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Supporting Online Material for

A Basal Alvarezsauroid Theropod from the Early Late Jurassic of Xinjiang, China

Jonah N. Choiniere,* Xing Xu, James M. Clark, Catherine A. Forster, Yu Guo, Fenglu Han

*To whom correspondence should be addressed. E-mail: jonah.choiniere@gmail.com

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A Basal Alvarezsauroid Theropod from the Early Late Jurassic of Xinjiang, China

Jonah N. Choiniere[1], Xing Xu[2], James M. Clark[1], Catherine A. Forster[1], Guo Yu[2] and Fenglu Han[2]
[1]Department of Biological Sciences, The George Washington University
[2]Laboratory of Evolutionary Systematics of Vertebrates, Institute of Vertebrate Paleontology and Paleoanthropology

Materials and methods

Phylogenetic analysis

Character/state definitions

Most characters are from published versions of the ThWiG matrix (*S1*, *S2*). Other characters have been added from the literature, with citations in "last name, year" format to facilitate comparisons between datasets. Explanations are provided for some characters. Numbered citations are given for the first mention of a dataset only.

The following characters are treated as ordered, either because they contain nested state-sets or because they represent multistate characters with one of the states as "absent": 22, 50, 73, 86, 92, 123, 125, 126, 130, 132, 135, 147, 164, 169, 179, 181, 207, 214, 228, 238, 243, 297, 307, 317, 338, 341, 344, 358, 370, 386, 397, 407, 412.

1. "Protofeathers" (A filamentous integument, as preserved in *Sinosauropteryx* and *Dilong*).
   (0) absent
   (1) present

2. Contour feathers (Rauhut, 2003, character #165 (*S3*))
   (0) absent
   (1) present

3. Vaned feathers on forelimb (Kirkland et al., 2005, character #1 (*S2*))
   (0) symmetric
   (1) asymmetric

4. Shape of premaxillary body (portion in front of the external naris) (Rauhut, 2003, character #1)
   (0) wider than high, or approx. as wide as high
   (1) significantly higher than wide

5. Premaxillary body in front of external nares (Rauhut, 2003, character #2; Smith et al., 2007, character #6 (*S4*))
   (0) rostrocaudally shorter than body below nares and angle between anterior margin and alveolar margin more than 75 degrees
   (1) rostrocaudally longer than body below the nares and angle less than 70 degrees

6. Ventral process at the posterior end of premaxillary body (gives the posterior process a forked appearance in lateral view) (Rauhut, 2003, character #4; Smith et al., 2007)
   (0) absent
   (1) present

7. Maxillary process of premaxilla (Kirkland et al., 2005, character #20; Rauhut, 2003, character #6 (with character states in different order); also scored from Smith et al., 2007, with states changed)
   (0) contacts nasal to form posterior border of nares
   (1) reduced so that maxilla participates broadly in external naris
   (2) extends posteriorly to separate maxilla from nasal posterior to nares

8. Internarial bar (Kirkland et al., 2005, character #21)
   (0) dorsoventrally rounded

(1) dorsoventrally flat

9. Crenulate margin on buccal edge of premaxilla (Kirkland et al., 2005, character #22)
    (0) absent
    (1) present

10. Caudal margin of naris (Kirkland et al., 2005, character #23)
    (0) farther rostral than the rostral border of the antorbital fossa
    (1) nearly reaching or overlapping the rostral border of the antorbital fossa

11. Premaxillary symphysis (Kirkland et al., 2005, character #24)
    (0) acute, V-shaped
    (1) rounded, U-shaped

12. Subnarial foramen
    (0) absent
    (1) present

13. Pronounced maxillary fenestra (Kirkland et al., 2005, character #27; Rauhut, 2003, character #17; Smith et al., 2007 character #29; originally in Gauthier, 1986 (*S5*))
    (0) absent
    (1) present

14. Accessory antorbital (maxillary) fenestra recessed within a shallow, caudally or caudodorsally open fossa, which is itself located within the maxillary antorbital fossa (Turner et al., 2007, character #239, see also Witmer 1997, p.43 (*S6*))
    (0) absent
    (1) present

15. Longitudinal position of maxillary fenestra (Kirkland et al., 2005, character #28; Smith et al., 2007, character #30)
    (0) situated at rostral border of antorbital fossa
    (1) situated posterior to rostral border of antorbital fossa

16. Latitudinal position of maxillary fenestra (Turner et al., 2007, character #237)
    (0) situated approximately mid-height of the antorbital fossa
    (1) displaced dorsally in antorbital fossa

17. Foramen perforates ventral margin of interfenestral bar between the maxillary and antorbital fenestrae
    (0) absent
    (1) present, pierces ventral portion of bar

18. Promaxillary fenestra (fenestra promaxillaris, also listed as ‘promaxillary foramen’) (Kirkland et al., 2005, character #29; Rauhut, 2003, character #16; Smith et al., 2007, character #32; originally in Carpenter 1992 (*S7*))
    (0) absent
    (1) present

19. Secondary palate formed by (Kirkland et al., 2005, character #25; Smith et al., 2007, character #34)
    (0) premaxilla only
    (1) premaxilla, maxilla and vomer

20. Palatal shelf of maxilla (Kirkland et al., 2005, character #26)

(0) flat
(1) with midline ventral "tooth-like" projection

21. Anteroposterior length of palatal shelf of maxilla
(0) short
(1) long, with extensive palatal shelves

22. Orientation of the maxillae towards each other as seen in dorsal view (Rauhut, 2003, character #10; Smith et al., 2007 character #23)
(0) acutely angled
(1) subparallel

23. Ascending process of the maxilla (Rauhut, 2003, character #11; Smith et al., 2007, character #24)
(0) confluent with anterior rim of maxillary body and gently sloping posterodorsally
(1) offset from anterior rim of maxillary body, with anterior projection of maxillary body shorter than high
(2) offset from anterior rim of maxillary body, with anterior projection of maxillary body as long as high or longer

24. Nasal process of maxilla, dorsal ramus (ascending ramus of maxilla) (Turner et al., 2007, character #240; modified from Gauthier, 1986, Cracraft 1986 (*S8*), Chiappe, 1996 (*S9*), Clarke and Norell 2002 (*S10*))
(0) prominent, exposed laterally and medially
(1) weakly developed, lacking lateral exposure and only slight medial exposure (Most theropods, including *Velociraptor mongoliensis*, have a prominent ascending ramus of the maxilla. In derived avialans this lamina becomes reduced or absent.)

25. Anterior margin of maxillary antorbital fossa (Rauhut, 2003, character #13)
(0) rounded or pointed
(1) squared

26. Dorsal border of the internal antorbital fenestra, lateral view (Turner et al., 2007, character #242)
(0) formed by lacrimal and maxilla
(1) formed by nasal and lacrimal

27. Dorsal border of the antorbital fossa, lateral view (Turner et al., 2007, character #243)
(0) formed by lacrimal and maxilla
(1) formed by nasal and lacrimal
(2) formed by maxilla, premaxilla and lacrimal

28. In lateral view, lateral lamina of the ventral ramus of nasal process of maxilla (Turner et al., 2007, character #244)
(0) present, large broad exposure
(1) present, reduced to small triangular exposure

29. Maxillary antorbital fossa in front of the internal antorbital fenestra (Rauhut, 2003, character #14; Smith et al., 2007, character #26; originally in Sereno et al., 1996 (*S11*))
(0) 40% or less of the length of the external antorbital fenestra
(1) more than 40% of the length of the external antorbital fenestra

30. Horizontal ridge on the lateral surface of maxilla at the ventral border of the antorbital fossa (Rauhut, 2003, character #15; Smith et al., 2007, character #28; originally in Rowe and Gauthier, 1990 (*S12*))
(0) absent

(1) present

31. Constriction between articulated premaxillae and maxillae (Rauhut, 2003, character #8; Smith et al., 2007, character #21)
    (0) absent
    (1) present

32. Subnarial gap between maxilla and premaxilla at the alveolar margin (Rauhut, 2003, character #9; Smith et al., 2007, character #22; also in Tykoski, 2005)
    (0) absent
    (1) present

33. Nasals (Smith et al., 2007, character #40)
    (0) unfused
    (1) fused

34. Dorsal surface of the nasals (Rauhut, 2003, character #18)
    (0) smooth
    (1) rugose

35. Pneumatic foramen in the nasals (Rauhut, 2003, character #19; Smith et al., 2007, character #38)
    (0) absent
    (1) present

36. Narial region (particularly anterior end of the nasals) (Kirkland et al., 2005, character #31)
    (0) apneumatic or poorly pneumatized
    (1) with extensive pneumatic fossae, especially along posterodorsal rim of fossa

37. Dorsal extent of antorbital fossa (Rauhut, 2003, character #20; originally Sereno et al., 1994; Smith et al., 2007, character #39)
    (0) dorsal rim of antorbital fossa below nasomaxillary suture or formed by this suture
    (1) antorbital fossa extending onto the lateroventral side of the nasals

38. Shape of nasals (Rauhut, 2003, character #21)
    (0) expanding posteriorly
    (1) of subequal width throughout their length

39. Pronounced lateral rims of the nasals, sometimes bearing lateral cranial crests (Rauhut, 2003, character #22)
    (0) absent
    (1) present

40. External nares (Rauhut, 2003, character #7)
    (0) facing laterally
    (1) facing strongly anterolaterally

41. Jugal pneumatic recess in posteroventral corner of antorbital fossa (Kirkland et al., 2005, character #34: Rauhut, 2003, character #26 (with states reversed); Smith et al., 2007, character #47; originally in Sereno et al., 1996)
    (0) present
    (1) absent

42. Medial jugal foramen (Kirkland et al., 2005, character #35; Smith et al., 2007, character #48)

(0) present on medial surface ventral to postorbital bar
(1) absent

43. Sublacrimal part of jugal (Rauhut, 2003, character #23; Smith et al., 2007, character #46)
(0) tapering
(1) bluntly squared anteriorly
(2) expanded

44. Anterior end of jugal (Rauhut, 2003, character #24)
(0) posterior to internal antorbital fenestra, but reaching its posterior rim
(1) excluded from the internal antorbital fenestra
(2) expressed at the rim of the internal antorbital fenestra and with a distinct process that extends anteriorly underneath it

45. Jugal antorbital fossa (Rauhut, 2003, character #25; originally in Holtz, 1994; Smith et al., 2007, character #50 with states reversed)
(0) absent or developed as a slight depression
(1) large, crescentic depression on the anterior end of the jugal

46. Jugal (Rauhut, 2003, character #27)
(0) broad, plate-like
(1) very slender, rod-like

47. Jugal (Kirkland et al., 2005, character #33)
(0) tall beneath lower temporal fenestra, twice or more as tall dorsoventrally as it is wide transversely
(1) rod-like

48. Jugal and postorbital (Kirkland et al., 2005, character #32)
(0) contribute equally to postorbital bar
(1) ascending process of jugal reduced and descending process of postorbital ventrally elongate

49. Jugal and quadratojugal (Kirkland et al., 2005, character #37)
(0) separate
(1) fused and not distinguishable from one another

50. Quadratojugal (Kirkland et al., 2005, character #36; Rauhut, 2003, character #47, Smith et al., 2007, character #84*)*
(0) hook-shaped, without posterior process
(1) with broad, short posterior process that wraps around the lateroventral edge of the quadrate

51. Supraorbital crests on lacrimal in adult individuals (Kirkland et al., 2005, character #38; Rauhut, 2003, character #32, Smith et al., 2007, character #52*)*
(0) absent
(1) dorsal crest above orbit
(2) lateral expansion anterior and dorsal to orbit

52. Enlarged foramen or foramina opening laterally at the angle of the lacrimal (Kirkland et al., 2005, character #39; Rauhut, 2003, character #28; originally in Molnar et al., 1990; Smith et al., 2007, character #51)
(0) absent
(1) present

53. Height of the lacrimal (Rauhut, 2003, character #29)
(0) significantly less than height of the orbit, and usually fails to reach the ventral margin of the orbit

(1) as high as the orbit, and contacts jugal at the level of the ventral margin of orbit

54. Lacrimal posterodorsal process (Kirkland et al., 2005 2003 #40; reductive coding (*S13*) by JNC; Smith et al., 2007, character #53)
    (0) absent
    (1) present

55. Morphology of posterodorsal prcess of lacrimal (Kirkland et al., 2005 2003 #40; state added by Senter, 2007, character #40)
    (0) Lacrimal T-shaped
    (1) anterodorsal process much longer than posterior process
    (2) posterodorsal process subvertical

56. Passage of the nasolacrimal duct (Rauhut, 2003, character #30)
    (0) leading through the body of the ventral process of the lacrimal
    (1) ventral process of lacrimal not pierced, lateral side depressed below the level of the surrounding bones, and nasolacrimal duct passes lateral to the process

57. Ventral ramus of lacrimal (Smith et al., 2007 character #59)
    (0) broadly triangular, articular end nearly twice as wide anteroposteriorly as lacrimal body at lacrimal angle
    (1) bar- or strut-like, roughly same width anteroposteriorly throughout ventral ramus

58. Prefrontal
    (0) absent
    (1) present

59. Prefrontal (Rauhut, 2003, character #34; Kirkland et al., 2005, character #41; Smith et al., 2007, character #61)
    (0) exposed dorsally on the anterior rim of the orbit in lateral view and with a slender ventral process along the posteromedial rim of the lacrimal
    (1) excluded from the anterior rim of the orbit in lateral view, being displaced posteriorly and/or medially; ventral process absent

60. Configuration of lacrimal and frontal (Rauhut, 2003, character #35; Smith et al., 2007, character #54)
    (0) lacrimal separated from frontal by prefrontal
    (1) lacrimal contacts frontal

61. Frontals (Kirkland et al., 2005, character #42; Rauhut, 2003, character #36; Smith et al., 2007, character #62 with states reversed)
    (0) narrow anteriorly as a wedge between nasals
    (1) end abruptly anteriorly, suture with nasal transversely oriented

62. Frontal supratemporal fossa (Turner et al., 2007, #245)
    (0) limited extension of supratemporal fossa onto frontal
    (1) supratemporal fossa coovers most of frontal process of the postorbital and extends anteriorly onto the dorsal surface of the frontal

63. Anterior emargination of supratemporal fossa on frontal (Kirkland et al., 2005, character #43)
    (0) straight or slightly curved
    (1) strongly sinusoidal and reaching onto postorbital process

64. Frontal postorbital process (dorsal view) (Kirkland et al., 2005, character #44)

(0) smooth transition from orbital margin
(1) sharply demarcated from orbital margin

65. Frontal edge (Kirkland et al., 2005, character #45)
(0) smooth in region of lacrimal suture
(1) edge notched

66. Postorbital in lateral view (Kirkland et al., 2005, character #4; Smith et al., 2007, character #70)
(0) with straight anterior (frontal) process
(1) frontal process curves anterodorsally and dorsal border of temporal bar is dorsally concave

67. Postorbital bar (Kirkland et al., 2005, character #5)
(0) parallels quadrate, lower temporal fenestra rectangular in shape
(1) jugal and postorbital approach or contact quadratojugal to constrict lower temporal fenesta

68. Contact between lacrimal and postorbital (Rauhut, 2003, character #39; originally in Sampson et al., 1998; Smith et al., 2007, character #55)
(0) absent
(1) present

69. Cross-section of the ventral process of the postorbital (Rauhut, 2003, character #41; originally in Sereno et 1994; Smith et al., 2007, character #71)
(0) triangular
(1) U-shaped

70. Jugal process of the postorbital (Rauhut, 2003, character #40; Kirkland et al., 2005, character #3 (with states reversed); Smith et al., 2007, character #69)
(0) ventrally directed and tapering
(1) with a small anterior spur indicating the lower delimitation of the eyeball

71. Orbit (Kirkland et al., 2005, character #2)
(0) round in lateral or dorsolateral view
(1) dorsoventrally elongate

72. Parietals (Kirkland et al., 2005, character #47)
(0) separate
(1) fused

73. Parietal supratemporal fenestra (Rauhut, 2003, character #43; Smith et al., 2007, character #75; originally in Molnar et al., 1990; State (0) of this character the same as state (0) of character #45 in Turner et al., 2007 supporting online material, but states (1) and (2) of that character are not comparable to those of Turner et al., 2007)
(0) separated by a horizontal plate formed by the parietals
(1) contact each other posteriorly, but separated anteriorly by an anteriorly widening triangular plate formed by the parietals
(2) confluent over parietals, parietals form a sagittal crest

74. Sagittal crest (Kirkland et al., 2005, character #46: state (0) removed and coded as state (0) for character #73, states (1) and (2) converted to (0) and (1), respectively)
(0) dorsal surface of parietals smooth with no sagittal crest
(1) parietals dorsally convex with very low sagittal crest along midline
(2) dorsally convex with well-developed sagittal crest

75. Posteriorly placed, knob-like dorsal projection of the parietals (Rauhut, 2003, character #42; originally in Coria and Currie 2002 (*S14*); Smith et al., 2007, character #77)
    (0) absent
    (1) present

76. Descending process of squamosal (2) (Kirkland et al., 2005, character #49; Rauhut, 2003, character #46; Smith et al., 2007, character #82 , with state (0) and (2) coded as (1) and state (1) coded as (0))
    (0) contacts quadratojugal
    (1) does not contact quadratojugal

77. Quadratojugal process of the squamosal (Rauhut, 2003, character #45; Smith et al., 2007, character #81)
    (0) tapering
    (1) broad, and usually somewhat expanded

78. Posterolateral shelf on squamosal overhanging quadrate head (Kirkland et al., 2005, character #50; Smith et al., 2007, character #80)
    (0) absent
    (1) present

79. Descending process of squamosal (Kirkland et al., 2005, character #48)
    (0) parallels quadrate shaft
    (1) nearly perpendicular to quadrate shaft

