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Gene controls beak morphology

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Scientists have pinpointed a molecular basis for size variations in the beaks of Galapagos finches', a phenomenon observed by Charles Darwin more than a century and a half ago.

In this week's issue of Science, Harvard University developmental biologist Cliff Tabin and colleagues identified *bone morphogenetic protein (Bmp)-4* as a key player in the pathway controlling avian beak development (*Science* 2004, **305:**1462-1465). His team includes Peter and Rosemary Grant, whose research endeavors on the islands were recorded in Jonathan Weiner's Pulitzer Prize-winning account.

"The idea is that these finches have evolved a mechanism for changing their jaw skeleton rapidly and in response to environmental pressures," explained cell biologist and orthopedic surgeon Jill Helms, who recently moved from the University of California, San Francisco, to Stanford University.

Helms, who was not involved in the study, said that Tabin's group tried to answer a question about beak variations first posed by Darwin himself. "He said they arose from 'causes of which we are wholly ignorant.' Basically, [Tabin's] paper is addressing that: what is the cause for this diversity in shape?"

Tabin's group examined eggs from six species of Galapagos finches (genus *Geospiza*): the sharp-beaked finch (*G. difficilis*), which has a small, symmetrical beak; the small, medium, and large ground finches (*G. fuliginosa*, *G. fortis*, and *G. magnirostris*), with their broad, deep beaks for crushing seeds; and cactus and large cactus finches (*G. scandens* and *G. conirostris*), which use their long, narrows beaks for sipping nectar.

While some growth factors that the team studied, such as *Sonic hedgehog* and *Fibroblast growth factor 8*, showed no differences in expression patterns between the six species, and others such as *Bmp2* and *Bmp7* correlated with beak size, only *Bmp4* exhibited a correlation with beak shape. Birds with deeper, wider beaks expressed the gene earlier and at higher levels in the mesenchyme of their upper beaks than their relatives. The researchers confirmed their results through a series of experiments misexpressing *Bmp4* in developing chicks.

Helms pointed out one caveat: "The stage at which they got the embryos, you can already tell their beaks look different. So, the change in *Bmp4* expression doesn't precede the morphologic variation, but you can only do so much."

"It's clear that you have a gene that is varying between these different species and that this variation is important for the morphology," explained Tabin. "At a more reductionist level, whether there are changes in the nucleic acids of the *Bmp4* gene itself is totally unclear. But we now at least know a pathway that's been modified... in these different birds, and knowing that, we can ask interesting evolutionary questions."

Helms also noted that these results are supported by earlier research done on the genetics underlying variation in cichlid jaws, where *Bmp4* expression is also altered, although *Bmp4* is "not the causal factor" of the variation in either cichlids or finches.

An accompanying study by Cheng-Ming Chuong and colleagues in the University of Southern California's Department of Pathology also found that *Bmp4* is a major molecular player in the development of chicken and duck beaks (*Science* 2004, **305:**1465-1466).

"We tried to understand how a particular organ takes its size or shape," explained Chuong. "Chickens have these very small and conical shaped beaks, but the duck's is wide, long, like a petal. So our question is how they form these different shapes during embryonic time."

Chuong's group addressed two sides of that question: where new cells are added during formation, and what molecule might control that. In later development, chickens have only one growth zone in their frontonasal mass, while ducks have two. After looking at several growth factors, they found that *Bmp4* colocalized with the activity in these growth zones, according to Chuong.

To verify that *Bmp4* was directing beak shape, they used gene therapy and protein delivery techniques to overexpress *Bmp4* and its antagonist, noggin, in developing chicks. Increased levels of *Bmp4* produced beaks with increased length, width, and depth; treatment with noggin reduced beak dimensions.

"Our results show that *Bmp4* is one of the major driving forces building beak mass," Chuong wrote in his report. He told us, "It is most satisfying that by modifying this molecular pathway, we were able to produce beaks that really mimic the diverse beaks existing in nature."

These papers are "beautiful examples of trying to bring new molecular and developmental studies to really classic systems of evolutionary biology," said Stanford University developmental biologist David Kingsley.

"I think what's now becoming possible is to take the sorts of tools and approaches that have only been used in laboratory organisms and begin applying them to these classic examples of evolution in nature," Kingsley told us.

Kingsley, who was not involved in the study, noted, "The thing that's really encouraging is that... in many cases these very interesting morphological changes can now be linked to real developmental pathways."

References

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