# Humans' Oldest Jawed Ancestor

***Recently discovered fossil evidence reveals that the ancestors of jawed vertebrates originated and diverged much earlier than previously thought.***

There are still many controversies regarding the evolutionary history of vertebrates. For example, there is a lack of straightforward and compelling fossil evidence indicating when jawed vertebrates began to diverge. Before this study, the earliest fossil evidence of jawed vertebrates was found in the Late Silurian strata, about 425 million years ago.[1,2] Interestingly, using differences in biomolecular mutation rates between living jawless and jawed vertebrates, molecular clock analysis predicts that the appearance of jawed vertebrates should be no later than 450 million years ago, which is probably during the Late Ordovician. However, this still leaves a time gap of about 25 million years between the prediction of the molecular clock analysis and the oldest fossil evidence. Unfortunately, due to the characteristics of sedimentary environments, few fossils from between the Late Ordovician and the Late Silurian strata have been discovered. An American vertebrate paleontologist, Alfred S. Romer from Harvard University, once mentioned that this period was "a persisting major gap in our paleontological record".

An international team of researchers from the Chinese Academy of Sciences (China), the University of Birmingham (UK), and the NSRRC discovered 439-million-year-old jawed and toothed fish fossils, including isolated teeth, scales, shield armor, and fin spines, from the Rongxi Formation at a site in Shiqian County, Guizhou Province of southern China. The results suggest that the ancestors of jawed vertebrates originated much earlier than was previously thought. This latest discovery was recently published in *Nature* and featured as a cover story of the journal.

The small, isolated teeth were identified as belonging to a kind of primitive jawed vertebrate, *Qianodus duplicis*, named after the ancient name of Guizhou Province.[3] *Qianodus* possesses a spiral-like dental element called a tooth whorl, which carries multiple generations of teeth. The tooth whorls rarely reach 2.5 mm and the tiny teeth above it are only a few hundred micrometers, so they has to be studied under magnification with high-resolution synchrotron X-ray microscopy and 3D tomography. The authors utilized high-resolution synchrotron X-ray computed tomography techniques at Taiwan Light Source (TLS) to precisely reconstruct the 3D structures of these tiny fossils. **Figure 1(a)** shows a high-resolution 3D tomography image of a *Qianodus* tooth whorl captured using the **TLS 01A1** X-ray micro-tomography. The raw tomographic datasets used in this study were all pre-processed using the joint-iterative fast projection matching (JI-Faproma) algorithm for image alignment before reconstruction processing.[4] This algorithm, developed by the **TLS 01B1** beamline group, can improve the accuracy of 3D computed tomography reconstruction immensely as shown in **Fig. 1(b)**. The tooth whorls feature a pair of tooth rows, which incrementally increase in size towards the lingual portion of the whorl. The tooth rows have a clear z-type offset arrangement that indicates positions on the opposing jaw rami. The apparent offset between the two primary tooth rows is also seen in some modern shark dentitions, but has not been identified in ancient fish fossils before. All the evidence supports the conclusion that *Qianodus* is a close relative of the extinct chondrichthyan groups. The discovery provides evidence of the existence of toothed vertebrates and shark-like dentition patterning occurring tens of millions of years earlier than previous fossil records show. Phylogenetic analysis identifies *Qianodus* as a primitive