80. Supratemporal fenestra (Kirkland et al., 2005, character #216; Smith et al., 2007, character #79)
    (0) bounded laterally and posteriorly by the squamosal
    (1) supratemporal fenestra extended as a fossa on to the dorsal surface of the squamosal

81. Quadrate head (Kirkland et al., 2005, character #213)
    (0) covered by squamosal in lateral view
    (1) quadrate cotyle of squamosal open laterally exposing quadrate head

82. Quadrate (Kirkland et al., 2005, character #53; Rauhut, 2003, character #48; Smith et al., 2007, character #87)
    (0) solid
    (1) hollow

83. Mandibular joint (Rauhut, 2003, character #51; Kirkland et al., 2005, character #52)
    (0) approximately straight below quadrate head
    (1) significantly posterior to quadrate head
    (2) significantly anterior to quadrate head

84. Dorsal end of the quadrate (Rauhut, 2003, character #50; Kirkland et al., 2005, character #51)
    (0) with a single head that fits into a slot on the ventral side of the squamosal
    (1) double-headed, medial head contacts the braincase

85. Quadrate foramen (reductive coding (*S13*) of Rauhut, 2003, character #49)
    (0) absent
    (1) present

86. Quadrate foramen (Rauhut, 2003, character #49; also scored with reference to Kirkland et al.,#55 with states reversed)
    (0) developed as a distinct opening between the quadrate and quadratojugal
    (1) almost entirely closed in the quadrate

87. Ectopterygoid (Rauhut, 2003, character #67; character states slightly changed by JNC; Smith et al., 2007, character #118)

(0) slender, without ventral fossa
(1) expanded, with a ventral depression medially
(2) expanded, with a deep groove leading into the ectopterygoid body medially
(3) deeply excavated and medial opening constricted into a foramen

88. Dorsal recess on ectopterygoid (Kirkland et al., 2005, character #61; Smith et al., 2007, character #117)

(0) absent
(1) present

89. Ectopterygoid (Rauhut, 2003, character #66)

(0) posterior to palatine
(1) lateral to palatine

90. Palatine and ectopterygoid (Kirkland et al., 2005, character #63 (after Currie, 1995 (*S15*)); Smith et al., 2007, character #116)

(0) separated by pterygoid
(1) contact

91. Contact between pterygoid and palatine (Rauhut, 2003, character #68; originally in Ostrom, 1969 (*S16*); Smith et al., 2007, character #119)

(0) continuous
(1) discontinuous in the mid-region, resulting in a subsidiary palatal fenestra

92. Flange of pterygoid (Kirkland et al., 2005, character #62)

(0) well developed
(1) reduced in size or absent

93. Shape of palatine in ventral view (Rauhut, 2003, character #65; Kirkland et al., 2005, character #64; originally in Harris, 1998 (*S17*); Smith et al., 2007, character #114)

(0) plate-like trapezoidal or subrectangular
(1) tetraradiate
(2) jugal process strongly reduced or absent

94. Suborbital fenestra (Kirkland et al., 2005, character #65)

(0) similar in length to orbit
(1) reduced in size or absent

95. Infratemporal fenestra (Rauhut, 2003, character #38; Smith et al., 2007, character #4)

(0) smaller than or subequal in size to orbit
(1) strongly enlarged, more than 1.5 times the size of the orbit

96. Postorbital part of the skull roof (Rauhut, 2003, character #44)

(0) as high as orbital region
(1) deflected ventrally in adult individuals

97. Preorbital region of the skull in post-hatchling individuals (Rauhut, 2003, character #71)

(0) elongate, nasals considerably longer than frontals, maxilla at least twice the length of the premaxilla
(1) shortened, nasals subequal in length to frontals or shorter, maxillary length less than twice the length of the premaxillary body

98. Basipterygoid processes (Kirkland et al., 2005, character #13)
(0) well-developed, extending as a distinct process from the base of the basisphenoid
(1) abbreviated or absent

99. Basipterygoid processes well developed and (Rauhut, 2003, character #58, state #2 added by JNC)
(0) anteroposteriorly short and finger-like (approximately as long as wide)
(1) longer than wide
(2) significantly elongated and tapering (Alvarezsauroids have extremely long, thin basipterygoid processes. In *Haplocheirus*, the process can be seen in left lateral view extending laterally beneath the quadrate ramus of the pterygoid).

100. Basipterygoid processes (Kirkland et al., 2005, character #12)
(0) ventral or anteroventrally projecting
(1) lateroventrally projecting
(2) caudally projecting (listed as a synapomorphy of the Ceratosauria by Sampson and Witmer, 2007 (*S18*))

101. Basipterygoid processes (Kirkland et al., 2005, character #14)
(0) solid
(1) hollow

102. Basipterygoid recesses on dorsolateral surfaces of basipterygoid processes (Kirkland et al., 2005, character #15)
(0) absent
(1) present

103. Basisphenoid recess (Rauhut, 2003, character #57; Smith et al., 2007, character #104)
(0) absent or poorly developed (with additional info from Kirkland et al., 2005, character #9 state (2))
(1) deep and well-developed

104. Basisphenoid recess position (Kirkland et al., 2005, character #9 (with state (2) removed and coded as (0) for character #103)
(0) between basisphenoid and basioccipital
(1) entirely within basisphenoid

105. Posterior opening of basisphenoid recess (Kirkland et al., 2005, character #10; Smith et al., 2007, character #105)
(0) single
(1) divided into two small, circular foramina by a thin bar of bone

106. Basisphenoid between basal tubera and basipterygoid processes (Rauhut, 2003, character #56; Smith et al., 2007, character #103)
(0) approximately as wide as long, or wider
(1) significantly elongated, at least 1.5 times longer than wide

107. Basisphenoid in lateral view
(0) oriented subhorizontally
(1) anterior portion located much more ventrally than posterior portion, recess visible in posterior view

108. Base of cultriform process (Kirkland et al., 2005, character #11; Rauhut, 2003, character #62)
(0) not highly pneumatised

(1) expanded and pneumatic (parasphenoid bulba)

109. Exits of CN X-XII (Kirkland et al., 2005, character #19)
 (0) flush with surface of exoccipital
 (1) located together in a bowl-like basisphenoid depression

110. Exits of CN X and XI (Rauhut, 2003, character #60)
 (0) laterally through the jugular foramen
 (1) posteriorly through a foramen (metotic foramen) lateral to the exit of cranial nerve XII and the occipital condyle

111. Paroccipital process (Kirkland et al., 2005, character #57; Smith et al., 2007, character #92)
 (0) elongate and slender, with dorsal and ventral edges nearly parallel
 (1) short, deep with convex distal end

112. Paroccipital process (2) (Kirkland et al., 2005, character #58; Rauhut, 2003, character #52; Smith et al., 2007, character #90)
 (0) straight, projects laterally or posterolaterally
 (1) distal end curves ventrally, pendant

113. Paroccipital process (3) (Kirkland et al., 2005, character #59; Smith et al., 2007, character #93; originally in Currie, 1995)
 (0) with straight dorsal edge
 (1) distal end twists rostrally, distal ends of the processes oriented transversely rather than vertically

114. Base of paroccipital processes (Rauhut, 2003, character #53)
 (0) solid
 (1) hollowed anteriorly by diverticulum of posterior tympanic recess

115. Ventral rim of the basis of the paroccipital processes (Rauhut, 2003, character #54; Smith et al., 2007, character #91)
 (0) above or level with the dorsal border of the occipital condyle
 (1) situated at mid-height of occipital condyle or lower

116. Foramen magnum (Kirkland et al., 2005, character #55)
 (0) subcircular, slightly wider than tall
 (1) oval, taller than wide

117. Occipital condyle (Kirkland et al., 2005, character #56)
 (0) without constricted neck
 (1) subspherical with constricted neck

118. Basal tubera (Rauhut, 2003, character #55; Smith et al., 2007, character #100)
 (0) equally formed by basioccipital and basisphenoid and not subdivided
 (1) subdivided by a lateral longitudinal groove into a medial part entriely formed by the basioccipital, and a lateral part, entirely formed by the basisphenoid

119. Basal tubera (Kirkland et al., 2005, character #222; originally in Holtz 200; Smith et al., 2007, character #102)
 (0) set far apart, level with or beyond lateral edge of occipital condyle and/or foramen magnum (may be connected by a web of bone or separated by a large notch)
 (1) tubera small, directly below condyle and foramen magnum, and separated by a narrow notch

120. Subcondylar recess (Kirkland et al., 2005, character #223; wording changed by JNC)
    (0) absent
    (1) present in basioccipital/exoccipital lateral and ventral to occipital condyle

121. Exit of mid-cerebral vein (Rauhut, 2003, character #61)
    (0) included in trigeminal foramen
    (1) vein exits braincase through a separate foramen anterodorsal to the trigeminal foramen

122. Brain proportions (Rauhut, 2003, character #64)
    (0) forebrain small and narrow
    (1) forebrain significantly enlarged and triangular

123. Anterior tympanic recess in the braincase (Rauhut, 2003, character #59; originally in Makovicky and Sues 1998 (*S19*); Smith et al., 2007, character #107)
    (0) absent
    (1) present

124. Depression for pneumatic recess on prootic (Kirkland et al., 2005, character #16)
    (0) absent
    (1) present as dorsally open fossa on prootic/opisthotic
    (2) present as deep, posterolaterally directed concavity

125. Crista interfenestralis (Kirkland et al., 2005, character #7)
    (0) confluent with lateral surface of prootic and opisthotic
    (1) distinctly depressed within middle ear opening

126. Dorsal tympanic recess (dorsal to crista interfenestralis) (Kirkland et al., 2005, character #17; states edited by JNC)
    (0) absent
    (1) small pocket present
    (2) extensive with indirect pneumatisation

127. Caudal (posterior) tympanic recess (Kirkland et al., 2005, character #18; Smith et al., 2007, character #94)
    (0) absent
    (1) present as opening on anterior surface of paroccipital process
    (2) extends into opisthotic posterodorsal to fenestra ovalis, confluent with this fenestra

128. Otosphenoidal crest (Kirkland et al., 2005, character #6)
    (0) vertical on basisphenoid and prootic, and does not border an enlarged pneumatic recess
    (1) well-developed, crescent-shaped, thin crest forms anterior edge of enlarged pneumatic recess

129. Subotic recess (pneumatic fossa ventral to fenestra ovalis) (Kirkland et al., 2005, character #8)
    (0) absent
    (1) present

130. Depression (possibly pneumatic) on ventral surface of postorbital process of laterosphenoid (Kirkland et al., 2005, character #221)
    (0) absent
    (1) present

131. Symphyseal region of dentary (Kirkland et al., 2005, character #66; see Rauhut, 2003, character #76)
    (0) Broad and straight, paralleling lateral margin
    (1) medially recurved slightly

(2) strongly recurved medially

132. Dentary symphyseal region in medial view (Kirkland et al., 2005, character #67)
  (0) in line with main part of buccal edge
  (1) end downturned

133. Posterior end of dentary (Kirkland et al., 2005, character #69; Rauhut, 2003, character #77)
  (0) without posterodorsal process dorsal to mandibular fenestra
  (1) with dorsal process above anterior end of mandibular fenestra
  (2) with elongate dorsal process extending over most of fenestra

134. Jaws (Kirkland et al., 2005, character #212; originally in Perez-Moreno et al., 1994; Smith et al., 2007, character #126)
  (0) occlude for their full length
  (1) diverge rostrally due to kink and downward deflection in dentary buccal margin

135. Labial face of dentary (Kirkland et al., 2005, character #70)
  (0) flat
  (1) with lateral ridge and inset tooth row

136. Nutrient foramina on external surface of dentary (Kirkland et al., 2005, character #72; state (2) added by JNC; this character not ordered because state (1) is not necessarily nested within state (2))
  (0) superficial
  (1) descend strongly posteriorly within a deep groove
  (2) descend posteriorly within triangular groove, caudal end of this groove is dorsoventrally expanded

137. Dentary shape (Kirkland et al., 2005, character #71)
  (0) subtriangular in lateral view
  (1) with subparallel dorsal and ventral edges
  (2) high triangular in lateral view (as in *Citipati*)

138. Ventral surface of dentary (Kirkland et al., 2005, character #224)
  (0) straight or nearly straight
  (1) descends strongly posteriorly

139. Pronounced coronoid eminence on the surangular (Rauhut, 2003, character #72; Kirkland et al., 2005 #68)
  (0) absent
  (1) present (Rauhut, 2003, character #72; Kirkland et al., 2005, character #68)

140. Foramen in lateral surface of surangular rostral to mandibular articulation (Kirkland et al., 2005, character #75)
  (0) absent
  (1) present

141. Laterally inclined flange along dorsal edge of surangular for articulation with lateral process of lateral quadrate condyle (Kirkland et al., 2005, character #209; Smith et al., 2007, character #134; originally in Holtz, 1998 (*S20*))
  (0) absent
  (1) present

142. Anterior portion of the surangular (Rauhut, 2003, character #75; originally in Gauthier, 1986; Smith et al., 2007, character #132)

(0) less than half the height of the mandible above the mandibular fenestra
(1) more than half the height of the mandible at the level of the mandibular fenestra

143. Retroarticular process of the mandible (Rauhut, 2003, character #73; Kirkland et al., 2005, character #79 (with states reversed); originally in Sereno et al., 1996; Harris, 1998; Smith et al., 2007, character #139)
(0) narrow, rod-like
(1) broadened, with groove posteriorly for the attachment of the m. depressor mandibulae

144. Attachment of the m. depressor mandibulae on retroarcticular process of mandible (Rauhut, 2003, character #74; originally in Sereno et al., 1996; Smith et al., 2007, character #140)
(0) facing dorsally
(1) facing posterodorsally

145. Retroarticular process (Kirkland et al., 2005, character #219)
(0) points caudally
(1) curves gently dorsocaudally

146. Articular (Kirkland et al., 2005, character #78)
(0) without elongate, slender medial, posteromedial, or mediodorsal process from retroarticular process
(1) with process

147. Angular (Kirkland et al., 2005, character #208; Smith et al., 2007, character #137)
(0) exposed almost to end of mandible in lateral view, reaches or almost reaches articular
(1) excluded from posterior end angular suture turns ventrally and meets ventral border of mandible rostral to glenoid

148. Coronoid ossification (Kirkland et al., 2005, character #77; Rauhut, 2003, character #80)
(0) large
(1) thin splint
(2) absent

149. Splenial (Kirkland et al., 2005, character #76; Smith et al., 2007, character #129 with states reversed)
(0) not widely exposed on lateral surface of mandible
(1) exposed as a broad triangle between dentary and angular on lateral surface of mandible

150. Foramen in the ventral part of the splenial (mylohyal foramen) (Rauhut, 2003, character #78; reductive coding by JNC; Smith et al., 2007, character #130)
(0) absent
(1) present

151. Form of mylohyal foramen
(0) completely enclosed in the splenial
(1) opened anteroventrally

152. Posterior end of splenial (Rauhut, 2003, character #79; Smith et al., 2007, character #131; originally in Sereno et al., 1996)
(0) straight
(1) forked

153. Mandibular articulation surface (Kirkland et al., 2005, character #80)
(0) as long as distal end of quadrate
(1) twice or more as long as quadrate surface, allowing anteroposterior movement of mandible

154. Mandibular foramen (Göhlich and Chiappe, 2006 #71 (*S21*))
	(0) large
	(1) absent or reduced

155. Shape of mandibular foramen (Kirkland et al., 2005, character #73)
	(0) oval
	(1) subdivided by a spinous rostral process of the surangular

156. Internal mandibular fenestra (Kirkland et al., 2005, character #74)
	(0) small and slit-like
	(1) large and rounded

157. Palatal teeth (Rauhut, 2003, character #69; Smith et al., 2007, character #120)
	(0) present
	(1) absent

158. Premaxillary teeth (Rauhut, 2003, character #81; Kirkland et al., 2005, character #81)
	(0) present
	(1) absent

159. Number of premaxillary teeth (Rauhut, 2003, character #5; Smith et al., 2007, character #(8))
	(0) three
	(1) four
	(2) five
	(3) more than five

160. First premaxillary tooth size (Turner et al., 2007, #251; Currie and Varrichio, 2004 #42; Currie, 1995)
	(0) slightly smaller or the same size as 2 and 3
	(1) much smaller than 2 and 3
	(2) much larger than 2 and 3

161. Second premaxillary tooth (Kirkland et al., 2005, character #82)
	(0) approximately equivalent in size to other premaxillary teeth
	(1) markedly larger than third and fourth premaxillary teeth

162. Serrations on premaxillary teeth (Rauhut, 2003, character #84; Smith et al., 2007, character #17)
	(0) present
	(1) absent

163. In cross section, premaxillary tooth crowns (Kirkland et al., 2005, character #91; Smith et al., 2007, character #18; originally in Bakker et al., 1988 (*S22*))
	(0) sub-oval to sub-circular
	(1) asymmetrical (D-shaped in cross section) with flat lingual surface

164. Maxillary teeth (Kirkland et al., 2005, character #83)
	(0) present
	(1) absent

165. Maxillary and dentary teeth (Kirkland et al., 2005, character #84; Rauhut, 2003; Smith et al., 2007, character #36; originally in Chiappe, 1996)
	(0) serrated
	(1) some without serrations anteriorly (except at base in *Saurornithoides mongoliensis*)

(2) all without serrations

166. Serration denticles (Kirkland et al., 2005, character #86)
- (0) large
- (1) small

167. Serrations (Kirkland et al., 2005, character #87)
- (0) simple, denticles convex
- (1) distal and often mesial edges of teeth with large, hooked denticles that point toward the tip of the crown

168. Maxillary tooth row (Rauhut, 2003, character #70; Smith et al., 2007, character #3)
- (0) extends posteriorly to approximately half the length of the orbit
- (1) ends at the anterior rim of the orbit
- (2) completely antorbital, tooth row ends anterior to the vertical strut of the lacrimal

169. Constriction between tooth crown and root (Rauhut, 2003, character #87; Kirkland et al., 2005, character #88 (with states reversed))
- (0) absent
- (1) present

