APPENDIX

Appendix 1: Quadrate-related Characters.

I. QUADRATE

1 Quadrate, elongation (ratio between the lateromedial width of mandibular articulation and the ventrodorsal length of the quadrate body): (0) strongly elongated, <0.35; (1) moderately elongated, 0.35-0.5; (2) short, >0.5 (**Ordered**; Based on Currie & Carpenter, 2000 #20)

2 Quadrate, height of quadrate head relative to orbit: (0) ≤ 80% of orbit height; (1) > 80% of orbit height (Modified from Sereno et al., 1994)

3 Quadrate, position of mandibular articulation relative to quadrate head when articulated within the cranium: (0) entirely posterior; (1) approximately aligned; (2) entirely anterior (**Ordered**; Modified from Gauthier, 1986)

4 Quadrate, ventral extension relative to the ventral margin of the rest of the cranium in lateral view: (0) project well ventral from the ventral margin of the cranium; (1) level with ventral margin of the cranium; (2) well dorsal from the ventral margin of the cranium (**Ordered**; Holtz, 1994)

II. QUADRATE BODY

Margins

5 Quadrate body, outline of posterior margin (mandibular articulation and head not included) in lateral view: (0) strongly concave; (1) roughly straight; (2) convex; (3) sigmoid, strongly convex dorsally and straight or concave ventrally; (4) sigmoid, concave dorsally and convex ventrally (Unordered; New)

6 Quadrate body, posterior surface, lateromedially, at one half of the bone in posterior view: (0) concave; (1) convex (**New**)

7 Quadrate body, outline of ventromedial extremity in posterior view: (0) rounded; (1) angular (**New**)

8 Quadrate body, bowed groove medial to the quadrate foramen and extending on the first third of the body: (0) absent; (1) present (**New**)

9 Quadrate body, protuberant ridge at one fourth of the body, dorsal to the ectocondyle: (0) absent; (1) present (**New**)

Quadrate ridge

10 Quadrate ridge, shape at mid-height of the quadrate in posterior view: (0) prominent and well-delimited; (1) shallow and poorly delimited; (2) ridge absent (Unordered; New)

11 Quadrate ridge at mid-height of the quadrate, shape in posterior view (ratio: latero-medial width of ridge/latero-medial width of quadrate body, not including pterygoid flange): (0) narrow crest (< 0.1); (1) rod-shaped (0.1-0.7); (2) very broad ridge (>0.7) (**Ordered**; New)

12 Quadrate ridge, inclination in posterior view: (0) present, ridge strongly inclined laterally; (1) absent, ridge subvertical (**New**)

13 Quadrate ridge, ventral extension in posterior view: (0) terminating well-above the entocondyle; (1) almost reaching the entocondyle; (2) reaching the entocondyle (Unordered; New)

14 Quadrate ridge, dorsal extension in posterior view: (0) extending to the quadrate head or just below it; (1) extending at two third of the quadrate bone; (2) extending at mid-height of the quadrate bone (Unordered; New)

15 Quadrate ridge, bifurcation of the ventral extremity: (0) absent; (1) present (**New**)

16 Quadrate ridge, separation of the ridge at two-third of the quadrate in dorsal view: (0) absent, ridge unique; (1) present, groove separating the ridge; (2) present, ridge flaring at two-third of the quadrate and repapering more dorsally (Unordered; New)

17 Quadrate ridge, protuberance at two third of the ridge in lateral view: (0) absent; (1) present (**New**)

III. MANDIBULAR ARTICULATION

General shape

18 Mandibular articulation, ratio between mediolateral length and anteroposterior width (perpendicular and at midlength): (0) <2; (1) 2-3; (2) 3-4; (3) >4 (**Ordered**; New)

19 Mandibular articulation, number of condyles: (0) two; (1) three (Chiappe, 2001 #21)

20 Mandibular articulation, important step between condyles and quadrate body: (0) absent; (1) present and weak, limit between mandibular condyles and quadrate body slightly concave; (2) present and important, limit between mandibular condyles and quadrate body strongly concave (**Ordered**; New)

21 Mandibular condyles, ventral margin in posterior view: (0) biconvex, limit between the two condyles angular or slightly concave; (1) biconvex, very large concavity separating the two condyles; (2) W-shaped, ventral margin of condyles roughly flattened and angular roughly convex (Unordered; New)

22 Mandibular condyles, posterior margin in ventral view: (0) strongly biconvex; (1) very slightly biconvex, roughly convex (**New**)

23 Mandibular condyles, size in ventral view (ratio: longest length ectocondyle/longest length entocondyle): (0) longer entocondyle (<0.9); (1) subequal in size (0.9-1.1); (2) longer ectocondyle (1.1-1.9); (3) much longer ectocondyle (>1.9) (**Ordered**; New)

24 Mandibular condyles, intercondylar notch in between the ecto- and entocondyles: (0) absent; (1) present on the anterior margin of the mandibular articulation; (2) present on the posterior margin of the mandibular articulation (Unordered; New)

Ectocondyle

25 Ectocondyle, ratio: width/length in ventral view: (0) >0.55, oval to subcircular; (1) 0.3-0.55, elliptical; (2) 0.3-0.55, parabolic; (3) <0.3, parabolic to sigmoid (Unordered; New)

