The hidden rule for flight feathers and how it could reveal which dinosaurs could fly

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The wing, highlighting the flight feathers, of Temminck's Lark. Credit: Yosef Kiat

Birds can fly—at least, most of them can. Flightless birds like penguins and ostriches have evolved lifestyles that don't require flight. However, there's a lot that scientists don't know about how the wings and feathers of flightless birds differ from their airborne cousins.

In a new study in the journal *PNAS*, scientists examined hundreds of birds in museum collections and discovered a suite of feather characteristics that all flying birds have in common. These "rules" provide clues as to how the dinosaur ancestors of modern birds first evolved the ability to fly, and which dinosaurs were capable of flight.

Not all dinosaurs evolved into birds, but all living birds are dinosaurs. Birds are members of the group of dinosaurs that survived when an asteroid hit the Earth 66 million years ago. Long before the asteroid hit, some of the members of a group of dinosaurs called Penneraptorans began to evolve feathers and the ability to fly.

Members of the Penneraptoran group began to develop feathers before they were able to fly; the original purpose of feathers might have been for insulation or to attract mates. For instance, Velociraptor had feathers, but it couldn't fly.

Of course, scientists can't hop in a time machine to the Cretaceous Period to see whether Velociraptors could fly. Instead, paleontologists rely on clues in the animals' fossilized skeletons, like the size and shape of arm/wing bones and wishbones, along with the shape of any preserved feathers, to determine which species were capable of true, powered flight. For instance, the long primary feathers along the tips of birds' wings are asymmetrical in birds that can fly, but symmetrical in birds that can't.

The primary feathers of a penguin. Credit: Yosef Kiat

The quest for clues about dinosaur flight led to a collaboration between Jingmai O'Connor, a paleontologist at the Field Museum in Chicago, and Yosef Kiat, a postdoctoral researcher at the Field.

"Yosef, an ornithologist, was investigating traits like the number of different types of wing feathers in relation to the length of arm bone they attach to, and the degree of asymmetry in birds' flight feathers," said O'Connor, the museum's associate curator of fossil reptiles, who specializes in early birds.

"Through our collaboration, Yosef is able track these traits in fossils that are 160–120 million years old, and therefore study the early evolutionary history of feathers."

Kiat undertook a study of the feathers of every order of living birds, examining specimens from 346 different species preserved in museums around the world. As he looked at the wings and feathers from hummingbirds and hawks, penguins and pelicans, he noticed a number of consistent traits among species that can fly.

For instance, in addition to asymmetrical feathers, all the flighted birds had between nine and 11 primary feathers. In flightless birds, the number varies widely— penguins have more than 40, while emus have none. It's a deceptively simple rule that's seemingly gone unnoticed by scientists.

"It's really surprising, that with so many styles of flight we can find in modern birds, they all share this trait of having between nine and 11 primary feathers," says Kiat. "And I was surprised that no one seems to have found this before."

