

**Supplementary information to**

**A basal ceratopsian with transitional features from the Late Jurassic of western  
China**

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1. Additional illustrations of *Yinlong downsi*
2. Brief review of ornithischian phylogeny
3. Cladistic analysis of the systematic position of *Yinlong downsi*

1. Additional illustrations of *Yinlong downsi*

Figure 1. Selected cranial elements of *Yinlong downsi* holotype. (A), Right exoccipital in posterior view; (B), Left exoccipital in anterior view; (C), Braincase in posterior view; (D), Braincase in ventral view; (E), Right premaxillary tooth in labial view; (F), Left premaxillary tooth in lingual view; (G), Left middle maxillary teeth in lingual view. Scale bar = 2 cm.

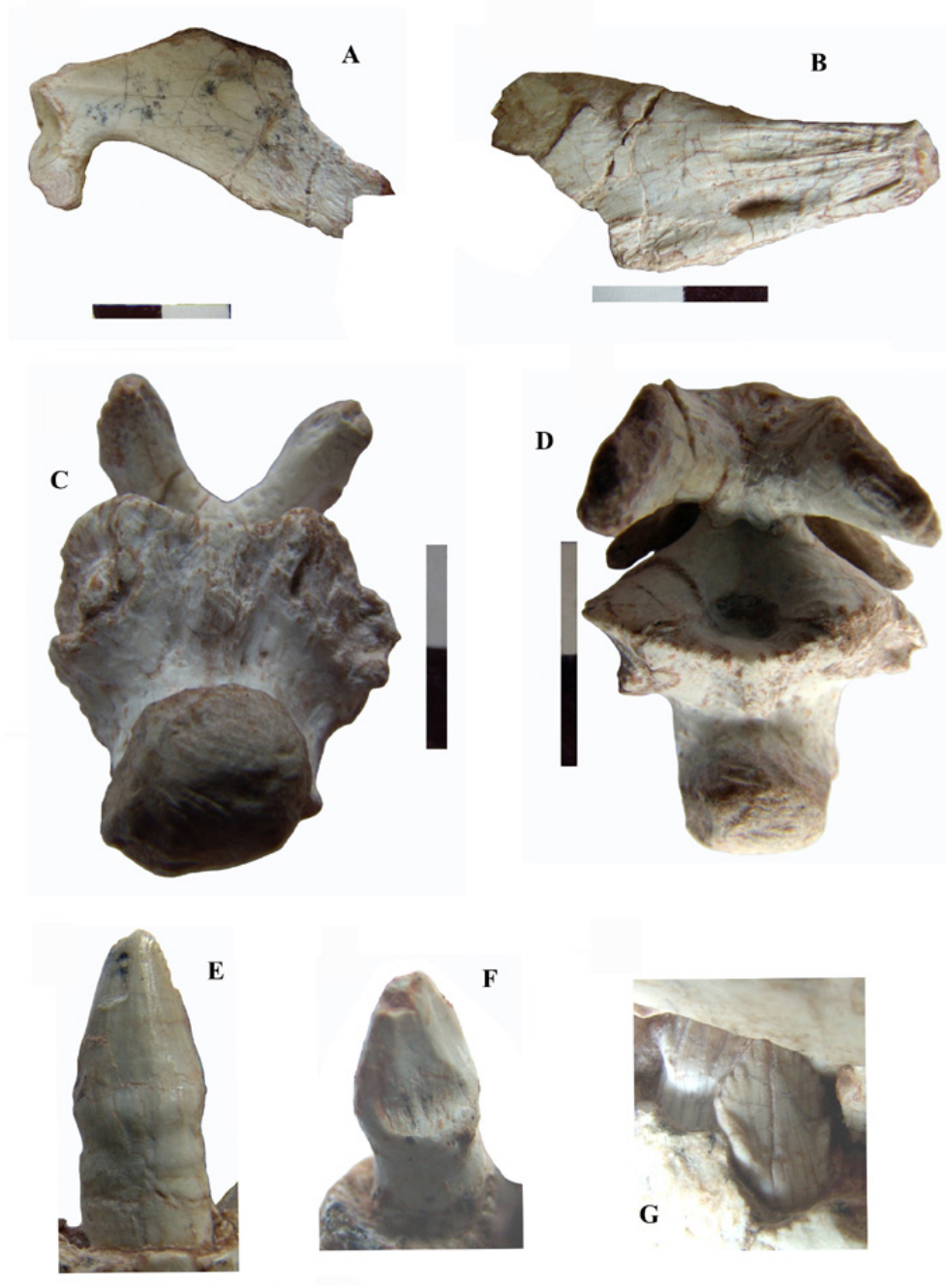


Figure 2. Selected postcranial elements of *Yinlong downsi* Holotype. Right ilium in lateral (A), medial (B), ventral (C), and dorsal (D) views; (E), Right femur in lateral view; (F), Left pubis in lateral view; (G), Pointed left manual ungual; (H), Round left manual ungual; (I), Four right pedal unguals. Scale bar = 3 cm for A-D, 2 cm for E, F, and I, and 1 cm for G and H.



## 2. Brief review of ornithischian phylogeny

The monophyly of ornithischians (bird-hipped dinosaurs) is universally accepted and the general framework of its phylogeny has been established, with successively more exclusive clades of Genasauria, Cerapoda, and Marginocephalia (Sereno 1986, 1999). However, several problems exist. The systematic positions of many supposed basal ornithopods remain controversial and it is likely some of them might be basal ornithischians, basal cerapods, or even on the Marginocephalian lineage. Both Ceratopsia and Pachycephalosauria are highly corroborated monophyletic groups (Sereno 2000; Maryanska et al. 2004; You and Dodson 2004), but their origins constitute two major problems in ornithischian phylogeny. These two groups are currently united as the Marginocephalia, but the evidence is weak. In his latest review, Sereno (1999) identified only three synapomorphies for this