A new brain-warp technique that helps to reconstruct fossil brains

July 21 2016, by Alice Clement, John Long

The Australian lungfish has a bigger brain than you might think. Credit: Alice Clement, Author provided

Fish have relatively small brains, especially in comparison to birds and mammals. But the picture of how brains evolved, as restored from the spaces inside fossil skulls, might not be as simple as once thought.

There are some groups of fish, such as some sharks and rays, that actually have a very large brain size relative to their body mass. Recent work shows that a group of fish called lungfish also have relatively large brains, one that fills more than 80% of the cranial cavity.

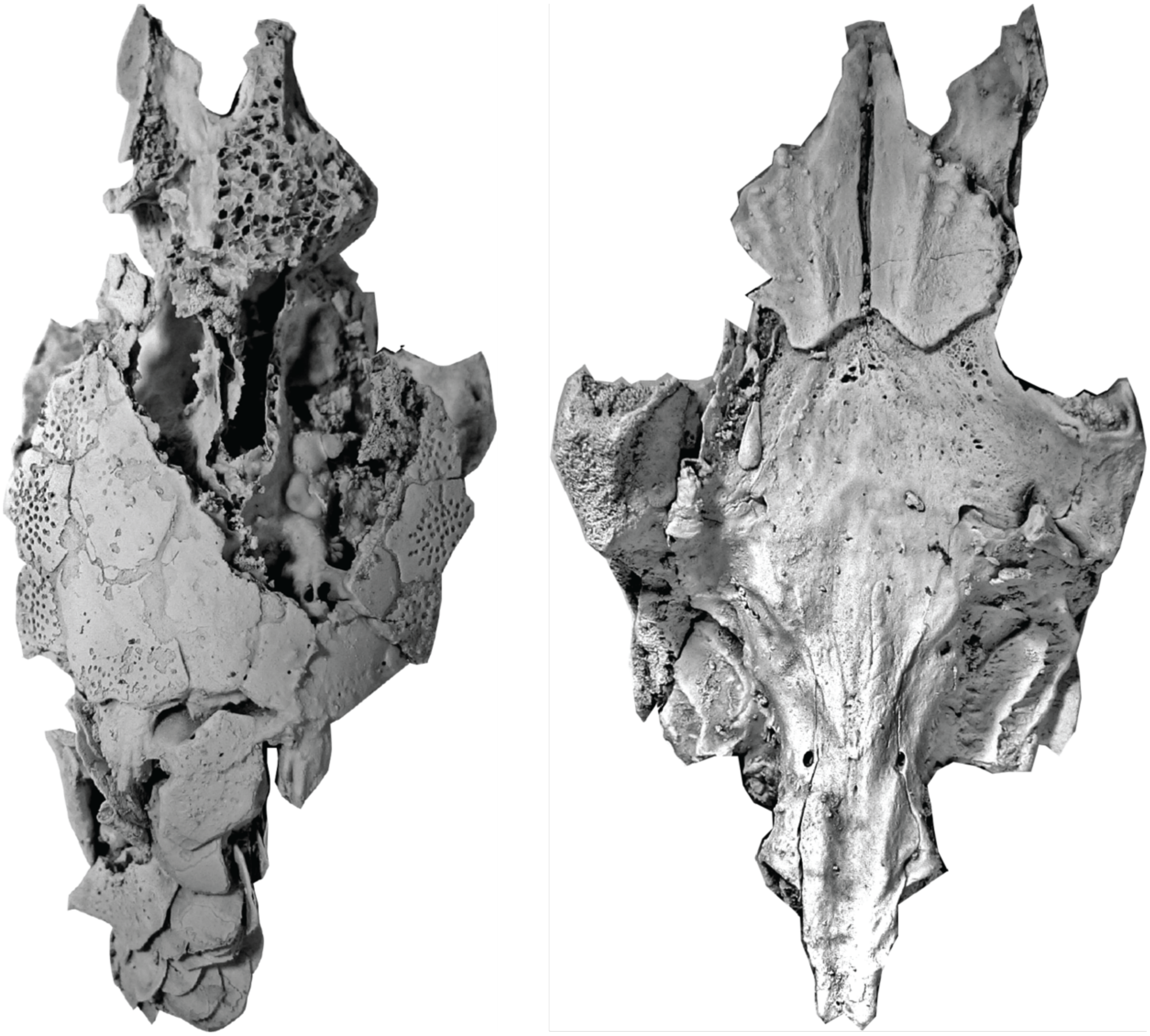
This is in great contrast to their close relative the coelacanth whose brain fills a very small percentage of its cranial cavity (thought to be only 1%).

