Fact sheet for dinosaur brain cooling story

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Porter, W. R., and L. M. Witmer. 2019. Vascular patterns in the heads of dinosaurs: evidence for blood vessels, sites of thermal exchange, and their role in physiological thermoregulatory strategies. *Anatomical Record*

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Website with downloadable resources

https://people.ohio.edu/witmerl/dinosaur_brain-cooling_strategies.htm

Common Language Summary

Keeping a cool head – Different dinosaurs evolved different cooling strategies. For more than a decade, a team of Ohio University researchers has been studying how large-bodied dinosaurs survived potentially fatal overheating. New research from this team, drawing on advanced imaging techniques and sophisticated quantitative analyses, has discovered evidence of often vast networks of blood vessels in the skulls of dinosaurs that were likely used to cool blood destined for the brain. It turns out that different groups of large dinosaurs emphasized different sites of evaporative cooling in the head. For example, armored ankylosaurs like *Euoplocephalus* used the nasal cavity as an air conditioner, whereas long-necked sauropods like *Diplodocus* and *Camarasaurus* also used the mouth to cool blood, probably through panting. The predatory theropod dinosaurs, such as *T. rex* and *Majungasaurus*, however, evolved a very different brain-cooling strategy, involving a highly vascular air sinus in the snout through which air was pumped by movements of the jaws. The famously huge body sizes of different dinosaur groups evolved independently from smaller-bodied ancestors. Thus, the picture that emerges is that different gigantic dinosaurs solved the problem of overheating in different ways by using different sites of evaporative cooling and different sets of blood vessels. The researchers are now exploring similar kinds of thermal physiological strategies to control brain temperatures in other groups of large dinosaurs such as horned ceratopsians like *Triceratops* and duck-billed hadrosaurs. This research was funded by grants from the National Science Foundation.

Main dinosaur species studied:

- *Diplodocus* (dih-PLAA-duh-kuhs): Sauropod dinosaur, quadrupedal herbivore, Late Jurassic (~150 million years ago), found in Utah & elsewhere, 80 feet long, 15 tons
- *Camarasaurus* (kuh-MARE-uh-SAWR-us): Sauropod dinosaur, quadrupedal herbivore, Late Jurassic (~150 million years ago), found in Utah & elsewhere, 60 feet long, 35 tons
- *Euoplocephalus* (YOU-oh-plo-SEF-alus): Ankylosaurian dinosaur, quadrupedal herbivore, Late Cretaceous (~75 million years ago), found in Alberta, Canada, 16 feet long, 4 tons
- *Stegoceras* (steg-OSS-er-us): Pachycephalosaurian dinosaur, bipedal herbivore, Late Cretaceous (~75 million years ago), found in Alberta, Canada, 6 feet long, 90 tons

- *Tyrannosaurus rex* (tie-RAN-oh-SAWR-us): Theropod dinosaur, bipedal carnivore, Late Cretaceous (~66 million years ago), found in Montana & elsewhere, 40 feet long, 13 tons
- *Majungasaurus* (mah-JUN-gah-SAWR-us): Theropod dinosaur, bipedal carnivore, Late Cretaceous (~68 million years ago), found in Madagascar, 20 feet long, 2.4 tons
- *Allosaurus* (AL-oh-SAWR-us): Theropod dinosaur, bipedal carnivore, Late Jurassic (~150 million years ago), found in Utah & elsewhere, 30 feet long, 2 tons

Major points:

a. Main problem addressed by the research: Large-bodied dinosaurs like sauropods, ankylosaurs, and large theropods like *T. rex* would have had very hot bodies because of (1) their low surface area compared to their huge volume and (2) the warm climates in which they lived. For comparison, a large pot of soup takes a long time to cool, whereas it seems your cup of coffee gets cold as soon as you turn your back on it. These dinosaurs were very large pots of soup! Hot blood from the body core would flow to the brain, potentially damaging the sensitive neural tissue. This new research discovered that these dinosaurs had physiological mechanisms that could allow the large bodies of big dinosaurs to be hot without causing heatstroke.

b. The researchers focused on known sites of cooling in the heads of modern-day relatives of dinosaurs (birds, crocodilians, lizards) where evaporation of moisture from the nose, mouth, and eyes cools blood destined for the brain region. The blood vessels in the modern-day animals were studied in deceased specimens that were injected with substances that allowed the blood vessels to be seen in microCT scans and dissected.