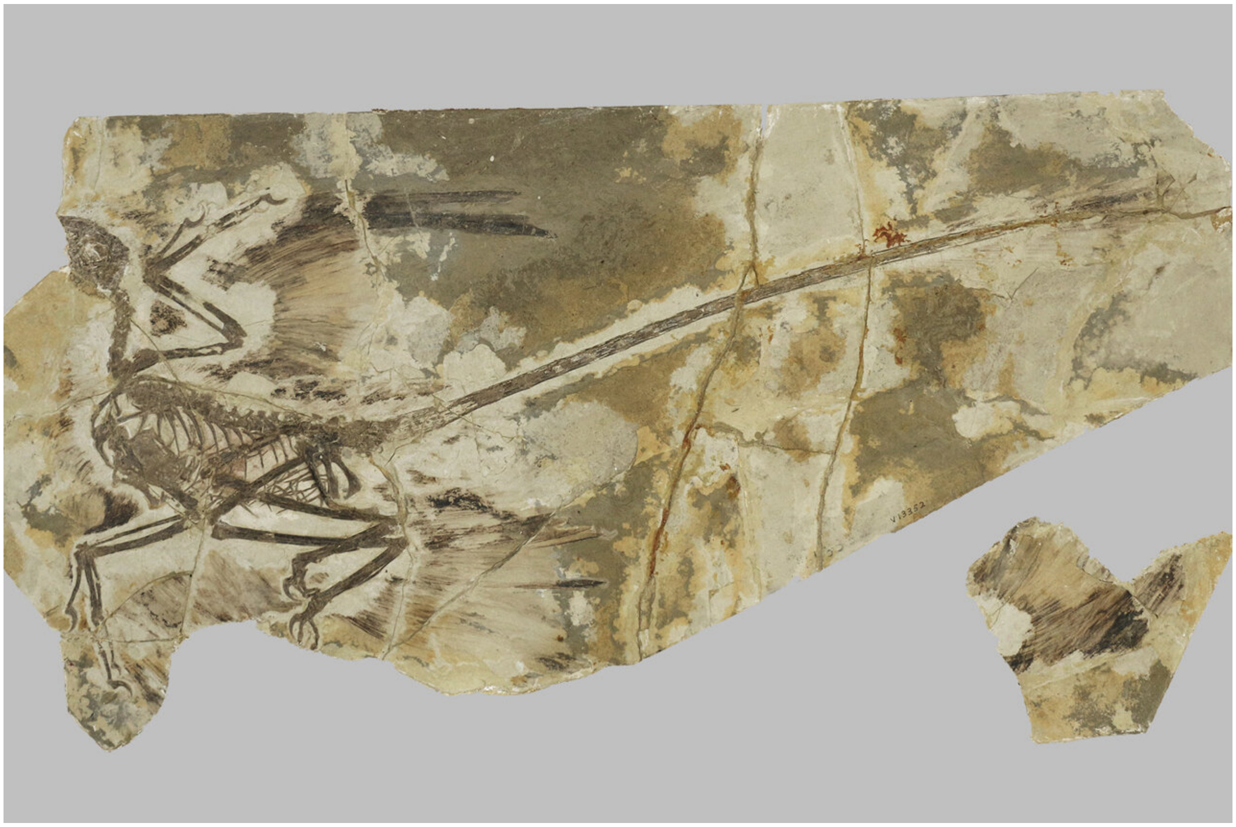
Fossil showing the wing and feathers of the prehistoric bird Confuciusornis. Credit: Yosef Kiat

By applying the information about the number of primary feathers to the overall bird family tree, Kiat and O'Connor also found that it takes a long time for birds to evolve a different number of primary feathers. "This trait only changes after really long periods of geologic time," says O'Connor. "It takes a very long time for evolution to act on this trait and change it."

In addition to modern birds, the researchers also examined 65 fossil specimens representing 35 different species of feathered dinosaurs and extinct birds. By applying the findings from modern birds, the researchers were able to extrapolate information about the fossils. "You can basically look at the overlap of the number of primary feathers and the shape of those feathers to determine if a fossil bird could fly, and whether its ancestors could," says O'Connor.

For instance, the researchers looked at the feathered dinosaur Caudipteryx. Caudipteryx had nine primary feathers, but those feathers are almost symmetrical, and the proportions of its wings would have made flight impossible. The researchers said it's possible that Caudipteryx had an ancestor that was capable of flight, but that trait was lost by the time Caudipteryx arrived on the scene.

Since it takes a long time for the number of primary feathers to change, the flightless Caudipteryx retained its nine primaries. Meanwhile, other feathered fossils' wings seemed flight-ready— including those of the earliest known bird, Archaeopteryx, and Microraptor, a tiny, four-winged dinosaur that isn't a direct ancestor of modern birds.



Fossil showing the wings and feathers of the dinosaur Microraptor. Credit: Yosef Kiat

Blackburnian Warblers in the collections of the Field Museum used in this study. Credit: Yosef Kiat

Taken a step further, these data may inform the conversation among scientists about the origins of dinosaurian flight. "It was only recently that scientists realized that birds are not the only flying dinosaurs," says O'Connor.

"And there have been debates about whether flight evolved in dinosaurs just once, or multiple separate times. Our results here seem to suggest that flight only evolved once in dinosaurs, but we have to really recognize that our understanding of flight in dinosaurs is just beginning, and we're likely still missing some of the earliest stages of feathered wing evolution."

"Our study, which combines paleontological data based on fossils of extinct species with information from birds that live today, provides interesting insights into feathers and plumage—one of the most interesting evolutionary novelties among vertebrates. Thus, it helps us learn about the evolution of these dinosaurs and highlights the importance of integrating knowledge from different sources for an improved understanding of evolutionary processes," says Kiat.

"Theropod dinosaurs, including birds, are one of the most successful vertebrate lineages on our planet," says O'Connor.

"One of the reasons that they're so successful is their flight. One of the other reasons is probably their feathers, because there's such versatile structures. So any information that can help us understand how these two important features co-evolved that led to this enormous success is really important."

More information: Kiat, Yosef et al, Functional constraints on the number and shape of flight feathers, *Proceedings of the National Academy of Sciences* (2024). DOI: 10.1073/pnas.2306639121

Provided by Field Museum