Lungfish have long fascinated researchers due to their close relationship with the tetrapods – the land-dwelling animals with a backbone, which includes ourselves.

Lungfish can be thought of as our fishy cousins, who can provide great insight into the anatomical changes in our ancient ancestors as they first crawled out of water onto land, some 370 million years ago. But how much did their brains evolve in the process?

The hunt for fossil brains

After an animal has died, soft tissue such as muscle breaks down quickly and doesn't get a chance to fossilise. Because of this, palaeontologists are usually only left with the hard skeletal remains, and almost never get to see organs, such as the heart or brain.



A skull of one of the exceptionally preserved 3D fossils from the Gogo Formation shown in two views (Rhinodipterus). Credit: Author provided

But there are some remarkable exceptions; such as a recently discovered 120 million-year-old fossilised heart. Hearts are made of muscle that can be more easily fossilised compared to brains, which are made of much softer material, and so very rarely ever fossilise.

In 2009, Alan Pradel, from France's Muséum National d'Histoire Naturelle, in Paris, and his team made an exceptional discovery: a fossilised brain preserved in a 300 million-year-old cartilaginous fish. Like the coelacanth, this fish had a very small brain, housed within a much larger skull cavity.

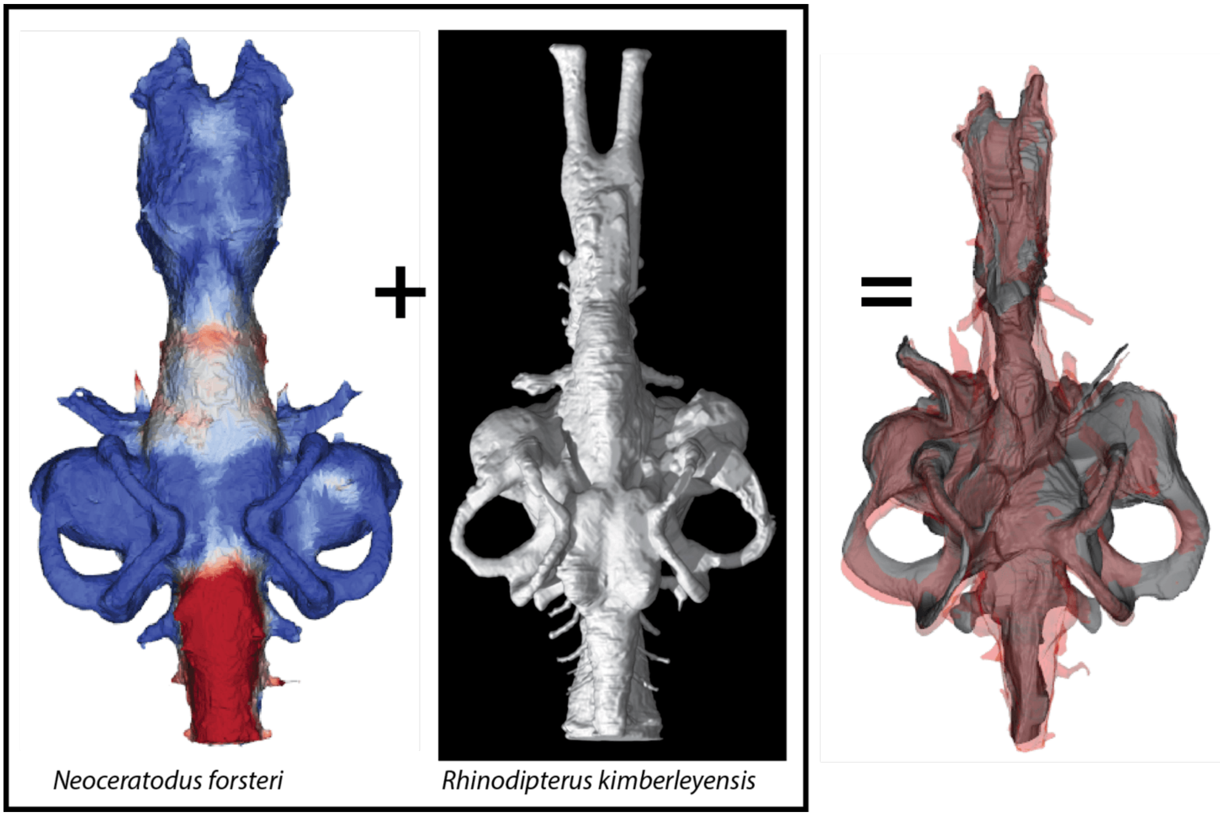
As actual fossilised brains are so frightfully rare, palaeontologists must instead look at the cranial endocast, a mould of the internal cavity that once housed the brain, to reconstruct brain shape.

