The Pulse of *T. Rex*

Were dinosaurs warm-blooded? Does it even matter?

By RICHARD MONASTERSKY

There's a moment in the movie *Jurassic Park*, a brief, unremarkable image, that bothers physiologist John Ruben. He doesn't mind the look of Spielberg's dinosaurs or even the way they act. Let them run, jump, stalk Jeff Goldblum, or even dance a jig if they want. What John Ruben doesn't like is their breath.

More precisely, he objects to the sight of vapor coming out of a dinosaur's snout – a small point that reveals a fundamental assumption the movie makes about the metabolism of these great beasts.

"The problem with *Jurassic Park* is that they portrayed dinosaurs as endothermic to underline the notion that they were interesting, active, and dangerous. How do I know that? Because they showed one of these dinosaurs lying there with steam coming out of its nose. The only way an animal can do that is if it's very tightly regulating its body temperature and is a lot warmer than its surroundings. That's why you never see reptile breath," says Ruben, a researcher at Oregon State University in Corvallis.

Welcome to the blood feud over dinosaur physiology – a debate about endothermy versus ectothermy, about warm-bloodedness versus cold-bloodedness. Paleontologists launched this war 25 years ago, and it has since spread from museums into magazines, best-selling books, and even public television shows.

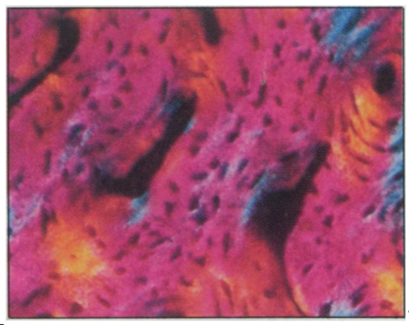
The zealousness of some combatants and the derogatory comments that have flown back and forth led paleontologist James O. Farlow to upbraid a few colleagues when he addressed the question of physiology in *The Dinosauria* (1990, University of California Press).

A dinosaur researcher from Indiana University-Purdue University at Fort Wayne, Farlow wrote: "Unfortunately, the strongest impression gained from reading the literature of the dinosaur physiology controversy is that some of the participants have behaved more like politicians or attorneys than scientists, passionately coming to dogmatic conclusions via arguments based on questionable assumptions and/or data subject to other interpretations."

The debate still simmers, in large part because researchers have failed to find any means of resolving the issue. Lacking conclusive evidence one way or the other, paleontologists have had the freedom to argue ad nauseam, driven by nothing more substantial than faith in their own theories.

New discoveries, however, are providing solid information that offers the hope of ending this long-standing controversy. "We are on the edge of finding out what the metabolic physiology of dinosaurs was really like," says Ruben.

When early paleontologists looked at the oversized femur of a *Triceratops* or a *Tyrannosaurus rex*, most of them envisioned a large reptile with a physiology to match. Reptiles typically take their temperature cues from the outside environment.



Chinsamy

***A** slice from the femur of the dinosaur* Syntarsus *shows abundant blood vessels and a woven texture, two indications that this animal grew rapidly.*

In the cold, their metabolism slows and they grow lethargic. When the air warms or the sun comes out, reptiles arise from their torpor and resume an active life. In contrast, birds and mammals keep their body temperatures continuously elevated, which requires them to consume more food than a reptile of similar size.

The idea of cold-blooded, slow-moving dinosaurs came under fire in the 1960s, after John H. Ostrom of Yale University discovered a sickle-clawed terror called *Deinonychus*. With its slashing weaponry and flexible skeleton, this dinosaur had the look of an active, agile predator – an image inconsistent with the concept most paleontologists had of typical reptiles. Ostrom suggested that dinosaurs may have had physiologies more like mammals and birds.

Since then, other researchers have argued that the sheer bulk of the larger dinosaurs would have kept them from cooling down during the night. By dint of their dimensions, these giants could have maintained a constant body temperature.