c. The bony canals and grooves created by the blood vessels were studied and measured in the microCT scans of the modern-day animals. These same bony canals and grooves were found in the dinosaurs, allowing their patterns of blood flow to be reconstructed in 3D.

d. Sophisticated statistical analyses showed that small-bodied species of modern-day animals—which have less of a problem with overheating—have relatively balanced patterns of blood flow and didn't particularly emphasize any of the known cooling sites (nose, mouth, or eyes). Small-bodied dinosaurs like *Stegoceras* showed similar patterns.

e. Large-bodied dinosaurs, however, which had major problems with overheating, tended to increase blood flow to one or more—but never all—cooling regions. The statistical analyses showed that they increased blood flow beyond what was necessary simply to nourish the tissues, suggesting that these were site of heat exchange.

f. Not all of the gigantic dinosaurs emphasized the same cooling regions. Ankylosaurs like *Euoplocephalus* primarily used the nose as a cooling region whereas sauropods like *Diplodocus* and *Camarasaurus* also used the mouth along with the nasal region to cool blood destined for the brain.

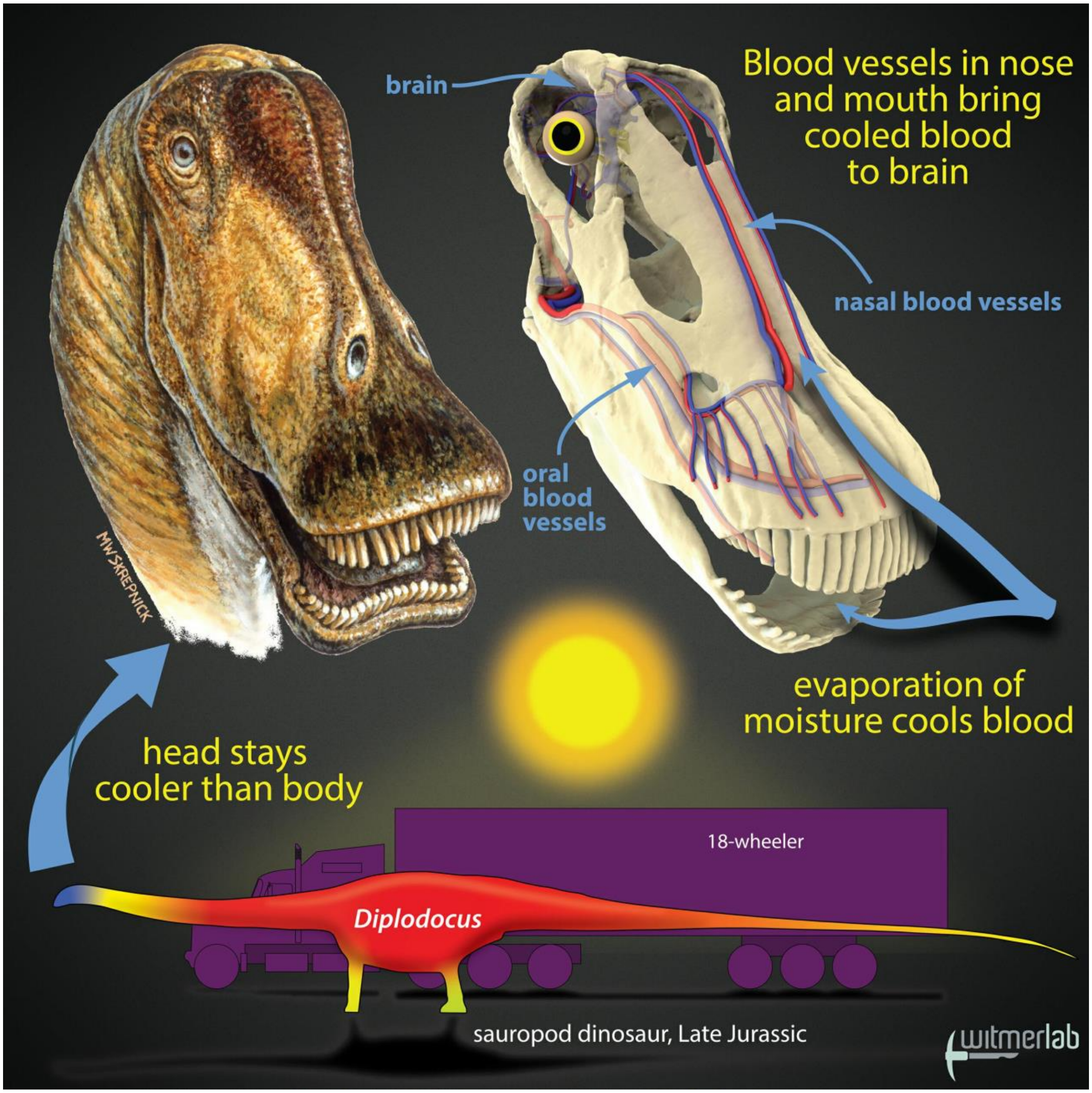
g. Theropods like *T. rex*, *Majungasaurus* and *Allosaurus* evolved a different pattern altogether. They didn't increase blood flow to the nose, mouth, or eye. Rather they increased the blood supply to an enlarged air sinus in their snout (called the antorbital air sinus). The relationship between this sinus and the jaw muscles meant that the opening and closing of the jaws caused air to be pumped in and out of the sinus, like an old-fashioned bellows pump.

