Expert insight into current research

News & views

Palaeontology

Fossil suggests ancestral bird beak was mobile

Christopher R. Torres

A 67-million-year-old fossil bird found in Europe provides evidence suggesting that scientists should reconsider centuries-old ideas about the nature of the ancestral avian beak. **See p.100**

When it comes to understanding the earliest evolution of modern birds, beak structure is crucial. It was mainly differences in the beak – specifically, the structure of the bony palate in the roof of the mouth that supports the beak – that enabled researchers to distinguish between the earliest-known divergence of modern birds: their split into two daughter lineages[1]. On one side of that divergence is a group termed Palaeognathae, comprising flightless birds called ratites (ostriches, emus, rheas, cassowaries and kiwis) and flying birds called tinamous. On the other side is a group called Neognathae, which consists of all other living birds. Those names hint at the conventional idea about which beak type came first: Palaeognathae (meaning 'ancient jaw') inherited their condition from pre-modern birds, whereas Neognathae ('new jaw') have a palate thought to have arisen later. On page 100, Benito *et al.*[2] turn that transition around with their report of *Janavis finalidens*, an ancient bird with surprising stories to tell about the early evolution of modern birds and the organization of that all-important palate.

The fossil at the heart of the study is a 67-million-year-old jumble of bones recovered from Belgium that includes bits of the vertebral column, wings, shoulders and legs. Only two traces of the skull, albeit crucial ones, are preserved: a tooth and a bone from the palate called the pterygoid (Fig. 1). The namesake of the new species is Janus, the Roman god of beginnings, endings and transitions, a fitting inspiration considering where *Janavis* is perched in the avian tree of life. *Janavis* belongs to a lineage of pre-modern birds called Ichthyornithes. Palaeornithologists continue to debate the precise relationship of Ichthyornithes to modern birds, but all agree it is a very close one – think of a connection equivalent to that of second or third cousins[3,4]. That closeness is a big part of why Ichthyornithes is so crucial to our understanding of the major transitions in life history that characterize the origins of modern birds. For example, the hypothesis that a toothless beak arose at the origin of modern birds is based on the fact that their closest known relatives, such as *Janavis* and other ichthyornithines, still had teeth.

Janavis expands our understanding of Ichthyornithes in several ways: depending on how the estimation is made, it is 2 to 13 times larger than its better-known fellow ichthyornithine *Ichthyornis*, and is 10 million to 20 million years younger[5], lingering in Europe until just before the end-Cretaceous mass extinction, around 66 million years ago, that wiped out all known dinosaurs except the ancestors of modern birds. *Janavis* also had a more air-filled (pneumatized) skeleton than did *Ichthyornis*, meaning that Ichthyornithes might shed light on how and why skeletons become pneumatized, a process poorly understood even for living birds. However, the most intriguing insights to be gleaned from *Janavis* concern the very features of the skull that gave Palaeognathae and Neognathae their names – no mean feat for a bird with only one unearthed skull bone: the pterygoid.

The pterygoid bone sits at the heart of key differences between the palates of palaeognath and neognath birds. In neognaths, the pterygoid forms mobile joints with the bones around it, including the palatine, the quadrate and, in some birds, the base of the skull. Thus, the bony palate is functionally decoupled from the rest