26 Ectocondyle, concavity on the anterior side in anterior view: (0) absent; (1) present, shallow; (2) present, deep (Unordered; New)

27 Ectocondyle, ventral margin in anterior view: (0) convex; (1) sigmoid (**New**)

28 Ectocondyle, extension of the articular surface on the posterior surface of the quadrate body (ratio: width/length of articular surface in posterior view): (0) limited, <0.3; (1) moderately extended, 0.3-0.5; (2) important, >0.5 (Unordered; New)

Entocondyle

29 Entocondyle, ratio: width/length in ventral view: (0) >0.4, oval to subcircular; (1) 0.3-0.4, elliptical and moderately elongated; (2) <0.3, elliptical and strongly elongated (**Ordered**; New)

30 Entocondyle, shape in ventral view: (0) not protruding anteriorly, or very slightly; (1) strongly protruding anteriorly (**New**)

31 Entocondyle, extension of the articular surface on the quadrate body (ratio: width/length of articular surface in posterior view): (0) <0.25, limited; (1) 0.25-0.6, moderately extent; (2) >0.6, important (Unordered; New)

Intercondylar sulcus

32 Intercondylar sulcus in ventral view: (0) well-delimited by the mandibular condyles; (1) shallow (**New**)

33 Intercondylar sulcus in ventral view: (0) narrow, narrower than the entocondyle width; (1) wide, same width or larger than the entocondyle width (**New**)

34 Intercondylar sulcus, angle between main axis of sulcus and long axis of mandibular articulation in ventral view: (0) >135°; (1) <135° (**New**)

IV. QUADRATE HEAD

35 Quadrate head, exposure in lateral view: (0) quadrate head entirely or almost entirely exposed; (1) quadrate head partially exposed; (2) quadrate head completely obscured (Unordered; Sereno and Novas 1994)

36 Quadrate head size relative to mandibular articulation (ratio: medio-lateral width of quadrate head/medio-lateral width of mandibular articulation in posterior view): (0) >0.31; (1) 0.29-0.31; (2) 0.28-0.24; (3) < 0.24 (Unordered; New)

37 Quadrate head, shape in dorsal view: (0) one single condyle, the squamosal capitulum; (1) two slightly differentiated condyles on the top of the columnar body of the quadrate; (2) two very distinct condyles, one large, the squamosal capitulum, and one small more ventrally positioned, the otic capitulum (Unordered; Modified from Gauthier, 1986 and Chiappe, 1995)

38 Quadrate head, shape in dorsal view: (0) subtriangular; (1) oval or subcircular; (2) Subquadrangular to subrectangular (Unordered; Modified from Sereno et al., 1998 #27)

39 Quadrate head, shape in posterior view: (0) convex or roughly flattened quadrate head; (1) strongly convex, conical and pointed quadrate head; (2) concave (Unordered; New)

V. CONTACTS

Lateral contact, general shape

40 Laterodorsal contact in lateral view: (0) only or mostly contacting quadratojugal; (1) mostly contacting squamosal; (2) contacting postorbital and squamosal (Unordered; New)

41 Lateral contacts, ratio: antero-posterior width of dorsal contact/antero-posterior width of ventral contact in lateral view: (0) <0.2; (1) 0.2-0.5; (2) >0.5 (Unordered; New)

Dorsal quadratojugal/squamosal/postorbital contact

42 Dorsal contact, shape in lateral view: (0) elongated line; (1) drop-shaped; (2) drop-shaped reversed; (3) elliptical; (4) subrectangular (Unordered; New)

43 Dorsal contact: (0) facing anteriorly; (1) facing laterally; (2) facing postero-laterally or completely posteriorly (Unordered; New)

44 Dorsal contact, surface: (0) roughly smooth; (1) irregular; (2) with two longitudinal furrows separated by a ridge; (3) with one longitudinal furrow (Unordered; New)

45 Dorsal contact, delimitation: (0) not delimited by any margin; (1) delimited posteriorly by a longitudinal ridge; (2) delimited by anterior and posterior margins (Unordered; New)
46 Dorsal contact, dorsal extension: (0) well-beneath the quadrate head; (1) almost reaching or reaching the quadrate head (**New**)
47 Dorsal contact, ventral projection bounding the quadrate foramen: (0) absent; (1) present, short projection; (2) present, elongate process (Unordered; New)

