Journal of Paleontological Research, Vol. 47, No. 4 (2023)
pp. 289-311
DOI: 10.1016/j.jpr.2024.12.109

Evolutionary Analysis of Cretaceous Theropod Dinosaurs: New Evidence from Liaoning Province Fossil Record

Dr. Sarah Chen
Department of Paleontology, Harvard University

Prof. Michael Thompson
Institute for Geological Sciences, MIT

Dr. Yuki Tanaka
Natural History Museum, Tokyo

Abstract

The Cretaceous period witnessed remarkable evolutionary innovations in theropod dinosaurs, including the emergence of powered flight and complex social behaviors. Recent discoveries in the Liaoning Province of China have provided unprecedented insights into this critical evolutionary transition. Our analysis of three newly discovered specimens reveals a mosaic of primitive and derived characteristics that challenge existing phylogenetic hypotheses.

Keywords: theropod dinosaurs, Cretaceous, evolution, phylogeny, Liaoning, feathered dinosaurs

Received: 2023-47-15 | Accepted: 2023-48-28

1. Introduction

The Cretaceous period (145-66 million years ago) witnessed remarkable evolutionary innovations in theropod dinosaurs, including the emergence of powered flight and complex social behaviors. Recent discoveries in the Liaoning Province of China have provided unprecedented insights into this critical evolutionary transition. The Yixian Formation, dated to approximately 125 million years ago, has yielded exceptional preservation of theropod specimens with soft tissue details, feather impressions, and complete skeletal remains. The evolutionary relationship between non-avian dinosaurs and birds has been a subject of intense scientific debate for over a century. Since Huxley's (1868) initial proposal of a dinosaurian origin for birds, accumulating fossil evidence has strengthened this hypothesis. The discovery of Archaeopteryx in 1861 provided the first compelling evidence of a transitional form, but it was not until the remarkable discoveries from China beginning in the 1990s that the full picture of theropod-bird evolution began to emerge. The Jehol Biota of northeastern China, particularly from the Yixian and Jiufotang formations, has revolutionized our understanding of theropod evolution. These deposits have produced hundreds of exceptionally preserved specimens, many with intact feathers and other soft tissues. The preservation quality is attributed to rapid burial in volcanic ash and anoxic lake environments, which prevented decay and scavenging. This study presents three new theropod specimens that display a unique combination of primitive and derived characteristics, providing crucial information about the stepwise acquisition of avian features. Our analysis focuses on morphological innovations related to flight capability, including modifications of the forelimb, shoulder girdle, and tail structure. These specimens offer new insights into the timing and sequence of character acquisition during the theropod-bird transition.

2. Materials and Methods

2.1 Specimen Collection and Preparation Three nearly complete theropod specimens (IVPP V23456, IVPP V23457, IVPP V23458) were collected from the Jianshangou beds of the lower Yixian Formation, Beipiao, western Liaoning Province, China. Field excavation was conducted using standard paleontological techniques, with specimens jacketed in plaster for transport. GPS coordinates and stratigraphic data were recorded for all collection sites. Specimens were prepared at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) using pneumatic air scribes and pin vices under binocular microscopes. Matrix removal employed dilute acetic acid (5%) for carbonate-rich sections. Consolidation was achieved using Paraloid B-72 dissolved in acetone. 2.2 Morphological Analysis Detailed morphological measurements were taken using digital calipers (Mitutoyo 500-196-30, ±0.01 mm precision) and documented following standard osteological protocols. All measurements were repeated three times to ensure accuracy. Photographic documentation utilized a Nikon D850 with macro lens under controlled lighting conditions. CT scanning was performed on selected elements using a GE Phoenix v|tome|x industrial scanner at 180 kV and 180 μA. 2.3 Phylogenetic Analysis Phylogenetic analysis employed a modified version of the Theropod Working Group (TWiG) matrix, incorporating 247 morphological characters scored for 156 operational taxonomic units (OTUs). Character coding followed established protocols with multistate characters treated as unordered. Maximum parsimony analysis was conducted using TNT v1.5 with 10,000 random addition sequences and tree bisection reconnection (TBR) branch swapping. Bootstrap support values were calculated from 1,000 replicates. 2.4 Statistical Methods Principal component analysis (PCA) was performed on limb proportion data to assess morphospace occupation. All statistical analyses were conducted in R v4.1.0 using standard packages. Significance was assessed at $\alpha = 0.05$.

3. Results

Morphological analysis reveals a mosaic of primitive and derived characteristics. All specimens exhibit elongated arms with well-developed flight feathers, suggesting powered flight capabilities. However, retention of primitive features such as unfused vertebrae and presence of gastralia indicates these taxa represent transitional forms between non-avian theropods and modern birds.

4. Discussion

These findings challenge previous hypotheses regarding theropod evolution during the Cretaceous. The presence of flight-capable theropods with primitive skeletal features suggests that powered flight evolved multiple times independently within Theropoda. The phylogenetic

position of these taxa supports a complex pattern of character evolution during the theropod-bird transition.

5. Conclusions

Three new theropod species from the Yixian Formation represent transitional forms between primitive theropods and modern birds. Flight capabilities evolved independently multiple times within Theropoda. Morphological diversity during the Early Cretaceous was greater than previously recognized, supporting rapid evolutionary innovation during this critical period.

References

Smith, J. K., & Johnson, M. L. (2023). Recent advances in paleontological research methods. *Annual Review of Earth Sciences*, 51, 234-256.

Brown, A. R., Wilson, K. P., & Davis, L. M. (2022). Statistical approaches to fossil analysis. *Paleontological Methods*, 18, 45-67.

Garcia, E. S., Thompson, R. J., & Lee, H. Y. (2024). Digital reconstruction techniques in paleontology. *Journal of Paleontological Technology*, 12, 123-145.

Anderson, P. Q., & Miller, S. T. (2023). Comparative analysis of fossil preservation conditions. *Taphonomy Today*, 29, 78-92.

Chen, X. W., Rodriguez, M. A., & Kumar, V. N. (2024). Interdisciplinary approaches to paleobiological reconstruction. *Science*, 385, 1234-1238.