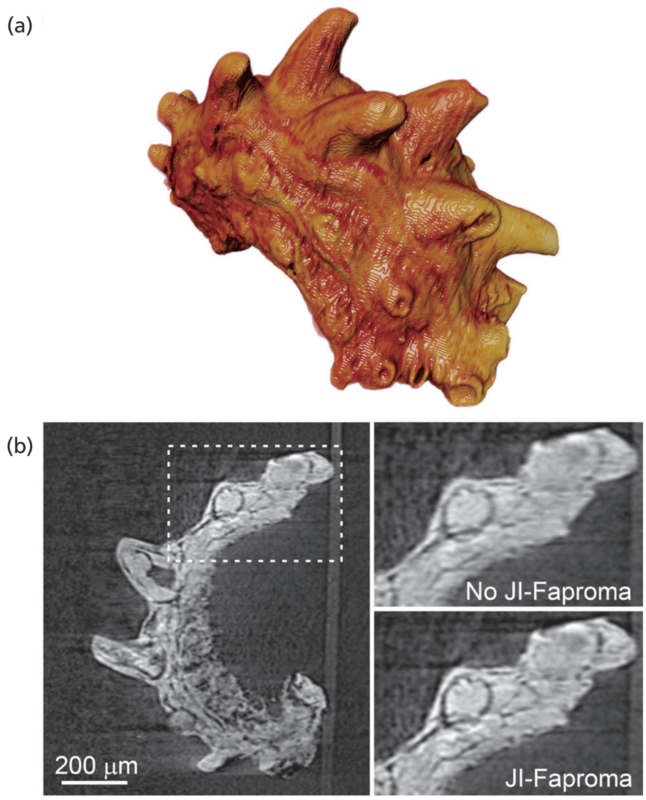


**Fig. 1**: 3D tomography of a *Qianodus* tooth whorl obtained using (a) synchrotron high-resolution X-ray tomography and (b) a high-precision 3D reconstruction technique called joint-iterative fast projection matching algorithm (JI-Faproma). [Figure courtesy of Chun-Chieh Wang]

chondrichthyan, implying that jawed vertebrates were already quite diverse during the Early Silurian

In contrast, the isolated scales, shield armor, and fin spines (**Fig. 2**) were identified as belonging to a primitive chondrichthyan fish named *Fanjingshania renovata*.[5] *Fanjingshania* has skin ossifications of the shoulder region and is anatomically close to groups of extinct acanthodians. Interestingly, the authors found that the fossil bones of *Fanjingshania* show extensive resorption and remodeling, which is typically associated with bony fish skeletal development (**Fig. 2**). X-ray tomography slices further reveal that this resorption was followed by deposition of replacement crown elements. However, unlike both extinct and living bony fishes, the resorption did not target individual teeth or skin denticles but instead removed a large area that included multiple skin denticles. This replacement mechanism is much more similar to skeletal repair than typical tooth or skin denticle substitution in bony fishes. Hard tissue modification is unprecedented in chondrichthyan fishes, implying that the developmental plasticity of the mineralized skeleton at the onset of jawed fish diversification is greater than previously understood. Also, *Fanjingshania* may be a transitional species between cartilaginous fishes and bony fishes, which implies that there may have been bony fishes at that time.

The discoveries of this study provide strong evidence that jawed vertebrates appeared as early as 439 million years ago in the Early Silurian, 14 million years earlier than suggested by previously discovered fossils. This result greatly shortens the time gap between the fossil record and the molecular clock analysis estimation of the differentiation of jawed vertebrates to approximately 11 million years. In other words, these results provide further support for the molecular clock analysis prediction that jawed vertebrates should have appeared no later than 450 million years ago. These findings indicate that the vertebrate jaw, including that of humans, may have originated earlier (in the Late Ordovician). These novel findings rewrite existing vertebrate evolutionary models and, furthermore, will substantially influence how evolutionary rates of early vertebrates are assessed. (Reported by Chun-Chieh Wang)

*This report features the works of Ming Chu, Ivan J. Sansom, Chun-Chieh Wang and their co-workers published in Nature **609**, 964 (2022) and Nature **609**, 969 (2022). These papers were selected as the cover of issue 7929.*

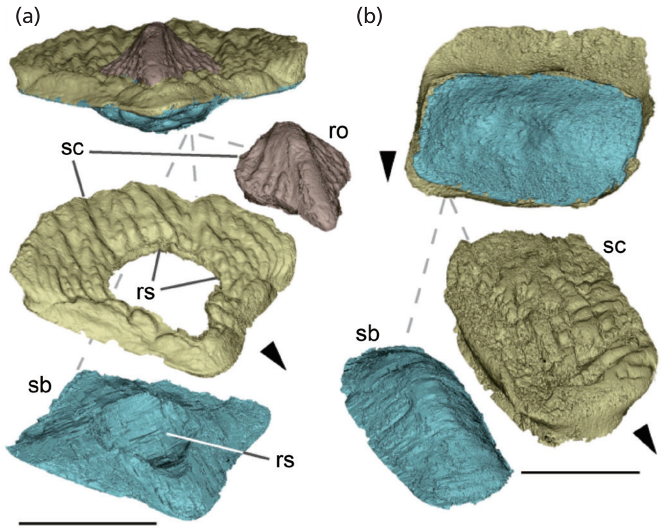


**Fig. 2**: Resorption features in the dermal skeleton of *F. renovata*. (a) Trunk scale with an anterior replacement odontode revealing the resorption surfaces in the scale crown and base. (b) An asymmetrical trunk scale and the crown and base of the same specimen in crown aspect demonstrating an absence of resorption surfaces in contrast to (a). [Reproduced from Ref. 5]

### TLS 01A1 White X-ray
### TLS 01B1 X-ray Microscopy

- High-resolution X-ray Tomography, High-precision 3D Reconstruction Algorithm
- Paleontology, Geosciences, Materials Science, Environmental Science

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