clade. More recently, You et al. (2003) added two more cranial features to the list, but both are problematic. One, a caudally reduced quadratojugal, is difficult to define and distinct states should be proposed to support this synapomorphy. The other, a caudodorsally sloped quadrate, appears to be present in many other non-marginocephalian taxa. Furthermore, the basal ceratopsians *Chaoyangsaurus* and *Psittacosaurus* appear to have a vertical or even anterodorsally sloped quadrate. The parietosquamosal shelf, absence of the premaxillary border of the internal nares, and a short postpubic process remain the only evidence for a monophyletic Marginocephalia. Even more problematic is the Heterodontosauridae, a group of basal ornithopods that share a few derived similarities with the Ceratopsia (Norman, 1984; Maryanska and Osmolska 1984, 1985; Cooper 1985; Zhao et al. 1999). Although several studies have proposed a close relationship between the Ceratopsia or Marginocephalia and the Heterodontosauridae (e.g., You et al. 2003), the evidence has yet to outweigh the alternative hypothesis: Heterodontosauridae as basal ornithopods (Norman et al. 2004). A recent numerical phylogenetic analysis suggests *Heterodontosaurus* is more closely related to the Marginocephalia than *Hypsilophodon* (You et al. 2003). Checking the published character list reveals that the data is flawed by omitting the characters that support the *Heterodontosaurus-Hypsilophodon* relationship. The mainstream view still considers the Heterodontosauridae as basal ornithopods (Norman et al. 2004). In conclusion, a better ornithischian phylogeny needs further support for a monophyletic Marginocephalia and additional information about the controversial status of the Heterodontosauridae, both of which are greatly improved with the discovery of *Yinlong*. Another recent analysis presents some interesting results: *Lesothosaurus* is a basal cerapod and the Ceratopsia and Pachycephalosauria are nested within the Ornithopoda (Butler 2005). These results are consistent with the pre-cladistic ornithischian phylogeny.

