

APPENDIX 1

MORPHOLOGICAL MATRIX USED IN THIS STUDY

1.1 List of morphological characters, derived primarily from Gao and Fox (2005), Ksepka et al., (2005), and Matsumoto et al., (2019). Due to different sampling between the current study and previous studies, characters having the same coding in all taxa are excluded in this matrix. In addition, 5 new characters are added.

1.External nares (modified from Matsumoto et al., 2013, character 1):

(0) paired, (1) confluent.

2.Lateral borders of frontals (Gao and fox, 2005, character 3):

(0) more or less parallel, (1) strongly constricted.

3.Preorbital skull proportions (Gao and fox, 2005, character 5):

(0) moderately short lack of elongation, (1) elongate but less than 50% of skull length, (2) more than 50% skull length.

4.Lacrimal extension (modified from Gao and fox, 2005, character 7):

(0) retracted posterior of narial opening, but remains elongate, (1) reduced to small triangular bone.

5.Lacrimal perforation (modified from Matsumoto et al., 2013, character 14):

(0) one or two foramina pierce lacrimal, (1) large opening between palatine, prefrontal and lacrimal, (2) large opening between prefrontal and lacrimal.

6.Nasals (Matsumoto et al., 2013, character 15):

(0) paired, (1) fused.

7.Nasal/premaxilla contact (Matsumoto et al., 2013, character 17):

(0) nasals contact but do not intervene between premaxillae, (1) nasals intervene between premaxillae, (2) nasals do not contact premaxillae.

8.Orbit size and orientation (Gao and fox, 2005, character 11):

(0) large and laterally directed, (1) large and dorsally directed, (2) small and dorsally directed.

Mengshanosaurus is coded “?” since the orbit size is strongly influenced from the developmental stage.

9.Postorbital and postfrontal (Matsumoto et al., 2013, character 30):

(0) postfrontal and postorbital discrete and both enter the orbital margin, (1) postfrontal and postorbital discrete, postorbital excluded from orbital margin, (2) postfrontal and postorbital fused.

10.Squamosal, dorsal process (Gao and fox, 2005, character 13):

(0) broad and short, (1) slender and elongate to middle level of inferior temporal opening, (2) dorsal process absent.

11.Supratemporal fenestra (Gao and fox, 2005, character 14):

(0) smaller than orbit, (1) about same size as orbit, (2) posteriorly flared and substantially larger than orbit.

12.Infratemporal fenestra (Gao and fox, 2005, character 15):

(0) present, (1) closed from expansion of surrounding elements.

13.Squamosal/parietal suture (Gao and fox, 2005, character 17):

(0) near posterior end of superior temporal fenestra, (1) located halfway along fenestra.

14.Nasal/prefrontal contact (modified from Matsumoto et al., 2013, character 19):

(0) straight-line contact dorsolateral on snout (1) short, broad V-shaped contact at dorsal midline,

(2) long, narrow pinched wedge.

15.Location of Choana (modified from Gao and fox, 2005, character 20):

(0) retracted close to midpoint of marginal tooth row, (1) choana displaced far back.

16.Palatal foramen (modified from Gao and fox, 2005, character 21):

(0) opening at juncture between vomer, palatine, and pterygoid, (1) between pterygoid and palatine, without contribution from the vomer.

17.Internarial (Matsumoto et al., 2013, character 20):

(0) absent, (1) present.

18.Basipterygoid/pterygoid joint (modified from Matsumoto et al., 2013, character 49):

(0) process and cotyle are reduced and two bones are sutured, (1) two bones are fused.

19.Parasphenoid/pterygoid contact (modified from Gao and fox, 2005, character 25):

(0) clear suture contact, (1) tight contact or fusion.

20.Quadratojugal/quadrato articulation (Matsumoto et al., 2013, character 32):

(0) having a simple overlapping facet for the quadrato (1) quadratojugal bears a cotyle meeting a rounded quadrato process.

21.Pterygoid process of quadrato (Matsumoto et al., 2013, character 51):

(0) broad, vertically orientated with a large pterygoid facet, (1) low, slender, and horizontal with a reduced pterygoid facet.

22.Postorbital (dorsal) process of jugal (modified from Gao and fox, 2005, character 28):

(0) prominent but much shorter than anteroventral process (1) little or no process.

