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VOLUME 16 :: ISSUE 2

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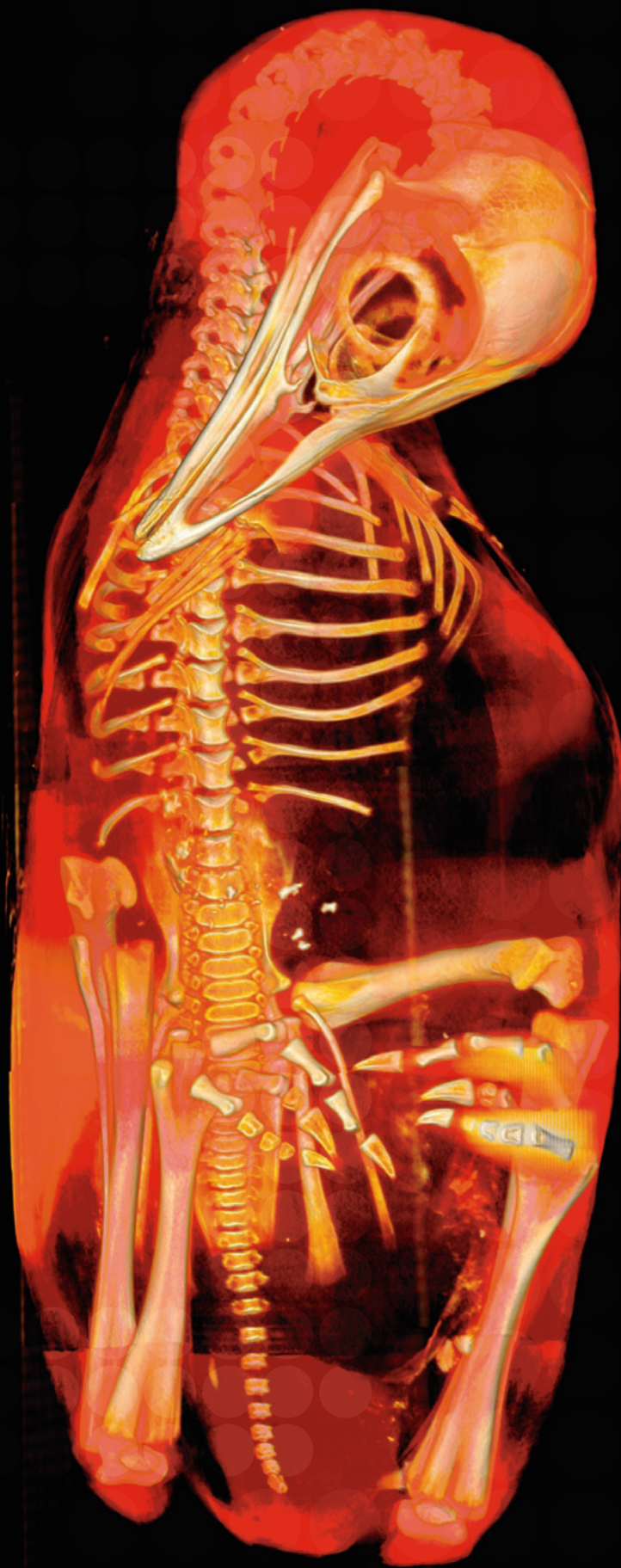
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ISSN 1520-4375
PRINTED ON RECYCLED PAPER.



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(At right) An embryo of a cassowary, a primitive flightless ratite bird from Australia, when run through Ohio University's microCT scanner, provides a high-resolution view of the skeleton of a modern-day dinosaur.

(Opposite page) Lawrence Witmer and his colleagues are creating the most realistic renderings of dinosaurs to date.

Digital

dinosaur



HOW DO SCIENTISTS RECONSTRUCT THE ANATOMY OF ANCIENT BEASTS?

Lawrence Witmer's lab uses low-tech dissections of birds, crocodiles, and other animals to create high-tech animations of dinosaurs.



by ADAM LIEBENDORFER

Jason Bourke starts his day in the anatomy lab with seven severed frozen ostrich heads and a Craftsman air compressor. Using a hose and a nozzle, the graduate student knocks the mucus out of the bird skulls to prep them for a trip through the local hospital's CT scanning machine. Nearby are dozens of dinosaur fossils, including creatures that are the ancient relatives of these feathered research subjects.