Ventral quadratojugal contact
48 Ventral quadratojugal contact, shape in posterior view: (0) concave; (1) straight; (2) convex (Unordered; New)
49 Ventral quadratojugal contact: (0) facing postero-laterally, contact overlapping the posteroventral part of the quadrate body; (1) facing laterally; (2) facing antero-laterally (Unordered; New)
50 Ventral quadratojugal contact, shape in lateral view: (0) ovoid to D-shaped; (1) drop-shape to d-shaped; (2) semi-circular; (3) subrectangular; (4) elongated ellipse (Unordered; New)
51 Ventral quadratojugal contact, surface: (0) with radiating ridges; (1) roughly smooth; (2) irregular and weakly grooved; (3) heavily and deeply grooved (Unordered; New)
52 Ventral quadratojugal contact, surface: (0) not delimited by any upper margin; (1) delimited by upper margins (**New**)
53 Ventral quadratojugal contact, extension on lateral surface of ectocondyle: (0) limited, occupies only part of the surface; (1) extensive, covers entire lateral surface of the ectocondyle Brusatte et al., 2010 #108)
54 Ventral quadratojugal contact, anterior projection in ventral view: (0) absent; (1) present, short; (2) present, elongated (Unordered; New)
55 Ventral quadratojugal contact, ventro-lateral projection in ventral view: (0) absent; (1) present (**New**)
56 Ventral quadratojugal contact, small perforation: (0) absent; (1) present (**New**)
57 Ventral quadratojugal contact, dorsal projection bounding the quadrate foramen: (0) absent; (1) present (**New**)

Pterygoid contact
58 Pterygoid contact, in posterior view: (0) contact on the pterygoid flange; (1) contact on the ventromedial or anteroventral side of the quadrate body (**New**)

59 Contact of the epipterygoid and the pterygoid flange, in medial view: (0) present; (1) absent, quadrate and epipterygoid remains separated (**New**)

Braincase contact

60 Braincase (opisthotic/exoccipital/paroccipital process) contact on the dorsal and/or medial part of the quadrate: (0) absent; (1) present (**New**)

VI. FORAMINA

Quadrate foramen

61 Quadrate foramen: (0) present; (1) absent (Modified from Novas, 1989 and Sereno et al., 1996 #36)

62 Quadrate foramen, position: (0) completely enclosed within the quadrate; (1) mostly delimited by the quadrate, only lateral border of foramen formed by quadratojugal; (2) developed as a distinct opening between the quadrate and quadratojugal. Lateral margin of the foramen formed by the quadratojugal and ventral and dorsal margins formed by both quadrate and quadratojugal; (3) developed as a distinct opening between the quadrate and postorbital. (**Ordered**; Modified from Novas, 1989)

63 Quadrate foramen, position: (0) situated more ventrally than the mid-height of the quadrate or covering most of the ventral part of the quadrate; (1) situated at mid height of the quadrate of the lateral process (Modified from Holtz, 2000)

64 Quadrate foramen, position: (0) facing postero-laterally and visible in lateral view; (1) facing posteriorly and not visible in lateral view (**New**)

65 Quadrate foramen, shape: (0) subcircular; (1) strongly ventrodorsally elongated and elliptical or bean-shaped; (2) strongly ventro-dorsally elongated and lenticular or tear drop shaped; (3) strongly latero-medially elongated (Unordered; New)

66 Quadrate foramen, size: (0) minute, long axis less than 7% of the dorsoventral depth of the quadrate; (1) small, long axis between 7 to 15% of the dorsoventral depth of the quadrate; (2) large quadrate fenestra, long axis greater than 15% of the dorsoventral depth of the quadrate (**Ordered**; Holtz,1998 #67; Carr and Williamson 2010 #123)

67 Inclination of the main axis of the quadrate foramen: (0) absent, main axis parallel to quadrate ridge; (1) present, foramen strongly medially inclined; (2) present, foramen perpendicular to quadrate ridge (Unordered; New)

Medial foramen

68 Medial foramen, at the ventralmost part of the pterygoid flange: (0) absent; (1) present (Benson, 2009 #57)

VII. FLANGE & PROCESS

Pterygoid flange

69 Pterygoid flange, anterior extension in medial view (ratio: antero-posterior length of flange/ventro-dorsal elongation of quadrate body): (0) >0.65; (1) 0.57-0.65; (2) 0.4-0.57; (3) <0.4 (**Ordered**; New)

70 Pterygoid flange, position of the anteriormost point: (0) at two-third of the quadrate or more dorsally; (1) at mid-height of the quadrate; (2) at one-third of the quadrate or more ventrally (Unordered; New)

71 Pterygoid flange, outline in medial view: (0) subtrapezoidal, formed by 3 sides with a short anterior one; (1) subrectangular, formed by 3 sides with a long anterior one; (2) parabolic, formed by 3 sides with a convex anterior one; (3) Semi-oval; (4) roughly M-shaped; (5) (Unordered; Modified from Chiappe, 2001 #18)

72 Pterygoid flange, shape and orientation of the most anterior side in medial view: (0) roughly straight and inclined posteriorly from the long axis of the quadrate body; (1) roughly straight, subparalell to long axis of quadrate body or inclined anteriorly; (2) rounded or sigmoid (Unordered; New)

73 Pterygoid flange, angle between the main axis of the ventral margin and the main axis of the quadrate body: (0) < 55°; (1) 55° - 75°; (2) > 75° (**Ordered**; New)

74 Pterygoid flange, ventral extension in medial (ratio: distance between dorsal margin of entocondyle and ventral end of flange/ventro-dorsal elongation of quadrate): (0) well above the condyle (>0.1); (1) just above the condyle but not reaching it (0.02-0.1); (2) reaching the condyle (<0.02) (**Ordered**; New)

75 Pterygoid flange, medial curvature in posterior view: (0) absent or weak, flange projecting mostly anteriorly; (1) present and important, flange projecting antero-medially (**New**)