170. Dentary (Kirkland et al., 2005, character #217)
- (0) fully toothed
- (1) only teeth rostrally
- (2) edentulous

171. Dentary teeth (Kirkland et al., 2005, character #231; Rauhut, 2003, character #83)
- (0) homodont
- (1) increasing in size anteriorly, becoming more conical in shape
- (2) Decreasing in size anteriorly, becoming more densely packed

172. Roots of dentary and maxillary teeth (Kirkland et al., 2005, character #228)
- (0) mediolaterally compressed
- (1) circular in cross-section

173. Maxillary teeth (added by JNC; state (3) added from Zhang et al., 2008 (*S23*), who depict this condition for some troodontids and detail state (2) as the condition in birds)
- (0) mediolaterally flattened and recurved
- (1) lanceolate and subsymmetrical (as in therizinosaurs)
- (2) simple, conical, incisive crowns (as in Alvarezsauroids)
- (3) labiolingually flattened and recurved, with crown in middle of tooth row less than twice as high as the basal mesiolateral width (fore-aft basal length)

174. Maxillary tooth implantation
- (0) separate alveoli
- (1) set in an open groove

175. Dentary tooth implantation (Turner et al., 2007, character #85; originally in Currie 1987 (*S24*))
- (0) separate alveoli
- (1) set in an open groove

176. Dentary teeth (Kirkland et al., 2005, character #230)

(0) mediolaterally flattened and recurved
(1) lanceolate and subsymmetrical

177. Dentary tooth size and number (Kirkland et al., 2005, character #85; Smith et al., 2007, character #127)
(0) large, fewer than 25 in dentary
(1) moderate number of small teeth (25-30 in dentary)
(2) relatively small and numerous (more than 30 in dentary)

178. Dentaries (Kirkland et al., 2005, character #90)
(0) lack interdental plates
(1) with interdental plates medially between teeth

179. Axial neural spine (Rauhut, 2003, character #93. Kirkland et al., 2005, character #94; Smith et al., 2007, character #145)
(0) flared transversely and sheet-like
(1) compressed mediolaterally, anteroposteriorly reduced, and rodlike

180. Epipophyses on axis (Rauhut, 2003, character #92. Kirkland et al., 2005, character #93)
(0) absent
(1) present as small ridges
(2) strongly pronounced (overhanging the zygapophyses)

181. Pleurocoel in axis (Rauhut, 2003, character #91; Smith et al., 2007, character #142)
(0) absent
(1) present

182. Epipophyses in anterior cervical vertebrae (Rauhut, 2003, character #102, Kirkland et al., 2005, #25; originally in Gauthier, 1986; Smith et al., 2007, character #159)
(0) absent or poorly developed
(1) well-developed, proximal to postzygapophyseal facets
(2) pronounced, strongly overhanging the postzygapophyses

183. Postzygapophyses of cervical vertebrae 2-4
(0) well-separated, or connected only at the base
(1) medially connected along their length by a web of bone that is dorsally concave for attachment of the interspinous ligaments

184. Anterior articular facet of anterior cervical vertebrae (Rauhut, 2003, character #101; Kirkland et al., 2005, character #98; Smith et al., 2007, character #154)
(0) approximately as high as wide or higher
(1) significantly wider than high
(2) wider than high and higher laterally than medially (kidney-shaped), with neural canal emarginating dorsal aspect

185. Cervical vertebral centra (Rauhut, 2003, character #95; Kirkland et al., 2005, character #101; Smith et al., 2007, character #151)
(0) amphi- to platycoelous
(1) opisthocoelous
(2) heterocoelous (state added from Turner et al., 2007)

186. Anterior cervical centra (Kirkland et al., 2005, character #96; Smith et al., 2007, character #155)
(0) level with or shorter than posterior extent of neural arch
(1) centra extending beyond posterior limit of neural arch

187. Carotid process on posterior cervical vertebrae (Kirkland et al., 2005, character #97)
(0) absent
(1) present

188. Cervical neural spines (Kirkland et al., 2005, character #99; Smith et al., 2007, character #164 with state (2) added)
(0) anteroposteriorly long
(1) anteroposteriorly short and centered on neural arch, giving arch an "X" shape in dorsal view
(2) extremely short anteroposteriorly, less than 1/3 length of neural arch

189. Number of cervical vertebrae (Kirkland et al., 2005, character #92)
(0) 10
(1) 12 or more

190. Pleurocoels in cervical vertebrae (Rauhut, 2003, character #88; Smith et al., 2007, character #147)
(0) absent
(1) present

191. Number of pleurocoels in cervicals (Rauhut, 2003, character #89; Kirkland et al., 2005, character #100 (with states reversed); Smith et al., 2007, character #148)
(0) two, arranged horizontally
(1) one

192. Pleurocoels developed as (Rauhut, 2003, character #90; Smith et al., 2007, character #149)
(0) deep depressions
(1) foramina

193. Interior pneumatic spaces in cervicals (Rauhut, 2003, character #96; Smith et al., 2007, character #152)
(0) Structure camerate (few chambers)
(1) Structure camellate (many chambers separated by delicate lamellae)

194. Ventral keel in anterior cervicals (Rauhut, 2003, character #97)
(0) present
(1) absent

195. Broad ridge from the diapophyses to the ventral rim of the posterior end of the vertebral centra in cervical vertebrae (Rauhut, 2003, character #98)
(0) absent
(1) present

196. Prezygapophyses in anterior cervicals (Rauhut, 2003, character #99; originally in Makovicky, 1995 (*S25*); Smith et al., 2007, character #156)
(0) transverse distance between prezygapophyses less than width of neural canal
(1) prezygapophyses situated lateral to the neural canal

197. Prezygapophyses in anterior postaxial cervicals (Rauhut, 2003, character #100; Originally in Gauthier, 1986; Smith et al., 2007, character #157)
(0) straight
(1) anteroposteriorly convex, flexed ventrally anteriorly

198. Hypapophyses in anterior dorsals (Rauhut, 2003, character #107; Kirkland et al., 2005, character #102)
(0) absent or poorly developed

(1) pronounced

199. Hyposphene-hypantrum articulation in dorsal vertebrae (Rauhut, 2003, character #103; Kirkland et al., 2005, character #104; Smith et al., 2007, character #173)
  (0) absent
  (1) present

200. Postzygapophyses of trunk vertebrae (Kirkland et al., 2005, character #105)
  (0) abutting one another above neural canal, opposite hyposphenes meet to form lamina
  (1) zygapophyses placed lateral to neural canal and separated by groove for interspinous ligaments, hyposphens separated

201. Neural spines on posterior dorsal vertebrae in lateral view (Kirkland et al., 2005, character #206; Rauhut, 2003, character #110; originally in Chen et al., 1998 (*S26*); Smith et al., 2007, character #176)
  (0) rectangular or square
  (1) anteroposteriorly expanded distally, fan-shaped

202. Neural spines of dorsal vertebrae in dorsal view (Kirkland et al., 2005, character #108; Smith et al., 2007, character #177)
  (0) not expanded distally
  (1) expanded laterally in dorsal view to form "spine table"

203. Scars for interspinous ligaments (Kirkland et al., 2005, character #109; Smith et al., 2007, character #178)
  (0) terminate at apex of neural spine in dorsal vertebrae
  (1) terminate below apex of neural spine

204. Neural spine of posterior dorsals (Rauhut, 2003, character #109; Smith et al., 2007, character #175)
  (0) broadly rectangular and approximately as dorsoventrally high as anteroposteriorly long
  (1) high rectangular, significantly higher than long

205. Hook-like extension on anterior end of dorsal neural spines in lateral view (Peyer, 2006)
  (0) absent
  (1) present (with associated depression immediately caudal to the projection for spinous ligament attachment)

206. Parapophyses of posterior trunk vertebrae (Kirkland et al., 2005, character #103; Smith et al., 2007, character #180)
  (0) flush with neural arch
  (1) distinctly projected on pedicels

207. Parapophyses in posteriormost dorsals (Rauhut, 2003, character #111; originally in Makovicky, 1995; Smith et al., 2007, character #179)
  (0) on same level as transverse process
  (1) distinctly below transverse process

208. Pleurocoels in dorsal vertebrae (Rauhut, 2003, character #106)
  (0) absent
  (1) present in anterior dorsals ('pectorals')
  (2) present in all dorsals

209. Transverse processes of anterior dorsal vertebrae (Kirkland et al., 2005, character #107)
  (0) long and thin
  (1) short, wide and only slightly inclined

210. Dorsal centra articular surfaces (Longrich and Currie, 2008 (*S28*); originally in Perle et al., 1993 (*S29*))
(0) amphiplatyan
(1) opisthocoelous

211. Ventral keel in anterior dorsals (Rauhut, 2003, character #108; Smith et al., 2007, character #170)
(0) absent or very poorly developed
(1) pronounced

212. Shape of dorsal centra in anterior view (Rauhut, 2003, character #105)
(0) subcircular or oval
(1) significantly wider than high
(2) triangular

213. Posterior dorsal vertebrae (Rauhut, 2003, character #112)
(0) strongly shortened, centra much shorter than high
(1) relatively short, centra approximately as high as long, or only slightly longer
(2) significantly elongated, much longer than high

214. Number of sacral vertebrae (Kirkland et al., 2005, character #110; Rauhut, 2003, character #113; states renumbered by JNC)
(0) two
(1) three
(2) four
(3) five
(4) six
(5) seven
(6) eight
(7) nine

215. Pleurocoels in sacral vertebrae (Kirkland et al., 2005, character #113; Rauhut, 2003, character #115)
(0) absent
(1) present on anterior sacrals only
(2) present on all sacrals

216. Ventral surface of posterior sacral centra (Rauhut, 2003, character #114)
(0) gently rounded, convex
(1) flattened ventrally, sometimes with shallow sulcus
(2) centrum strongly constricted transversely, ventral surface keeled (Kirkland et al., 2005, character #112, after Novas, 1997; Rauhut, 2003, character #114)

217. Sacral ribs (Rauhut, 2003, character #116; Originally in Rowe and Gauthier, 1990; Smith et al., 2007, character #187)
(0) slender and well-separated
(1) forming a more or less continuous sheet in ventral or dorsal view
(2) very massive and strongly expanded

218. Sacral vertebrae (Kirkland et al., 2005, character #111)
(0) with unfused zygapophyses
(1) with fused zygapophyses forming a sinuous ridge in dorsal view

219. Last sacral centrum (Kirkland et al., 2005, character #114)
(0) with flat posterior articular surface

(1) convex articulation surface

220. Ventral surface of posterior sacral centra (Character modified from Longrich and Currie, 2008 character #19; originally from Perle et al., 1994 (*S30*), also in Novas, 1996 (*S31*))
(0) rounded or flat
(1) strong ventral keel

221. Number of caudal vertebrae (Kirkland et al., 2005, character #121; Rauhut, 2003, character #117)
(0) more than 40
(1) 25-40
(2) fewer than 25
(3) tail short and fused into a pygostyle

222. Caudal vertebrae (Kirkland et al., 2005 #115)
(0) with distinct transition point, from shorter centra with long transverse processes proximally to longer centra with small or no transverse processes distally
(1) homogeneous in shape, with no transition point

223. Caudal vertebral centra (Longrich and Currie, 2008 #21; originally from Novas, 1996)
(0) amphiplatyan
(1) procoelous

224. Position of transition point (Turner et al., 2007, character #116; Rauhut, 2003, character #119)
(0) distal to the tenth caudal vertebra
(1) between the 7th and 10th caudal vertebrae
(2) proximal to the 7th caudal vertebra

225. Location of transverse processes of proximal caudals (Longrich and Currie, 2008, character #22, listed as a ‘mononykine’ synapomorphy)
(0) centrally positioned on centrum
(1) posteriorly displaced (Longrich and Currie (2008) list this character state as “anteriorly displaced,” but the transverse processes are located posteriorly on the neural arch so we have changed the wording.

226. Shape of anterior caudal centra (Rauhut, 2003, character #127; Kirkland et al., 2005; Smith et al., 2007, character #190)
(0) oval
(1) subrectangular and box-like
(2) laterally compressed with a ventral keel (This state taken from Göhlich and Chiappe, 2006 character #117 (*S21*))

227. Ventral groove in anterior caudals (Rauhut, 2003, character #120)
(0) absent
(1) present

228. Ventral surface of anterior caudals (Rauhut, 2003, character #121; Kirkland et al., 2005, character #117)
(0) Rounded
(1) with a distinct keel bearing a narrow, shallow groove on its midline

229. Neural spines on distal caudals (Kirkland et al., 2005, character #119)
(0) form a low ridge
(1) spine absent
(2) midline sulcus in center of the neural arch

230. Neural spines of caudal vertebrae (Kirkland et al., 2005, character #118; the "anterior spur" of Rauhut, 2003 character #125 is the same; Smith et al., 2007, character #198)
(0) simple, undivided
(1) separated into anterior and posterior alae throughout much of caudal sequence

231. Neural spines of mid-caudals (Rauhut, 2003, character #124; Smith et al., 2007, character #197)
(0) rod-like and posteriorly inclined
(1) subrectangular and sheet-like
(2) rod-like and vertical

232. Prezygapophyses of distal caudal vertebrae (Combination of Kirkland et al., 2005, character #120 and Rauhut, 2003, character #122)
(0) between 1/3 and whole centrum length
(1) with extremely long extensions of the prezygapophyses (up to 10 vertebral segments in some taxa)
(2) strongly reduced as in *Archaeopteryx lithographica*

233. Anterior margin of neural spines of anterior mid-caudal vertebrae (Rauhut, 2003, character #123; Smith et al., 2007, character #195)
(0) straight
(1) with distinct kink, dorsal part of anterior margin more strongly inclined posteriorly than ventral part

234. Relative length of distal caudal centra (Rauhut, 2003, character #126)
(0) significantly elongated in relation to centrum height
(1) not elongated in relation to centrum height

235. Cranial process at base of chevrons (Rauhut, 2003, character #128; Smith et al., 2007, character #199)
(0) absent
(1) present

236. Distal chevrons (Rauhut, 2003, character #129; Smith et al., 2007, character #202)
(0) rod-like or L-shaped
(1) skid-like

237. Mid-caudal chevrons (Rauhut, 2003, character #130; originally Sereno et al., 1996; Smith et al., 2007, character #201)
(0) rod-like or only slightly expanded ventrally
(1) L-shaped

238. Proximal end of chevrons of proximal caudals (Kirkland et al., 2005, character #122; Smith et al., 2007, character #200)
(0) short anteroposteriorly, shaft cylindrical
(1) proximal end elongate anteroposteriorly, flattened and plate-like

239. Distal caudal chevrons (Kirkland et al., 2005, character #123)
(0) simple
(1) anteriorly bifurcate
(2) bifurcate at both ends

240. Long, hair-like cervical ribs
(0) absent
(1) present

241. Shaft of cervical ribs (Kirkland et al., 2005, character #124; Smith et al., 2007, character #167)
(0) slender and longer than vertebra to which they articulate
(1) broad and shorter than vertebra

242. Ossified uncinate processes (Kirkland et al., 2005, character #125; Smith et al., 2007, character #203)
(0) absent
(1) present

243. Lateral gastral segment (Kirkland et al., 2005, character #127)
(0) shorter than medial one in each arch
(1) distal segment longer than proximal segment

244. Ossified sternal plates (Kirkland et al., 2005, character #128; Smith et al., 2007, character #208)
(0) separate in adults
(1) fused
(2) fused with ventral keel (in alvarezsauroids, the sternal plate is pitted and forks anteriorly)

245. Sternum (Kirkland et al., 2005, character #129)
(0) without distinct lateral xiphoid process posterior to costal margin
(1) with lateral xiphoid process

246. Furcula (Rauhut, 2003, character #131)
(0) absent
(1) present

247. Hypocleidium on furcula (Kirkland et al., 2005, character #132)
(0) absent
(1) present

248. Articular facet of coracoid on sternum (Kirkland et al., 2005, character #131; Xu et al., 1999 (*S32*))
(0) anterolateral or more lateral than anterior
(1) almost anterior

249. Anterior edge of sternum (Kirkland et al., 2005, character #130)
(0) grooved for reception of coracoids
(1) without grooves

250. Coracoid in lateral view (Kirkland et al., 2005, character #136; Rauhut, 2003, character #138; originally in Gauthier, 1986; Smith et al., 2007, character #219)
(0) subcircular, with shallow ventral blade
(1) subquadrangular with extensive ventral blade
(2) shallow ventral blade with elongate posteroventral process
(3) strut-like

251. Posterior edge of coracoid (Kirkland et al., 2005, character #218)
(0) not or shallowly indented below glenoid
(1) posterior edge of coracoid deeply notched just ventral to glenoid, glenoid lip everted

252. Anterior surface of coracoid ventral to glenoid fossa (Kirkland et al., 2005, character #134)
(0) unexpanded
(1) expanded, forms triangular subglenoid fossa bounded laterally by coracoid tuber

253. Coracoid tubercle
- (0) absent
- (1) present

254. Coracoid tubercle form
- (0) anteroposteriorly short, mound-like
- (1) anteroposteriorly elongated, ridge-like

255. Scapula shape (Rauhut, 2003, character #132; Smith et al., 2007, character #212)
- (0) short and broad (ratio length/minimal height of shaft <9)
- (1) slender and elongate (ratio >10)

256. Acromion margin of scapula (Kirkland et al., 2005, character #133. Rauhut, 2003, character #134 (with states reversed); Smith et al., 2007, character #214 (with states reversed))
- (0) continuous with blade
- (1) anterior edge laterally everted

257. Flange on supraglenoid buttress on scapula (see Nicholls and Russell, 1985; Kirkland et al., 2005, character #220)
- (0) absent
- (1) present

258. Distal end of scapula (Rauhut, 2003, character #133; Smith et al., 2007, character #213; originally in Gauthier, 1986)
- (0) expanded
- (1) not expanded