If you spend any time in this lab, managed by Ohio University's renowned dinosaur anatomy expert Lawrence Witmer, you'll notice these dichotomies again and again: The skulls of modern animals, from crocodiles and rhinos to flamingos, share space with those of dinosaurs such as *T. rex* and *Diplodocus*. Low-tech equipment, from air compressors and chainsaws to stovetop burners, supports some rather high-tech efforts to digitally scan and visualize the anatomy of myriad creatures.

Using modern animals to re-create ones that have been extinct for millions of years is the focus of the lab run by Witmer, whose pioneering work of CT scanning of fossils has moved dinosaur research out of the badlands and into the high-tech science lab. Because soft tissue—long ago decomposed—leaves tiny signatures on dinosaur bones, Witmer has been able to use a technology typically reserved for human head exams to create models of how the dinosaur brains, nasal cavities, eyes, jaws, and auditory systems actually worked. Over the course of his 30-year career, Witmer has not only contributed new research findings to his field, but also has focused on educating the public about the science behind these prehistoric titans.

"What we've always tried to do here at WitmerLab is to have one foot in the past and one in the present. We're trying to flesh out dinosaurs beyond the metaphorical sense of the word," Witmer says. "That is to restore the tissues that the millennia have stripped away from these fossil bones."

(Above right) 3D imaging of growth in tyrannosaurs reveals that young animals were quicker, more agile predators than were their more powerful but lumbering parents. Skull of a 2-year-old juvenile Tarbosaurus, a Cretaceous tyrannosaur from Mongolia, with an adult skull at right and a teenage skull behind for comparison.



AN EVOLVING SCIENCE

When Witmer was a kid, dinosaurs were viewed as “dull-witted, slow-moving, swamp-dwelling behemoths” that lumbered around the earth until their inevitable extinction, he recalls. In the late 1960s, however, scientists made two key discoveries: Birds descended from dinosaurs, and dinosaurs were warm-blooded animals.

“In the late 1960s and early 1970s, just as there were upheavals in just about every corner of our society, there was an upheaval in our sense of what dinosaurs were like,” Witmer says.

In the wake of this dinosaur revolution, Witmer pursued biological studies at Cornell University, the University of Kansas (where he published a thesis on cranial air sacs in prehistoric birds), and Johns Hopkins University. He completed his dissertation on what soft-tissue analysis could tell us about the evolution of the faces of archosaurs, the branch in the animal kingdom that contains crocodiles, birds, and their dinosaur ancestors. This was during a time in which scientists began using comparative anatomy to draw similarities between dinosaurs and their living descendants.

In 1993, the year after Witmer completed his dissertation, dinosaurs returned to the public eye via the *Jurassic Park* series, which shattered box-office records and provided the most realistic re-creation of dinosaurs yet.

Soon Witmer and other scientists would give them an even closer, more accurate view. Researchers began to look to CT scanning as an appealing tool, as the technology was becoming easier and more reliable to use. Witmer and

others familiar with radiology as a tool for learning human anatomy began to explore how it might also be used to take a closer look at dinosaur bones. Unlike picks and shovels in the field, X-rays wouldn’t damage these specimens, they reasoned.

Witmer’s early work with CT scanning in the mid-1990s helped to get the technique featured in the journal *Science*. The process, however, took a lot of patience.

“In 1996, scanning was a *huge* deal because it was incredibly slow,” Witmer recalls. “The way I took my data away was on sheets of X-ray film that you had to put up to a light box. So we couldn’t do any of the computer stuff. All we could do is look inside.”

When Witmer’s lab went digital in 2000, researchers could stack the hundreds of X-ray pictures, which showed cross-section slices of heads, to create 3D models. Today, using sophisticated and customized computer software, Witmer and research associate Ryan Ridgely turn these data into animations that have breathed new life into dinosaur and animal skulls.

“We’ve done the first-ever CT scanning of dozens of different species, which has been a hugely exciting enterprise,” Witmer says. “The classic paleontology thing is to be stumbling around the badlands and you





“We’ve done the first-ever CT scanning of dozens of different species, which has been a hugely exciting enterprise.”