### 3. Cladistic analysis of the systematic position of *Yinlong downsi*

#### Character list

#### Characters from Xu et al. (2002)

1. Head size: small relative to body, less than 10% body length, (0) or large relative to body, more than 13%, (1).
2. Head shape in dorsal view: elongate, ovoid (0), or triangular, wide over jugals (1).
3. Rostral bone: absent (0) or present (1).
4. Rostral ventral process: absent (0) or present (1).
5. Rostral, shape of anterior face: round, convex (0) or sharply keeled (1).
6. Premaxillary palatal region: flat in ventral view (0) or vaulted dorsally (1).
7. Relative height of snout at nares to orbital region: low, height at mid-naris level about 35% of that at the mid-orbit level (0) or deep, about or more than 60% (1). (modified)
8. Nares position relative to buccal margin: close to buccal margin, below orbital level (0) or dorsally removed from buccal margin (1).
9. Maxilla-maxilla contact: separated by vomers at anterior border of the internal choanae (0) or maxillae contact each other anterior to choanae (1).
10. Epijugal ossification: absent (0) or present (1).
11. Postorbital: inverted "L"-shaped (0) or triangular and plate like (1).
12. Lower temporal opening: postorbital participation in margin (0), postorbital excluded from margin (1) (modified)
13. Basioccipital: excluded from basal tubera by basisphenoid and limited to occipital midline (0) or forms basioccipital tubera (1).
14. Basispterygoid process orientation: anterolateral (0), ventral (1), or posteroventral (2) when braincase is oriented with condyle pointing posteriorly.
15. Notch between posteroventral edge of basisphenoid and base of basispterygoid process: deep (0) or notch shallow with base of basispterygoid process close to basioccipital tubera (1).
16. Supraoccipital shape: tall, triangular (0) or wide, more sub-rectangular (1) (modified)
17. Coronoid process position: close to main axis of dentary and posterior to tooth row (0) or set lateral to posteriorly expanded tooth row (1) (modified).
18. Premaxillary teeth: five or more (0), one to three (1), or absent (2) (modified).
19. Maxillary teeth, primary ridge: absent (0) present (1) (modified).
20. Scapular blade relative to glenoid: at an acute angle (0) or almost perpendicular (1).
21. Preorbital region: about or more than 40% (0) or much less than 40% the length of the skull (premaxilla-quadrates).
22. Ventral border of external nares: below (0) or at or above the level (1) of the orbit (modified).
23. Premaxilla-prefrontal contact: absent (0) or present (1).

24. Eminence on the rim of the buccal emargination of the maxilla near the junction with the jugal: absent (0) or present (1).
25. Distinctive indentation on posterior cranial midline between the parietals: present (0) or absent (1).
26. Pterygoid, prominent posterior process: absent (0) or present (1).
27. Dentary ventral flange: absent (0) or present (1).
28. Mandible, prominent medial expansion on the central mandible: absent (0) or present (1).
29. Retroarticular process: long, exceeding the length of the glenoid (0) or short or absent (1).
30. Axis neural spine: anteroposteriorly short (0); long, extending caudally to the posterior end of the centrum of C3 (1).
31. Squamosal, posterior edge: angled anteromedially (0) or posteromedially, contributes to frill margin (1).
32. Surangular lateral surface: flat to weakly convex (0) or with pronounced laterally convex curvature (1).
33. Prementary tip: horizontal (0) or upturned (1).

From Sereno (1999)

34. Premaxilla-lacrimal contact: absent (0) or present (1).
35. Paroccipital process shape: subrectangular (0) or crescentic (1).
36. Jaw articulation, position: slightly ventral to (0), or significantly offset ventral to (1) or level with or dorsal to (2), the maxillary tooth row (modified)
37. Premaxillary tooth row (or bill margin), position: level with (0) or ventral to (1), the maxillary tooth row.
38. Antorbital fenestra, maximum diameter: 75% or more of orbital diameter (0), approximately 50% of orbital diameter (1) or very small or absent (2).
39. Quadrate foramen location: on posterolateral aspect of quadrate shaft (0) or on lateral aspect of quadrate or quadratojugal (1).
40. Quadrate foramen size: small (0) large (1).
41. External mandibular fenestra length: large, more than 50% maximum depth of the lower jaw (0) or small or absent (1).
42. Humeral deltopectoral crest form: projecting from shaft (0) or low or rounded (1) in lateral or medial view.
43. Prepubic process length: less than (0) or longer than (1) the length of the preacetabular process of the ilium (modified).
44. Ischial obturator process: absent (0); present (1).