76 Pterygoid flange, curvature of the ventroposterior part at the level of the quadrate body: (0) present, important; (1) present, short; (2) absent (Unordered; New)

77 Pterygoid flange, ventral shelf on the anteroventral margin in medial view: (0) absent; (1) present (**New**)

78 Pterygoid flange, posteromedial projection of the ventral part in posterior view: (0) absent; (1) present (**New**)

Lateral process

79 Lateral process: (0) present; (1) absent (Currie, 1995 and Sereno et al., 1996 #58)

80 Lateral process, ventral extension: (0) process extending to the quadrate foramen or at mid-height of the bone; (1) process extending below the mid-height of the bone, just above the ectocondyle or reaching it. (**New**)

81 Lateral process, maximum width: (0) large, >40% the latero-medial length of the mandibular articulation; (1) short, <40% the latero-medial length of the mandibular articulation (Modified from Forster, 1999)

82 Lateral process, outline of lateral margin: (0) angular; (1) parabolic (**New**)

83 Lateral process, main orientation: (0) lateral; (1) antero-lateral; (2) anterior (Unordered; New)

84 Lateral process, dorsal extension: (0) reaching the quadrate head; (1) not reaching the quadrate head (**New**)

85 Lateral process, extension of the dorsal contact: (0) contact extending entirely along the lateral process; (1) contact restricted to the ventral part of the lateral process; (2) contact restricted to the dorsal part of the lateral process (Unordered; New)

VIII. QUADRATE FOSSAE

Medial fossae

86 Medial fossa between pterygoid flange and quadrate body, excluding the pneumatopore fossa, in medial view: (0) shallow fossa; (1) deep depression (**New**)

87 Small fossa on the ventralmost part to the pterygoid flange and dorsal to the entocondyle in medial view: (0) absent; (1) present (**New**)

Posterior fossa

88 Posterior fossa, on the quadrate body in posterior view: (0) absent; (1) present, does not lead to the quadrate foramen; (2) present, leads to the quadrate foramen and surrounds it (Unordered; New)

89 Posterior fossa, on the quadrate body in posterior view: (0) small oval and poorly delimited depression; (1) ventro-dorsally elongated, diagonally oriented, and poorly delimited depression; (2) ventro-dorsally elongated, well-delimited depression (Unordered; New)

Anterior fossa

90 Anterior fossa, at one third of the quadrate, lateral to the ventral extremity of the pterygoid flange in anterior view: (0) absent or shallow concavity; (1) present, deep depression (**New**)

IX. PNEUMACITY

91 Quadrate, pneumaticity: (0) absent; (1) present (Gauthier, 1986; Molnar, 1991)

92 Pneumatic depression on the posterior side inside the posterior fossa, in posterior view: (0) absent; (1) present and ventral to the quadrate foramen; (2) present and at the same level or dorsal to the quadrate foramen; (3) present and at the same level than quadrate foramen (Unordered; New)

93 Posterior pneumatopore, size (ratio between the maximum length of the pneumatopore and the latero-medial width of the mandibular articulation): (0) large, >30%; (1) small, <30% (**New**)

94 Pneumatic depression on the medial side, in medial view: (0) absent; (1) present, with no septum; (2) present and divided by a septum (Unordered; New)

95 Medial pneumatopore, size (ratio between the maximum length of the pneumatopore and the latero-medial width of the mandibular articulation): (0) small, <20%; (1) large, >20% (**New**)

96 Pneumatic depression on the anteroventral margin of the quadrate body, in ventral view: (0) absent; (1) present, small circular pneumatopore; (2) present, large pneumatic recess (Unordered; New)

97 Pneumatic depression on the anterodorsal side, below the quadrate head, in anterior view: (0) absent; (1) present (**New**)

