A mechanism of how biodiversity arises

May 26 2014

For these experiments, Hu and Albertson consider the fish skull not simply as a collection of bones, ligaments and muscle, but as a dynamic mechanical device capable of a complex range of movements. Preparation of a cichlid craniofacial skeleton in the ventral view. The bone is stained red and cartilage blue. Credit: R. Craig Albertson

A new study of how biodiversity arises, by evolutionary biologists at the University of Massachusetts Amherst, shows how a mutation in a single gene during development can lead to different consequences not only in how animals' skull and jaw are shaped, but how this leads to different feeding strategies to exploit different ecological niches.

The study in the cichlid fish model by Yinan Hu, a doctoral student in organismic and evolutionary biology, with his advisor Craig Albertson, is among the first to address how a single genetic change can influence both trait development and function. Results appear in the current early online issue of *Proceedings of the National Academy of Sciences.*

Until now, Albertson explains, the field of evolutionary developmental biology (evo-devo) has focused mainly on connecting gene-level changes with the evolution of different anatomical shapes, or morphology, but the field has been less successful in revealing how these anatomical changes influence how an organism performs in its specific environment. This has left a gap in understanding of what allows species to adapt to new environments.

"It is not the shape of an organism that determines fitness per se," he notes, "rather it is how an organism interfaces with its environment that determines its survival. Shape tells part of this story, but function gets you a lot closer to understanding how well suited an animal is to its surroundings. In this paper, I think we have extended the discussion of how genes and genetic variation influence ecological fitness."

For this work, Hu and Albertson combined traditional genetic mapping and experimental embryology to show how changes in the ptch1 ("patch1") gene, a member of the hedgehog signaling pathway, alter skull and jaw development in African cichlid fishes, leading to pronounced shape changes in the adult. They also modeled the skulls of these fishes to show how this genetic variation and its anatomical consequences predict differences in feeding mechanics.

African cichlids are an ideal model system for studying how biodiversity originates and it is maintained over time, Albertson says, because it is "unprecedented in terms of the number of species that have evolved in a brief period of geological time."

As Hu explains, "Patch1 is a well studied gene involved in various aspects of building organisms over development. What we show is how differential deployment of this gene over development can lead to changes in the skull that should have pronounced effects on how that fish makes a living."

"One form of the gene helps to produce faster moving jaws that are better able to collect highly mobile prey. The alternate form leads to the development of jaws that are slower but more powerful, which is better for consuming hard prey. It accomplishes this by altering many bones in the head at once. In other words, these simple genetic variants should go a long way toward allowing organisms to carve out different ecological niches," he adds.

For these experiments, Hu and Albertson consider the fish skull not simply as a collection of bones, ligaments and muscle, but as a dynamic mechanical device capable of a complex range of movements. Specifically, they borrowed the mechanical engineering principal of four-bar linkages, a simple movable chain with four joints, to understand how genetically induced changes in the skull translate to differences in jaw movement efficiency.

Fish skulls are dynamic entities with many bony elements capable of moving independently of one another. Biologists have used mechanical engineering concepts to help make sense of this complexity. Hu and Albertson note in this study that genetic changes in ptch1 result in changes in the length of two of three movable links in this four-bar system. The result is two different skull forms with different predicted kinematics, or geometries of jaw motion.

Speaking to these changes in jaw shape and kinematics, Albertson says, "The effects of different ptch1 variants on jaw development may help to explain how this group has managed to evolve so many species in such a brief period of time. A single genetic change affects multiple skeletal elements in a way that influences feeding mechanics. Natural selection doesn't need to coordinate changes at multiple places in the genome to enable a species to adapt to a new environment. A small number of changes is likely sufficient to enable competing species to carve out different niches, enabling their coexistence. This is really the crux of biodiversity, how efficiently species are able to adapt in a changing environment."

While the effects of ptch1 on cichlid development described here are limited to the lower jaw, in another recent paper in *Nature Communications* Albertson and colleagues show how changes in a second well characterized molecular pathway, the Wnt/β-catenin pathway, can lead to functionally relevant changes in the cichlid upper jaw.

More information: Hedgehog signaling mediates adaptive variation in a dynamic functional system in the cichlid feeding apparatus, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1323154111

Provided by University of Massachusetts Amherst