

Supplementary Information for:

A new basal bird from China with implications for morphological diversity in early birds

Min Wang, Xiaoli Wang, Yan Wang & Zhonghe Zhou

Supplementary information includes following files:

1. Phylogenetic nomenclature
2. Additional anatomical description of STM9-9
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1. Phylogenetic nomenclature

In this paper, definitions of higher-level theropod taxa follows ref.1,2,3

-**Avialae**, the most inclusive clade containing *Passer domesticus* Linnaeus, 1758 but not *Dromaeosaurus albertensis* Matthew and Brown, 1922 or *Troodon formosus* Leidy, 1956.

-**Scansoriopterygidae**, the least inclusive clade including *Epidendrosaurus ninchengensis* Zhang, Zhou and Xu, 2002 and *Epidexipteryx hui* Zhang, Zhou, Xu, Wang and Sullivan, 2008.

-**Pygostylia**, the most inclusive clade containing *Confuciusornis sanctus* Hou, Zhou, Gu and Zhang, 1995 but not *Jeholornis prima* Zhou and Zhang, 2002.

-**Ornithothoraces**, the most inclusive clade containing *Iberomesornis romerali* Sanz and Bonaparte, 1992 but not *Sapeornis chaoyangensis* Zhou and Zhang, 2002 or *Confuciusornis sanctus* Hou, Zhou, Gu and Zhang, 1995.

-**Enantiornithes**, the most inclusive clade containing *Sinornis santensis* Sereno and Rao, 1992 but not *Passer domesticus* Linnaeus, 1758.

-**Ornithuromorpha**, the most inclusive clade containing *Passer domesticus* Linnaeus, 1758 but not *Sinornis santensis* Sereno and Rao, 1992.

2. Additional anatomical description of STM9-9

The vertebral column is poorly preserved and incomplete. The neural spine is fused to the centrum (Supplementary Fig. S1a). The cervical vertebral foramen is more than half the vertical height of the centrum. The synsacrum is estimated to comprise 7–8

vertebrae. The prezygapophyses of the first sacral vertebra projects further cranially than its centrum (Supplementary Fig. S1b). Two free caudal vertebrae are recognized (Supplementary Fig. S1c). The caudal vertebrae are considerably shorter in proportional terms than in *Archaeopteryx* and *Jeholornis*. The transverse processes are caudolaterally directed, exceeding the width of the centrum in length. The prezygapophyses project beyond the cranial articular facet by a distance approximately half the centrum length. At least five pairs of gastralia are present. The bones are slender than the preserved ribs, curved, and taper at their cranial and caudal ends.

The furcula is more robust than in many other basal avialans and more advanced taxa such as enantiornithines and ornithuromorphs. As in *Archaeopteryx*, *Xiaotingia* and *Confuciusornis*^{1,4,5}, the furcula is boomerang-shaped without a hypocleidium, but the interclavicular angle is smaller. The bone is weakly curved craniocaudally. As in other basal birds, the acromion process is absent⁴. The left coracoid and scapula is exposed in medial view and jointed at an angle of 90°. The scapula is fused to the shoulder end of the coracoid. Whether the coracoid is strut-like cannot be determined.

The forelimb is slightly longer than the hindlimb as in *Confuciusornis*, but proportionally shorter than in *Jeholornis* and *Sapeornis* (Supplementary Table S1 and S2)⁶. The humerus is stouter than in *Archaeopteryx*. In contrast to the condition of non-avian theropods such as *Xiaotingia*^{1,7}, the humerus is longer than the femur as in most Mesozoic birds^{4,8,9}. The humerus is curved over its proximal half and straight distally, without the sigmoid shape present in enantiornithines and ornithuromorphs.

The deltopectoral crest approaches the width of the mid-shaft of the humerus. The ventral tubercle is not developed. The left humerus is exposed in dorsal aspect, revealing that the dorsal condyle is primarily located on the cranial surface.

