Dinosaur frills were likely the result of sexual selection

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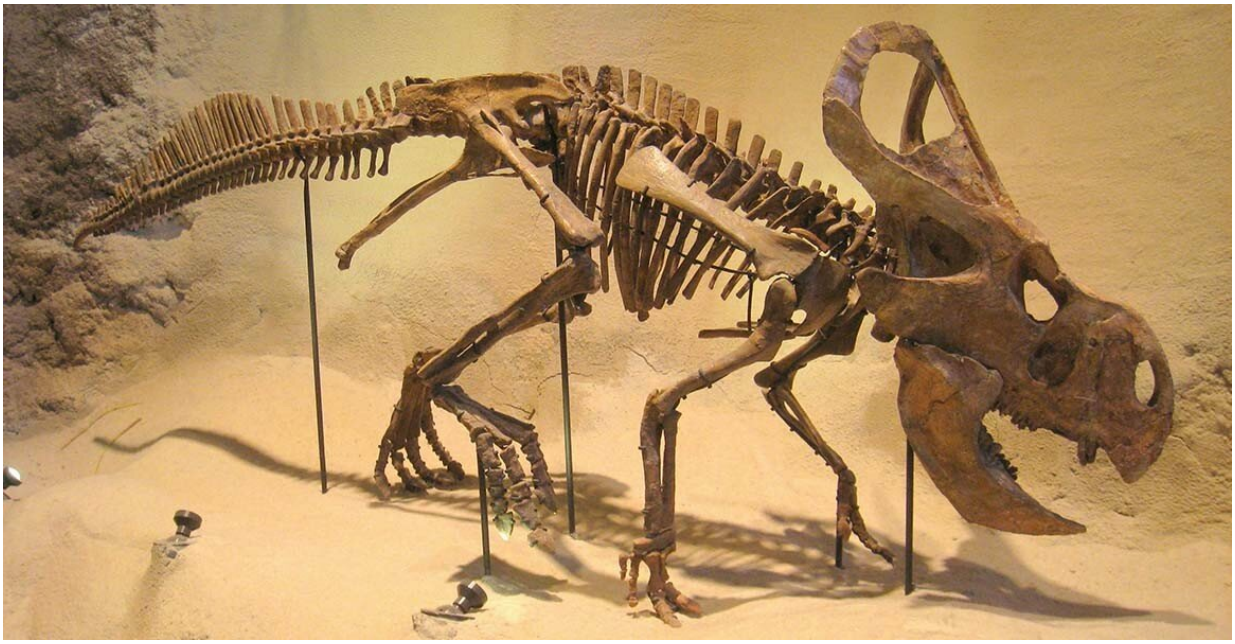


Protoceratrops was a ceratopsian dinosaur from the Cretaceous that grew to around the size of a sheep. Credit: Daderot/Wikimedia Commons

Why dinosaurs evolved such a huge diversity of crests and frills on their skulls has long been an enigma.

But by using modern technology and data analysis, a new study has taken a fresh look at whether some of these features may have been a result of sexual selection.

Dinosaurs are well known for their elaborate horns and crests, and none more so than the iconic frilled dinosaurs such as Triceratops.

Known properly as the ceratopsians, they are characterised by the large horns and ubiquitous neck frills that many of the species sported. What role these ostentatious ornaments played for the living animals has long been debated.

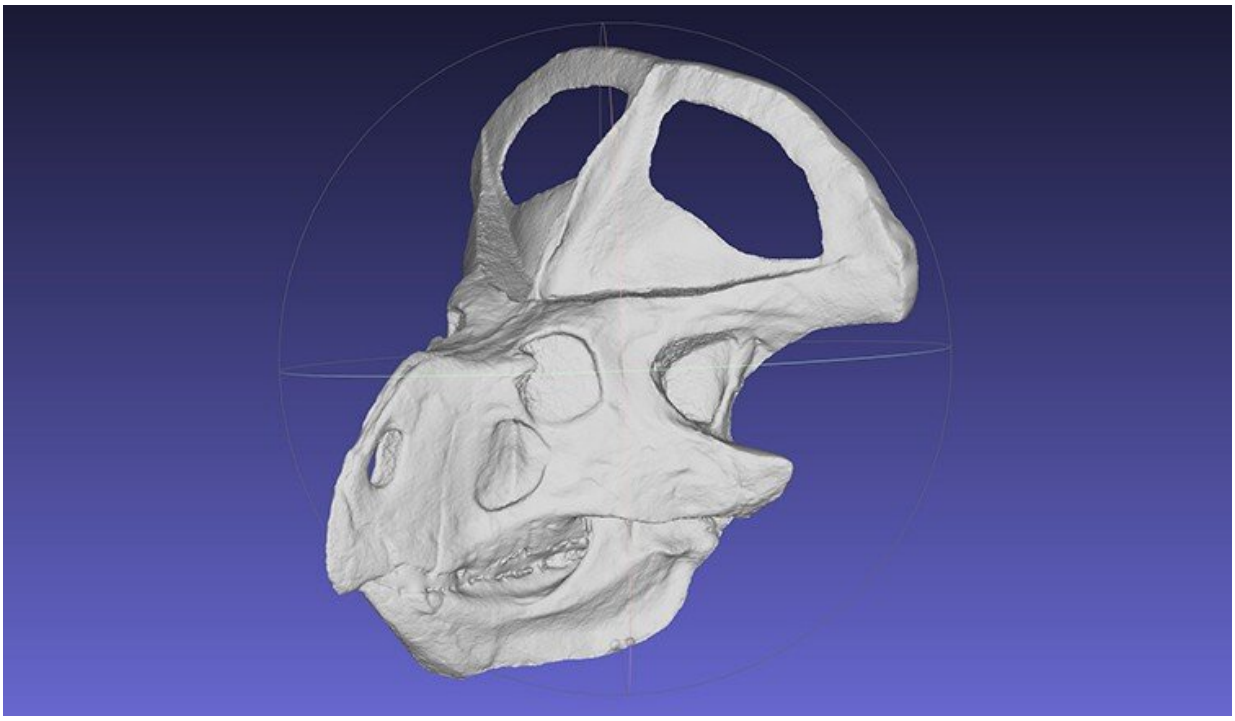
Some theories have suggested that the neck frills were used for protection, others that they played a role in cooling the large herbivores down. It has also been proposed that they allowed animals to recognise different members of their own species.