From Sereno (1999) and Maryanska et al. (2004)

45. Parietosquamosal shelf: absent (0) or present (1).
46. Premaxillary border of internal nares: present (0) or absent, excluded by maxillae (1).
47. Postpubic process length, distal symphysis: long, symphysis present (0) or

- very short, symphysis absent (1).
48. Preacetabular process, shape of distal end: tapered (0) or expanded (1).
  49. Postorbital-squamosal tubercle row: absent (0) or present (1).
  50. Iliac blade, lateral deflection of preacetabular process: weak (0) or marked (1).

Additional Characters:

51. Rostral size relative to the premaxilla: small (0) or large (1).
52. Snout, anterior margin shape: sloped posterodorsally, snout shallow (0) or more vertical anterior margin, snout deep (1).
53. Antorbital fossa margins: all sharply defined (0) or some margin poorly delineated (1).
54. Cheek ramus of maxilla: shallow (0) or deep (1).
55. Jugal anterior process: shallow and tapered (0) or expanded dorsoventrally (1).
56. Lateral crest on jugal: absent (0) or present (1). (Serenó, 1986)
57. Postorbital bar shape: narrow, subequal to the temporal bar in width (0) or broad, wider than the temporal bar (1).
58. Supratemporal fenestra length relative to the basal skull length: short, less than 25% BSL (0) or elongated, more than 25% BSL (1).
59. A paraquadratic foramen restricted within the posterior margin of quadrate absent (0) or present (1).
60. Parietal, location of posterior margin relative to squamosal: anterior to (0) or level with or posterior to (1) that of squamosal.
61. Parietal, posterior margin relative to rest of skull: below the level of the anterior skull roof (0) or elevated, level with or higher than the anterior skull roof (1).
62. Pterygoid, vomeral process: anteriorly oriented (0) or dorsally oriented (1).
63. Deep external mandibular fossa: absent (0) or present (1).
64. Dentary, sub-buccal portion: shallower than postdentary region (0) or as deep as postdentary region (1).
65. Surangular size: more than (0) or less than (1) half the mandibular length.
66. Premaxillary teeth, shape: transversely compressed (0), strongly convex labially (1) or strongly convex both labially and lingually (2).
67. Quadratojugal position: posterior (0) or medial (1) to jugal.
68. Palpebral: present (0) or absent (1).
69. Jugal with prominent flange: absent (0) or present (1).
70. Limb proportions, relative length of forelimb and hindlimb: forelimb about 50% or less (0) or 65% or more (1) that of hindlimb.
71. Parietal fenestration: absent (0) or present (1).
72. Jugal-squamosal contact: absent, separated by postorbital (0) or present (1).
73. Posterior premaxillary teeth, size: equivalent to (0) or much larger than (1) maxillary teeth.
74. Premaxillary tooth crown orientations in lateral view: recurved (0) or straight