LAWRENCE WITMER

THE PROCESS: (At right) Reconstructing the lifestyle of a “terror bird.” The massive 15-inch skull of the 6-million-year-old terror bird *Andalgalornis* (top) was CT scanned (middle) and digitally restored (bottom) to shed light on the biomechanics of the skull and feeding behavior of the predatory bird.

happen to find a little piece of bone sticking out of a rock and it leads to a whole dinosaur skeleton. Really, it’s that same sense of discovery—looking at something that hasn’t been seen for hundreds of millions of years.”

Witmer’s team uses the CT scanner at O’Bleness Memorial Hospital in Athens to scan the heads of modern-day animals, as well as the fossilized skulls of dinosaurs. In preparation, the team may shoot latex through veins and arteries or soak specimens in a special iodine solution to make certain spaces in the skulls pop out.

Scheduling a time slot can be tricky, as the machine is one of only a handful of scanners serving Southeast Ohio. On numerous occasions, Witmer has cut short the hours-long process of setting up the scanner because a doctor called in an emergency CT scan on a patient. Once the system is set up, however, technician Heather Rockhold and Witmer run specimens through the scanner. The process generates gigabytes upon gigabytes of computer files.

If the specimen is tiny, Witmer and his team can use Ohio University’s MicroCT Facility to image and digitize animals, fossils, and objects smaller than 10 centimeters.

After CT scanning modern-day animals, Witmer and his graduate students, including Bourke, dissect the soft tissues of the specimen and ultimately skeletonize it so that they can see the signatures that the soft tissues leave on the bones. They rely on their scalpel skills and low-tech methods such as the air compressor or saw to cut bones apart.

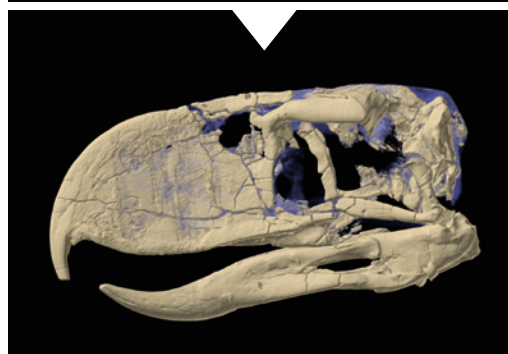
The most straightforward way of getting down to the bare bones is to let an animal thaw enough to skin and pick it apart manually. (All of the animals used in the lab are salvage specimens donated for research.) Other times researchers boil specimens on a lab stove to soften them up. A stewed specimen, however fetid, can be cleaned in minutes. Skinned and stripped animals hang under the ventilation hood for a few days. Then the bugs take over.

Flesh-eating dermestid beetles are the most efficient way to get rid of the nonskeletal parts researchers can’t pick off. The lab currently plays host to two colonies, “thousands of little mouths to feed,” Witmer says. Leave a skinned bird in one of their bins for a few days, and you’ll get a skeleton neatly strung together by connective tissues. Leave it in there a few more days and you’ll have a pile of bones.

A BODY OF DISCOVERIES

The most common body part making the trip through the CT scan machine is the skull. That’s because the heads of dinosaurs and modern-day animals contain intriguing traces of the soft tissue responsible for so many key biological functions: how these living creatures breathed, smelled, kept cool, vocalized, ate, and absorbed the sounds of the environment around them.

Witmer made international news headlines in 2001 with his finding that dinosaur nasal passages were located at the front of the head, near the mouth, and not at the top of



the skull. (The misconception stemmed from the assumption that large dinosaurs such as *Diplodocus* were probably aquatic and equipped with a top blowhole like a whale.) In 2003, he published another influential article in the journal *Nature* that suggested that a specialized brain and inner ear structure allowed pterosaurs to fly and target prey. A 2008 study found that dinosaurs had large airways inside their skulls that most likely reduced the weight of their massive heads and allowed for quick movements. The same project showed that dinosaur nasal passages could be twisted like a “crazy straw,”



AT WORK: (Above) Witmer’s team has a long-standing partnership with O’Bleness Memorial Hospital in Athens to CT scan dinosaurs and their modern-day relatives. (At left) Doctoral students such as Jason Bourke and Ashley Morhardt are an integral part of Witmer’s research team. Several alumni are leading independent dinosaur studies around the globe.

