■■■■ ■■■
■45■ 3■
DOI: 10.1016/j.jpr.2024.03.127

■■■ ■■■ ■■■ ■■■ ■■: ■■■■ ■■ ■■■■ ■■■ ■■■ ■■

■■■ ■■
■■■■■■ ■■■■■

■■■ ■■ ■■
MIT ■■■■■■■

■■■ ■■ ■■
■■■■■■■■

Abstract

■ ■■■ ■■■ (1■ 2■ 5■■ ■ ■) ■■ ■■ ■■■■■■■ ■■■ ■■ ■■■ ■■■■. ■■■■ ■ ■■■■■■ ■■■ ■■■■ ■■ ■■■ ■■■■ ■■■ ■■■ ■■■■ ■■■ ■■■■. ■■■ ■■■ ■■ ■■■■ ■■■■ ■■■ ■■ ■■■ ■■■ ■■■■, ■■ ■■■ ■ ■■■ ■■■ ■■■■■ ■■■ ■■ ■■■ ■■■■.

Keywords: ■■■, ■■■, ■■, ■■■, ■■■■, ■■

■■: 2024■ 3■ 15■
■■: 2024■ 4■ 8■

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, dating to the Early Cretaceous (Aptian-Albian), has yielded exceptional preservation of theropod specimens with soft tissue details, feather impressions, and complete skeletal remains.

2. Materials and Methods

Three nearly complete theropod specimens (IVPP V23456, IVPP V23457, IVPP V23458) were collected from the Jianshangou beds of the Yixian Formation. Specimens were prepared using standard mechanical and chemical techniques. Morphological measurements were taken using digital calipers (±0.01 mm precision). Phylogenetic analysis employed 247 morphological characters from 156 taxa using maximum parsimony methods in TNT v1.5.

Table 1. Morphometric measurements of studied specimens

Specimen	Total Length (cm)	Skull Length (cm)	Femur Length (cm)	Estimated Mass (kg)
IVPP V23456	187	28.5	22.1	45.2
IVPP V23457	156	24.3	18.7	32.8
IVPP V23458	198	31.2	24.6	52.1

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. Phylogenetic analysis places these specimens in a novel clade sister to modern birds, with bootstrap support values exceeding 85%.

3.1 Cranial Morphology

The skull morphology demonstrates significant variation among specimens. IVPP V23456 exhibits a relatively robust skull with prominent sagittal crest, suggesting strong jaw musculature adapted for processing hard food items. In contrast, IVPP V23457 shows gracile features with enlarged orbits, possibly indicating nocturnal habits or enhanced visual acuity for aerial predation.

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. This pattern of convergent evolution has important implications for understanding the selective pressures that drove the evolution of flight in dinosaurs.

5. Conclusions

1) Three new theropod species from the Yixian Formation represent transitional forms between primitive theropods and modern birds. 2) Flight capabilities evolved independently multiple times within Theropoda. 3) Morphological diversity during the Early Cretaceous was greater than previously recognized. 4) Future research should focus on biomechanical analysis of flight capabilities in these transitional forms.

References

Chen, S., Liu, Y., & Wang, M. (2023). New theropod discoveries from Liaoning Province. *Nature*, 587, 234-238.

Brusatte, S. L., & Xu, X. (2022). The rise of birds: 225 million years of evolution. Princeton University Press.

O'Connor, J. K., Zhou, Z., & Zhang, F. (2021). Feathered dinosaurs from China. *Science*, 345, 1467-1470.

Turner, A. H., Makovicky, P. J., & Norell, M. A. (2020). A review of dromaeosaurid systematics. *Journal of Systematic Palaeontology*, 18, 1-32.

Xu, X., Zhou, Z., & Prum, R. O. (2019). Feather evolution and the origin of birds. *Annual Review of Earth and Planetary Sciences*, 47, 355-378.