259. Glenoid fossa (Kirkland et al., 2005, character #138; Rauhut, 2003 character #135)
- (0) faces posteriorly or posterolaterally
- (1) faces laterally

260. Scapula and coracoid (Kirkland et al., 2005, character #135)
- (0) separate
- (1) fused into scapulocoracoid

261. Scapula and coracoid angle (Smith et al., 2007, character #216)
- (0) continuous arc in posterior and anterior views
- (1) coracoid inflected medially, scapulocoracoid L shaped in lateral view

262. Scapular length (Turner et al., 2007, character #139)
- (0) longer than humerus
- (1) shorter than humerus

263. Deltopectoral crest (Kirkland et al., 2005, character #140)
- (0) large and distinct, proximal end of humerus quadrangular in anterior view
- (1) less pronounced, forming an arc rather than being quadrangular
- (2) very weakly developed, proximal end of humerus with rounded edges
- (3) extremely long (as in *Shuvuuia* and *Mononykus*)
- (4) proximal end of humerus extremely broad, triangular in anterior view

264. Anterior surface of deltopectoral crest (Turner et al., 2007, character #141; Smith et al., 2007, character #224)
- (0) smooth

(1) with distinct muscle scar near lateral edge along distal end of crest for insertion of biceps muscle

265. Ratio femur/humerus (Rauhut, 2003, character #139)
   (0) more than 2.5
   (1) between 1.2 and 2.2
   (2) less than 1

266. Outline of proximal articular facet of humerus (Rauhut, 2003, character #140; Smith et al., 2007, character #221)
   (0) broadly oval (more than twice as broad transversely than anteroposteriorly)
   (1) distinctly rounded, often globular (less than twice as broad anteroposteriorly than transversely)

267. Internal tuberosity of humerus (JNC, with reference to Chiappe et al., 2003, Novas, 1996)
   (0) small and confluent with humeral head
   (1) offset from humeral head by distinct notch, often projects proximally above humeral head
   (2) hypertrophied but not distinct from humeral head (as in *Suchomimus*)

268. Shape of internal tuberosity on humerus in anterior view (Rauhut, 2003, character #141)
   (0) triangular, often rounded
   (1) rectangular

269. Humerus in lateral view (Rauhut, 2003, character #143; originally in Holtz, 1994 (*S33*); Smith et al., 2007, character #220)
   (0) sigmoidal
   (1) straight

270. Ectepicondyle of humerus (lateral epicondyle)
   (0) small, often rectangular and does not form articular surface
   (1) large, rounded and forms articular surface

271. Entepicondyle of humerus (medial epicondyle) (Kirkland et al., 2005, character #225, edited by JNC)
   (0) absent or small and tabular
   (1) large, projects medially from ulnar condyle as a distinct process and is distally separated from ulnar condyle by a groove

272. Distal humeral condyles (Kirkland et al., 2005, character #226)
   (0) primarily developed on distal end of humerus, but may also have some articular surface extending to anterior edge
   (1) limited to anterior surface, condylar surfaces not present on distal end

273. Olecranon process of ulna (Rauhut, 2003, character #144; Kirkland et al., 2005, character #142; originally in Novas, 1996; Smith et al., 2007, character #227)
   (0) well-developed
   (1) strongly reduced or absent

274. Proximal surface of ulna (Kirkland et al., 2005, character #144; Smith et al., 2007, character #228)
   (0) single continuous articular facet
   (1) divided into two distinct fossae

275. Distal articular surface of ulna (Kirkland et al., 2005, character #143)
   (0) flat
   (1) convex, semilunate surface

276. Distal condyle articular surface of ulna (Longrich and Currie, 2008, character #33)
    (0) unexpanded or spatulate, articular surface limited to distal end
    (1) bulbous, trochlear articular surface extends onto dorsal surface of ulna

277. Radius (Rauhut, 2003, character #145; Smith et al., 2007, character #229)
    (0) more than half the length of humerus
    (1) less than half the length of humerus

278. Radius and ulna (Kirkland et al., 2005, character #211)
    (0) well-separated
    (1) with distinct adherence or syndesmosis distally

279. Distal end of radius
    (0) unexpanded, distal end is round or elliptical
    (1) expanded dorsoventrally, flange projects ventrally from elliptical distal end

280. Ossified carpals
    (0) absent
    (1) present

281. Lateral proximal carpal (ulnare?) (Kirkland et al., 2005, character #145; Smith et al., 2007, character #231)
    (0) quadrangular
    (1) triangular in proximal view

282. "Semilunate" distal carpal (modified from Rauhut, 2003, character #146)
    (0) absent (same as state (0) for Rauhut, 2003, character #146)
    (1) present (coded as (1) for Rauhut, 2003, character #146: states (1), (2) or (3))

283. Two distal carpals (Kirkland et al., 2005, character #146; Smith et al., 2007, character #232)
    (0) in contact with metacarpals, one covering the base of Mc I (and perhaps contacting Mc II) , the other covering the base of Mc II
    (1) two distal carpals not present, single distal carpal capping Mc I and II

284. Distal carpals (Kirkland et al., 2005, character #147)
    (0) not fused to metacarpals
    (1) fused to metacarpals, forming carpometacarpus

-for the positional homology of the metacarpals and digits, we follow the scheme presented by Xu et al. (*S34*), where all maniraptorans are hypothesized to have digits II, III and IV.

285. Rectangular buttress on the proximal surface of Mc II
    (0) absent
    (1) present

286. Length of Mc II (derived from Kirkland et al., 2005, character #149; Smith et al., 2007, character #234 with states reversed)
    (0) half or less than half the length of Mc III
    (1) subequal in length to Mc III

287. Shape of Mc II (Rauhut, 2003, character #164; Kirkland et al., 2005, character #149; Smith et al., 2007, character #235)
    (0) significantly longer than broad

(1) very stout, approximately as long as broad

288. Contact between Mc II and Mc III (Rauhut, 2003, character #148; Smith et al., 2007, character #236)
(0) metacarpals contact each other at their bases only
(1) Mc II closely appressed to Mc III, at least the proximal half of McI flattened

289. Distal end of Mc II (Rauhut, 2003, character #149)
(0) condyles more or less symmetrical
(1) condyles strongly asymmetrical, the medial condyle being positioned more proximally than the lateral

290. Distal articular end of metacarpal II (Kirkland et al., 2005, character #210; redefined by JNC)
(0) ginglymoid
(1) rounded and smooth

291. Medial side of Mc III (Rauhut, 2003, character #150; Smith et al., 2007, character #238)
(0) expanded proximally
(1) not expanded

292. Distal articular end of Mc III
(0) ginglymoid
(1) rounded and smooth

293. Shaft of Mc IV (Rauhut, 2003, character #151; Smith et al., 2007, character #239)
(0) subequal in width to Mc III
(1) considerably more slender than Mc III (less than 70% of the width of Mc III)

294. Proximal articular end of Mc IV (Rauhut, 2003, character #152; originally Gauthier, 1986; Smith et al., 2007, character #240)
(0) expanded and similar in width to Mc II and III
(1) not expanded, very slender when compared to Mc II and III

295. Proximal outline of Mc IV (Rauhut, 2003, character #156; Smith et al., 2007, character #244)
(0) subrectangular
(1) triangular, apex dorsal

296. Shaft of Mc IV (Rauhut, 2003, character #157; character #245of Smith et al., 2007)
(0) straight
(1) bowed laterally

297. Extensor pits on the dorsal surface of the distal end of metacarpals (Rauhut, 2003, character #155; Smith et al., 2007, character #243)
(0) absent or poorly developed
(1) deep, well-developed

298. Number of fingers (Rauhut, 2003, character #153)
(0) five
(1) fifth finger absent and fourth finger reduced to a metacarpal with only one phalanx
(2) fourth finger absent
(3) two fingers, third finger either strongly reduced or absent (As in Tyrannosaurus rex)

299. Flexor surface of manual phalanx II-1 (Added by JNC with reference to Chiappe et al., 2002)
(0) convex or flat

(1) concave, 'axial furrow' along proximodistal axis

300. Shaft diameter of phalanx II-1 (Kirkland et al., 2005, character #207; Smith et al., 2007, character #246)
(0) less than shaft diameter of radius
(1) greater than shaft diameter of radius

301. Ratio phalanx II-1/Mc II (Rauhut, 2003, character #158)
(0) 1 or less
(1) between 1 and 1.5
(2) more than 1. 5

302. Penultimate phalanx of the third finger (Rauhut, 2003, character #159)
(0) shorter than first phalanx
(1) longer than first phalanx

303. Penultimate phalanx of the fourth finger (Rauhut, 2003, character #160)
(0) as long as, or shorter than, more proximal phalanges
(1) longer than each of the more proximal phalanges
(2) longer than both proximal phalanges taken together

304. Length of fourth manual digit (Rauhut, 2003, character #154; originally from Gauthier, 1986)
(0) longer than second finger
(1) shorter than second finger

305. Proximal articular surface of manual ungual II-2 (Longrich and Currie, 2008 #46)
(0) dorsoventrally much taller than mediolaterally wide
(1) mediolaterally as broad as tall

306. Unguals on all manual digits (Kirkland et al., 2005, character #152)
(0) generally similar in size
(1) digit II bearing large ungual and unguals of other digits distinctly smaller

307. Proximodorsal lip on some manual unguals - a transverse ridge immediately dorsal to the articulating surface (Kirkland et al., 2005, character #153; Rauhut, 2003, character #162; Originally from Currie and Russell 1988; Smith et al., 2007, character #250)
(0) absent
(1) present

308. Flexor tubercle placement (Zhang et al., 2008, character #151)
(0) proximal
(1) distal
(2) absent
(3) reduced to pyramidal nubbins, as in *Limusaurus*

309. Curvature of manual ungual II (Zhang et al., 2008, character #298)
(0) strongly curved
(1) weakly curved
(2) straight

310. Curvature of manual unguals III and IV (Zhang et al., 2008, character #299)
(0) strongly curved
(1) weakly curved
(2) straight

311. Flexor tubercle size (Zhang et al., 2008, character #348)
- (0) large (>1/3 articular facet height)
- (1) small (<1/3 articular facet height)

312. Lateral grooves of manual ungual II-2 in ventral view (Longrich and Curre, 2008 #45)
- (0) unenclosed
- (1) proximal end of grooves partially enclosed by lateral notches
- (2) proximal end of grooves passes through foramena on ventral surface of ungual

313. Ilium (Rauhut, 2003, character #166)
- (0) brachyiliac
- (1) dolichoiliac

314. Ventral edge of anterior ala of ilium (Kirkland et al., 2005, character #154; Rauhut, 2003, character #168; Smith et al., 2007, character #253)
- (0) straight or gently curved
- (1) ventral edge hooked anteriorly
- (2) very strongly hooked

315. Preacetabular part of ilium (Rauhut, 2003, character #169; Kirkland et al., 2005, character #155; Smith et al., 2007, character #254)
- (0) significantly shorter than postacetabular part
- (1) subequal in length to postacetabular part
- (2) significantly longer than postacetabular process

316. Anterior rim of ilium (Rauhut, 2003, character #173. Kirkland et al., 2005, character #156; Smith et al., 2007, character #256)
- (0) gently convex or straight
- (1) distinctly concave dorsally
- (2) anterior end strongly curved
- (3) pointed at the anterodorsal corner

317. Preacetabular part of ilium (height) (Rauhut, 2003, character #170)
- (0) approximately as high as postacetabular part (excluding the ventral expansion)
- (1) significantly higher than postacetabular part

318. Cuppedicus fossa (Kirkland et al., 2005, character #164)
- (0) deep, ventrally concave
- (1) fossa shallow or flat, with no lateral overhang
- (2) absent

319. Cuppedicus fossa position (Kirkland et al., 2005, character #163; Smith et al., 2007, character #264)
- (0) ridge bounding fossa terminates rostral to acetabulum or curves ventrally onto anterior end of pubic peduncle
- (1) rim extends far posteriorly and is confluent or almost confluent with acetabular rim

320. Preacetabular portion of ilium (Kirkland et al., 2005, character #229)
- (0) parasagittal
- (1) moderately laterally flaring

321. Brevis fossa shape (Rauhut, 2003, character #176. Kirkland et at, character #161)
- (0) shelf-like, narrow with subparallel margins

(1) deeply concave, expanded posteriorly with lateral overhang

322. Brevis fossa lateral view (Turner et al., 2007, character #217)
(0) Poorly developed adjacent to ischial peduncle, without lateral overhang and medial edge of the brevis fossa is visible
(1) well developed fossa along full length of postacetabular blade, lateral overhang extends along full length of fossa, medial edge of brevis fossa covered in lateral view

323. Medial brevis shelf (Longrich and Currie, 2008 character #53)
(0) strongly developed, projects medially
(1) low ridge on medial surface of postacetabular ala

324. Postacetabular ala of ilium in lateral view (Kirkland et al., 2005, character #158; Rauhut, 2003, character #174; Smith et al., 2007, character #260)
(0) squared
(1) acuminate

325. Articulation of iliac blades with sacrum (Rauhut, 2003, character #171; Smith et al., 2007)
(0) vertical, well-separated above sacrum
(1) strongly inclined mediodorsally, almost contacting each other or sacral neural spines at midline

326. Vertical ridge on iliac blade above acetabulum (Rauhut, 2003, character #172)
(0) absent or poorly developed
(1) well-developed

327. Pubic peduncle of ilium (Rauhut, 2003, character #175; Smith et al., 2007, character #265)
(0) transversely broad and roughly triangular in outline
(1) anteroposteriorly elongated and narrow

328. Pubic peduncle (Rauhut, 2003, character #177; Smith et al., 2007, character #266)
(0) subequal in length to ischial peduncle
(1) significantly longer than ischial peduncle, ischial peduncle tapering ventrally and without clearly defined articular facet
(2) craniocaudally shorter than the ischial peduncle (This character state added by JNC; this characteristic of alvarezsauroids is first mentioned in Martinelli and Vera 2007, pg. 7 (*S36*))

329. Articulation facet of pubic peduncle of ilium (Rauhut, 2003, character #178)
(0) facing more ventrally than anteriorly, and without a pronounced kink
(1) with pronounced kink and anterior part facing almost entirely anteriorly

330. Anterior margin of pubic peduncle (Rauhut, 2003, character #179)
(0) straight or convex
(1) concave

331. Supraacetabular crest
(0) absent
(1) present

332. Supraacetabular crest on ilium (Kirkland et al., 2005, character #157)
(0) separate process from antitrochanter, forms hood over femoral head
(1) reduced, not forming hood

333. Antitrochanter posterior to acetabulum (Kirkland et al., 2005, character #162; Smith et al., 2007, character #269 with states reversed)
    (0) absent or poorly developed
    (1) prominent

334. Postacetabular blades of ilia in dorsal view (Kirkland et al., 2005, character #159)
    (0) parallel
    (1) diverge posteriorly

335. Tuber along dorsal edge of ilium, dorsal or slightly posterior to acetabulum (Kirkland et al., 2005, character #160; Smith et al., 2007, character #259)
    (0) absent
    (1) present

336. Dorsal margin of postacetabular ala in lateral view (Turner et al., 2007, character #226; originally in Novas, 2004 (*S37*))
    (0) convex or straight
    (1) concave, brevis shelf extends caudal to lateral ilium making it appear concave in lateral view

337. Caudal end of postacetabular ala in dorsal view (Turner et al., 2007, character #227; originally in Makovicky et al., 2003 (*S38*))
    (0) rounded or squared in dorsal view
    (1) lobate, with brevis shelf extending caudally beyond caudal terminus of the postacetabular ala

338. Ilium and ischium articulation (Kirkland et al., 2005, character #227; Smith et al., 2007, character #274)
    (0) flat or slightly concavo-convex
    (1) with process projecting into socket in ischium

339. Pubic orientation (Kirkland et al., 2005, character #175; Smith et al., 2007, character #252)
    (0) propubic
    (1) vertical (Acc. to Kirkland et al., 2005, character #175)
    (2) moderately posteriorly oriented
    (3) opisthopubic

340. Strongly expanded pubic boot (Rauhut, 2003, character #184; Kirkland et al., 2005, character #176, state (2) (no anterior or posterior projections); originally in Gauthier, 1986; Smith et al., 2007, character #280)
    (0) absent
    (1) present

341. Pubic boot projects (Kirkland et al., 2005, character #176; see Rauhut, 2003, character #s 184-187)
    (0) anteriorly and posteriorly
    (1) with little or no anterior process
    (2) only expanded anteriorly

342. Pubic apron (Kirkland et al., 2005, character #177; also see Rauhut, 2003, character #167)
    (0) extends medially from middle of cylindrical pubic shaft
    (1) shelf extends medially from anterior edge of anteroposterioly flattened shaft
    (2) absent

343. Pubic apron (Kirkland et al., 2005, character #179; Smith et al., 2007, character #278)
    (0) about half of pubic shaft length
    (1) less than 1/3 of shaft length

344. Pubic apron (Rauhut, 2003, character #182; Smith et al., 2007, character #279)
(0) completely closed
(1) with medial opening distally above the pubic boot

345. Obturator foramen in pubis (Rauhut, 2003, character #180; originally in Holtz, 1994; Smith et al., 2007, character #276)
(0) completely enclosed
(1) open ventrally (obturator notch)
(2) absent

346. Pubic fenestra below obturator foramen (Rauhut, 2003, character #181; Smith et al., 2007, character #277)
(0) absent
(1) present

347. Pubic shafts in lateral view (Rauhut, 2003, character #183; Kirkland et al., 2005, character #178)
(0) straight
(1) anteriorly convex
(2) anteriorly concave

348. Lateral face of pubic shafts (Turner et al., 2007, character #231; originally in Senter et al., 2004 (*S39*))
(0) smooth
(1) with prominent lateral tubercle about halfway down the shaft