The ulna is approximately of the same length as the humerus. The shaft is bowed over its proximal fourth length and straight distally. An olecranon is absent. As in other basal birds, no quill knobs for attachment of the second remiges are developed^{4,5,10}. The radius is straight and robust, and its midshaft width is approximately 83% that of the ulna, proportionally wider than in *Jeholornis*, *Sapeornis* and *Confuciusornis*. The ulnare is rectangular with little differentiation into the ventral and dorsal rami.

The major and minor metacarpals are fused proximally to each other and to the semilunate carpal. The alular metacarpal is only proximally fused to the major metacarpal. As in *Archaeopteryx* and *Sapeornis*, the cranial margin of the alular metacarpal is slightly concave over its central portion, but the proximal and distal parts of the cranial margin are level in cranial projection. Whereas, the proximocranial margin surpasses the distal articular facet in cranial extent in *Jeholornis* and *Confuciusornis*^{5,11}. The extensor process is not developed. The alular metacarpal is longer relative to the carpometacarpus than in other basal birds. The major metacarpal is robust and straight. The minor metacarpal is strongly bowed caudally, forming a wide intermetacarpal space with the major metacarpal, resembling that of *Jeholornis*. The first phalanx of the alular digit is slender and gently curved as in *Jeholornis*. Although disarticulated, the preserved length indicates that this phalanx reaches the

distal end of the major metacarpal as in the basalmost enantiornithine *Protopteryx*¹², but shorter than in *Archaeopteryx* and *Confuciusornis*^{4,5}; by contrast, it terminates proximal to the major metacarpal in *Jeholornis* and *Sapeornis*^{6,11,13}. The first phalanx of the major digit is straight and robust, close to the craniocaudal width of the major metacarpal. As in *Sapeornis* and more advanced birds such as enantiornithines and ornithuromorphs¹⁴, the penultimate phalanx of the major digit is shorter than the proximal phalanx; by contrast, the proximal phalanx is longer in most non-avian theropods and basal avialans, including *Archaeopteryx*, *Jeholornis* and *Confuciusornis*^{1,15}. One manual claw is preserved closed to the major metacarpal. The bone is recurved with well developed flexor process. Its affinity cannot be ascertained.

The pubes are retroverted and have an oval cross section. Distally, the shafts converge and form the symphysis; although the preserved symphysis is short, the beaded medial surface indicates that the symphysis is longer during life. A pubic boot is absent.

The femur is approximately 88% the length of the tibiotarsus. The bone is gently bowed craniocaudally. Proximally, the femoral head protrudes medially, and a distinct neck is not developed. The femoral head is badly preserved, preventing the observation of the pit-shape fossa for the capital ligament. The patellar groove is lacking.

Contrary to non-avian dinosaurs and basal avialans such as *Archaeopteryx* and *Jeholornis*^{11,16}, the calcaneum and astragalus are fused to the tibia, forming a true

tibiotarsus as in *Confuciusornis*, *Sapeornis* and more advanced birds. The fibula is more than 70% the length of the tibiotarsus, failing to contact with the proximal tarsals as in non-ornithothoracine birds except *Archaeopteryx*¹⁷. The proximal end is expanded and the shaft rapidly narrows distally to a splint form.

As in *Jeholornis*, *Sapeornis*, *Confuciusornis* and enantiornithines^{5,6,11,18}, metatarsals II–IV are fused proximal to each other and to the distal tarsals, but the three major metatarsals are separated along their distal lengths. As in *Archaeopteryx*, *Jeholornis*, *Confuciusornis* and *Sapeornis*, metatarsal V is present. The proximal margin of the tarsometatarsus is straight, and an intercondylar eminence is absent. The proximal articular surface of the tarsometatarsus is wider than the combined width of metatarsals II–IV at the proximal end. The tarsometatarsus narrows below the proximal margin, and reach its narrowest point one fourth of the distance from the distal end; at this point, the shaft begins to widen. Metatarsal III is the longest, closely followed by metatarsal IV, which projects distally well beyond the proximal margin of the metatarsal III trochlea. As in *Archaeopteryx* and *Confuciusornis*, metatarsal II is shorter than metatarsal IV. Whereas in *Jeholornis* and *Sapeornis*^{6,14}, these two bones are subequal in length.