98 Pneumatic depression on the lateral side, dorsal to the ectocondyle: (0) absent; (1) present (**New**)

Appendix 2: Illustration of States of Quadrate-based Characters

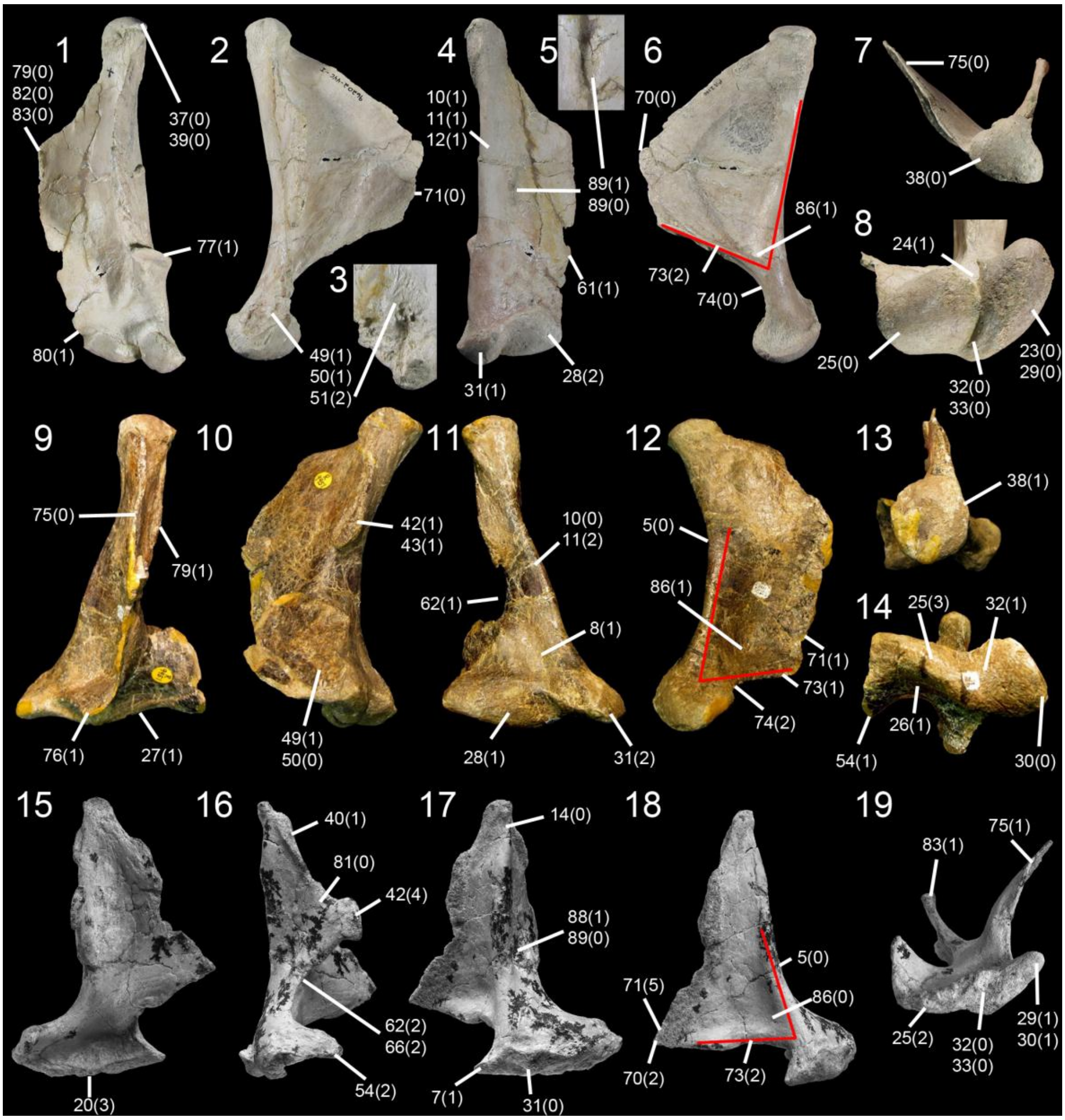

FIGURE S1. States of quadrate-based characters. Right quadrate (**1**–**6**) of *Majungasaurus crenatissimus* (FMNH PR 2100) in (**1**) anterior, (**2**–**3**) lateral, (**4**–**5**) posterior, (**6**) medial, (**7**) dorsal and (**8**) ventral views (courtesy of Lawrence Witmer), and detail on (**3**) the ventral quadratojugal contact and (**5**) posterior fossa of the left quadrate (FMNH PR 2100). In posterior view, the quadrate display a lateral process (char. 79:0) with an angular outline (char. 82:0), oriented mainly laterally (char. 83:0) and reaching the mandibular articulation (char. 80:1), as well as a quadrate head with a convex dorsal margin (char. 39:0) and made of a single condyle (char. 37:0). A ventral shelf exists on the ventral margin of the pterygoid flange (char. 77:1). In lateral view, the ventral quadratojugal contact is drop-shaped (char. 50:1), faces laterally (char. 49:1), and its surface is irregular and weakly grooved (char. 51:2). The pterygoid flange is subtrapezoidal, with a short anterior sides (char. 71:0), and the quadrate ridge is poorly delimited (char. 10:1), rod-shaped (char. 11:1) and subvertical (char. 12:1). The quadrate shows, in dorsal view, a posterior fossa, centrally positioned on the quadrate body and not connected to the quadrate foramen (C1, char. 88:1), and relatively poorly delimited and oval in outline (char. 89:0). There is no quadrate foramen (char. 61:1), and the entocondyle moderately extends on the body (char. 31:1) whereas the ectocondyle strongly extend on the posterior margin of the quadrate (char. 28:2). The pterygoid flange gets attached to the quadrate body well above the mandibular articulation (char. 74:0) and its ventral margin makes an angle of more than 75° with the main axis of the dorsal part of the quadrate body (char. 73:2). The anteriormost point of the pterygoid flange is located at two-third of the quadrate (char. 70:0), and the medial fossa corresponds to a deep depression (char. 86:1). In dorsal view, the pterygoid flange does not show any medial curvature and only projects anteriorly (char. 75:0) and the quadrate head has a subtriangular outline (char. 38:0). In ventral view, the mandibular articulation of *Majungasaurus* displays an ovoid/subcircular ectocondyle with a width/length ratio of more than 0.55 (char. 25:0), a longer entocondyle (char. 23:0) with an ovoid outline (char. 29:0), a well-delimited (char. 32:0) and narrow (char. 33:0) intercondylar sulcus, and an intercondylar notch on the anterior margin of the mandibular articulation (char. 24:1). Left quadrate (**9–14**) of *Baryonyx walkeri* (BMNH R9951) in (**9**) anterior, (**10**) lateral, (**11**) posterior, (**12**) medial, (**13**) dorsal and (**14**) ventral views. The pterygoid flange of *Baryonyx* projects anteriorly and the anterior part does not curve medially (char. 75:0), contrarily to the ventral margin of the flange that bends medially (char. 76:1). There is no lateral process on the lateral surface of the quadrate body (char. 79:1) and the ventral margin of the ectocondyle is sigmoid in anterior view (char. 27:1). The dorsal quadratojugal contact is drop-shaped (char. 42:1) and faces laterally (char. 43:1), whereas the ventral quadratojugal contact is D-shaped (char. 49:1) and