Team first to directly measure body temperatures of extinct vertebrates

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The Caltech-led team first tested their method for directly measuring the body temperatures of vertebrates on teeth from living animals, such as elephants and sharks. Credit: Caltech/Robert Eagle

Was Tyrannosaurus rex cold-blooded? Did birds regulate their body temperatures before or after they began to grow feathers? Why would evolution favor warm-bloodedness when it has such a high energy cost?

Questions like these -- about when, why, and how vertebrates stopped relying on external factors to regulate their body temperatures and began heating themselves internally -- have long intrigued scientists.

Now, a team led by researchers at the California Institute of Technology has taken a critical step toward providing some answers.

Reporting online this week in the early edition of the Proceedings of the National Academy of Sciences (*PNAS*), they describe the first method for the direct measurement of the body temperatures of large extinct vertebrates—through the analysis of rare isotopes in the animals' bones, teeth, and eggshells.

"This is not quite like going back in time and sticking a thermometer up a creature's back end," says John Eiler, Robert P. Sharp Professor of Geology and professor of geochemistry at Caltech. "But it's close."

Studying the mechanisms of and changes in temperature regulation in long-extinct animals requires knowing what their body temperatures were in the first place. But the only way scientists have had to study temperature regulation in such creatures was to make inferences based on what is known about their anatomy, diet, or behavior. Until now.

The technique the team has developed to measure body temperature in extinct vertebrates looks at the concentrations of two rare isotopes—carbon-13 and oxygen-18. "These heavy isotopes like to bond, or clump together, and this clumping effect is dependent on temperature," says Caltech postdoctoral scholar Robert Eagle, the paper's first author. "At very hot temperatures, you get a more random distribution of these isotopes, less clumping. At low temperatures, you find more clumping."

In living creatures, this clumping can be seen in the crystalline lattice that makes up bioapatite—the mineral from which bone, tooth enamel, eggshells, and other hard body parts are formed. "When the mineral precipitates out of the blood—when you create bone or tooth enamel—the isotopic composition is frozen in place and can be preserved for millions of years," he adds.

In addition, work in Eiler's lab has "defined the relationship between clumping and temperature," says Eagle, "allowing measurements of isotopes in the lab to be converted into body temperature." The method is accurate to within one or two degrees of difference.

"A big part of this paper is an exploration of what sorts of materials preserve temperature information, and where," notes Eiler.

To do this, the team looked at bioapatite from animals whose form of body-temperature regulation is already known. "We know, for instance, that mammals are warm-blooded; all the bioapatite in their bodies was formed at or near 37 degrees centigrade," says Eagle.

After showing proof of concept in living animals, the team looked at those no longer roaming the earth. For instance, the team was able to analyze mammoth teeth, finding body temperatures of between 37 and 38 degrees—exactly as expected.

Going back even further in time, they looked at 12-million-year-old fossils from a relative of the rhinoceros, as well as from a cold-blooded member of the alligator family tree. "We found we could measure the expected body temperature of the rhino-like mammal, and could see a temperature difference between that and the alligator relative, of about 6 degrees centigrade," Eagle says.

There are, however, limitations to this sort of temperature sleuthing. For one, the information that the technique provides is only a snapshot of a particular time and place, Eiler says, and not a lifelong record. "When we look at tooth enamel, for instance, what we get is a record of the head temperature of the animal when the tooth grew," he notes. "If you want to know what his big-toe temperature was two years later, too bad."

And, of course, the technique relies on the quality of the fossils available for testing. While teeth tend to withstand the rigors of burial and time, eggshells are "fragile and prone to recrystallization during burial," says Eiler. Finding good specimens can be difficult.

But the rewards are worth the effort. "The main reason to do this sort of work is because gigantic land animals are intrinsically fascinating," Eiler says. "We want to look at where warm-bloodedness emerged, and where it didn't emerge. And this technique will help us to reconstruct food webs. In the distant past, dinosaurs and other large animals were the crown of the food web; we'll be able to figure out how they went about their business."

Now that they've pinned down an accurate paleothermometer, the research team has gone further back in time, and has begun looking at the body temperatures of vertebrates about whom less is known. "Before mammals and birds," says Eagle, "we have no good idea what physiology these ancient creatures had."

First up? Dinosaurs, of course. "We're looking at eggshells and teeth to see whether the most conspicuous dinosaur species were warm- or cold-blooded," says Eiler.

In addition, he says, the researchers would like to apply their approach to better understand some key evolutionary transitions.

"Take birds, for instance," Eiler says. "Were they warm-blooded before or after they started to fly? Before or after they developed feathers? We want to take small birds and track their body temperature through time to see what we can learn."

Finally, they hope to get a peek at the paleoclimate, through the body-temperature data derived from ancient cold-blooded animals. "With this method, we can track changes in body temperature as a proxy for changes in air or water temperature."

More information: "Body temperatures of modern and extinct vertebrates from 13C-18O bond abundances in bioapatite," *PNAS*.

Provided by California Institute of Technology

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