The left foot is complete and remains in loose articulation. The third pedal digit is the longest and approximately of the same length as the tarsometatarsus. The second digit is slightly longer than the fourth digit as in some enantiornithines¹⁰, contrary to *Archaeopteryx*, *Jeholornis* and *Confuciusornis*^{5,11,13}. The non-ungual phalanges are spool-shaped with well formed distal trochlea. The non-ungual phalanges of the

fourth digit are shorter than these of other digits. Phalanx IV-1 is longer than its following three phalanges, which are subequal in length. The unguals are recurved, with well developed flexor tubercles, and excavated laterally by the neurovascular sulci.

3. Differential diagnosis of *Chongmingia*

Chongmingia differs from *Archaeopteryx* in having a robust furcula with a smaller interclavicular angle (68° compared to 83°), a fused scapulocoracoid, a robust humerus with a large deltopectoral crest, an alular metacarpal proportionally longer, a strongly bowed minor metacarpal, a proximal phalanx of the alular digit that is subequal to the major metacarpal in distal projection, a penultimate phalanx of the major digit that is shorter than its preceding phalanx, the calcaneum and astragalus that are fused to the tibia, and the distal tarsals that are fused to the proximal ends of metatarsals II–IV.

Chongmingia differs from Jeholornithiformes in following features: the scapula and coracoid are fused; the procoracoid process is lacking, but present in *Jeholornis curvipes*¹³; the furcula is robust than in *Jeholornis prima* and *J. curvipes*; the proximal margin of the humerus is concave, a feature absent in *J. prima* and *J. curvipes*; the mid-shaft width ratio of radius and ulna is 0.83, compared to 0.64 in *J. prima* and 0.54 in *J. curvipes*; the alular metacarpal is proximally fused with the major metacarpal, but completely unfused in *J. prima* and *J. curvipes*; the alular metacarpal is long relative to the major metacarpal, with a length ratio of 0.32, compared to 0.25 in *J.*

prima and 0.17 in *J. curvipes*, respectively; the proximal alular digit extends to the distal end of the major metacarpal, which terminates proximally to the distal end of the major metacarpal in *J. prima* and *J. curvipes*; the proximal phalanx of the major digit is longer than the penultimate phalanx of the same digit, but the opposite is true in *J. prima* and *J. curvipes*; the proximal tarsals are fused with the tibia, but are unfused in *J. prima*; the second pedal digit is longer than the fourth digit, in contrast to *J. prima* and *J. curvipes*; in *J. curvipes* the penultimate phalanx is longer than other phalanx, but this feature is absent in *Chongmingia*; the ratio of forelimb (humerus + ulna + the major metacarpus length) to hindlimb (femur + tibiotarsus + metatarsal III) is 1.07, compared to *J. prima* (1.3), *J. curvipes* (1.23), and *J. palmapenis* (1.2¹⁹).

Chongmingia is distinguishable from *Jixiangornis orientalis* in following features: the forelimb is proportionally shorter than in *J. orientalis* (the length ratio of forelimb to hindlimb is about 1.34); the proximal margin of the humerus is concave in *Chongmingia*, but is convex in *J. orientalis*; the proximal phalanx of the alular digit fails to reach the distal end of the major metacarpus in *J. orientalis*; the penultimate phalanx of the major digit is longer than its preceding one in *Chongmingia*, but the opposite is true in *J. orientalis*; the alular metacarpal is proximally fused with the major metacarpal in *Chongmingia* but not in *J. orientalis*; the pedal digit II is longer than pedal digit IV, whereas the fourth digit is longer in *J. orientalis*.

Chongmingia differs from *Sapeornis* in following features: the furcula lacks the hypocleidium; the interclavicular angle is smaller (68° versus 108°); the coracoid and scapula are fused; the humerus lacks the fenestra in the deltopectoral crest; the distal

margin of the deltopectoral crest is concave in *Sapeornis*, but not in *Chongmingia*; the forelimb is proportionally shorter (the forelimb are about 1.5 times the length of the hindlimb in *Sapeornis*); the minor metacarpal is strongly bowed in *Chongmingia*.