349. Length of ischium (Kirkland et al., 2005, character #171; Rauhut, 2003, character #191; originally from Gauthier, 1986; Smith et al., 2007, character #284)
(0) more than two-thirds pubis length
(1) two thirds or less of pubic length

350. Obturator process of ischium (Kirkland et al., 2005, character #167; Rauhut, 2003, character #189)
(0) absent
(1) proximal in position
(2) located near middle of ischiadic shaft
(3) located at distal end of ischium

351. Ischiac shaft (Turner et al., 2007, character #166; originally in Makovicky et al., 2005)
(0) Rodlike
(1) anteroposteriorly wide and plate like

352. Lateral blade of ischium (Turner 2007 #168)
(0) flat
(1) laterally concave
(2) with longitudinal ridge subdividing lateral surface into anterior (including obturator process) and posterior parts

353. Ischium (Kirkland et al., 2005, character #166)
(0) straight
(1) ventrodistally curved anteriorly
(2) twisted at midshaft and with flexure of obturator process toward midline so that distal end is horizontal
(3) with laterally concave curvature in anterior view
(4) distal portion curved posteriorly

354. Contact of obturator process of ischium (Kirkland et al., 2005, character #168)
(0) does not contact pubis
(1) contacts pubis

355. Ventral notch at distal edge of ischial obturator process (Rauhut, 2003, character #190; originally in Sereno et al., 1996; Smith et al., 2007, character #289)
(0) absent, grades smoothly into ischial shafts
(1) present, makes obturator process triangular in lateral view

356. Obturator process on ischium (Rauhut, 2003, character #188. Kirkland et al., 2005, character #169 (with states reversed); Smith et al., 2007, character #287)
(0) confluent with pubic peduncle
(1) offset from pubic peduncle by a distinct notch

357. Morphology of offset triangular obturator process of ischium (Turner et al., 2007, character #234)
(0) wide base along ischiac shaft, rostral process short
(1) narrow base, rostral process elongate

358. Distal end of ischium (Rauhut, 2003, character #193. Kirkland et al., 2005, character #173; Smith et al., 2007, character #290)
(0) slightly expanded
(1) strongly expanded, forming ischial "boot"
(2) tapering

359. Distal ends of ischia (Kirkland et al., 2005, character #172; Smith et al., 2007, character #291)
(0) form symphysis
(1) approach one another but do not form symphysis
(2) widely separated

360. Distally placed process on caudal margin of ischium (Turner et al., 2007, character #232; originally Forster et al., 1998 (*S40*))
(0) absent
(1) present

361. Tubercle on anterior edge of ischium (Kirkland et al., 2005, character #174; Smith et al., 2007, character #285)
(0) absent
(1) present

362. Posterior process (ischial tuberosity) on posteroproximal part of ischium (Rauhut, 2003, character #192; Kirkland et al., 2005, character #165; Smith et al., 2007, character #286)
(0) absent
(1) well-developed

363. Form of posteroproximal ischial process (ischial tuberosity) (Turner et al., 2007, character #230)
(0) small, tablike
(1) large, proximodorsally hooked and separated from the iliac peduncle by a notch

364. Semicircular scar on posterior part of the proximal end of the ischium (Kirkland et al., 2005, character #170)
(0) absent
(1) present

365. Femoral length (Zhang et al., 2008, character #309)
(0) longer than tibia
(1) shorter than tibia

366. Femoral head (Kirkland et al., 2005, character #180; Rauhut, 2003, character #197; "fovea ligamentum capitis" of Baumel and Witmer 1993: pg. 64 (*S41*)); Smith et al., 2007, character #295)
(0) without fovea capitalis
(1) circular fovea present in center of medial surface of head

367. Oblique ligament groove on the posterior surface of femoral head (originally in Rauhut, 2003; all scorings taken from Smith et al., 2007 #296)
(0) absent or very shallow
(1) deep, bound medially by a well-developed posterior lip

368. Femoral head (Rauhut, 2003, character #194; originally in Holtz, 1994; Smith et al., 2007, character #292)
(0) confluent with greater trochanter
(1) separated from greater trochanter by a distinct cleft

369. Femoral head (2) (Rauhut, 2003, character #195; Smith et al., 2007, character #293)
(0) directed anteromedially
(1) directed strictly medially

370. Greater trochanter (Rauhut, 2003, character #196)
(0) anteroposteriorly narrow and narrowing from medial to lateral
(1) anteroposteriorly expanded, forming a trochanteric crest

371. Lesser trochanter (Kirkland et al., 2005, character #181)
(0) separated from greater trochanter by a deep cleft
(1) trochanters separated by small groove
(2) completely fused (or absent) to form crista trochanteris (Additional taxa coded using state (3) of Rauhut, 2003, character #198 "fused with greater trochanter")

372. Lesser trochanter shape (Kirkland et al., 2005, character #181)
(0) alariform (Some taxa coded from state (2) of Rauhut, 2003 character #198)
(1) cylindrical in cross section

373. Placement of lesser trochanter (Rauhut, 2003, character #199; Smith et al., 2007, character #298)
(0) at distal end of femoral head
(1) more proximally placed, but distal to greater trochanter
(2) as proximal or more proximal than greater trochanter

374. Vertical ridge on lesser trochanter (Kirkland et al., 2005, character #215)
(0) present
(1) absent

375. Posterolateral trochanter (Kirkland et al., 2005, character #183; Rauhut, 2003, character #200; "lateral ridge" of Turner et al., 2007)
(0) absent or represented only by rugose area
(1) posterior trochanter distinctly raised from shaft, mound-like

376. Fourth trochanter on femur (Kirkland et al., 2005, character #184; Rauhut, 2003, character #201; originally Gauthier, 1986; Smith et al., 2007, character #301)

(0) present
(1) absent

377. Accessory trochanteric crest distal to lesser trochanter (Kirkland et al., 2005, character #185)
(0) absent
(1) present

378. Broad groove on cranial surface of distal femur (Rauhut, 2003, character #202; Kirkland et al., 2005, character #186; originally in Forster 1998; Smith et al., 2007, character #302)
(0) absent or poorly developed
(1) well developed and bounded medially by an expanded medial lamella

379. Popliteal fossa on distal end of femur (Kirkland et al., 2005, character #187)
(0) open distally
(1) closed off distally by contact between distal condyles

380. Distal end of femur (Rauhut, 2003, character #203)
(0) anteroposteriorly broad and distally flattened
(1) less broad and well rounded

381. Lateral femoral distal condyle
(0) distally rounded, projects only slightly more distally than medial condyle
(1) distally conical, projects considerably further distally than medial condyle

382. Lateral accessory cnemial crest (This refers to the vertical ridge sometimes present on the lateral surface of the cnemial crest of a variety of theropods)
(0) absent
(1) present

383. Medial cnemial crest (Kirkland et al., 2005, character #192)
(0) absent
(1) present on proximal end of tibia

384. Fibular condyle on proximal end of tibia (Rauhut, 2003, character #204; Smith et al., 2007, character #305)
(0) confluent with cnemial crest anteriorly in proximal view
(1) strongly offset from cnemial crest

385. Medial proximal condyle on tibia
(0) round in proximal view
(1) arcuate and posteriorly angular in proximal view

386. Posterior cleft between medial part of the proximal end of the tibia and fibular condyle (Rauhut, 2003, character #205; Smith et al., 2007, character #307)
(0) absent
(1) present

387. Fibular crest (ridge on lateral side of tibia for connection with fibula) (Rauhut, 2003, character #206; originally in Gauthier, 1986; Smith et al., 2007, character #308)
(0) absent
(1) present, extending from proximal articular surface distally
(2) present, clearly separated from proximal articular surface

388. Shape of fibular crest (Longrich and Currie, 2008, character #64; they find this character synapomorphic for Alvarezsauroidea)
    (0) quadrangular
    (1) low and rounded

389. Bracing for ascending process of astragalus on anterior side of distal tibia (Rauhut, 2003, character #207)
    (0) distinct 'step' running obliquely from mediodistal to lateroproximal
    (1) bluntly rounded vertical ridge on medial side
    (2) anterior side of tibia flat

390. Fibula (Kirkland et al., 2005 character #188)
    (0) reaches proximal tarsals
    (1) short, tapering distally, and not in contact with proximal tarsals

391. Insertion of m. iliofibularis on fibular shaft (Rauhut, 2003, character #211; Smith et al., 2007, character #316; originally in Mader and Bradley, 1989 (*S42*); Holtz, 1994)
    (0) not especially marked
    (1) present as a well-developed anterolateral tubercle

392. Ridge on medial side of proximal end of fibula, that runs anterodistally from the posterproximal end (Rauhut, 2003, character #209; originally in Rowe and Gauthier, 1990; Smith et al., 2007, character #314)
    (0) absent
    (1) present

393. Medial surface of proximal end of fibula (Kirkland et al., 2005, character #189; see Rauhut, 2003, character #210; originally from Sereno et al., 1996; Smith et al., 2007, character #315 with states reversed)
    (0) concave along long axis
    (1) flat

394. Deep oval fossa on medial surface of fibula near proximal end (Kirkland et al., 2005, character #190; see Rauhut, 2003, character #210)
    (0) absent
    (1) present

395. Astragalus and Calcaneum (Kirkland et al., 2005, character #191)
    (0) condyles indistinct or poorly separated
    (1) distinct condyles separated by prominent vertical tendinal groove on anterior surface

396. Astragalus and calcaneum (Kirkland et al., 2005, character #195; Sereno et al., 1996; Smith et al., 2007, character #327)
    (0) separate from tibia
    (1) fused to each other and to the tibia in late ontogeny

397. Fibular facet on astragalus (Rauhut, 2003, character #213)
    (0) large and facing partially proximally
    (1) reduced and facing laterally or absent

398. Height of ascending process of the astragalus (Rauhut, 2003, character #215; Smith et al., 2007, character #321)
    (0) lower than astragalar body
    (1) higher than astragalar body
    (2) more than twice the height of astragalar body

399. Shape of ascending process of the astragalus (Kirkland et al., 2005, character #193)
(0) tall and broad, covering most of anterior surface of distal end of tibia
(1) short and slender, covering only lateral half of anterior surface of tibia
(2) tall with a medial notch that restricts it to lateral side of anterior face of distal tibia

400. Ascending process of astragalus (Rauhut, 2003, character #216; Kirkland et al., 2005, character #194; Smith et al., 2007, character #322; originally from Welles and Long 1974 (*S43*))
(0) confluent or only slightly offset from astragalar body
(1) offset from astragalar body by a pronounced groove

401. Astragalar condyles (Rauhut, 2003, character #217; Originally in Sereno et al., 1996; Smith et al., 2007, character #324)
(0) almost entirely below tibia and face distally
(1) significantly expanded proximally on anterior side of tibia and face anterodistally

402. Horizontal groove across astragalar condyles anteriorly (Rauhut, 2003, character #218; originally in Welles and Long, 1974; Smith et al., 2007, character #325)
(0) absent
(1) present

403. Calcaneum (Rauhut, 2003, character #219)
(0) without facet for tibia
(1) well-developed facet for tibia present

404. Distal tarsals (Kirkland et al., 2005, character #196; Smith et al., 2007, character #329)
(0) separate, not fused to metatarsals
(1) form metatarsal cap with intercondylar prominence that fuses to metatarsal early in postnatal ontogeny

405. Metatarsals (Kirkland et al., 2005, character #197)
(0) not co-ossified
(1) co-ossification of metatarsals begins proximally
(2) begins distally

406. Metatarsal I
(0) present
(1) absent

407. Metatarsal I (Kirkland et al., 2005, character #203)
(0) attenuates proximally ,without proximal articulating surface
(1) proximal end of Mt I similar to that of Mt II-IV

408. Metatarsal I (Rauhut, 2003, character #222 and Kirkland et al., 2005, character #202)
(0) contacts the ankle joint
(1) reduced, elongated and splint-like, articulates in the middle of the medial surface of Mt II
(2) broadly triangular and attached to the distal quarter of Mt II
(3) Absent

409. Distal end of metatarsal II (Kirkland et al., 2005, character #198)
(0) smooth, not ginglymoid
(1) with developed ginglymus

410. Tuber along extensor surface of MtII (Turner et al., 2007; from Chiappe, 2002)

(0) Absent
(1) Present (Turner et al., 2004 #235, originally Chiappe 2002)

411. Posteromedial margin MtII diaphysis (this seems to be developed independently of the ridge on MtIV)
    (0) well-developed flange absent or area rugose
    (1) with flange projecting caudally or medially

412. Distal end of metatarsal III (Kirkland et al., 2005, character #199)
    (0) smooth, not ginglymoid
    (1) with developed ginglymus

413. Metatarsal III (Rauhut, 2003, character #220, with state (2) added from Kirkland et al., character #200)
    (0) subequal in width to Mt II and IV proximally
    (1) pinched between II and IV and not visible in anterior view proximally
    (2) does not reach the proximal end of the metatarsus

414. Shaft of MT IV (Kirkland et al., 2005, character #204)
    (0) round or thicker dorsoventrally than wide in cross section
    (1) shaft of Mt IV mediolaterally widened and flat in cross section

415. Length of MtIV (Taken from Longrich and Currie, 2008)
    (0) subequal to Mt II
    (1) markedly longer than Mt II

416. Posterolateral margin of MtIV diaphysis (Turner et al., 2007, character #229; originally in Novas and Pol, 2005 (*S44*))
    (0) well-developed flange absent or area rugose
    (1) with flange projecting caudally or laterally

417. Metatarsal V (Rauhut, 2003, character #223)
    (0) with rounded distal articular facet
    (1) strongly reduced and lacking distal articular facet
    (2) short, without articular surface, transversely flattened and bowed anteriorly distally

418. Pedal digit IV (Rauhut, 2003, character #221; see Kirkland et al., 2005, character #205.)
    (0) significantly shorter than III and subequal in length to II, foot is symmetrical
    (1) significantly longer than II and only slightly shorter than III, foot is asymmetrical

419. Ungual and penultimate phalanx of pedal digit II (Kirkland et al., 2005, character #201; Rauhut, 2003, character #224)
    (0) similar to those of III
    (1) highly modified for extreme hyper-extension, ugual more strongly curved and about 50% larger than that of III

420. Pedal phalanges of digit IV (Turner et al., 2009 (*S45*))
    (0) anteroposteriorly short, with proximal and distal articular surfaces very close together, particularly in distal elements
    (1) anteroposteriorly long, proximal and distal articular surfaces well-separated

421. Extensor ligament pits on dorsal surface of pedal phalanges (Turner et al., 2009)
    (0) shallow, extensor ridges not sharp
    (1) deep and extensive proximally, corresponding extensor ridges sharply defined in dorsal view

Character-taxon matrix

Uncertainty in scoring or variable character states in terminal taxa (polymorphism) is indicated by square brackets []. Inapplicable scorings are indicated with a -.

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Sapeornis
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Yixianornis
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?????1?????1?1?????1[12]?01????0????00??
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Methods

The character/taxon matrix was constructed in Mesquite v2.71 (*S46*). The matrix was analyzed under the parsimony criterion using equal weightings with TNT v1.1 (*S47*), using heuristic search algorithms designed for large datasets (*S48*-*S50*). Analysis consisted of 1000 iterations of heuristic tree searches using Sectorial Search, Ratchet, Tree Drift, and Tree Fuse with default parameters ("New Technology" search regime), followed by an additional round of TBR branch swapping on the MPTs. Bremer support was calculated in TNT by TBR swapping on the most parsimonious trees (MPTs) and saving 10,000 suboptimal topologies up to 10 steps longer than the minimum length.

Manhattan Stratigraphic Measure* (MSM*) analysis

Methods

To test whether the discovery of *Haplocheirus* improved stratigraphic fit to phylogeny, we performed an MSM* (*S51*-*S53*) analysis. The MSM* measures the fit of an irreversible stratigraphic character on the tree, where character states are time intervals and state transformations are given a cost proportional to the absolute amount of time between intervals. An improved version of this method, detailed by Pol and Norell (*S51*), allows the incorporation of stratigraphic uncertainty (e.g., the 16 million year range of dates for the Daohugou Fm. (*S54*)) by using a re-sampling procedure to sample from the range of first appearance dates for a given taxon.

We limited our dataset to the higher taxa within Coelurosauria. Although the higher taxa we selected do not all bear the same taxonomic rank (e.g., Therizinosauroidea, Ornithomimosauria, Alvarezsauroidea), they are comparable in that most contain similar numbers of taxa (within one order of magnitude) and constitute reciprocally monophyletic clades within the larger theropod tree. The single genera we included (*Coelurus* and *Ornitholestes*) had well-resolved phylogenetic positions and conveyed important Jurassic stratigraphic information. Our strict consensus tree had a four-way polytomy between Paraves, Alvarezsauroidea, Therizinosauroidea and Oviraptorosauria. The MSM* has not been extensively used on polytomous topologies, and although there are no special provisions about such a use, the fit of the stratigraphic character will be significantly decreased on polytomous trees relative to fully-bifurcating trees. We therefore only considered fully-bifurcating topologies in our analysis. Among our MPTs, only two sets of alternative relationships between higher taxa remained after collapsing side branches within Coelurosauria (see Fig. S2), and we therefore analyzed the stratigraphic fit of these two topologies (topology 1 and 2).

In all trees, we used *Eoraptor* as an outgroup. This was desirable for rooting purposes and because the first appearance date for *Eoraptor* is well before that of *Epidendrosaurus*, the oldest coelurosaur in the dataset. We resolved Avialae with *Archaeopteryx* at the base and with the Scansoriopterygidae sister to Ornithothoraces, a relationship supported in all of the fundamental cladograms in this analysis, although the membership of Ornithothoraces varied.

An MSM* analysis incorporating stratigraphic uncertainty returns a series of resampled fit values for a given topology using a given set of first appearance data. We performed 1000 iterations for each topology listed above, first considering Alvarezsauroidea to have originated in the Late Cretaceous (the extent of the fossil record before the discovery of *Haplocheirus*) and then considering Alvarezsauroidea to have originated in the earliest Late Jurassic (incorporating the stratigraphic information from the Shishugou Fm.). Each topology therefore had two sets of 1000 resampled fit values for the stratigraphic character, one set with alvarezsauroids as Cretaceous and one set with alvarezsauroids as Jurassic.