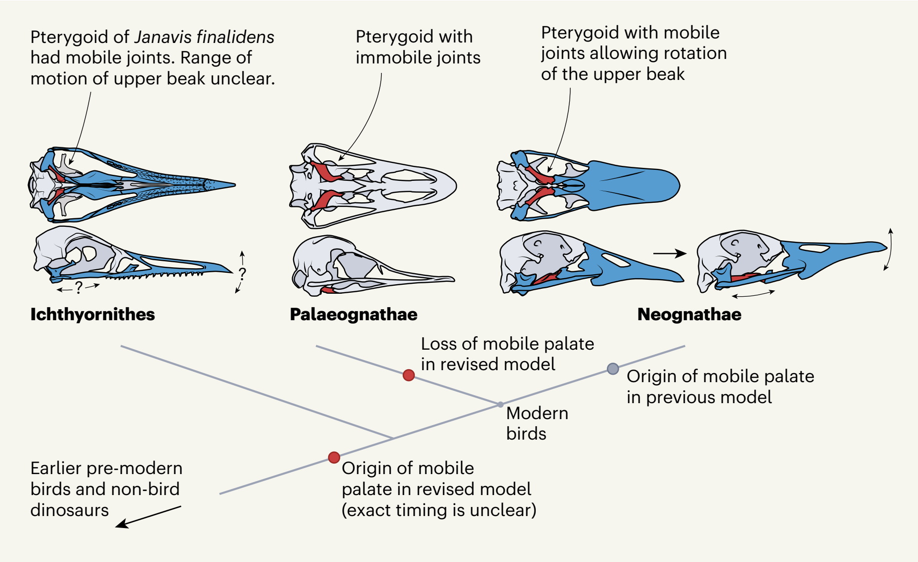

Figure 1 | Evolution of the bird beak. In the group of modern birds called Neognathae, the pterygoid bone (red) forms mobile joints with nearby bones, allowing the bony palate in the roof of the mouth and the upper beak to move relative to the rest of the skull (blue bones can move relative to the skull). By contrast, in the other group of modern birds, termed Palaeognathae, the pterygoid is immobile, restricting motion of the upper beak. Historically, a mobile palate was thought to have arisen after the origin of modern birds. However, Benito *et al.*[2] report a fossil of *Janavis finalidens*, a bird belonging to a lineage of pre-modern birds called Ichthyornithes (illustrated here using the skull of fellow ichthyornithine *Ichthyornis*, for which no pterygoid has yet been discovered). The pterygoid of *Janavis* clearly formed mobile joints with nearby bones, suggesting that, like neognaths, it had a mobile palate. This discovery supports a revised model in which a mobile palate arose before the origin of modern birds and was lost in palaeognaths. (Figure adapted from Fig. 2 of ref. 2 and figures in refs 3 and 4.)

of the cranium and provides the upper jaw with a remarkable range of mobility. Mobility of the upper jaw is severely restricted in palaeognaths, in which the pterygoid instead forms rigid, immobile joints with the palatine and the base of the skull. Other dinosaurs, including the earliest non-modern birds, had immobile palates similar to those of palaeognaths, and so it has long been assumed that the ancestor of all living birds must also have had an immobile palate. In that scenario, palaeognaths would indeed live up to their name of 'old jaw'.

Benito *et al*. used 3D imaging and quantitative shape analyses to demonstrate that the pterygoid of *Janavis* is decidedly more like those of neognaths (especially ducks and chickens) than those of palaeognaths, and show that it is complete with mobile joints with the palatine and skull base. The presence of a neognath-like palate in a close relative of modern birds supports a revised sequence of evolutionary events, in which neognaths are the true inheritors of the ancestral avian condition, and palaeognaths represent a surprising reversion to the characteristics of a pre-modern-bird state.

This report of *Janavis* is auspiciously timed. Some studies have described nearly complete bony palates from other close relatives of living birds, including *Ichthyornis*, that are more consistent with a neognath-like palate than a palaeognath-like one[4,6], calling into question the historical reputation of neognaths as palatal innovators. Unfortunately, those bony palates did not preserve the most telling element, the pterygoid. *Janavis* finally fills that gap, and in so doing, poses some surprising new questions and reframes some old ones.

What evolutionary pressures drove the ancestors of palaeognaths to evolve back along a pathway to having an immobile palate? That transition seems to have been a bad move – popular hypotheses implicate the palate in helping to drive the staggering diversification in Neognathae (comprising more than 11,000 living species) when compared with Palaeognathae (less than 100 living species)[7]. A mobile palate provides neognaths with a range of advantages over palaeognaths, including wider gapes, stronger bite forces and the ability to handle food more dexterously[8,9]. Although the link between palate type and species diversification bears further testing, discoveries such as *Janavis* provide an intriguing new context for consideration.

Janavis and other near relatives of living birds have a lot more to tell us, not only about which beak type came first, but also how those beak types evolved in the first place. Adult ichthyornithines have a bone in the palate called the hemipterygoid that is known only in hatchling neognaths and is lost in adults[4,6]. What effect, if any, does that extra bone have on the potential mobility of the beak in early birds? Why was it lost in adult neognaths? What happened to it in palaeognaths? Some of those stories might come from the beaks of birds such as *Janavis* – but only if we keep looking for them.