Paleontologist Robert T. Bakker pushed the physiology argument further than other scientists in his popular book THE DINOSAUR HERESIES (1986, William Morrow). Bakker claimed that all dinosaurs were "automatic" endotherms – animals with fast, stable metabolisms that supply enough internal heat to keep their body temperatures constant. Ectotherms are just the opposite, having body temperatures that fluctuate with outside conditions.

Among his different points, Bakker contended that the structure of dinosaur bone closely resembles that of mammals and birds and does not match that of modern reptiles. He concluded that the internal structure of dinosaur bone proved such animals grew quickly, as modern endothermic mammals do.

New work on dinosaur bones, however, paints a more complex picture, suggesting that these once ruling reptiles do not fit neatly into any physiological category.

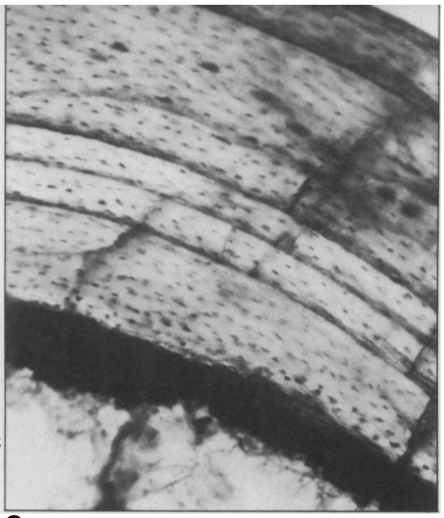
Although researchers have examined slices of dinosaur bone for decades, Anusuya Chinsamy of the University of Pennsylvania in Philadelphia advanced this work recently by comparing the bones of young and old animals from a single species. Charting the variations among the samples enabled her to reconstruct how dinosaurs grew.

Chinsamy's work has yielded a confusing array of results. When she examined cross sections of femurs from one type of dinosaur called *Syntarsus*, she found growth rings – dark bands similar to those that appear in trees. Growth rings develop when an animal temporarily stops building new bone, most often during a difficult season such as wintertime. Because the bones of mammals and other endotherms do not show growth rings, their presence in *Syntarsus* links that animal with ectotherms.

But Chinsamy also found evidence that this small predatory dinosaur stopped growing when it reached adulthood – a pattern typical of endotherms and not of ectotherms. What's more, the structure of the *Syntarsus* bone indicated that the animal grew rapidly, another characteristic of endotherms.

Seen from one side, this dinosaur looked like a typical reptile; seen from another angle, it seemed more like a mammal or a bird.

Another type of dinosaur, *Dryosaurus*, revealed the opposite pattern. This or-



Growth rings in the femur of a Cretaceous bird reveal that this creature had not yet evolved the warm-blooded physiology of modern birds.

nithopod did not show any growth rings, meaning it grew at a fairly high, sustained rate, much as mammals do. But unlike pandas and people, a mature *Dryosaurus* did not stop growing.

David J. Varricchio of Montana State University in Bozeman found a similarly complex picture when he analyzed a small, big-eyed dinosaur called *Troodon*. This animal also grew quickly, possibly reaching adult size within 3 to 5 years, Varricchio calculates. However, rings in the bone suggest that *Troodon* stopped growing occasionally – more like an ectotherm than an endotherm.

Chinsamy and Varricchio both conclude that dinosaurs may not fit neatly into the physiological categories occupied by modern animals. Instead, they may have existed somewhere in the middle. "They could have been souped-up cold-blooded animals," Varricchio offers.

Chinsamy recently took a different look at the physiology question by examining early birds from the Cretaceous period, the culmination of the dinosaur's reign on Earth. Contrary to what many paleontologists might have expected, she found that ancient birds had growth rings, suggesting that they had not yet achieved the endothermy of their modern offspring. Chinsamy and her colleagues reported their findings in the March 17 NATURE.

Many paleontologists think that birds must have been endothermic from the start because active flight consumes tremendous amounts of energy, something only endothermic animals can provide for long periods of time. Furthermore, when it became fashionable to call dinosaurs endotherms, ancient birds automatically gained similar footing because they evolved from dinosaurs.

