Tooth loss in birds occurred about 116 million years ago

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The absence of teeth or "edentulism" has evolved on multiple occasions within vertebrates including birds, turtles, and a few groups of mammals such as anteaters, baleen whales and pangolins. Where early birds are concerned, the fossil record is fragmentary. A question that has intrigued biologists is: Based on this fossil record, were teeth lost in the common ancestor of all living birds or convergently in two or more independent lineages of birds?

A research team led by biologists at the University of California, Riverside and Montclair State University, NJ, has found an answer. Using the degraded remnants of tooth genes in birds to determine when birds lost their teeth, the team reports in the Dec. 12 issue of *Science* that teeth were lost in the common ancestor of all living birds more than 100 million years ago.

"One of the larger lessons of our finding is that 'dead genes,' like the remnants of dead organisms that are preserved in the fossil record, have a story to tell," said Mark Springer, a professor of biology and one of the lead authors of the study along with Robert Meredith at Montclair State University who was previously a graduate student and postdoctoral researcher in Springer's laboratory. "DNA from the crypt is a powerful tool for unlocking secrets of evolutionary history."

Springer explained that edentulism and the presence of a horny beak are hallmark features of modern birds.

"Ever since the discovery of the fossil bird *Archaeopteryx* in 1861, it has been clear that living birds are descended from toothed ancestors," he said. "However, the history of tooth loss in the ancestry of modern birds has remained elusive for more than 150 years."

All toothless/enamelless vertebrates are descended from an ancestor with enamel-capped teeth. In the case of birds, it is theropod dinosaurs. Modern birds use a horny beak instead of teeth, and part of their digestive tract to grind up and process food.

Tooth formation in vertebrates is a complicated process that involves many different genes. Of these genes, six are essential for the proper formation of dentin (*DSPP*) and enamel (*AMTN, AMBN, ENAM, AMELX, MMP20*).

The researchers examined these six genes in the genomes of 48 bird species, which represent nearly all living bird orders, for the presence of inactivating mutations that are shared by all 48 birds. The presence of such shared mutations in dentin and enamel-related genes would suggest a single loss of mineralized teeth in the common ancestor of all living birds.

Springer, Meredith, and other members of their team found that the 48 bird species share inactivating mutations in both dentin-related (*DSPP*) and enamel-related genes (*ENAM*, *AMELX, AMTN*, *MMP20*), indicating that the genetic machinery necessary for tooth formation was lost in the common ancestor of all modern birds.

"The presence of several inactivating mutations that are shared by all 48 bird species suggests that the outer enamel covering of teeth was lost around ~116 million years ago," Springer said.

On the basis of fossil and molecular evidence, the researchers propose a two-step scenario whereby tooth loss and beak development evolved together in the common ancestor of all modern birds. In the first stage, tooth loss and partial beak development began on the anterior portion of both the upper and lower jaws. The second stage involved concurrent progression of tooth loss and beak development from the anterior portion of both jaws to the back of the rostrum.

"We propose that this progression ultimately resulted in a complete horny beak that effectively replaced the teeth and may have contributed to the diversification of living birds," Springer said.

The research team also examined the genomes of additional toothless/enamelless vertebrates including three turtles and four mammals (pangolin, aardvark, sloth, and armadillo) for inactivating mutations in the dentin- and enamel-related genes. For comparison, the researchers looked at the genomes of mammalian taxa with enamel-capped teeth.

"All edentulous vertebrate genomes that we examined are characterized by inactivating mutations in *DSPP*, *AMBN*, *AMELX*, *AMTN*, *ENAM*, and *MMP20*, rendering these genes non-functional," Springer said. "The dentin-related gene *DSPP* is functional in vertebrates with enamelless teeth - sloth, aardvark, armadillo. All six genes are functional in the American alligator, a representative of Crocodylia, the closest living relatives of birds, and mammalian taxa with enamel capped teeth."

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Springer and Meredith were joined in the research by Guojie Zhang at China National GeneBank, China; M. Thomas P. Gilbert at the University of Copenhagen Oster Voldgade, Denmark; and Erich D. Jarvis at Duke University Medical Center, NC.

All the scientists are coauthors with several others, including UC Riverside biologist John Gatesy, on a second paper in the same issue of *Science*. This paper employs the same 48 bird genomes to ask the question: "What makes a bird a bird?"

"The new bird genomes represent a major advance given that only a handful of bird genomes - zebra finch, turkey, chicken and duck - were previously available," Springer said.

More information: "Evidence for a single loss of mineralized teeth in the common avian ancestor," by R.W. Meredith et al. *Science*, www.sciencemag.org/lookup/doi/ … 1126/science.1254390

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