Christopher R. Torres is at the Heritage College of Osteopathic Medicine, Ohio University, Athens, Ohio 45701, USA.
e-mail: chris.robert.torres@gmail.com

1. Pycraft, W. P. *Trans. Zool. Soc. Lond.* **15**, 149–290 (1900).
2. Benito, J., Kuo, P.-C., Widrig, K. E., Jagt, J. W. M. & Field, D. J. *Nature* **612**, 100–105 (2022).
3. Field, D. J. *et al. Nature* **557**, 96–100 (2018).
4. Torres, C. R., Norell, M. A. & Clarke, J. A. *Sci. Adv.* **7**, eabg7099 (2021).
5. Clarke, J. A. *Bull. Am. Mus. Nat. Hist.* No. 286 (2004).
6. Bell, A. & Chiappe, L. M. *Life* **10**, 62 (2020).
7. del Hoyo, J. *All the Birds of the World* (Lynx, 2020).
8. Hu, H. *et al. Proc. Natl Acad. Sci. USA* **116**, 19571–19578 (2019).
9. Gussekloo, S. W. S. *et al. Evolution* **71**, 1327–1338 (2017).

The author declares no competing interests.

Climate science

Rapid warming linked to leap in tropical seasonality

Alyssa R. Atwood

Seasonal variation in tropical sea surface temperatures doubled during an abrupt warming event 11,700 years ago. This shows that seasonal changes must be considered when inferring past climatic events, and predicting those to come. **See p.88**

Since the peak of the last glacial state 21,000 years ago, Earth's climate system has warmed to the present interglacial state, known as the Holocene. But this trend was not smooth – temperatures jumped by up to 10° C over a period of years to decades during two warming events around 14,700 and 11,700 years ago[1–3]. No modern analogue exists for these abrupt climate events. This makes such events crucial for grasping the erratic way in which the climate system can respond to external changes, with relevance to understanding current anthropogenic warming trends. Although these deglacial changes are generally well characterized on decadal and longer timescales, little is known about them on shorter timescales. On page 88, Wörmer *et al.*[4] report that data on these shorter timescales reveal that surface temperatures in the tropical Atlantic Ocean showed a large increase in seasonal variation at the start of the Holocene.

The warming of the past 21,000 years was caused by gradual changes in Earth's orbit. These changes led to an increase in the amount of sunlight received during summers in the Northern Hemisphere, which melted the large ice sheets there, allowing more sunlight to be absorbed at Earth's surface and triggering further warming. In contrast to the gradual pace of the orbital changes, however, the climate system warmed in fits and starts, highlighting the existence of tipping points, or thresholds, at which small changes can induce new states.

Around 14,700 years ago, an event known as the Bölling–Allerød warm period brought the climate system abruptly out of the last ice age, with temperatures rising rapidly from glacial to interglacial conditions in just a few decades. Temperatures eventually dropped back into glacial conditions, culminating in a period known as the Younger Dryas cold event around 12,900 years ago[1–3,5]. This event was probably driven by a large injection of meltwater from the ice sheets into the North Atlantic Ocean that disrupted ocean circulation patterns[6,7]. The cooling terminated abruptly around 11,700 years ago, marking the onset of the Holocene, and involved a second period of rapid warming of up to 10 °C over several decades or less[1,2].

These events are well characterized for the polar regions, but high-resolution data detailing how tropical temperatures varied during this time are sparse. This is especially true in the tropical oceans, because these data typically come from the chemical composition of marine sediments, which accumulate slowly and get mixed by organisms living on the sea floor. The Cariaco Basin is an exception – a source of palaeoclimate information of high temporal resolution in the tropics. The basin lies off the northern shelf of Venezuela, so it accumulates material from both the land and ocean, and an absence of oxygen in its deep waters leads to conditions that prevent marine organisms from mixing the sediment.

At 10° N latitude, the Cariaco Basin is situated at the northernmost boundary of the Atlantic Intertropical Convergence Zone, which is a region characterized by heavy rainfall from converging moist, low-level winds. Seasonal changes in sea surface temperatures in this region produce a strong annual cycle of rainfall, winds and upwelling (the wind-driven upward