Chongmingia is distinguishable from *Confuciusornis* in having a robust furcula with a smaller interclavicular angle, a smaller humeral deltopectoral crest that is imperforated, a minor metacarpal that is strongly bowed caudally, a proximal phalanx of the alular digit that terminates to the distal end of the major metacarpal, and a proximal phalanx of the major digit that is longer than its following phalanx.

4. Supplementary Table S1. Selected measurements of *Chongmingia zhengi* gen. et sp. nov. holotype (STM9-9). Lengths are measured in millimetres.

Element	Length
Scapula	44.6
Humerus	72.6
Ulna	77.8
Radius	74.2
Alular metacarpal	9.6
Carpometacarpus	30.4
Alular digit-1	17.0
Major digit-1, 2	18.9, 15.7
Femur length	61.6
Tibiotarsus	69.4
Fibula	54.1
Metatarsal II	33.3
Metatarsal III	37.3
Metatarsal IV	35.6
Metatarsal V	4.1
Digit I-1, 2	9.5, -
Digit II-1, 2, 3	11.5, 12.1, 10.9
Digit III-1, 2, 3, 4	11.2, 9.6, 9.5, 9.3
Digit IV-1, 2, 3, 4, 5	7.3, 5.4, 4.8, 5.7, 7.6

5. Supplementary Table S2. Comparative measurements of *Chongmingia zhengi* gen.

et sp. nov. and other basal avialans. Lengths are measured in millimetres.