- (1).
75. Maxillary tooth crown, shape: triangular and pointed (0), chisel-shaped with parallel sides (1) or ovate (2) in lateral view.
  76. Maxillary teeth, mesial and distal ridges: weak (0), or prominent (1).
  77. Antorbital fenestra, position: entirely anterior to orbit (0), or fenestra below orbit (1).
  78. Prominent horizontal ridge under the antorbital fossa: absent (0) or present (1).
  79. Jugal contribution to antorbital fossa: small (0) or significant (1).
  80. Jugal transverse thickening: absent (0) or present (1).
  81. Jugal ornamentation: absent (0) or present (1).
  82. Nasal, longitudinal fossa along the midline: absent (0) or present (1).
  83. Squamosal process of postorbital relative to the jugal process: much shorter (0) or subequal or longer than (1).
  84. Squamosal with significant overhang lateral to the descending process and quadrate: absent (0) or present (1).
  85. Parietal occiput exposure: large, with a posteriorly-faced ramus (0) or limited to the dorsal margin (1).
  86. Postorbital surface: smooth (0) or with a prominent vertical ridge (1).
  87. Infratemporal fenestra size: small, much smaller than the orbit (0) or large, subequal or larger than the orbit (1).
  88. Angular surface sculpturing: absent (0) or present (1).
  89. Mandible, significant medial expansion of the posterior end: absent (0) or present (1).
  90. Ilium relative length: shorter than (0), or longer than (1) the length of the femur.
  91. Ilium postacetabular process: much deeper than (0) or subequal to (1) that of the preacetabular process.
  92. Ilium, eversion of dorsal margin of postacetabular process: absent or weak (0) or prominent (1).
  93. Predeantary length of lateral process relative to the ventral process: short (0) or long (1).
  94. Exoccipital orientation: sharply deflects ventrally in posterior view (0) or transits smoothly (1).
  95. Basioccipital, a longitudinal ridge below condyle: present (0) or absent (1)
  96. Basipterygoid process articular facet for the pterygoid small and oval (0) or large and elliptical (1) in outline.
  97. Basipterygoid process articular facet orientation: mainly directed anteriorly (0) or laterally (1)
  98. Pterygoid posterior and medial extension: weak, basicranium mostly exposed in ventral view, (0) strong, basicranium mostly obscured in ventral view (1)
  99. Basal tubera shape: thick anteroposteriorly, with basisphenoid positioned anterior to the basioccipital, obscured from posterior view (0) or narrow anteroposteriorly, with basisphenoid positioned more laterally and with a





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Ceratopsidae  
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200001000110000011011?000?111110

Agilisaurus 000--000?000?0??000?00000000?000011100010010?0100-  
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### Phylogenetic analysis

The data matrix was analyzed cladistically using the NONA (ver 2.0) software package (Goloboff, 1993) and formatting and character exploration was performed in WinClada (Nixon, 2000). The analysis protocol consisted of 1000 Tree Bisection and Regrafting tree searches followed by branch swapping. Settings included collapsing unsupported branches and counting all states in polymorphic codings. All characters are unordered. *Lesothosaurus* and *Thyreophora* were employed as outgroups, and trees were rooted on *Lesothosaurus*. The analysis resulted in a single parsimonious tree with a length of 206 steps, a CI of 0.53 and a RI of 0.68 (see below). A bootstrap analysis was also done. The bootstrap values are 67% for Cerapoda, 50% for (*Jeholosaurus* + *Hypsilophodon* + Iguandontia), 43% for Heterodontosauriformes, 71% for Marginocephalia, and 87% for Ceratopsia and low for a (Heterodontosauridae+*Agilisaurus*+(*Jeholosaurus* + *Hypsilophodon* + Iguandontia)) clade (10%) and or a ((*Jeholosaurus* + *Hypsilophodon* + Iguandontia)+Marginocephalia) clade (5%).

Synapomorphies for clades found in the analysis of the data set presented below (fast optimization). The first number refers to the character on the listed above, and the derived state is given after the dot.

