strategy is used by many modern sea turtles.

Supplementary Materials.

Males and females, eggs, and nests:
Laelaps: Secret of the dinosaur sexes locked in bone. [Blog post]

Schweitzer MH, Wittmeyer JL, Horner JR. 2005. Gender-specific reproductive tissue in ratites and *Tyrannosaurus rex*. Science 308:1456-1460. [PDF of peer-reviewed paper]

Dinosaur Tracking: Baby dinosaur mystery. [Blog post]

National Geographic Daily News: Oldest dinosaur nests found in South Africa. [Image slideshow with captions]

Ontogeny:
Dinosaur Tracking: How domed dinosaurs grew up. [Blog post]

Dinosaur Tracking: Tiny *Tarbosaurus* shows how tyrants grew up. [Blog post]

Dinosaur Tracking: The *Torosaurus* identity crisis continues. [Blog post]

Laelaps - Getting to know Joe, an adorable little dinosaur [Blog post]

This website about Joe is also a really good resource. The section "Joe's Life" is the only required reading but you may find the other sections helpful as well.

Reproduction and parental care:
Tetrapod Zoology: Dinosaurs and their 'exaggerated structures': species recognition aids, or sexual display devices? [Blog post]

Tetrapod Zoology: Teenage pregnancy in Mesozoic dinosaurs. [Blog post]

ARKive: Ostrich parental care [Video]

ARKive: Nile crocodile parental care [Video]