also faces laterally (char. 50:0). In posterior view, the quadrate foramen is mostly delimited by the quadrate (char. 62:1), the quadrate ridge is broad (char. 11:2), prominent and well-delimited (char. 10:0), and a shallow furrow curving basally from the foramen towards the mandibular articulation exists on the ventral half of the quadrate body (char. 8:1). The ectocondyle moderately extends on the posterior margin of the quadrate body (char. 28:1), while the posterior extension of the entocondyle is important (char. 31:2). In medial view, the posterior margin of the quadrate body is concave (char. 5:0), the medial fossa is deep (char. 86:1), and the pterygoid flange consists of a subrectangular ala with a long anterior side (char. 71:1), reaching the quadrate body at the level of the mandibular articulation (char. 74:2), and whose the ventral margin makes an angle of 55° to 75° with the main axis of the quadrate body (char. 73:1). In dorsal view, the quadrate head is subcircular in outline (char. 38:1) and, in ventral view, the ventral quadratojugal contact projects anteriorly (char. 54:1) while the mandibular articulation corresponds to a sigmoid ectocondyle (char. 25:2) separated from a non-protruding entocondyle (char. 30:0) by a shallow intercondylar sulcus (char. 32:1). Right quadrate (**15–19**) of *Tsaagan mangas* (IGM 100/1015) in (**15**) anterior, (**16**) lateral, (**17**) posterior, (**18**) medial, and (**19**) ventral views (courtesy of Mick Ellison © AMNH). The ventral margin of the mandibular articulation of *Tsaagan* is roughly convex in anterior/posterior view (char. 30:3), and the laterodorsal contact of the quadrate body mostly contact the squamosal (char. 40:1) in lateral view. Tsaagan quadrate shows a large lateral process (char. 80:0) terminated anteriorly by a subrectangular dorsal quadratojugal contact (char. 42:4). The quadrate foramen is equally delimited by the quadrate and quadratojugal (char. 62:2) and corresponds to a large fenestra (char. 66:2). The ventral quadratojugal contact well projects anteriorly and the anterior process is well-developed (char. 54:2). In posterior view, the quadrate ridge reaches the quadrate head dorsally (char. 14:0) and the posterior surface of the quadrate display a small oval posterior fossa (char. 89:1) centrally positioned on the quadrate body and not leading to or surrounding the quadrate foramen (char. 88:1). The medioventral corner of the quadrate body is pointed and angular (char. 7:1) and the extension of the entocondyle on the posterior surface of the quadrate is relatively limited (char. 31:0). In medial view, the pterygoid flange corresponds to a subtriangular wing (char. 71:5) in which the anteriormost point is located at one third of the quadrate body (char. 70:2). The ventral margin of the pterygoid flange makes an angle of more than 75° with the main axis passing through the quadrate body (char. 73:2). The medial fossa of the pterygoid wing is shallow (char. 86:0) and the posterior margin of the quadrate body is strongly concave (char. 5:0). In ventral view, the lateral process extends anterolaterally (char. 83:1) whereas the pterygoid flange curves anteromedially (char. 75:1). The ectocondyle of the mandibular articulation is parabolic (char. 25:2), while the entocondyle is moderately elongated (char. 29:1) and strongly protrudes anteriorly (char. 30:1). A narrow (char. 33:0) and well-delimited (char. 32:0) intercondylar sulcus separates the two condyles.