To do this, you need some very well-preserved (uncrushed) fossils such as those coming from the world famous Gogo Formation in the Kimberley region of Western Australia.

The fossils from Gogo are truly exceptional. The site is world renowned because 385 million-year-old fish fossils can be prepared out of limestone to yield beautifully preserved three-dimensional skulls. They look like they died only yesterday.

Until recently, only a few endocasts were known. These were fossils that had been split in half with hammers or serially ground away to reveal glimpses of the internal anatomy. Although this method can reveal amazing results, it requires destroying rare and irreplaceable specimens.

Palaeontologists have recently found a way around this dilemma. We now routinely scan our specimens using CT scan machines, like those used in hospitals, to reveal internal features without destroying the specimen. This enables us to see inside fossil skulls and start piecing together the evolutionary history of the vertebrate brain.



Reconstructing a fossil brain. Take the brain of the living lungfish and brain-warp it to fit inside a fossil endocast. Credit: Author provided

The first fossil lungfish to receive this treatment was one of those spectacular Gogo fossils called *Rhinodipterus* – named Rhino for its long nose.

Doing the brain-warp

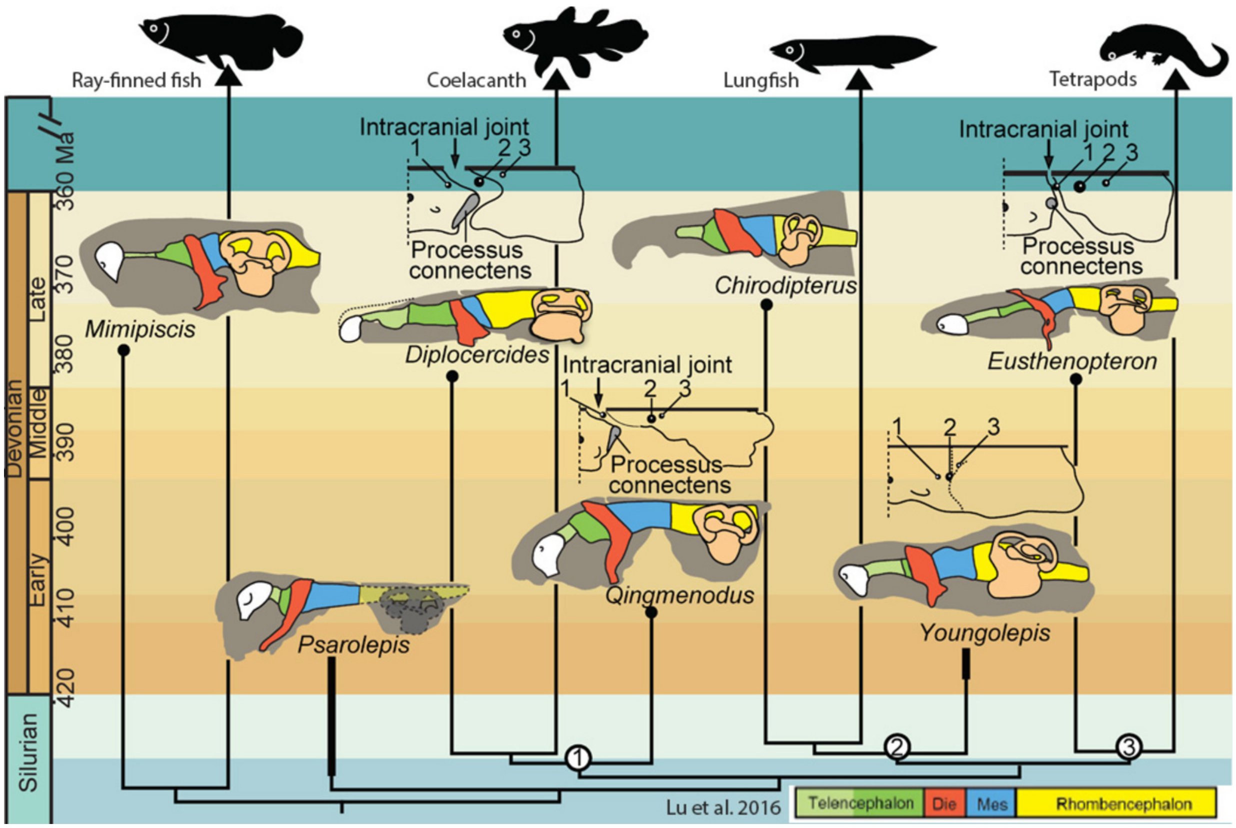
Our team identified 12 points (distinct regions) on both skulls to make direct comparison between the endocasts of the living Australian lungfish *Neoceratodus* and our fossil *Rhinodipterus*. The results are published this week in the *Royal Society Open Science* journal.

Using custom software, we warped the modern lungfish brain and squeezed it to fit inside the fossil lungfish endocast. In the process, we maintained the same spatial relationship between the brain and endocast in the living lungfish, and then applied this 3-D data to the fossil.