Heterodontosauriformes:

18.1, 34.1, 58.1, 69.1, 83.1, 87.1, 91.1, 92.1, and 103.1

Marginocephalia:

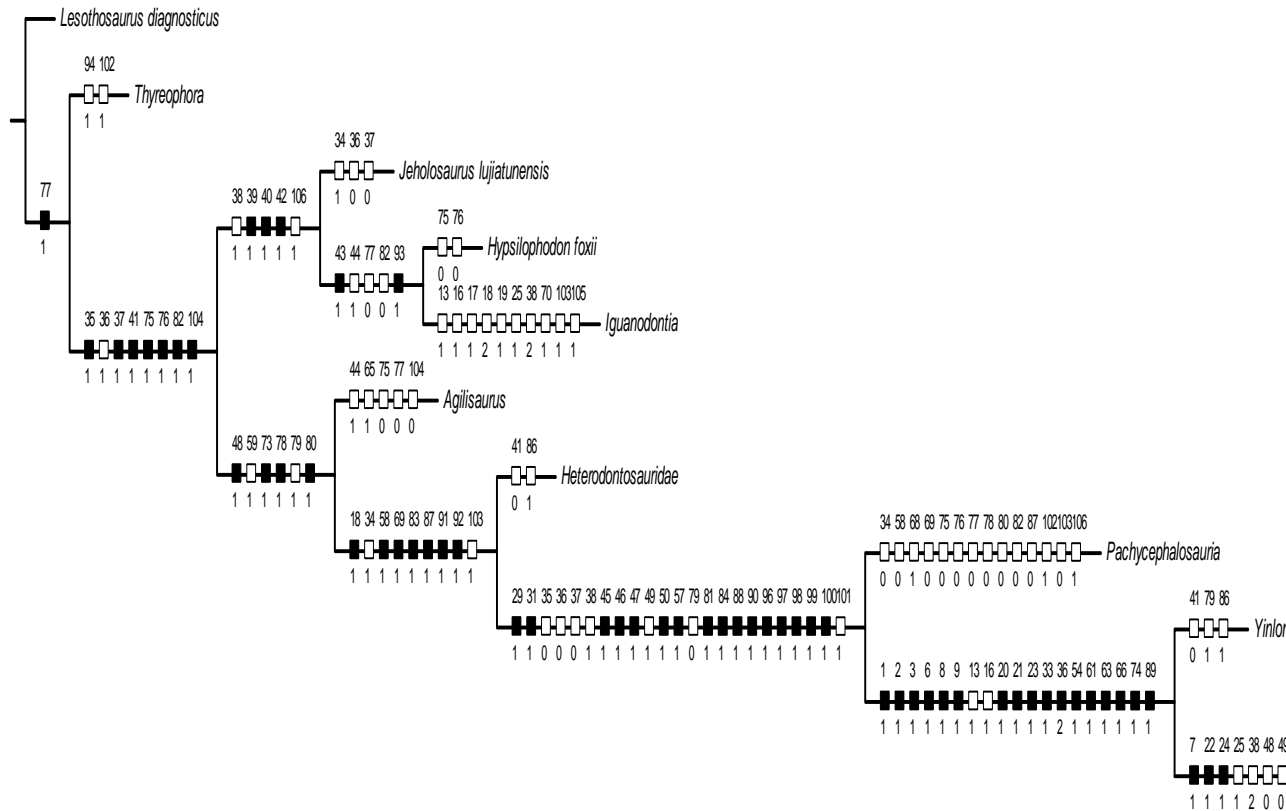
29.1, 31.1, 35.0, 36.0, 37.0, 38.1, 45.1, 46.1, 47.1, 49.1, 50.1, 57.1, 79.0, 81.1, 84.1, 88.1, 90.1, 96.1, 98.1, 99.1, 100.1 and 101.1.

Ceratopsia:

1.1, 2.1, 3.1, 6.1, 8.1, 9.1, 13.1, 16.1, 20.1, 21.1, 23.1, 33.1, 36.2, 54.1, 58.1, 61.1, 63.1, 66.1, 74.1, and 89.1

*Chaoyangsaurus*-Ceratopsidae clade:

7.1, 22.1, 24.1, 25.1, 38.2, 48.0, 49.0, 50.0, 51.1, 52.1, 55.1, 59.0, 60.1, 62.1, 64.1, 65.1, 66.2, 73.0, 85.1, 90.0, 94.1, 97.0, 99.0, and 101.0.



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