23.Nasopalatal trough (Matsumoto et al., 2013, character 40):

(0) absent, (1) present.

24.Palatal teeth (Gao and fox, 2005, character 30):

(0) palate covered from shagreen of small teeth, (1) paired pterygoid tooth batteries separated from nasopalatal trough, (2) narrow rows of pterygoid teeth separated from nasopalatal trough.

25.Midline contact of pterygoids (Gao and fox, 2005, character 31):

(0) separate or just touching in the midline anteriorly, (1) long midline suture.

26.Location of interpterygoid vacuity (modified from Gao and fox, 2005, character 32):

(0) anteriorly located, with its anterior margin extending to the level of the suborbital fenestra, (1) posteriorly located, with its anterior margin located posterior to the suborbital fenestra.

27.Enclosure of interpterygoid vacuity (Matsumoto et al., 2013, character 53):

(0) enclosed anteriorly from pterygoids and posteriorly from parasphenoid, (1) enclosed from pterygoid only.

28.Shape of parasphenoid (Gao and fox, 2005, character 34):

(0) isocles triangle with long rostrum, (1) broad anteriorly with short rostrum and moderate posterolateral expansion, (2) slender anteriorly with long rostrum and strong posterolateral wing-like expansion.

29.Basal tuberculae of braincase (Gao and fox, 2005, character 35):

(0) weakly developed, (1) moderately expanded laterally, (2) strongly expanded posterolaterally and wing-like.

30.Basal infolding of tooth enamel (Gao and fox, 2005, character 37):

(0) absent, (1) present.

31.Location of craniomandibular joint (Matsumoto et al., 2013, character 70):

(0) about the same level as mandibular condyle, (1) anterior to condyle, (2) posterior to condyle.

32. Shape of suborbital fenestra (Gao and fox, 2005, character 39):

(0) narrow, elongate, (1) subtriangular with straight medial edge, (2) short, kidney - shaped.

33. Paroccipital process/quadrata contact (Matsumoto et al., 2013, character 59):

(0) mostly attached to squamosal only tip of process meets quadrata, (1) elongate process lies in trough of quadrata and neomorph, (2) elongate process lies in trough of quadrata lined with thin sheet of neomorph.

34. Mandibular symphysis (modified from Gao and fox, 2005, character 43):

(0) small and terminal, (1) slightly extended but confined anterior without inclusion of splenial, (2) slightly extended with inclusion of the tip of the splenial, (3) strongly elongate with longer inclusion of splenial.

35. Lateral exposure of splenial (Matsumoto et al., 2013, character 75):

(0) splenial confined to medial side of mandible, (1) exposed on ventrolateral surface of mandible.

36. Orientation of paroccipital processes (Gao and fox, 2005, character 45):

(0) horizontal, (1) slightly depressed, (2) strongly deflected ventrally.

37. Supraoccipital/parietal contact (modified from Gao and fox, 2005, character 46):

(0) supraoccipital lightly arched, suture surfaces for parietal placed anteriorly, (1) supraoccipital keeled, parietal facets extend to posterior margin.

38. Posttemporal fenestra (Matsumoto et al., 2013, character 67):

(0) present, (1) absent from loss.

39. Pila antotica (Matsumoto et al., 2013, character 68):

(0) remains unossified, (1) ossified as part of the sphenoid.

40. Posterior opening of the interior carotid artery (Gao and fox, 2005, character 49):

(0) opens ventrolaterally without penetrating parasphenoid, (1) opens ventrally, penetrates parasphenoid.

41. Neurocentral sutures (Gao and fox, 2005, character 51):

(0) closed in adult, (1) remain open in adult.

42. Articular surface shape of vertebral centra (modified from Gao and fox, 2005, character 52):

(0) amphicoelous, (1) amphiplatyan.

43. Presacral vertebral centra (Gao and fox, 2005, character 52):

(0) longer than wide, (1) short and spool – like.

44. Vertromedial crest of dorsal vertebrae (Matsumoto et al., 2013, character 85):

(0) anterior dorsal vertebrae are strongly keeled like the cervical vertebrae, (1) low or no keels

45. Small spinous processes below presacral zygapophyses (modified from Gao and fox, 2005, character 55):

(0) absent, (1) present.