Pol and Norell (*S51*) suggest evaluating the stratigraphic consistency of competing phylogenies of identical taxa by calculating the MSM*Diff. The MSM*Diff is the difference in the fit value of the stratigraphic character between competing topologies. Analyzing the distribution of the MSM*Diff over the resampled data determines whether stratigraphic fit is consistently better for one topology or another. A histogram of MSM*Diffs calculated between pairs of resampled values for two competing topologies A and B would be centered on 0 if the stratigraphic fit was roughly equal among topologies, or right-skewed if the stratigraphic fit of A was consistently worse than B or vice versa. Here, rather than considering two competing topologies, we investigated the difference in stratigraphic fit for identical topologies when the first appearance date for Alvarezsauroidea varied between the Late Jurassic (reflecting the addition of *Haplocheirus*) and Late Cretaceous (the first appearance date for Alvarezsauroidea before the discovery of *Haplocheirus*).

Measures of stratigraphic fit to phylogeny are sensitive to tree shape, size, and scope (observed stratigraphic range), and thus attaching significance values to comparisons of the MSM* values of different phylogenies is problematic (*S55*). Comparisons between identical topologies where the stratigraphic information is varied are not subject to problems of tree shape or size, but could be sensitive to the scope of the analysis if a very narrow age range for the terminals is being compared to a much wider set of age values for the terminals. In our analysis, we avoided this latter issue because the overall age range for all taxa remains consistent regardless of whether alvarezsauroids are considered to be Jurassic or Cretaceous. Despite eliminating these confounding factors, we do not attach statistical significance to our results and we present the following data as descriptive statistics only.

Data files

The following three data files are designed to work with a TNT (*S47*) script designed by Pol and Norell (*S51*) to perform MSM* analyses (*S53*) incorporating stratigraphic uncertainty (available from the authors).

Age files:
Alvarezsauroids are Late Jurassic

```
/*0 Eoraptor*/
set min[0] 206;
set max[0] 227;

/*1 Tyrannosauroidea*/
set min[1] 158;
set max[1] 162;

/*2 Ornithomimosauria*/
set min[2] 125;
set max[2] 130;

/*3 Compsognathidae*/
set min[3] 151;
```

```
set max[3] 156;

/*4 Ornitholestes*/
set min[4] 145;
set max[4] 156;

/*5 Alvarezsauroidea*/
set min[5] 158;
set max[5] 162;

/*6 Therizinosauroidea */
set min[6] 122;
set max[6] 125;

/*7 Oviraptorosauria*/
set min[7] 112;
set max[7] 125;

/*8 Troodontidae*/
set min[8] 151;
set max[8] 161;

/*9 Dromaeosauridae*/
set min[9] 127;
set max[9] 132;

/*A Archaeopteryx*/
set min[10] 145;
set max[10] 151;

/*B Scansoriopterygidae*/
set min[11] 151;
set max[11] 167;

/*C Ornithoraces*/
set min[11] 112;
set max[11] 125;

/*D Coelurus*/
set min[12] 145;
set max[12] 156;

p/;
```

Alvarezsauroids are Late Cretaceous

```
/*0 Eoraptor*/
set min[0] 206;
set max[0] 227;
```

```
/*1 Tyrannosauroidea*/
set min[1] 158;
set max[1] 162;

/*2 Ornithomimosauria*/
set min[2] 125;
set max[2] 130;

/*3 Compsognathidae*/
set min[3] 151;
set max[3] 156;

/*4 Ornitholestes*/
set min[4] 145;
set max[4] 156;

/*5 Alvarezsauroidea*/
set min[5] 158;
set max[5] 162;

/*6 Therizinosauroidea */
set min[6] 122;
set max[6] 125;

/*7 Oviraptorosauria*/
set min[7] 112;
set max[7] 125;

/*8 Troodontidae*/
set min[8] 151;
set max[8] 161;

/*9 Dromaeosauridae*/
set min[9] 127;
set max[9] 132;

/*A Archaeopteryx*/
set min[10] 145;
set max[10] 151;

/*B Scansoriopterygidae*/
set min[11] 151;
set max[11] 167;

/*C Ornithoraces*/
```

```
set min[11] 112;
set max[11] 125;

/*D Coelurus*/
set min[12] 145;
set max[12] 156;

p/;
```

Tree file:

```
tread 'Coelurosauria family level'
(Eoraptor (Coelurus (Tyrannosauroidea (Ornithomimosauria (Ornitholestes (Compsognathidae
(Alvarezsauroidea (Therizinosauroidea (Oviraptorosauria ((Archaeopteryx (Scansoriopterygidae
Ornithoraces)) (Dromaeosauridae Troodontidae))))))))))*
(Eoraptor (Coelurus (Tyrannosauroidea (Ornithomimosauria (Ornitholestes (Compsognathidae
((Therizinosauroidea Oviraptorosauria) (Alvarezsauroidea ((Archaeopteryx (Scansoriopterygidae
Ornithoraces)) (Dromaeosauridae Troodontidae)))))))))*
proc/;
```

Data file:

```
xread
'Coelurosauria'
1 15
Root 0
Eoraptor 0
Tyrannosauroidea 1
Ornithomimosauria 2
Compsognathidae     3
Ornitholestes  4
Alvarezsauroidea    5
Therizinosauroidea 6
Oviraptorosauria 7
Troodontidae 8
Dromaeosauridae 9
Archaeopteryx A
Scansoriopterygidae B
Ornithoraces C
Coelurus D;
p/;
```

Body size calculations

We used the methods of recently published studies to calculate body length and body mass for alvarezsauroid taxa considered in this study (Table S1). Body mass was calculated with the equations of Christiansen and Fariña (*S56*), using femur length and with the equations of Therrien and Henderson (*S57*), using skull length. Body length was calculated with the equations of Therrien and Henderson (*S57*) using skull length and with the equations of Turner et al., (*1*) who used femur length to calculate a regression specific to paravians.

Body mass (BM):

Therrien and Henderson:

$$BM\ (kg) = 1.00419 \times 10\ \text{^}\ (3.6022 * \text{Log}_{10}(\text{skull length (m)}) +3.4426)$$

Christiansen and Fariña

$$\text{Log}_{10}BM\ (kg) = -6.288 \pm 0.5 +3.222 \pm 0.0181 * \text{Log}_{10}\ \text{femur length (mm)}$$

Body length (BL):

Therrien and Henderson:

$$BL\ (m) = 1.03161 \times 10\ \text{^}\ (.85673 * \text{Log}_{10}(\text{skull length (m)} + 0.93482)$$

Turner et al., 2007

$$BL\ (mm) = 8.8889\ (\text{femur length (mm)}) - 34.257$$

The sizes of the South American taxa *Patagonykus* and *Alvarezsaurus*, the North American taxon *Albertonykus*, and the recently-described Mongolian taxon *Kol* could not be confidently estimated because they lack complete femora and complete skulls.

Results and discussion

Phylogenetic analysis

Analysis of the full dataset yielded 69 MPTs of length 1998, CI= 0.26, RI=0.65. The strict consensus of these trees (Fig. S1a,b) is poorly resolved for basal Tetanurae. Within the Maniraptora, *Ornitholestes* is always found as the basalmost taxon, and Compsognathidae are recovered within Maniraptora at the next higher node. A monophyletic Oviraptorosauria, Alvarezsauroidea, Therizinosauroidea and Paraves are recovered in all fundamental cladograms, although they constitute a polychotomy crownward of Compsognathidae. Inspection of the fundamental cladograms reveals that only two general topologies exist for the relationships between these groups (Fig. S2). In all topologies where Oviraptorosauria and Therizinosauroidea form a sister group, Alvarezsauroidea are positioned as the sister group to Paraves (Fig. S2). In all other fundamental cladograms, Oviraptorosauria is the sister-taxon to Paraves, followed by Therizinosauroidea and then Alvarezsauroidea as successive outgroups (Fig. S2).

Bremer support (*S58*) for a monophyletic Alvarezsauroidea including *Haplocheirus* (Fig. S1a,b) was modest at 2, despite 17 unambiguous synapormorphies for the clade. We therefore suspected that certain incomplete alvarezsauroid taxa included in the analysis may vary in position in suboptimal trees. For example, within the Alvarezsauroidea, the recently discovered mononykine genus *Albertonykus* (*S28*) is only known from a partial forelimb and hindlimb, and the South American taxon *Achillesaurus* (*S36*) cannot be scored for any of the characters that diagnose the basal node of the Alvarezsauroidea (although it possesses characters that place it in a more derived position within the clade). The large number of taxa, and thus the enormous number of potential topologies (*S60*), precluded a complete double-decay analysis (*S60*) to search for hidden support in the data. Instead, we employed a reduced consensus Bremer support approach (*S59*) where we searched for suboptimal trees with the complete dataset, but then calculated support values with certain taxa excluded from the consensus. Removal of *Achillesaurus* and *Albertonykus* in this manner improved the support for the monophyly of the

Alvarezsauroidea from 2 to 5. Bremer support also improved for Oviraptorosauria and Paraves in the reduced analysis.

To determine the amount of evidence needed with the full dataset to return Alvarezsauroidea as members of Avialae, we analyzed the full dataset under a constraint tree that represented a monophyletic, but fully polytomous, grouping of the constituent members of Avialae + Alvarezsauroidea from the full analysis (tree not shown). The shortest tree in this constrained analysis was 2005 steps, CI= 0.26, RI= 0.64, or 7 steps longer than the MPTs produced with the full dataset with no constraints.

We also considered the position for Alvarezsauroidea hypothesized by Sereno (*S61*), who found them to be sister to Ornithomimosauria, although he did not present a supporting phylogenetic analysis. We constructed a constraint tree that held Ornithomimosauria and Alvarezsauroidea as sister taxa, but did not constrain relationships within either group. The shortest tree found using this constraint tree was length 1999, CI=0.26, RI=0.65, one step longer than the MPTs produced under no constraints. In this constrained analysis, *Ornitholestes* is the most primitive maniraptoran and Alvarezsauroidea+Ornithomimosauria are recovered as the basalmost maniraptoran group in all MPTs. Interestingly, Compsognathidae move to a position outside of Maniraptora in these trees.

Analysis of the dataset without *Haplocheirus* changes the topologies of the MPTs in several ways. First, in all trees without *Haplocheirus*, the Ornithomimosauria are basal members of Maniraptora and Compsognathidae move to a position outside of Maniraptora. Second, the Alvarezsauroidea are sister to Oviraptorosauria + Paraves, a position that is closer to Avialae than in some of the MPTs from the full dataset. Third, the taxon *Pelecanimimus*, usually regarded as the most primitive ornithomimosaur, moves into the Alvarezsauroidea as the most primitive member of the group. This relationship is supported by the following characters:

10: 1→0: Caudal margin of the naris does not overlap antorbital fenestra

175: 0→1: Teeth set in an open groove.

177: 0→1: Small and numerous dentary teeth

250: 1→2: Shallow coracoid with elongate posteroventral process

285: 0→1: Metacarpal II subequal in length to metacarpal III (the hypothesis from the full dataset is that metacarpal II of most ornithomimids has been elongated and that metacarpal II of alvarezsaurids has been widened but maintained its size as metacarpals III and IV have decreased in length.)

308: 0→1: Distally-located flexor tubercles

309: 0→1: Manual ungual II-2 weakly curved

311: 0→1: Flexor tubercles small

Haplocheirus is important because it establishes the primitive states for the characters that otherwise unite *Pelecanimimus* and the remaining alvarezsauroids, which in turn changes the interpretation of characters shared between these groups from homologies to homoplasies. The presence of *Haplocheirus* excludes Ornithomimosauria, and includes Compsognathidae, as a member of Maniraptora, although the reasons for this are unclear and Bremer supports for these relationships are low (Ornithomimosauria is 1, Alvarezsauroidea is 1, most nodes within Maniraptora are 1). Finally, *Haplocheirus* seems to be providing information that suggests a more primitive position for the Alvarezsauroidea in some trees.

Alvarezsauroid taxonomy

Alvarezsauroidea Bonaparte, 1991: The superfamilial rank Alvarezsauroidea was first used by Livezey and Zusi (*S62*),who defined it as the clade containing *Patagonykus*, *Alvarezsaurus* and *Mononykus*. In their usage, Alvarezsauroidea is synonymous with Alvarezsauridae Bonaparte, 1991 as defined by Novas (*S31*). We elect to circumscribe Alvarezsauroidea as a stem-based taxon here, and define it as the most inclusive clade sharing a more recent common ancestor with *Alvarezsaurus calvoi* than with *Passer domesticus*. Following the ICZN (International Code of Zoological Nomenclature) Article 36.1 (Principle of coordination) its author is the author of the family name.

Alvarezsauridae Bonaparte, 1991: the least inclusive clade containing *Alvarezsaurus*, *Mononykus* and their most recent common ancestor.

Parvicursorinae Karhu and Rautian 1996: the least inclusive clade containing *Parvicursor*, *Mononykus* and their most recent common ancestor. Although our analysis cannot resolve the relationships of *Parvicursor*, *Mononykus*, *Shuvuuia* and *Albertonykus*, we find these taxa form a monophyletic clade with relatively high Bremer support (Fig. S1). Following ICZN Article 36.1, Parvicursorinae Karhu and Rautian 1996 is a valid subfamilial name and according to ICZN Article 23.1 (Statement of priority), it has priority over Mononykinae Chiappe et al., 1998.

Phylogenetic relationships within the Alvarezsauroidea

The data matrix was constructed to test the monophyly of the Alvarezsauroidea and the phylogenetic position of *Haplocheirus* rather than to investigate alvarezsauroid ingroup relationships. Relationships within the Alvarezsauroidea were recently tested by Longrich and Currie (*S28*), who found that *Alvarezsaurus*, *Achillesaurus* and *Patagonykus* formed a paraphyletic stem group of South American alvarezsauroids, with the former two taxa unresolved at the base of the tree. Our study consistently finds *Haplocheirus* as the basalmost alvarezsauroid taxon in all the MPTs, followed by *Alvarezsaurus* as the basal-most alvarezsaurid, and then *Patagonykus* and *Achillesaurus* in an unresolved trichotomy with the Parvicursorinae plus *Albertonykus*. Although Longrich and Currie found the North American taxon *Albertonykus* to be outside the Asian parvicursorines, the phylogenetic results of our study find multiple most-parsimonious positions for this taxon. The location of *Albertonykus* in some MPTs as nested within the least inclusive clade formed by *Parvicursor*, *Shuvuuia* and *Mononykus* makes it ambiguous whether *Albertonykus* is a parvicursorine. The failure to return a resolved position for *Albertonykus* may be because we did not include three unnamed putative alvarezsauroid specimens (YPM 1049, UCMP 154584, and ‘Tugrik Alvarezsaur’) that were included in the Longrich and Currie matrix. These taxa were not included in this analysis because we did not have access to the material. Although the phylogenetic position of *Haplocheirus* contradicts the prevailing biogeographic hypothesis (*S31, S28*) that the Alvarezsauroidea originated in South America, it does not contradict the hypothesis that the common ancestor of the Mononykinae dispersed from South America to Asia via North America.

Phylogenetic definition of Maniraptora

Ornitholestes, *Archaeopteryx*, their most common recent ancestor and all of its descendants.

Composition of Maniraptora

A basal position for the Compsognathidae within Maniraptora has been recovered in previous analyses (*S5, S63-S65*), although a maniraptoran affinity for this clade is not widely accepted (*S1, S66*).

Alvarezsauroidea have almost always been regarded as maniraptorans (but see Alifanov and Barsbold (*S67*) for a contradicting view), but hypotheses for their position within Maniraptora have varied, with early research considering them as either members of Avialae or the sister taxon to Avialae (*S9*, *S29*, *S35*, *S68*). Recent research has called into question the avian relationships of alvarezsauroids and alternative hypotheses posit the Alvarezsauroidea as the sister-taxon to Ornithomimosauria (*S61*), or as more basal within Maniraptora (*S1, S69*). These latter phylogenetic hypotheses were previously hampered by the limited character evidence available from the fragmentary skeletons of *Alvarezsaurus*, *Patagonykus*, and *Achillesaurus*, the most primitive alvarezsauroids known before the discovery of *Haplocheirus*.

Character optimizations

The following unambiguous synapomorphies are common to all MPTs.

Full dataset:

Alvarezsauroidea: 8, 60, 99, 107, 146, 147, 206, 207, 270, 271, 275, 276, 299, 306, 312, 381, 421

Char. 8: 0→1: Internarial bar dorsoventrally flattened (also present in Troodontidae and Ornithomimosauria)

Char. 60: 1→0: Lacrimal separated from the frontal by the prefrontal (this character is tentatively scored for *Haplocheirus*, due to poor preservation in this region).

Char. 99: 01 → 2: Basipterygoid processes long and tapering (unique synapomorphy for the Alvarezsauroidea)

Char. 107: 0 → 1: Vertically-oriented basisphenoid (seen in some derived Oviraptorosaurs, and is independently evolved in that group)

Char. 146: 0→1: Articular with elongate medial process (also present in Dromaeosauridae, Tyrannosaurines and *Ornithomimus*)

Char. 147: 0 → 1: Regardless of the placement of the Alvarezsauroidea within the Maniraptora, the ventral turn of the angular suture anterior to the end of the mandible is interepreted as a synapomorphy of the Alvarezsauroidea, and is homoplastically derived in the Ornithomimidae and Tyrannosauroidea.