FIGURE S2. States of quadrate-based characters. Left (**1**–**4**) coosified quadrate and quadratojugal of *Acrocanthosaurus atokensis* (NCSM 14345) in (**1**) posterior and (**2**–**3**) medial views, and (**3**) details on the medial pneumatopore of the right quadrate in medial view (courtesy of Drew Eddy). In posterior view, the quadrate of *Acrocanthosaurus* displays a short lateral process (char. 81:1) with an angular lateral margin (char. 82:0), and extending ventrally to the quadrate foramen (char. 80: 0). The quadrate ridge is prominent, well-delimited (char. 10:0) and rod-shaped (char. 11:1), while the posterior pneumatopore is large (char. 93:0) and dorsal to the quadrate foramen (char. 92:2). The latter is mostly delimited by the quadrate bone (char. 62:1) and relatively small in size (char. 66:0). The extension of the entocondyle on the posterior surface of the quadrate is limited whereas the entocondyle extends moderately on the quadrate body. In medial view, there is a deep concavity delimiting the mandibular articulation from the rest of the quadrate body (char. 20:2). The medial pneumatopore is a large opening (char. 95:1) divided by a septum (char. 94:2), and there is a medial shelf medially oriented (char. 77:2) at the ventral margin of the pterygoid flange. Left quadrate (**4**–**6**) of *Mapusaurus roseae* (MCFPVPH-108.102) in (**4**) posterior, (**5**) medial and (**6**) anterior (ventral part) views. As seen in *Acrocanthosaurus*, the lateral process of *Mapusaurus* is short (char. 81:1) and its lateral margin is angular (char. 82:0). Nevertheless, the quadrate foramen is developed as distinct opening equally delimited by the quadrate and quadratojugal (char. 62:2), and the posterior fossa corresponds to a ventro-dorsally elongated and poorly delimited depression (char. 89:1) leading to the quadrate foramen (char. 88:2). In medial and anterior views, there is no concavity delimiting the mandibular articulation from the rest of the quadrate body (char. 20:0). The medial fossa is shallow (char. 86:0), the medial pneumatopore is large (char. 95:1) with no septum (char. 94:1) dividing it, and the anterior pneumatopore corresponds to a small aperture (char. 98:1) ventral to the pterygoid flange. Left (**7, 14**) quadrate of *Allosaurus* '*jimmadseni*' (SMA 005/02) in (**7**) ventral and (**14**) medial (dorsal part) views. The mandibular articulation of *Allosaurus* includes an elliptical entocondyle (char. 29:1) that does not protrude anteriorly (char. 30:1), an elliptical entocondyle as well having a width/length ratio between 0.3 and 0.55 (char. 25:1), and an intercondylar notch on the posterior margin of the quadrate (char. 24:2). In medial view, the quadrate ridge of *Allosaurus* displays a marked protuberance at two-third of the quadrate body (char. 17:1). Left quadrate (**8**–**13**, **15**) of *Aerosteon riocoloradensis* (MCNA-PV-3137) in (**8**) anterior, (**9**–**10**) lateral, (**11**–**12**) posterior, (**13**) medial, and (**15**) ventral views, with details on (**10**) the lateral pneumatopore in lateral view and (**12**) the quadrate ridge groove in posterior view (courtesy of Martin Ezcurra). In anterior view, the anterior part of the pterygoid flange extends antero-medially (char. 75:1), and the medial curvature of the ventral margin of the flange is relatively short (char. 76:1). The ventral margin of the ectocondyle is convex in anterior view (char. 27:0) and, in lateral view, the lateral process projects anterior (char. 83:2) and reaches the ectocondyle ventrally (char. 80:1), and its anterior margin is parabolic in outline (char. 82:1). There is a lateral depression corresponding to a lateral pneumatopore (char. 98:1) on the ventral part of the lateral process, just above the ectocondyle. In posterior view, the quadrate ridge almost reaches the entocondyle ventrally (char. 13:1), and its posterior surface is separated by a narrow groove (char. 16:1), just below the quadrate head. The quadrate foramen is enclosed within the quadrate body (char. 62:0) and a large pneumatopore (char. 93:0) occurs beneath the quadrate foramen (char. 92:1). In medial view, the pterygoid flange corresponds to a parabolic ala (char. 71:2) in which the anteriormost side is rounded (char. 72:2). The ventral margin of the pterygoid flange reaches the quadrate body well above the mandibular articulation (char. 74:0) and makes an angle of less than 55° with the main axis of the quadrate ridge. The quadrate body is sigmoid in outline (char. 5:3) and the medial fossa is shallow (char. 86:0). The mandibular articulation of *Aerosteon* encompasses an elliptical and moderately elongated entocondyle (char. 29:1) protruding anteriorly (char. 30:1), and an elliptical ectocondyle as well (char. 25:1). The condyles are separated by a shallow, poorly delimited (char. 32:1) and lateromedially wide (char. 33:1) intercondylar sulcus. Left quadrate (**16**–**19**) of *Alioramus altai* (IGM 100/1844) in (**16**) anteroventral, (**17**) lateral, (**18**) posterior and (**19**) medial views (courtesy of Mick Ellison © AMNH). The quadrate of *Alioramus* displays a large anteroventral pneumatic recess (char. 96:2) in the ventral part of the pterygoid flange in anteroventral view and, in lateral view, the dorsal quadratojugal contact is tear-drop shaped (char. 42:1) and not delimited by margins anteriorly or posteriorly (char. 45:0). The ventral quadratojugal is D-shaped (char. 50:3), with a smooth surface (char. 51:0) and a short anterior projection (char. 54:1). A small concavity delimiting the mandibular articulation from the rest of the quadrate body is visible in *Alioramus* quadrate (char. 20:1). In posterior view, the dorsal quadratojugal contact also shows a smooth surface (char. 44:0) as well as a small ventral projection (char. 47:1), and this articulating surface faces posterolaterally (char. 43:2). The ventral quadratojugal contact is convex in posterior view. Right quadrate of *Tyrannosaurus rex* (cast of BHI 3033) in (**20**) ventral view (Larson 2008). The mandibular articulation of *Tyrannosaurus* is typical of tyrannosaurids by having subsymmetrical mandibular condyles (char. 23:1) separated by a large (char. 33:1) and shallow (char. 32:1) intercondylar sulcus. Both ecto- and entocondyle are ovoid (char. 25:0; char. 29:0) and the entocondyle does not protrude anteriorly (char. 30:0). The pterygoid flange mostly extends anteriorly (char. 75:0), and its ventral part is separated into two laminae delimiting a large anteroventral pneumatic recess (char. 96:2).