This means, for example, that the forebrain, which has a very close fit to the cranial cavity in the living Australian lungfish was reconstructed with the same closeness of fit inside the fossil endocast.

Similarly, the midbrain has a looser fit compared to the forebrain, and is also reconstructed with only a loose fit inside the prehistoric lungfish.

Thus, for the first time ever, the brain of an ancient animal has been quantitatively reconstructed using algorithms that take all the data from the living representative (and its brain shape) to create a fossil reconstruction.



Brain evolution in early fishes leading up to tetrapods (right), reconstructed mostly from fossils by Lu Jing et al (2016). Lungfish are here shown by Chirodipterus from the Gogo site. Credit: Dr Lu Jing, IVPP.

We believe our new brain-warp technique can be adopted across many other fossil groups and will revolutionise the way scientists restore fossil brains and how they study them.

Our approach is much more rigorous than what has gone before. It means scientists can now draw greater inferences from endocast material and study many changes in brain evolution within fossil lineages.

In evolution, it is vital to understand how the brain has changed through time. Brains are the powerhouses that control everything from your heartbeat and breathing, to learning and emotional intelligence.

It is our hope that our new technique for reconstructing fossil brains will be utilised by other workers to shed more light on the early evolution of the vertebrate brain.

Understanding changes in the early evolution of the brain can help us understand when certain senses such as smell or vision became more important than others, and how the development of higher cognitive centres may have helped some animals flourish while others floundered.

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