A new look

Fossils don't always give up their secrets easily. Teasing apart the details of a life lived 70 million years ago requires examination of all the clues left by nature, using the latest in high-tech medical imaging.

№1

THE FOSSIL

This rare skeleton of a 2 to 3-year-old *Tarbosaurus*, a close cousin from Mongolia of our own *T. rex*, preserves a unique glimpse into the changing lifestyles of dinosaurs as they grow up.



№2

ANALYSIS

The fossil skull was carefully removed from the block and brought to WitmerLab for analysis. The skull was CT scanned (top), which allowed the team to see parts of the tyrannosaur-toddler's skull that are still entombed in stone, such as the delicate bony eye-ring (bottom).



№3

RENDERING

The original fossil of skull (bottom) is the primary document. Even the rock remaining within the skull provides clues about the living tyrannosaur's environment. An artist's sketch (middle) simplifies the analysis, but the 3D "virtual" skull rendering (top) provides the key analytical tool, allowing access to all details of anatomical structure.



Witmer says, which could have led to unique vocalization patterns for different beasts.

In the last few years, Witmer increasingly has turned up as a key collaborator on a wide variety of scientific articles that draw on his CT scan work and his unique method of anatomical analysis—an approach he calls the Extant Phylogenetic Bracket that's now so widely used, he doesn't always get credited for it—to expand our understanding of dinosaur biology. In a project with Casey Holliday of the University of Missouri published in 2010, the scientists found that dinosaurs had thick layers of cartilage in their joints, which means they may have been considerably taller than previously thought. In work with Takanobu Tsuihiji of the National Museum of Nature and Science in Tokyo, Witmer helped reveal how young tyrannosaurs used speed and agility to hunt prey.

These two collaborations are no coincidence: Both Holliday and Tsuihiji are part of a growing corps of Witmer protégés who have taken their training from Ohio University and gone on to lead or start programs around the world. Witmer has served as main advisor or on an advisory committee for 20 students, 17 of whom have passed through the lab.

As a way to say thanks for the skills he learned at WitmerLab, Holliday named a new fossil croc he found last January *Aegisuchus witmeri*.

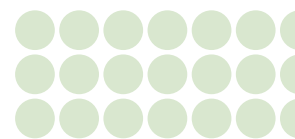
"Larry is successful because he's a brilliant anatomist. His ability to conceptualize and illustrate are second to none," Holliday says. "WitmerLab is known in the community for putting out paleontologists who are highly skilled, well-rounded anatomists."

This collaborative network of scientists is fueling the latest Witmer endeavor, the Visible Interactive Dinosaur project. Funded by a grant from the National Science Foundation, Witmer is working with Holliday and other researchers around the world on a long-term project to create the most realistic renderings of dinosaurs to date. Sophisticated science allows the researchers—for the first time ever—to view anatomically accurate restorations of all the tissues in a dinosaur's head at once. Through the 3D computer environment, the scientists can run interactive simulations of how the heads worked.

"Because these computer-generated animations are so engaging," he says, "we can attract the attention of the public as well, giving us an opportunity to use our digital dinosaurs to educate and maybe even excite people about physiology, biomechanics, and neuroscience."



"Larry is successful because he's a brilliant anatomist. His ability to conceptualize and illustrate are second to none."