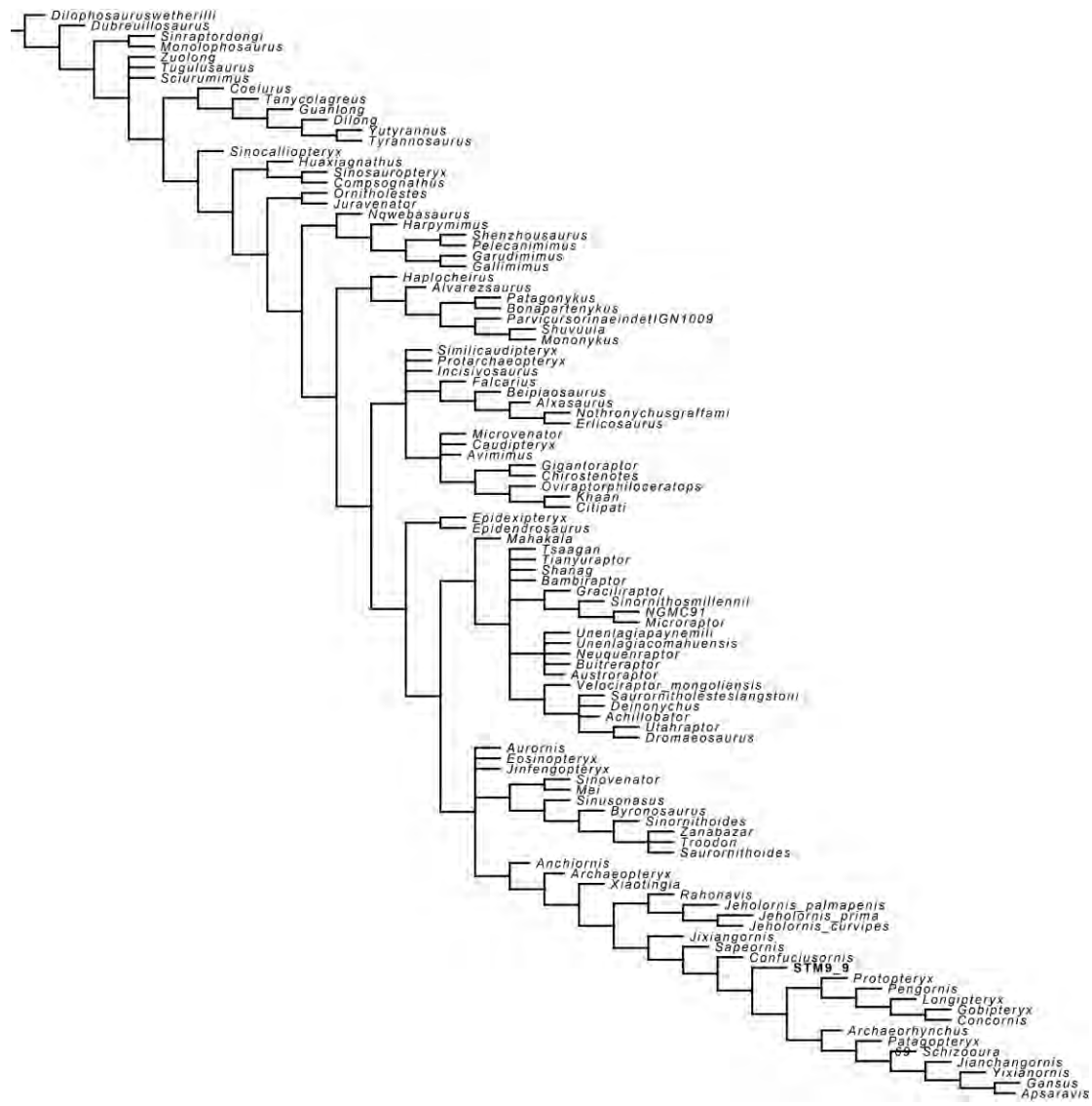
Element	<i>Chongmingia zhengi</i> STM 9-9	<i>Archaeopteryx</i> <i>x</i> <i>siemensii</i> WDC-CSG-1 00	<i>Jeholornis</i> <i>is prima</i> IVPP V13353	<i>Jeholornis</i> <i>s</i> <i>curvipes</i> YFGP-yb 2	<i>Sapeornis</i> <i>chaoyangensis</i> <i>is</i> IVPP V13276	<i>Confuciusornis</i> <i>sanctus</i> IVPP V13156
Hu	72.6	57.8	88.6	102	121.5	61.3
Ul	77.8	51.6	90.2	108	123.5	55.6
Al	9.6	6.9	9.6	10	13.6	8.4
Ma	30.4	25.1	46.2	59	59.3	30.5
Fe	61.6	51.4	63.4	76	73.2	53.4
Ti	69.4	76.5	73.7	94	85.1	60.4
Mt	37.3	40.7	36.1	48	41.2	31.3
A/M	0.32	0.27	0.21	0.17	0.23	0.28
F/H	1.07	0.80	1.30	1.23	1.52	1.01

Data of *Archaeopteryx siemensii* (WDC-CSG-100) is based on illustration in ref.4; data of *Jeholornis curvipes* (YFGP-yb2) is from ref.13, and the alular metacarpal is based on image therein; the rest data is measured directly from the corresponding specimens. Abbreviations: Al, alular metacarpal; Fe, femur; Hu, humerus; Ma, major metacarpal; Mt, metatarsal III; Ti, tibiotarsus; Ul, ulna; A/M, alular metacarpal length/ major metacarpal length; F/H, humerus + ulna + major metacarpal length/ femur + tibiotarsus + metatarsal III length.

