Engineers, Biologists Join to Explore Bat-Biting Mechanics

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The ability to bite off more than one can chew is related to the anatomy of the skull, contend University of Massachusetts Amherst scientists, who are putting their heads together to explore the relationship between the biomechanics of biting and the evolution of skull shape diversity in bats.

The researchers are using a virtual analysis tool commonly employed by engineers, laying groundwork for a technique that could help scientists tackle questions in a number of fields from evolutionary biology to medicine.

The interdisciplinary team headed by biologist Elizabeth Dumont and mechanical engineer Ian Grosse is using a computer-based method known as Finite Element Analysis (FEA), normally used for predicting the behavior of engineered products such as planes, bridges and cars. FEA will allow the researchers to create virtual skeletal models that are more accurate, less time consuming and less costly than traditional methods.

“We’ve made significant progress in streamlining the process of building very accurate 3-D models of complex biological structures,” says Dumont. “It will truly unlock many new ways to go about looking at biomechanical problems we haven’t had access to.”

Dumont and Grosse are applying FEA to the feeding behavior and bite forces of several bat species to shed light on the evolutionary pressures that drive development in mammals. To study how bite forces are transmitted through the skull, biologists would normally catch animals in the field, bring them into the lab and surgically implant strain gauges to measure strains induced in the skull during biting or feeding. But these bats are too small for such an approach. So Dumont and Grosse run the creatures through a micro-CT scanner that pictures hundreds of razor-thin slices of the skulls. The scientists can then digitally reconstruct each bat skull and use FEA to study how the skull transmits bite forces.

FEA works by taking an object like a skull and breaking it down into many discrete, small chunks or “elements.” The behavior of each little element is predicted by a set of mathematical equations that describe everything from load to velocity to density (for example, of bone). The sum behavior of all these pieces, given the laws of physics, should yield the behavior that can be expected of the actual object. Because each element has a set of equations, and there may be hundreds of thousands of elements, a computer is required to do the math that yields the behavior of the object.

Engineers rely on Finite Element Analysis to optimize their designs, says Grosse, noting that the airflow behavior around airplane wings, combustion in an automobile engine, and stresses in structures of all sizes—ranging from bridges to household appliances to microelectronic devices— have all been modeled with FEA.

For Dumont and Grosse, FEA gives them a model that’s a “global snapshot” of each skull, depicting how the bones of the skull interact during biting, and the stresses that are produced in the process. The model is very accurate and can be created within a matter of weeks, much faster than most previous methods.

Grosse and Dumont hope to get at three key questions: how do particular biting styles affect the distribution of stress and strain over the facial skeleton? Is skull shape constrained by sensory systems, such as eye size or shape? And how does the strength of the facial skeleton, relative to loads imposed during feeding, compare to the relative strength of the postcranial skeleton during loads imposed by locomotion? Answers to these questions might help explain why some mammal lineages have a variety of skull shapes and others do not.

“Food is essential to survival—feeding is one of the most fundamental interactions between animals and their environment,” says Dumont. But selection can shape anatomy in a number of ways—because the energetic cost of flight increases as body mass increases, bats are also probably under selective pressure to be small and light. This could constrain skull size. If having a really big head lets you eat more nutritious foods, but also adds lots of weight, the big head won’t give you much of an advantage. So selection may favor the evolution of new skull shapes, which can break apart foods as effectively as large skulls but retain small size.

From an engineering point of view, the solution to eating more fruit and flying is to have a jaw and skull with a very high strength to weight ratio, says Grosse, one that is light, but able to transmit large feeding forces. FEA is helping the researchers to test some of these predictions. If their analyses reveal that a section of skull can handle more of a stress load than is actually applied when it eats, that suggests that forces other than feeding pressures are influencing skull shape.

“In engineering, FEA is a mature technology” says Grosse. “It’s used to predict the behavior of almost every engineered product you can think of, and there’s no reason it shouldn’t be a powerful tool in other disciplines.”

Recently the technique has been wending its way into the world of biology, and Grosse and Dumont want to help it along. Some scientists are using FEA to look at the evolution of skull shape in humans and their ancestors, others are applying it to dinosaur bones. And medical researchers have begun to use FEA to better design prosthetics and facial reconstructive implants. Grosse and Dumont want to establish some protocols for efficiently translating CT-scans into the 3-D FEA models, and make the approach widely accessible to researchers in a variety of fields.

After a presentation at a recent conference for the Society for Integrative and Comparative Biology several colleagues asked Dumont if she planned to offer workshops on their methods of applying the FEA. The researchers are eager to do so, and hope the work will foster future collaborations across disciplines.

“We’re really promoting the use of this technique to the biology community,” says Dumont, “We want to be the go-to people for how to do this

Source: University of Massachusetts Amherst

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