CASEY HOLLIDAY

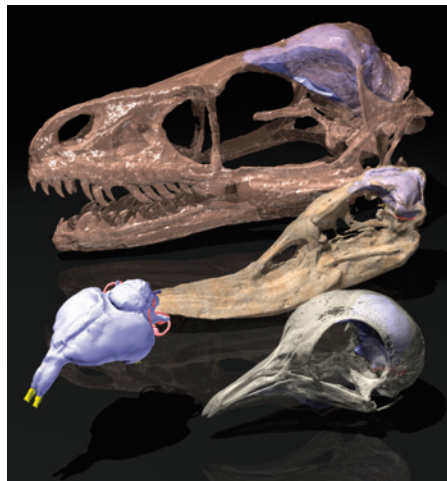


(Top) *The Visible Interactive Dinosaur project is shedding new light on the function, physiology, and behavior of dinosaurs like this predator from Madagascar, Majungasaurus.*



(Above left) *The Visible Interactive Dinosaur project is a highly collaborative project, requiring the effort and expertise of almost all WitmerLab members as well as scholars from around the globe. Here the team restores the eyeball and its muscles in the long-necked plant-eating dinosaur Diplodocus.*

(Above right) *The evolution of the brain and sensory systems has been a key part of understanding the behavior and biology of extinct dinosaurs. Here the brain of the 75-million-year-old predatory dinosaur Bambiraptor (top) is compared with the isolated brain of the 58-million-year-old primitive bird Lithornis (left), the 50-million-year-old duck relative Presbyornis (middle), and a modern-day pigeon (bottom). CT scanning and 3D imaging make such comparisons easy to understand for scientists and the public alike.*



AN AUDIENCE OF DINOSAUR ENTHUSIASTS

Dinosaurs have been a perennial public favorite, so it's not uncommon for Witmer to host tours of his lab on an almost weekly basis. His work has attracted visits from the Girl Scouts, college biology classes, and budding science teachers. One mom drove several hours through a blizzard to make good on a promise to have her son experience a day at WitmerLab.

Witmer sees himself in many of these kids. He never had the chance to visit a lab like his during his youth, so he relishes the opportunity to share his resources and discoveries with the public.

"I meet lots of young Larrys. I meet them all the time," he says. "I meet them as the 6-year-old. I meet them as the 14-year-old. I meet them as the prospective graduate student or undergraduate student. I often say that those sessions that have those extremely narrow audiences—just a kid and his mom—those might actually be the most important thing I do."

Witmer remembers when his son, Sam, was the age of some of the children who come to visit. Witmer was beginning to make waves in the media for his high-profile discoveries and telegenic knack for giving sound bites. Sam's classes were starting to cover biology and evolution, and the debate of how to teach the subject in school was picking up in ferocity. Some evolutionary biologists entered the fray. Colleagues called on Witmer, a rising star in the field, to become a voice for evolution, but he was concerned that participating in the intelligent design debate in the media would take time from his own research.

Instead of engaging directly in the evolution vs. creationism battle, Witmer chose to use the media spotlight to show how evolution is woven into the fabric of his scientific work. "I

never shy away from discussing evolution—we talk about it all the time, but in the context of our own research," he explains.

Witmer feels that the outreach activities pay off in breaking down the wall between what might be perceived as "ivory tower academics" and the general public, who learn that scientists are regular people, too, he says. Visitors learn that "science isn't scary or dreary or boring. It can be fun and creative and even, dare we say, cool," he says.

Witmer's ability to discuss dinosaur findings and put them into context for the lay person has attracted documentary and commercial television producers from media outlets such as the Discovery Channel and History Channel. He's become a *de facto* dinosaur expert for shows such as *Dino Gangs*, *Jurassic Fight Club*, *Clash of the Dinosaurs*, and *Prehistoric Monsters REVEALED*. The lab's YouTube page has garnered hundreds of thousands of views. Witmer also runs a blog for the lab, his own professional site, a site for the Ohio University MicroCT Scanning Facility, and two professional Facebook pages: one for the lab and one for the International Congress of Vertebrate Morphology, of which he serves as president.

Ringleader of an internationally renowned lab, telegenic face of modern paleontology, and mentor to the next generation of dinosaur scientists, Larry Witmer is at the height of his career. He says he eventually would like to reduce the number of projects he's involved in and focus on deeper topics. Maybe even write a book for a general audience.

"The young Larry Witmer would probably ask the old Larry Witmer, 'Is it worth doing? Is it worth investing your life to go down this path?' Which really is a fundamental question for anybody, because kids have lots of passions," he reflects. "And I would say yes. Most kids probably have in their minds this prosaic, stomping-through-the-badlands thing—and I've done my share of dinosaur-hunting in the field. But it turns out that's not where all the answers lie."