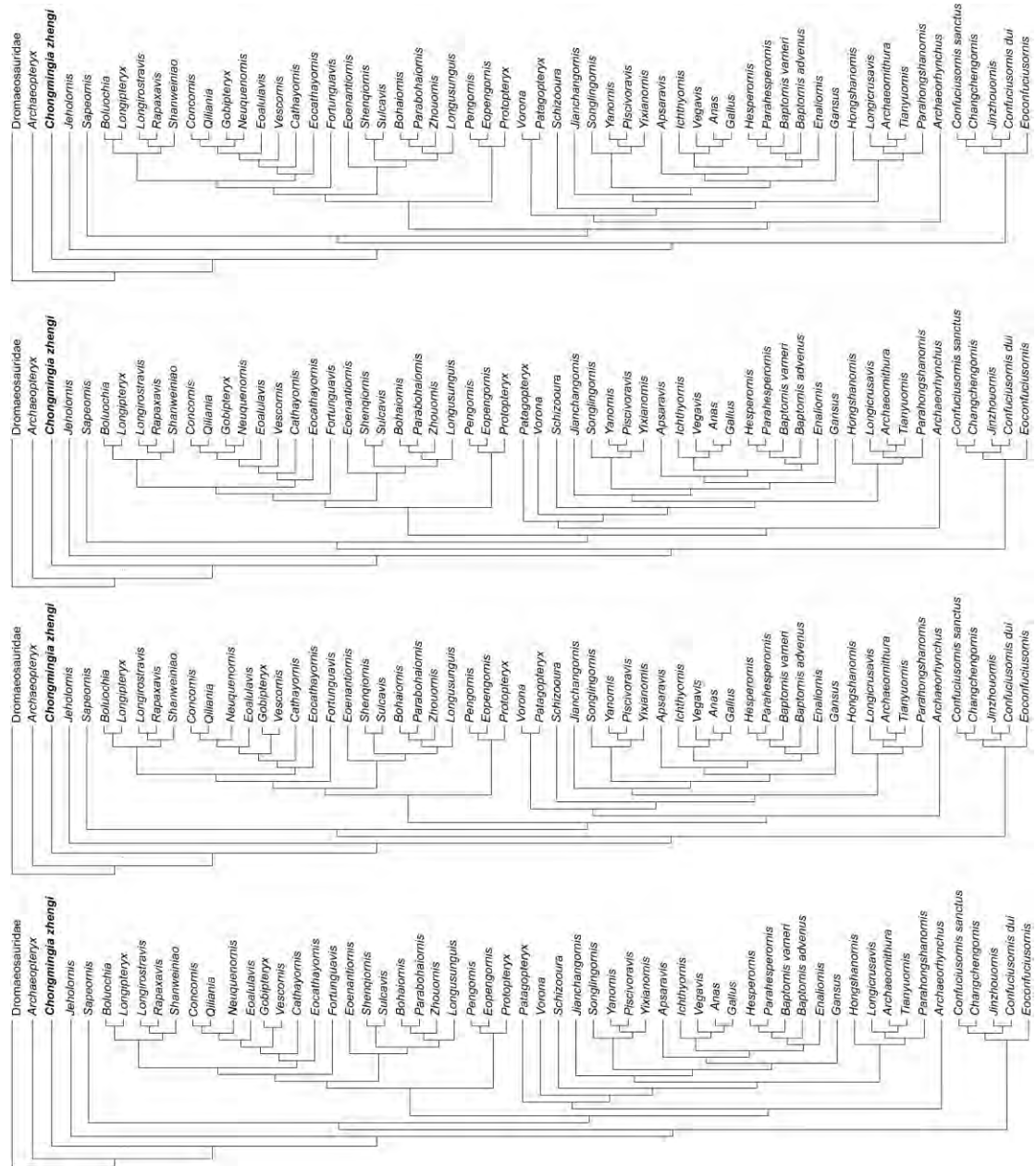
6. Supplementary Figures



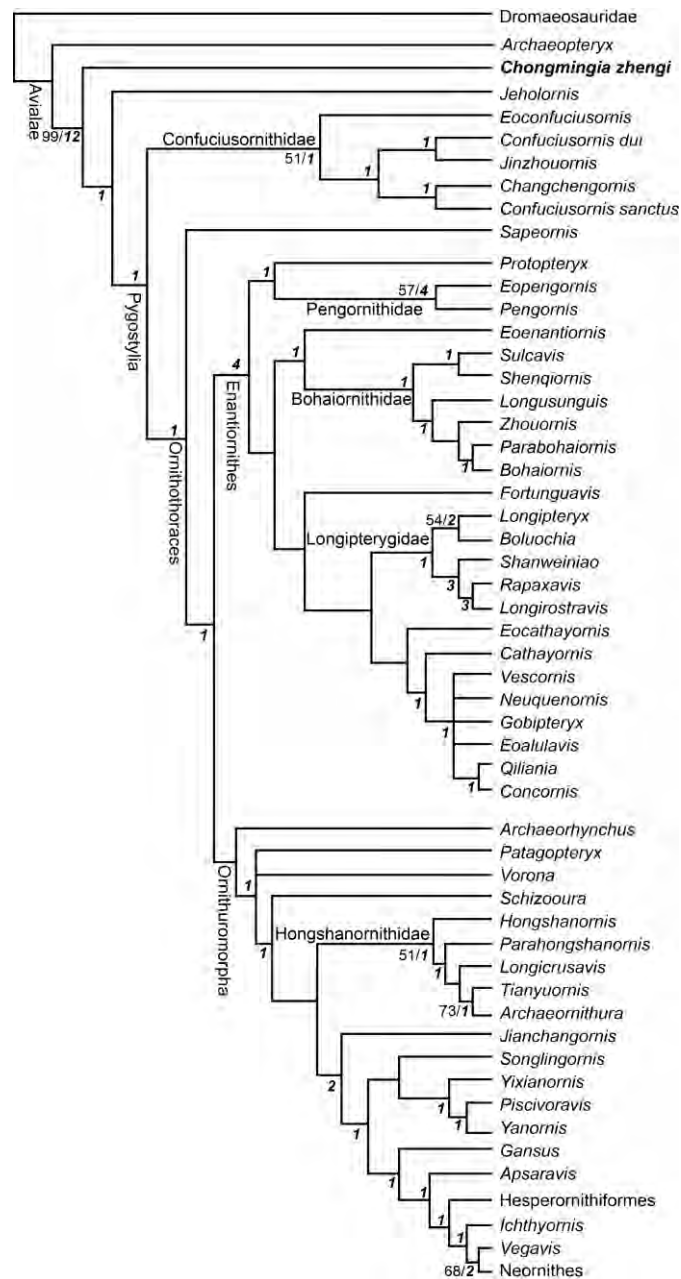
Figure S1. Axial skeletons of *Chongmingia zhengi* (STM9-9). (a) Cervical vertebra and gastroliths; (b) synsacrum; (c) caudal vertebrae. Abbreviations: ca, caudal vertebra; cv, cervical vertebra; ga, gastroliths; gs, gastralia; po, postzygapophysis; pr, prezygapophysis; sy, synsacrum; tp, transverse process. Scale bars, 5 mm (a,c), 10 mm (b).



Supplementary Figure S2. The strict consensus tree of 630 most parsimonious trees of 4523 steps (Consistency index = 0.266, Retention index = 0.578) resulted from analysis with addition of STM9-9 to a matrix on coelurosaurian phylogeny¹³.



Supplementary Figure S3. The four most parsimonious trees (Tree length = 1009 steps; Consistency index = 0.363; Retention index = 0.683) resulted from analysis with addition of STM9-9 in a matrix on Mesozoic avian phylogeny¹⁹.



Supplementary Figure S4. The strict consensus tree of four most parsimonious trees of 1009 steps (Consistency index = 0.363, Retention index = 0.683) resulted from analysis with addition of *Chongmingia* to a matrix on Mesozoic avian phylogeny¹⁹. Bootstrap and Bremer values are spelled out near the corresponding nodes in normal and bold italic formats, respectively.

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Confuciusornis

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Microraptor

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Microvenator

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Monolophosaurus

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Shenzhousaurus

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Shuvuuia

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Sinovenator

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Sinasonasus

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Yixianornis

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Zanabazar

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Zuolong

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Auornis

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Gobipteryx

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Longirostravis

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Pengornis

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Eopengornis

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Protopteryx

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Rapaxavis

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Shanweinia

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Sulcavis
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Parabohaiornis
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8. Supplementary References

1. Xu, X., You, H., Du, K. & Han, F. An *Archaeopteryx*-like theropod from China and the origin of Avialae. *Nature* **475**, 465–470 (2011).
2. Chiappe, L. M. in *Mesozoic Birds: Above the Heads of Dinosaurs* (eds Chiappe, L. M. & Witmer, L. M.) 448–472 (University California Press, 2002).
3. Godefroit, P., Cau, A., Hu, D., Escuillie, F., Wu, W. & Dyke, G. A Jurassic avialan dinosaur from China resolves the early phylogenetic history of birds. *Nature* **498**, 359–362 (2013).