Char. 206: 0→1: The parapophyses of the posterior trunk vertebrae project on pedicels (also present in Dromaeosauridae, *Mei* and *Confuciusornis*)

Char. 207: 1 → 0: Parapophyses in posteriormost dorsals on the same level as the transverse process (in all coelurosaurs and some basal tetanurans, the parapophyses are below the transverse processes in the posterior dorsals)

Char. 270: 0 → 1: Ectepicondyle of humerus (lateral epicondyle) is large and rounded with articular surface (unique synapomorphy of Alvarezsauroidea)

Char. 271: 0 → 1: Entepicondyle of humerus (medial epicondyle) is large and medially projecting in all alvarezsauroids and in Confuciusornis
Char. 275: 0→1: The distal condyle of the ulna is convex and semilunate in Alvaresauridae and some paravians.
Char. 276: 0 → 1: Distal condyle articular surface of ulna is bulbous and extends onto dorsal surface (unique synapomorphy of Alvarezsauroidea).
Char. 299: 0 → 1: The flexor surface of manual phalanx II-1 bears a ventral axial furrow in Alvarezsauroidea. A ventral furrow has been reported for putative spinosauroid *Megaraptor (S83)*, but this furrow is interrupted by a flat section at the midpoint rather than being a continuous feature. The Cretaceous theropod *Tugulusaurus* from western China (*S84*) bears an axial furrow on phalanx II-1, but including this observation in our data matrix did not support a close phylogenetic relationship between *Tugulusaurus* and Alvarezsauroidea. We therefore consider this feature an unambiguous synapomorphy for the Alvarezsauroidea. The discovery of more skeletal elements for *Tugulusaurus* may clarify its relationships and the distribution of the axial furrow in theropods.
Char. 306: 0 → 1: Digit one bears a greatly enlarged ungual in spinosaurids, alvarezsauroids and *Ingenia*.
Char. 312: 0→1: The lateral grooves on ungual II-2 are partially or fully enclosed in all alvarezsauroids (unique synapomorphy).
Char. 381: 0 → 1: The lateral femoral distal condyle is conical in alvarezsauroids, *Garudimimus*, some troodontids, and in some avialans.

Alvarezsauridae: 216, 219, 223, 305, 308, 309, 318, 421
Char. 216: 0→2: Last sacral centrum keeled
Char. 219: 0 → 1: The posterior surface of the last sacral centrum is convex in derived alvarezsauroids, but in *Haplocheirus* it is flat. Interestingly, this condition has also been reported in *Epidexipteryx*.
Char. 223: 0 → 1: Procoelous caudal vertebrae (unique derived alvarezsaur synapomorphy).
Char. 305: 0→1: The proximal articular surface of manual ungual II-2 is as broad as tall in alvarezsauroids more derived than *Haplocheirus*. In *Haplocheirus*, the ungual is proximally broader than in many theropods, but does not approach the derived condition.
Char. 308: 0 → 1: Distally placed flexor tubercles. *Haplocheirus* shows flexor tubercles that are somewhat displaced from the proximal articular surface, but not nearly to the same degree as those of ornithomimids or more derived alvarezsauroids.
Char. 309: 0→1: Manual ungual II-2 is very weakly curved in all alvarezsauroids more derived than *Haplocheirus*. The radius of curvature of this ungual is reduced in *Haplocheirus* relative to some theropods but does not approach the derived condition.
Char. 318: 1→2: The cuppedicus fossa is lost in all alvarezsauroids other than *Haplocheirus* where the ilium is known. In *Haplocheirus*, the cuppedicus fossa is reduced.
Char. 421: 0→1: The extensor pits on the pedal phalanges are deep and proximally extensive in alvarezsauroids, and *Ingenia*. This character is present in the newly-described large alvarezsaur *Kol* (*S34*).

Parvicursorinae: 413

Char. 413: 0 → 2: In the derived alvarezsauroid family Parvicursorinae, the arctometatarsalian condition (*S25*) is pronounced, and the third metatarsal often does not reach the midpoint of the tarsus. In *Haplocheirus*, all three metatarsals form components of the tarso-metatarsal joint. Other research (*S85*) has documented the intriguing homoplasy in this character, and it is not surprising that a non-arctometatarsalian condition is primitive for alvarezsauroids.

The Parvicursorinae have a highly apomorphic skeleton relative to the remaining alvarezsaurids, but missing data in the possible parvicursorine *Albertonykus* makes the optimization of some characters ambiguous in some MPTs. Therefore, we list characters below that optimize to the base of Parvicursorinae in some but not all trees, with the caveat that these characters may later be optimized to different nodes if more material is recovered for *Albertonykus*.

Additional synapomorphies of the Parvicursorinae under DELTRAN

Char. 199: 1→0: Parvicursorines lose the hyposphene/hypantrum articulation in the dorsal vertebrae. The dorsal vertebrae are unknown for *Albertonykus*, so the character is ambiguous for the Parvicursorinae in some trees.

Char. 210: 0→1: The dorsal centra are opisthocoelous in parvicursorines other than *Albertonykus*, where the condition is unknown.

Char. 225: 0→1: The transverse processes of the proximal caudals are posteriorly displaced in parvicursorines other than *Albertonykus*, where the condition is unknown.

Char. 339: 1→3: The pubis of parvicursorines approaches the degree of retroversion seen in derived birds, but the pubis of *Albertonykus* is unknown.

Char. 371: 1→2: The greater and lesser trochanters of parvicursorines are fused but the condition is unknown in *Albertonykus*.

Char. 376: 0→1: The fourth trochanter is lost in *Mononykus* and *Shuvuuia*, but the condition is unknown in *Parvicursor* and *Albertonykus*.

Char. 379: 0→1: The popliteal fossa of parvicursorines is distally closed but the condition of *Albertonykus* is unknown.

Char. 383: 0→1: Parvicursorines develop a medial cnemial crest that is interpreted here as convergent with that of birds. The condition in *Albertonykus* is unknown.

Char. 393: 0→1: The medial surface of the proximal fibula is flat in parvicursorines other than *Albertonykus*, where it is unknown.

Char. 395: 0→1: The astragalar and calcaneal condyles are separated by a vertical groove in *Mononykus* and *Shuvuuia*, but the condition is unknown in other parvicursorines.

Char. 399: 1→2: All parvicursorines have a notch on the ascending process of the astragalus, except in *Albertonykus* where the condition is unknown.

Maniraptora: 44, 60, 111, 200, 229, 339, 411

Char. 44: 1→0: Anterior end of jugal only reaches posterior rim of antorbital fenestra (also present in *Sinraptor* and *Carnotaurus*)

Char. 60: 0→1: The lacrimal contacts the frontal in all maniraptoran taxa except Alvarezsauroidea, and also in Abelisauridae and *Tyrannosaurus*

Char. 111:0→1: The paroccipital processes are short and deep, with a convex distal end in all maniraptorans except Therizinosauroidea, Dromaeosauridae and *Epidendrosaurus*. The paroccipital processes of *Haplocheirus* are distally convex and pendant, but are slightly longer than in some other maniraptorans.

Char. 200: 0 → 1: Postzygapophyses of the dorsal vertebrae lateral to neural canal.

Char. 229: 0→1: The distal caudal neural spines are absent in all maniraptorans except for derived therizinosauroids, oviraptorosaurs, *Sapeornis* and *Yixianornis*.

Char. 339: 0→1: Pubis vertical. The orientation of the pubis has a complex evolution within Coelurosauria, with *Guanlong* having a vertical pubis and numerous maniraptoran taxa showing an anteriorly-projecting pubis.

Char. 411: 0 → 1: Metatarsal II with flange on the lateral margin of the flexor surface projecting caudally or medially. The distribution of this character is poorly documented outside of paravians, as it was proposed recently (*S1*).

MSM* analysis results

The differences in MSM* values (MSM*Diff) between Jurassic and Cretaceous first appearance dates (FADs) of the Alvarezsauroidea for topologies 1 and 2 are summarized in Fig. S3. MSM*Diffs between FADs for both topologies were positive in 99.9% of comparisons. On average, the inclusion of the stratigraphic information provided by *Haplocheirus* improved the stratigraphic fit to the hypothesized phylogeny by 14%. These results indicate that despite the large stratigraphic uncertainty for the first appearance dates of both Troodontidae and Scansoriopterygidae, a Jurassic origin for the Alvarezsauroidea is much more consistent with our hypothesized phylogeny than the Cretaceous origin implied by previous fossil data. The normal distribution of MSM*Diff values (Fig. S3) is an indication that the stratigraphic uncertainty in the terminals was not apportioned in such a way that there were subsets of first appearance dates that would have implied a much worse fit to the phylogeny.

In general, the stratigraphic character had a better fit to topology 2 than topology 1 regardless of whether alvarezsauroids were considered to be Jurassic or Cretaceous. This result is not surprising because balanced trees tend to produce higher MSM* values than pectinate trees (*S53*), and topology 2 is more balanced. Therefore, we caution that the increased fit values should not be construed as evidence in favor of the phylogenetic relationship hypothesized in topology 2.

MSM* discussion

A frequently-cited criticism of the theropod origin of birds is the ‘temporal paradox’ (*S70*), the observation that the phylogenetically closest theropod relatives of birds appear much later in the stratigraphic record than *Archaeopteryx*, the (then) oldest-known avialan. Brochu and Norell (*S71*) refuted the ‘temporal paradox’ and the use of the stratigraphic record to falsify prevailing hypotheses about the theropod origin of birds by showing that the theropod hypothesis was more stratigraphically consistent than competing hypotheses for bird origins, such as a crocodylomorphs sister group. Since the publication of Brochu and Norell, discoveries of new fossil theropod taxa, particularly ones from China, have strengthened the morphological support for a theropod-bird link (*S1, S72-S74*). These discoveries have not, however, greatly improved the fit of the theropod stratigraphic record to the hypothesized phylogeny for these taxa, because they are largely from Early Cretaceous or younger deposits. Other discoveries of theropods within the temporal gap have improved stratigraphic sampling but not stratigraphic fit to the phylogeny. For example, recent discoveries of scansoriopterygid taxa (*S75*, *S23*) from the Jurassic Daohugou Formation (*S54*) potentially predate *Archaeopteryx*. The phylogenetic position of these taxa is nested within Avialae, however, and therefore they increase the temporal gap between Avialans and other paravians.

The basalmost maniraptoran *Ornitholestes* is known from the Late Jurassic (Kimmeridgian). We therefore hypothesize that the early diversification of the Maniraptora must have been underway by the early part of the Late Jurassic, and it is reasonable to suspect that this diversification might have taken place considerably earlier. Despite this expectation, maniraptoran fossils from the Late Jurassic have remained exceedingly rare. The provenance of the putative therizinosauroid taxon *Eshanosaurus deguchiianus* from the Early Jurassic Lufeng Formation has recently been called into question (*S76*), and the Late Triassic taxon *Protoavis* is widely regarded as an indeterminate archosaur rather than a maniraptoran theropod, although certain elements may be coelurosaurian (*S77*). The recent description of the two closely related scansoriopterygid taxa *Epidendrosaurus* and *Epidexipteryx* from the Daohugou formation of China have offered a rare glimpse of Jurassic maniraptoran morphology. Radiometric and biostratigraphic dating of the Daohugou Formation, however, have been contentious and the age of the formation remains poorly constrained temporally (*S54, S78, S79*).

Haplocheirus fills in this gap in the fossil record of Maniraptora. The precise dates for the Shishugou Formation of 158.7 ± 0.3 and 161.2 ± 0.2 ma (*S80*) predate *Archaeopteryx* by a minimum of 7 million years, and fall at the older end of the date range for the Daohugou formation. The relatively basal phylogenetic position of *Haplocheirus* (see main text and Phylogenetics sections of Supporting Online Material) within Maniraptora is also important for improving the congruence between the stratigraphic record and our phylogenetic hypotheses. Thus, we expected *Haplocheirus* to improve the stratigraphic fit to maniraptoran phylogeny.

Additional morphological description

The nasal process of the premaxilla is broken above the anterior end of the external naris, but the morphology of the base suggests that it was dorsoventrally flattened. The external naris is unusually large, as in many basal coelurosaurs (*S81*), and an extensive narial fossa on the premaxilla bears four pneumatic foramina (Fig. S4). The palatal shelves of the maxillae converge at the anterior end of the antorbital fenestra, forming the extensive secondary palate in conjunction with the premaxillae and the vomers, the latter of which are not preserved. At least 30 separate alveoli can be discerned in the maxilla (Fig. S5), and allowing for sections of the maxilla where alveoli aren't preserved, we estimate that there were 35 maxillary teeth. The posteriormost alveoli are extremely small (approximately 1mm in diameter) and very densely packed, as are the maxillary teeth in *Shuvuuia* (*S35*, *S82*). Few maxillary tooth crowns are preserved, and it is unclear what crown morphology was present for these posterior maxillary teeth. Complete sclerotic rings are preserved in the orbits.

A nearly complete set of gastralia is preserved *in situ* with approximately 18 gastralia per side. The gastralia have a compound, sigmoid curvature in dorsal view. The first gastral rib is the longest. Gastralia 14-18 were joined along the midline. Other gastralia may have also been joined medially, but this cannot be confirmed due to poor preservation. The posterior two sets of gastralia have shafts that are markedly wider than those of more rostral elements.

The deltopectoral crest is incomplete on the right humerus and is covered by matrix on the left humerus. The humeral head is large and extends to the anterior margin of the proximal end of the humerus. This indicates that if a well-developed deltopectoral crest were present, it would be displaced distally, as in *Mononykus* and *Shuvuuia* (*S30*, *S35*). Metacarpal III is strongly reduced (only 46% of the length of McII), slender and closely appressed proximally to McII. The proximal articular surface is triangular, with a ventrally concave base and a dorsal apex. The distal articular surface is triangular in distal view, with well-developed collateral ligament pits.

Only the anterior margin of the pubic peduncle is preserved. In lateral view, the anterior margin is straight and projects anteroventrally. Based on the proximal articular surface of the pubis, the pubic peduncle was anteroposteriorly elongated and rectangular. No ridge bounding the cuppedicus fossa is present either anterior to the acetabulum or on the lateral surface of the pubic peduncle. This indicates that the cuppedicus fossa was either reduced or absent, a condition present in alvarezsauroids (*S31*).

Figures and Tables

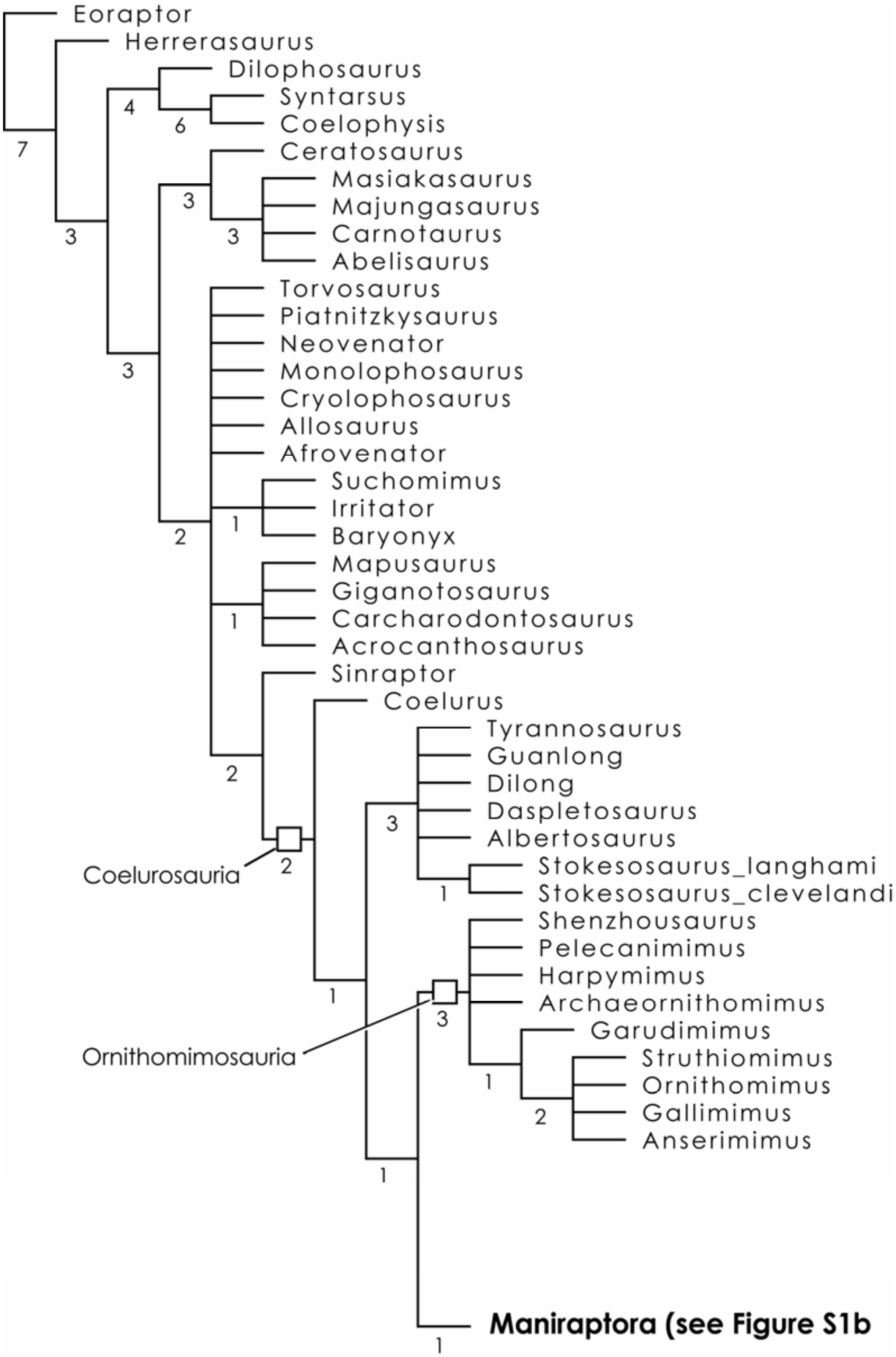

Fig. S1a: Strict consensus of 69 MPTs resulting from heuristic search on the full dataset, length 1998, CI=0.26, RI=0.65. Numbers below nodes indicate Bremer support, italicized numbers above nodes indicate reduced consensus Bremer support (see Supporting Online Material text). Solid squares indicate named clades. Maniraptora is collapsed here to fit tree on one page (see Fig. S1b).