46. Centra of anterior caudal vertebrae (defined as vertebrae that bear caudal ribs)

(Matsumoto et al., 2013, character 99):

(0) Bear shallow ventral groove for caudal blood vessels and without flanges (1) groove is flanked from deep ventral flanges.

47. Number of ossified carpal elements (Matsumoto et al., 2013, character 110):

(0) nine or more, (1) seven or fewer.

48. Bone structure (Gao and Fox, 2005, character 62)

(0) cancellous, (1) having reduced medullary cavity, (2) pachyostotic in adult.

- 49. Iliac blade, dorsal margin** (Matsumoto et al., 2013, character 112):
(0) Essentially vertical or at a steep angle to the horizontal in adults, (1) dorsal margin essentially horizontal, blade expanded, often triangular.
- 50. Interclavicle shape** (Matsumoto et al., 2013, character 106):
(0) rhomboid, (1) T – shape.
- 51. Cervical vertebral count** (Matsumoto et al., 2013, character 79):
(0) eight or nine, (1) sixteen or more.
- 52. Cervical vertebral centra length** (Matsumoto et al., 2013, character 80):
(0) longer than high, (1) equal or shorter than high.
- 53. Gastral thickness** (Matsumoto et al., 2013, character 104):
(0) thin, lightly built, (1) robust, almost as thick as axial ribs, and pachyostotic.
- 54. Caudal neural spines:** (Gao and fox, 2005, character 72):
(0) low, (1) tall and narrow.
- 55. Entepicondylar foramen of humerus** (Matsumoto et al., 2013, character 109):
(0) present, (1) absent.
- 56. Constriction of ilium between iliac blade and acetabulum** (Gao and fox, 2005, character 74):
(0) absent or poorly defined, (1) well – defined neck present.
- 57. Posterior process of ischium** (Gao and fox, 2005, character 75):
(0) absent, (1) strongly developed.
- 58. Premaxilla, incisive foramen** (New):
(0) absent, (1) present.
- 59. Position of external Nares** (modified from Gao and fox, 2005, character 1):
(0) dorsal placed, (1) terminal.
- 60. Tip of snout** (New):
(0) unexpanded, (1) expanded.
- 61. Internarial, position** (New):
(0) the frontal ends about level with premaxilla – maxilla suture, (1) extends well anterior of premaxilla – maxilla suture.
- 62. Postfrontal** (New):
(0) enters border of upper temporal fenestra, (1) excluded from border of upper temporal fenestra from parietal – postorbital contact.
- 63. Nasals, length** (modified from Gao and fox, 2005, character 9):
(0) short, (1) long.
- 64. Number of dorsal vertebrae** (New):
(0) 16, (1) 17, (2) 19.
- 65. Cervical neural spines** (modified from Matsumoto et al., 2013, character 81):
(0) moderate dorsal projection, (1) very low.

1.2 Character codings for all taxa.

Cteniogenys antiquus

1?1000200?100?0000000000000000?0?100??00110001?10??00010??10?1??
Coeruleodraco jurassicus
00012001000001??000010??01101?000??1??0{0 1}01?10??1000?1?1000?100?
Simoedosaurus dakotensis
10101112212011010001111110111211201111111110?21?0110?10111?-1?0
Simoedosaurus lemoinei
1010111221201101000111111011121110111111111012110110110111?-1?0
Tchoiria klauseni
?0{1 2}011?22120??01??1?011100??121?20?0??111111??1??010110??-1??
Tchoiria namsarai
1?{1 2}0?1?2?120??010001101110011121?20101?111111??{1 2}?1?01?1??1??1??
Ikechosaurus sunailinae
10101112212011010001101110011101?201111111110??11?010100?10?-1??
Ikechosaurus pijiagouensis
1010?11211201??????0??????1?????11??11??1?110010100?10?110?
Champsosaurus gigas
102111121120021111110121012211223120000111100?2110010110?1101110
Champsosaurus natator
10211112112002111111012101221122312000011110?12110010110?111011?
Champsosaurus lindoei
10211112112002111111012101221122312000011?10????0????01111011?
Mengshanosaurus minimus
1010211?21200??00110?100??111?10??1??1??1??1??1??1??1??1??1??1??-1??
Hyphalosaurus baitaigouensis
0000?0012??0?10?00????00010001?0??1??0101???001011100?00?-021
Philydrosaurus proseilus
011000010201000?00010011100100110000?1?101?101??010000001?00?0000

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