Chinsamy's findings now punch a hole in that argument by suggesting that ancient birds were not endotherms. "If she is right about that, it seems unlikely that their [dinosaurian] ancestors would have had the full suite of endothermic features either," Farlow says.

Although he once firmly supported the idea of endothermic dinosaurs, Farlow now describes himself as a militant agnostic. "A lot of people, including myself, have done work that suggests maybe it's not quite as simple as all that. Some people, who were at one point very big enthusiasts of endothermy, have backpedaled quite furiously," says Farlow. Most academic paleontologists have taken a similarly conservative view, he says, leaving only a tiny, but vocal, minority to champion the theory of warm-blooded dinosaurs, principally in the popular media.

Ruben describes the situation in even harsher terms. "The amount of misinformation that is out there on dinosaur endothermy is so unbelievable. Most of the people who have worked on dinosaur physiology don't know what they're talking about," contends the Oregon State physiologist.

According to Ruben, studies done to date have focused on factors only indirectly related to metabolism and therefore could not reveal whether an animal was ectothermic or endothermic. In fact, he thinks that paleontologists have been looking in the wrong place. Instead of examining slices of a femur, researchers might find more information by looking up a dinosaur's nose.

Ruben's former student, Willem J. Hillenius, recently demonstrated that endothermic animals have a special set of nasal bones directly related to their metabolism. Called the maxilloturbinals, the bones form thin, folded sheets inside the nasal passages of birds and mammals.

Through experiments with live rats, squirrels, ferrets, rabbits, and opossums, Hillenius showed that the maxilloturbinals function as a water conservation mechanism, recovering moisture from the breath of mammals.

Animals with a fast metabolism need such protection because they inhale and exhale 5 to 10 times more frequently than reptiles. Without these bones, mammals would lose far too much water simply through breathing, says Hillenius, now a researcher at the University of California, Los Angeles.

The maxilloturbinals work as a humidifier-dehumidifier system. When a mammal inhales, air moving through the nasal passage evaporates water from the tissue covering the maxilloturbinals. That process not only provides necessary moisture for the lungs, it also cools the maxilloturbinals. Then, as the animal exhales, the cool tissue reabsorbs moisture from the breath, drying the air before it leaves the body.

Looking back in the fossil record, Hillenius traced the evolution of endothermy in mammals by searching for maxilloturbinals or the internal ridges to which they attached. In the April EVOLUTION, he reports that the initial development of a mammal-like metabolism began as far back as 260 million years ago, some 45 million years before the first mammals appeared.

If mammalian ancestors did indeed take such a long time to evolve a faster-revving engine, Hillenius' discovery offers some hints to explain the physiological transition. Many researchers have speculated that endothermy developed because it helped animals maintain a high body temperature. But the reptilian ancestors of mammals wouldn't have received such thermal benefits because their metabolism, while slightly elevated, was still too low to provide enough heat.

Instead, Hillenius' findings support a different idea: Endothermy evolved because it enhanced an animal's ability to maintain strenuous activity. Even a modest increase in aerobic fitness would have given these creatures an edge.

Having tackled the mammal question, Hillenius now plans to address the dinosaur problem. By looking for maxilloturbinal bones in dinosaur skulls, paleontologists may eventually determine whether these creatures had a fast metabolism, he thinks. "We've still got to do our homework, but I think we've got a potential test," he says.

If dinosaurs don't have such bones, that doesn't necessarily relegate them to some physiological backwater where lethargic animals doze the day away. Paleontologists are now learning what physiologists have known for years – that some modern ectotherms can grow rapidly and have extremely active lifestyles. In particular, many lizards can sprint just as fast as, if not faster than, mammals of equivalent size, says Ruben. What ectothermic animals lack is the endurance of mammals and birds.

Mazelike maxilloturbinal bones in a wolf's snout humidify ingoing air and dehumidify outgoing air.

"It's hard for a lot of people to imagine that you can have an animal that's fast-growing, fast, and interesting unless it's like we are. It's sort of a chauvinistic perspective," Ruben says. "I think in the end we're going to find out that dinosaurs were probably fairly typical ectotherms, metabolically. But that doesn't mean that they were sluggish or uninteresting." □