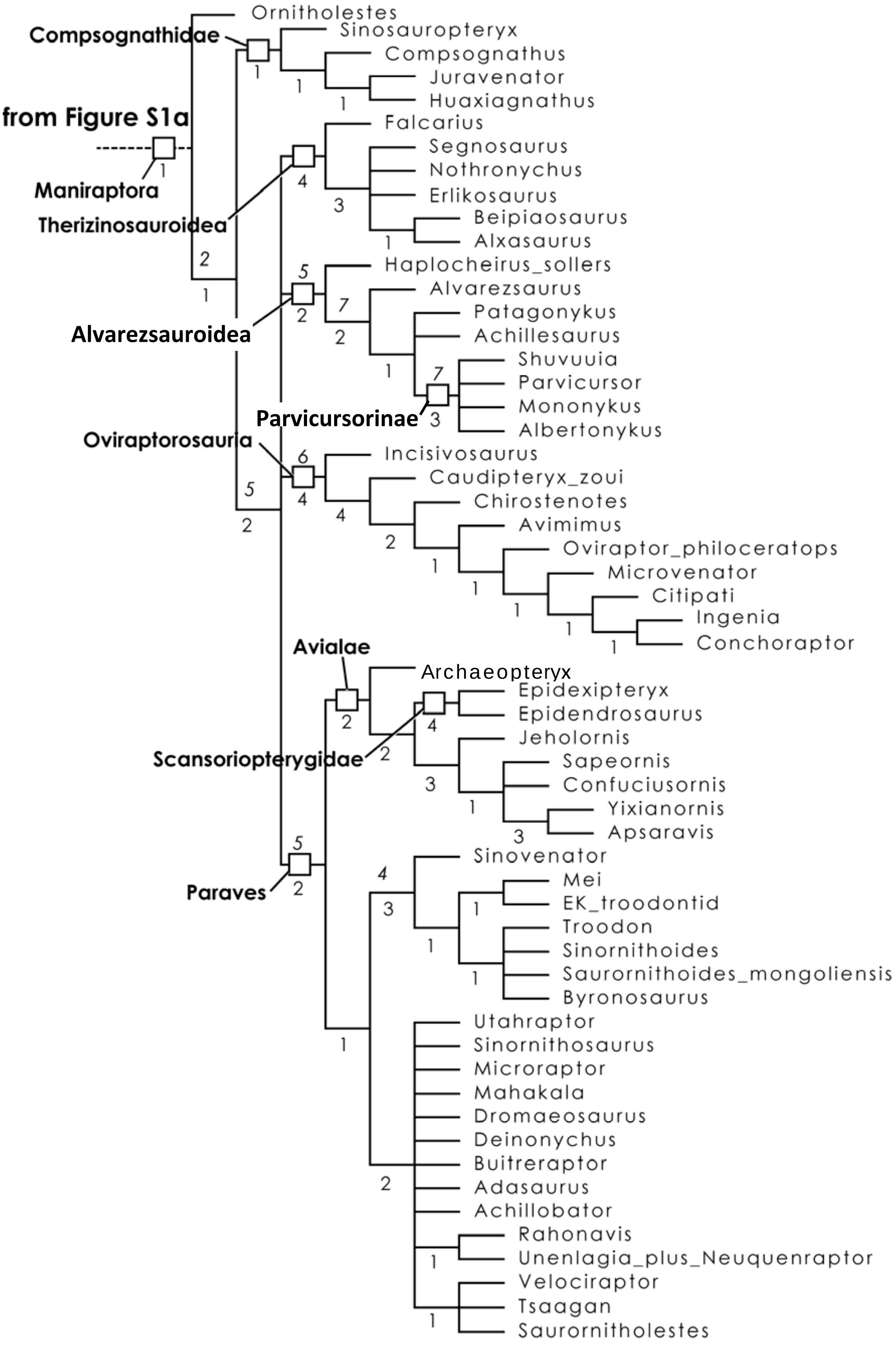
Ornitholestes
Compsognathidae
Sinosauropteryx
Compsognathus
1
Juravenator
1
Huaxiagnathus
1
from Figure S1a
Falcarius
1
Maniraptora
Segnosaurus
Nothronychus
4
Erlikosaurus
3
Therizinosauroidea
Beipiaosaurus
Alxasaurus
2
1
1
Haplocheirus_sollers
5
Alvarezsaurus
2
7
Alvarezsauroidea
Patagonykus
2
Achillesaurus
Shuvuuia
1
7
Parvicursor
Mononykus
Parvicursorinae
3
Albertonykus
Oviraptorosauria
Incisivosaurus
6
Caudipteryx_zoui
5
4
Chirostenotes
4
2
Avimimus
2
Oviraptor_philoceratops
1
Microvenator
1
Citipati
1
Ingenia
1
Conchoraptor
1
Avialae
Archaeopteryx
Epidexipteryx
2
Epidendrosaurus
4
Scansoriopterygidae
2
Jeholornis
Sapeornis
3
Confuciusornis
1
Yixianornis
Apsaravis
3
Sinovenator
5
4
Mei
Paraves
2
3
EK_troodontid
1
Troodon
1
Sinornithoides
Saurornithoides_mongoliensis
1
Byronosaurus
Utahraptor
Sinornithosaurus
1
Microraptor
Mahakala
Dromaeosaurus
Deinonychus
Buitreraptor
Adasaurus
2
Achillobator
Rahonavis
Unenlagia_plus_Neuquenraptor
1
Velociraptor
Tsaagan
1
Saurornitholestes

Fig. S2b: Strict consensus of 69 MPTs resulting from heuristic search on the full dataset, length 1998, CI=0.26, RI=0.65. Numbers below nodes indicate Bremer support, italicized numbers above nodes indicate reduced consensus Bremer support (see supporting online material text). Solid squares indicate named clades.

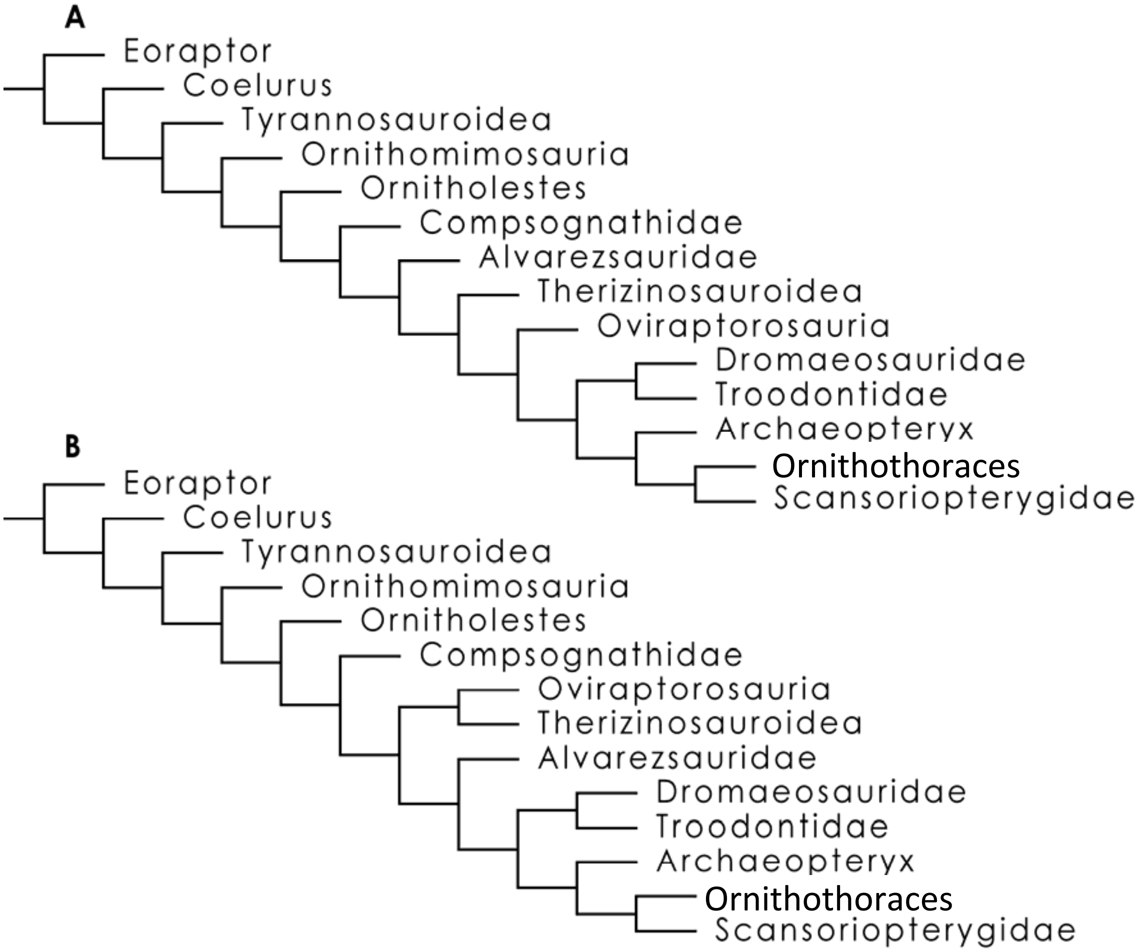

Fig. S3: Summarized relationships between maniraptoran clades found in 69 fundamental cladograms resulting from heuristic analysis of the full dataset. **A**, ‘Topology 1’, Alvarezsauroidea are basal to Therizinosauroidea and Oviraptorosauria, **B**, ‘Topology 2’, Alvarezsauroidea are sister to Paraves.

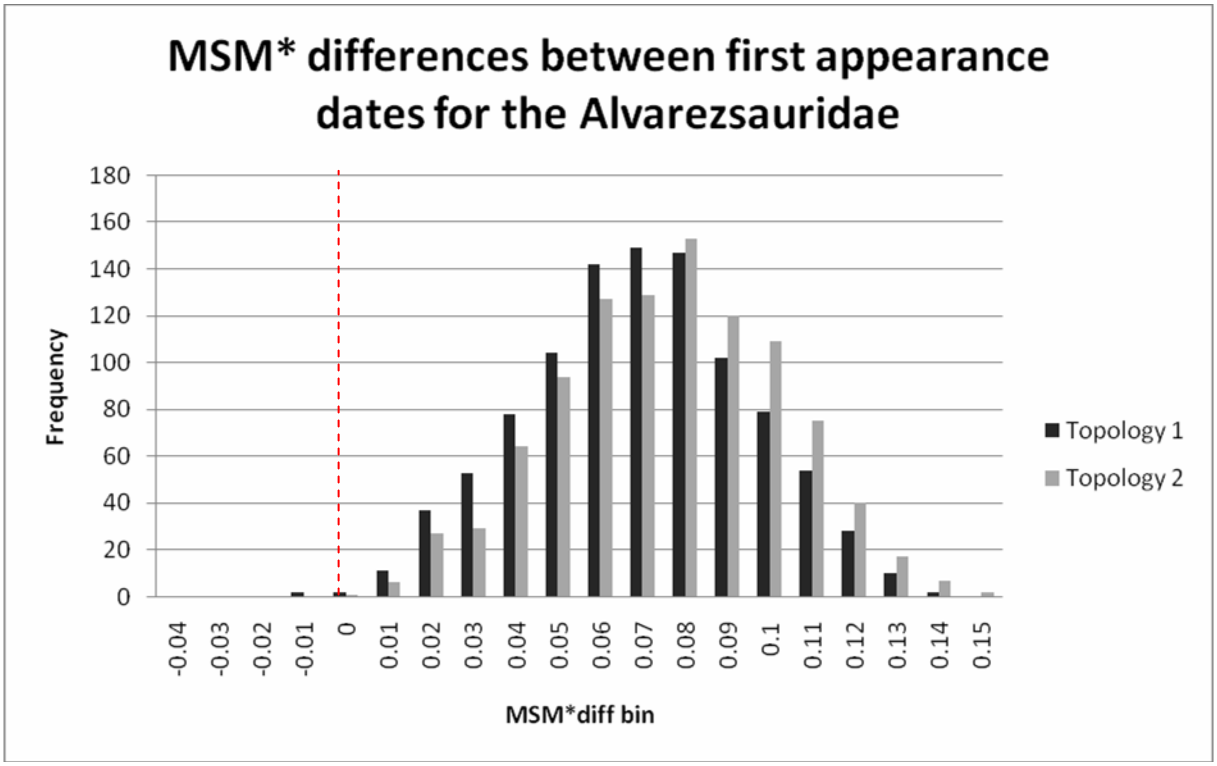

Fig. S3: Difference in Manhattan Stratigraphic Measure* replicate values (MSM*Diff) between pairwise topologies when first appearance datum for Alvarezsauroidea is varied between early Late Jurassic and Late Cretaceous. Values are calculated with the following formula: MSM*Diff = MSM*value of replicate R for topology T when Alvaresauridae are considered Jurassic – MSM* value of replicate R for topology T when Alvarezsauroidea are considered Cretaceous. Dashed red line indicates an MSM*Diff of 0.

Fig. S4: Premaxilla and anterior maxilla of *Haplocheirus* IVPP V 15988, left lateral view, showing foramina in narial fossa, convex alveolar margin of anterior dentary and rostral dentition. Scale bar in 1cm increments.

Fig. S5: Posterior maxillary alveoli of *Haplocheirus* IVPP V15988 in left ventrolateral view. Red ellipse indicates numerous small alveoli in the posterior maxilla.

Fig. S6: Rostrum of *Haplocheirus* in right caudolateral view, showing antorbital fossa. Red arrow indicates foramen piercing the ventral margin of interfenestral pila (see main text).

Figure S7: Skull of *Haplocheirus* IVPP V15988 in dorsal view. Scale bar units are one cm.

Figure S8: *Haplocheirus* IVPP V15988 holotype specimen in right lateral view after skull was removed for further preparation. Scale bar units are one cm.

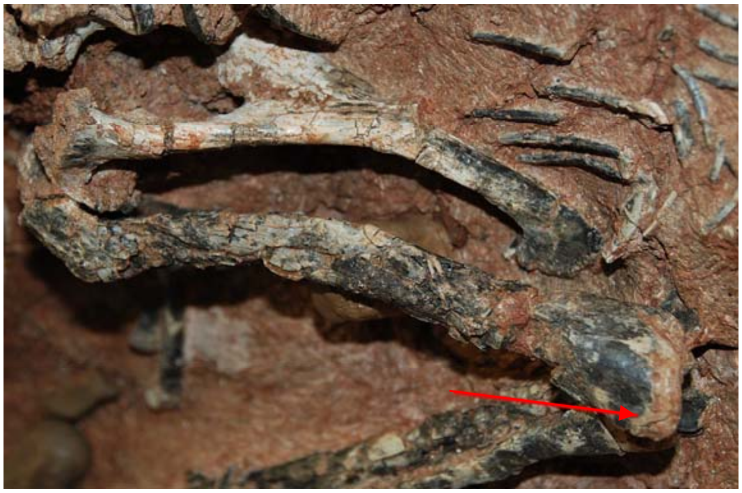

Fig. S9: Right pubis, femur and proximal tibia/fibula of *Haplocheirus* in right lateral view. Red arrow indicates conical lateral femoral condyle.

Table S1: Size estimates for select alvarezsauroid taxa. The sizes of South American taxa *Alvarezsaurus*, *Patagonykus*, and *Achillesaurus* and of *Albertonykus* from North America cannot be estimated because they do not have complete skulls or femora. *The Mongolian taxon *Ceratonykus* was not included in the phylogenetic analysis because we did not examine the specimen, but is included here because it probably represents a parvicursorine. Abbreviations: **BL**, body length; **BM**, body mass.

Taxon	**Skull length (m)**	**Source**	**Femoral length (m)**	**Source**	**BM Christiansen and Farina (kg)**	**BM Therrien and Henderson (kg)**	**BL Therrien and Henderson (m)**	**BL Turner (m)**
Haplocheirus sollers	.2128	Measured	.2143	Measured	4.80 – 58.2	10.56	2.3	1.9
Mononykus olecranus	X	X	.1386	Perle et al., 1993	1.18 - 14.7	X	X	1.2
Shuvuuia deserti	.0821	Estimated from Chiappe et al., 1998	X (not reported in publication)	X	X	.3417	1.04	X
Parvicursor remotus	X	X	.0526	Karhu and Rautian, 1996	.053 - .614	X	X	.43
*Ceratonykus oculans**	.06	Alifanov and Barsbold, 2009	X	Alifanov and Barsbold, 2009	X	.11	.80	X

Table S2: Measurements of holotype of *Haplocheirus sollers* (IVPP V15988). Measurements taken with dial calipers and are in millimeters.

Element	Measurement taken	mm
Right humerus	Length	104.32
	diameter of shaft	13.03
Left ulna	Length	90.11
	diameter of shaft	x
Left radius	Length	86.03
	diameter of shaft	x
Left McII	Length	22.64
	diameter of shaft	12.8
	width of proximal articular surface	17.48
Left McIII	length	57
	diameter of shaft	x
	width of proximal articular surface	9.06
Left McIV	length	26.2
	diameter of shaft	4.56
	width of proximal articular surface	6.26
Right femur	Proximodistal length	214.32
	Mediolateral width at femoral head	48.97
	Mediolateral width at distal condyles	34.05
	Midshaft diameter (mediolateral)	17.48
	Midshaft diameter (anteroposterior)	21.59
Right tibia	Proximodistal length	269.26
	Mediolateral width at distal condyles	33.38
Rght Metatarsal V	Proximodistal length	44.58
Right Metatarsal IV	Proximodistal length	134.45
Right Metatarsal III	Proximodistal length	144.58

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