Hard-to-find fish reveals shared developmental toolbox of evolution

January 10 2011

(PhysOrg.com) -- A SCUBA expedition in Australia and New Zealand to find the rare embryos of an unusual shark cousin enabled American and British researchers to confirm new developmental similarities between fish and mammals.

Elephant fish, a relative of sharks, utilize the same genetic process for forming skeletal gill covers that lizards and mammals use to form fingers and toes, researchers at the University of Chicago and the University of Cambridge found. The precise timing of when and where that gene is expressed during embryonic development produces dramatic anatomical differences between elephant fish and their close relatives, the dogfish.

The study, published online January 10th by the Proceedings of the National Academy of Sciences, confirms that organisms separated by hundreds of millions of years of evolution share similar genetic programs for body formation.

"The research highlights how evolution is extremely efficient, taking advantage of preexisting mechanisms, rather than inventing new ones," said Andrew Gillis, PhD, at the University of Cambridge and lead author. "By simply tinkering with the timing of when or where a gene is expressed in an embryo, you can get very different anatomical outcomes in adults."

"You have a common nail that's used for many different pieces of furniture," said Neil Shubin, PhD, Robert R. Bensley Professor of Organismal Biology & Anatomy at the University of Chicago and senior author of the paper. "This esoteric fish with this esoteric anatomical system is showing us something very fundamental about the evolutionary tree: that there's a common process at work among disparate types of organisms."

The holocephalans are a family of fish that share a cartilage-based skeleton with better known animals such as sharks and rays. Another shared feature is the presence of appendages called branchial rays, structures that grow outward from the skeleton's central gill arches. While sharks form several sets of these rays, holocephalans only grow a single set near their head, which eventually supports covers for their gills.

Evolutionary biologists looking for the genetic mechanisms behind these anatomical differences have long sought to study the embryos of holocephalans and sharks. But the experiment was easier said than done, because of the inconvenient location where holocephalan eggs are laid: at the bottom of the ocean floor.

Undeterred, Dr. Gillis, now a postdoctoral researcher at Cambridge, used accounts from local fishermen and fishery biologists to find potentially accessible areas of elephant fish breeding in Australia and New Zealand. By conducting SCUBA surveys of those regions, Gillis and colleagues were able to collect a precious supply of elephant fish embryos to bring back to laboratories in Chicago and Cambridge for further experimental analysis.

"Diving for elephant fish eggs was not always a pleasure trip," says Dr Gillis. "Unfortunately, elephant fish like to lay their eggs in cold, muddy, shark-infested bays, so we spent months seeking out sites like this in southeastern Australia and New Zealand. When you finally find a few eggs in the muck, it feels like winning the lottery."

The embryos of elephant fish and dogfish, a kind of shark, were stained at different ages for the sonic hedgehog (Shh) gene, a factor first isolated in the late 1970's in fruit flies for its ability to control body development. At early stages of development, researchers detected Shh expression at the hyoid arch and four of the gill arches in both species.

But within a few weeks, Shh is only expressed in the hyoid arch of the elephant fish embryo, while the dogfish embryo continues to express the gene along all five arches. Therefore, the different patterns of Shh expression match the eventual anatomical differences in the growth of branchial rays.

"It's a real feat because we had a limited number of eggs, and with that limited number, each specimen had to be a home run," Shubin said. "You had to get the techniques to work. Andrew was kind of swinging for the fences; not only was he hoping to collect rare embryos, but also to get them to work in the lab, and that was really impressive."

The data demonstrate how a small change in the timing of gene expression can produce dramatically different anatomical outcomes in closely related species. The specific dynamics in elephant fish – who initially carry the potential for five sets of branchial rays, before reducing the number to one – is parallel to genetic programs in other, vastly different species, such as lizards who have reduced numbers of fingers on their limbs.

"It's basically showing that the limb story is part of a much more general narrative, which is the story of outgrowths," said Shubin, who led the team that discovered the important transitional fossil Tiktaalik fossil in 2008. "There's a common development toolkit for all the outgrowths that we know in the body; they're all versions of one another in a developmental sense."

More information: The study, "Holocephalan embryos provide evidence for gill arch appendage reduction and opercular evolution in cartilaginous fishes," is published online January 10, 2011 in *PNAS Early Edition* and is freely available.

Provided by University of Chicago Medical Center