h. The various groups of large-bodied dinosaurs evolved those large bodies independently from small-bodied ancestors. So, although the gigantic dinosaurs all faced the same thermal problems, many of them evolved different solutions to it—although all the solutions were based on the same concept: evaporation of moisture will cool blood that can then be diverted to the brain region to help moderate temperatures.

i. Future directions: The researchers are now looking at other groups of gigantic dinosaurs to see what physiological mechanisms they evolved.

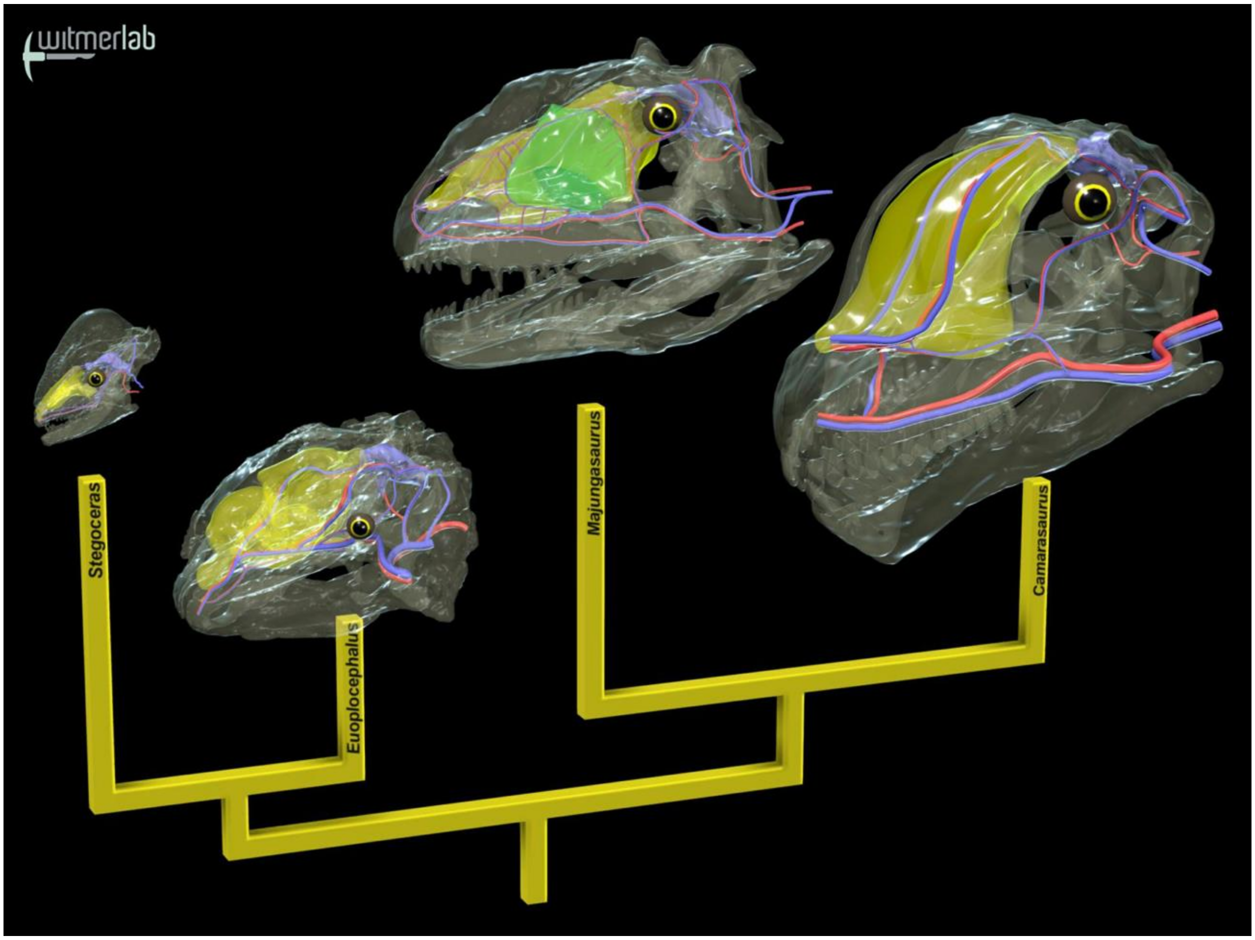
Images and animations

(Note: Images are compressed for this document. Click the links to download larger files).



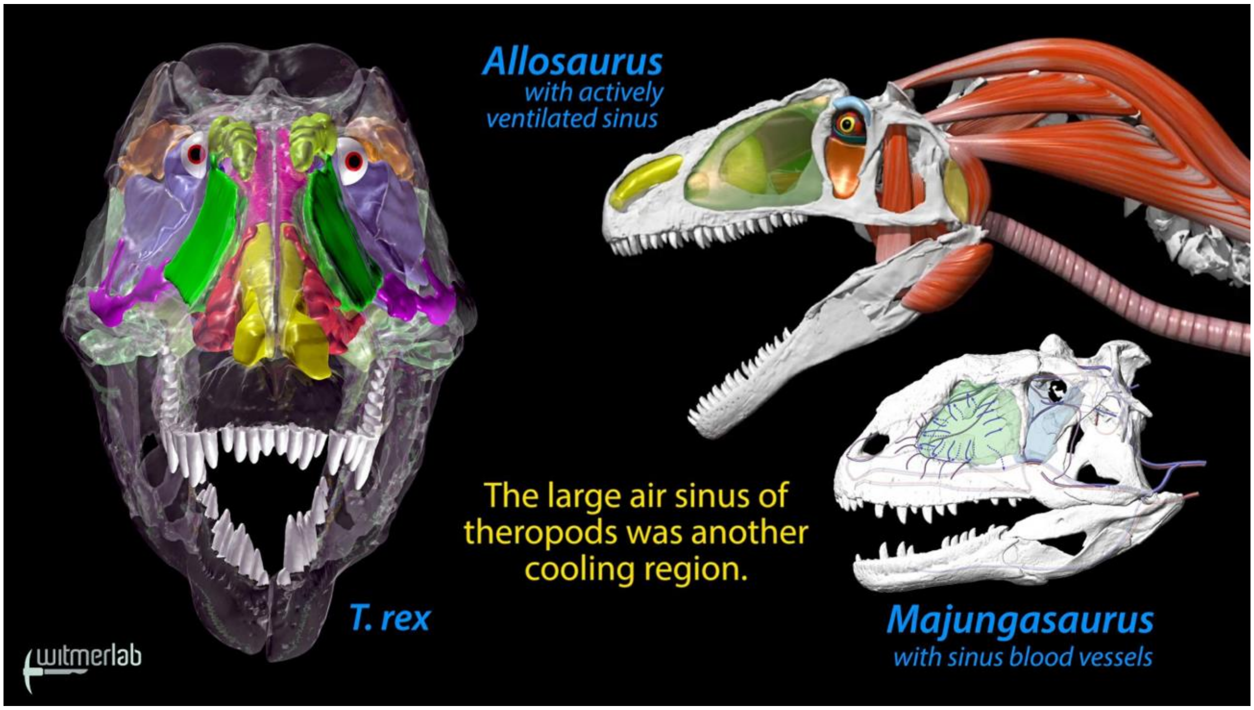
Gigantic dinosaurs like the sauropod *Diplodocus*, which weighed over 15 tons and was longer than an 18-wheeler truck, would have had problems with potentially lethal overheating. Hot blood from the body core would have been pumped to the head, damaging the delicate brain. New research shows that in sauropods, evaporation of moisture in the nose and mouth would have cooled extensive networks of venous blood destined for the brain. Other large dinosaurs evolved different brain-cooling mechanisms, but all involving evaporative cooling of blood in different regions of the head. Life restoration by Michael Skrepnick. Courtesy of WitmerLab at Ohio University.
https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Diplodocus_infographic.jpg