4. Mayr, G, Pohl, B., Hartman, S. & Peters, D. S. The tenth skeletal specimen of *Archaeopteryx*. *Zool. J. Linn. Soc.* **149**, 97–116 (2007).
5. Chiappe, L. M., Ji, S., Ji, Q. & Norell, M. A. Anatomy and systematics of the Confuciusornithidae (Theropoda: Aves) from the Late Mesozoic of northeastern China. *Bull. Am. Mus. Nat. Hist.* **242**, 1–89 (1999).
6. Zhou, Z. & Zhang, F. Anatomy of the primitive bird *Sapeornis chaoyangensis* from the Early Cretaceous of Liaoning, China. *Can. J. Earth Sci.* **40**, 731–747 (2003).
7. Dececchi, T. A. & Larsson, H. C. E. Assessing arboreal adaptations of bird antecedents: testing the ecological setting of the origin of the avian flight stroke. *PLoS ONE* **6**, e22292 (2011).
8. Wang, M. *Taxonomical revision, ontogenetic, ecological and phylogenetic analyses of Enantiornithes (Aves: Ornithothoraces) of China* (University of Chinese Academy of Sciences, 2014).
9. Dyke, G. J. & Nudds, R. L. The fossil record and limb disparity of enantiornithines, the dominant flying birds of the Cretaceous. *Lethaia* **42**, 248–254 (2009).
10. Wang, M., Zhou, Z., O'Connor, J. K. & Zelenkov, N. V. A new diverse enantiornithine family (Bohaiornithidae fam. nov.) from the Lower Cretaceous of China with information from two new species. *Vertebr. Palasiat.* **52**, 31–76 (2014).
11. Zhou, Z. & Zhang, F. A long-tailed, seed-eating bird from the Early Cretaceous of China. *Nature* **418**, 405–409 (2002).
12. Zhang, F. & Zhou, Z. A primitive enantiornithine bird and the origin of feathers. *Science* **290**, 1955–1959 (2000).

13. Lefèvre, U., Hu, D., Escuillié, F., Dyke, G. & Godefroit, P. A new long-tailed basal bird from the Lower Cretaceous of north-eastern China. *Biol. J. Linn. Soc.* **113**, 790–804 (2014).
14. Zhou, Z. & Zhang, F. *Jeholornis* compared to *Archaeopteryx*, with a new understanding of the earliest avian evolution. *Naturwissenschaften* **90**, 220–225 (2003).
15. Zhang, F., Zhou, Z., Xu, X. & Wang, X. A juvenile coelurosaurian theropod from China indicates arboreal habits. *Naturwissenschaften* **89**, 394–398 (2002).
16. McGowan, C. Tarsal development in birds: evidence for homology with the theropod condition. *J. Zool.* **206**, 53–67 (1985).
17. Elzanowski, A. in *Mesozoic Birds: Above the Heads of Dinosaurs* (eds Chiappe, L. M. & Witmer, L. M.) 129–159 (University California Press, 2002).
18. Chiappe, L. M. & Walker, C. A. in *Mesozoic Birds: Above the Heads of Dinosaurs* (eds Chiappe, L. M. & Witmer, L. M.) 240–267 (University California Press, 2002).
19. O’Connor, J. K., Sun, C., Xu, X., Wang, X. & Zhou, Z. A new species of *Jeholornis* with complete caudal integument. *Hist. Biol.* **24**, 29–41 (2011).
20. Wang, M., *et al.* The oldest record of Ornithuromorpha from the Early Cretaceous of China. *Nat. Commun.* **6**, 6987 (2015).