A fourth theory, first raised by the early twentieth century palaeontologist Franz Nopsca, suggests that they instead played a role in sexual selection. This is the idea that certain traits in animals are favoured by members of the opposite sex, and so in time can become more elaborate and fancy.

But with so few fossils of most species of dinosaurs, this theory of sexual selection in these extinct creatures is notoriously difficult to prove .

Dr. Andrew Knapp, a postdoctoral researcher at the Museum, has been applying modern technology and analysis to the skulls of one species of ceratopsian called Protoceratops. He wanted to see if sexual selection could explain what is going on with their frills.

"In many fossil animals we have unusual structures and traits which aren't really seen in living animals today," explains Andy. "Protoceratops didn't have any horns but they still had a huge frill."



The skulls of Protoceratops are characterised by a large frill projecting out the back, the function of which is still not entirely know. Credit: Andrew Knapp

About the size of a large sheep, Protoceratops is a fairly common and well-studied species of dinosaur that would have lived in what is now Mongolia's Gobi Desert.

While Andy and his colleagues were able to show that the frill of Protoceratops likely evolved as a result of social behaviour between members of the species as opposed to, for example, defence, it is difficult to be conclusive that if it was a result of sexual selection.

The results have been published in the journal *Proceedings of the Royal Society B*.

Complex selection

The structures and features that we see on living species have evolved, by and large, due to the process of natural selection. This is when environmental conditions favour individuals with particular traits, such as horns or long necks, that help them survive. Over time, these traits become more common within the species.

There is another force in play, however, known as sexual selection. Rather than these features helping an animal to survive, they are instead favoured through competition with members of the same sex and by members of the opposite sex. This is how extraordinary characteristics, such as the tail feathers of a peacock, have come to evolve.

The way in which individuals within species can vary depending on their observed sex is knowns as sexual dimorphism.

"But people have come to realise that in actual fact, sexual selection is quite often more complicated than just males being big and flashy and females being dull," explains Andy.

"While there are quite a few examples in living animals where usually females select males based on the size of their tail feathers or calls, it is quite often overlooked that males do the same thing with females as well."

For example, in a species of bird known as the crested auklet, both males and females have a wonderful plume of feathers curling from the tops of their heads. This is because the plume is used by each sex to signal their health.

So while the plume of feathers is a sexually selected trait, it has not led to sexual dimorphism.

"It looks like things are a bit more complex than the bigger the male trait the more successful it is," says Andy.

Looking at the Protoceratops fossils, Andy and his colleagues found their findings to be equally complex.

A detailed look at Protoceratops

Andy was able to look at the 3-D scans of 30 complete skulls of Protoceratops, which makes this the largest complete set of 3-D data for any one dinosaur. These ranged in size from tiny hatchlings to fully grown adults, giving him a full growth series of the species.

He then compared how different regions of the skull vary and how the skull changed shape as the animal grew. From this, he could look for indications that the shapes of the frills were a result of sexual selection.

In living creatures, certain features show a distinct pattern of growth, known as allometry. When the allometry is positive, meaning they show a much greater rate of change in growth when compared to other traits, it is almost always a sexually selected feature, such as the antlers of a deer.

Positive allometry often evolves in these traits because it emphasises body size. Bigger, more mature animals often have proportionally larger traits.

With what is possibly the most complete set of 3D skull scans for any one dinosaur ranging from adults to tiny hatchlings, Andy was able to look at an entire growth series for Protoceratops. Credit: Andrew Knapp

The growth pattern of Protoceratops' frills matched this, indicating that the frills were very possibly sexually selected. However, the team couldn't show any sexual dimorphism among Protoceratops.

"That could be because there was none, or that the differences were very minimal," explains Andy.

"There almost certainly were differences between males and females but quite often differences are in body size, so females will be bigger than males or vice versa. It could also have been through something else like colouration, which doesn't preserve."

This means that while the frills of dinosaurs like ceratopsians were likely down to sexual selection, in reality it is impossible to say this for certain. In extinct animals, there is no way to definitively prove that the individuals with particular traits were more successful and had more offspring.

It is for this reason that Andy and his colleagues conclude that the frills were the result of the more general socio-sexual selection, a term that includes other social behaviour associated with such fancy ornaments.

"In reality, many 'sexually selected' traits perform additional functions such as establishing dominance in a population, which can improve an individual's access to resources like food, water and territory," explains Andy.

"So really, the boundaries between sexual and social selection are quite blurred, and social selection will quite often be an important factor too."

More information: A. Knapp et al. Three-dimensional geometric morphometric analysis of the skull of Protoceratops andrewsi supports a socio-sexual signalling role for the ceratopsian frill, *Proceedings of the Royal Society B: Biological Sciences* (2021). DOI: 10.1098/rspb.2020.2938

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