Gigantic dinosaurs like the sauropod *Diplodocus* would have had problems with potentially lethal overheating. New research shows that in sauropods, evaporation of moisture in the nose and mouth would have cooled extensive networks of venous blood destined for the brain. Other large dinosaurs evolved different brain-cooling mechanisms, but all involving evaporative cooling of blood in different regions of the head. Life restoration by Michael Skrepnick. Courtesy of WitmerLab at Ohio University. https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Diplodocus_head_&_skull.jpg



Different kinds of dinosaurs had different physiological strategies for dealing with the problem of overheating. Small dinosaurs like *Stegoceras* could cool down by simply running into the shade and so they lacked elaborate cooling mechanisms in the head. Gigantic dinosaurs, however, were so large that their bodies remained hot and continuously pumped hot blood to the head, potentially damaging the delicate brain. New research shows that different kinds of large dinosaurs evolved different brain-cooling mechanisms, but all involving evaporative cooling of blood in different regions of the head. The ankylosaur *Euoplocephalus* emphasized its convoluted nasal region as a cooling site, whereas huge sauropods like *Camarasaurus* used not only its nose as a cooling site, but also its mouth. Theropods like *Majungasaurus* evolved a different strategy, increasing the blood supply to a large air sinus in its snout through which air was pumped by movements of the jaws. Courtesy of WitmerLab at Ohio University. https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_dinosaur_heads.jpg

Note: This image is actually a still from a 3D interactive model that is available on Sketchfab and which can be embedded in webpages and social media posts. The 3D model can be turned, zoomed in and out, and examined from all angles.
https://sketchfab.com/3d-models/ce6163daf99c4947956386049416fe67



The bipedal predatory theropod dinosaurs, such as *T. re*x, *Allosaurus*, and *Majungasaurus* evolved a brain-cooling strategy involving a highly vascular air sinus in the snout through which air was pumped by movements of the jaws. Gigantic theropods like *T. rex* would have had major problems with overheating and had extensive air sinuses, many of which show signs of enhanced blood flow. As *Allosaurus* shows, the opening and closing of the jaws caused air to move in and out of the air sinus, ventilating the sinus like an old-fashioned bellows pump. Blood surrounding the sinus, as shown in *Majungasaurus* would have been cooled by evaporation of moisture in the sinus and directed to the brain to help moderate temperatures. Courtesy of WitmerLab at Ohio University.
https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Theropods.jpg

Note: This image is actually a still from a movie that animates the opening and closing of the jaws, demonstrating the bellows-pump action that ventilates the air sinus.

- This movie is available for download as an MP4 (1920x1080, 5 MB): https://people.ohio.edu/witmerl/Movies/Dinosaur_brain-cooling_strategies_Theropods.mp4
- This movie is available on YouTube: https://youtu.be/E1h6rJWtngg
- This movie is available as an animated GIF in three sizes:
    - 640x360 (0.5 MB): https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Theropods_640x360.gif
    - 960x540 (1.4 MB): https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Theropods_960x540.gif
    - 1280x720 (2.4 MB): https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Theropods_1280x720.gif

The two authors of the new dinosaur brain-cooling study—Ruger Porter, PhD (left) and Lawrence M. Witmer, PhD (right)—surrounded by skulls of some of the dinosaurs studied in the new research: clockwise from top right, *Majungasaurus*, *Tyrannosaurus rex*, *Diplodocus*, *Ankylosaurus*, *Stegoceras*, *Allosaurus*, and *Camarasaurus*. Courtesy of WitmerLab at Ohio University.
https://people.ohio.edu/witmerl/images/Dinosaur_brain-cooling_strategies_Porter_&_Witmer_Oct-2019.jpg