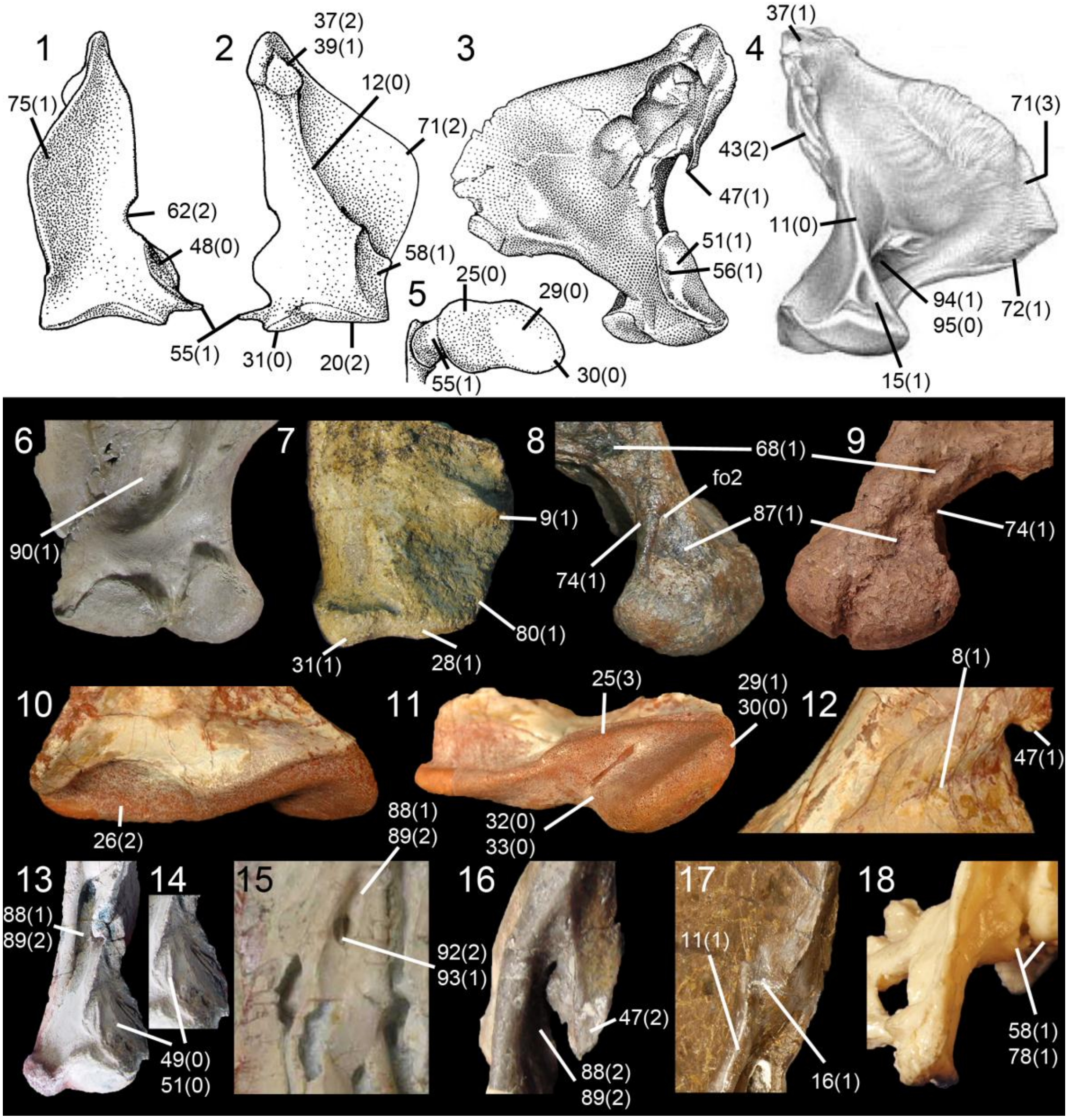

FIGURE S3. States of quadrate-based characters. Left (**1-2, 5**) quadrate of an indeterminate Oviraptoridae (based on specimens GIN A, B, ZPAL MgD-II/95, 96) in (**1**) anterior, (**2**) posterior, and (**5**) ventral views (modified from Maryańska & Osmólska, 1997: fig. 3A-C). In some oviraptorids, the anterior part of the pterygoid ala curves anteromedially (char. 75:1) and the quadrate foramen is equally delimited by the quadrate and quadratojugal (char. 62:2). The ventral quadratojugal contact is concave (char. 48:0) in anterior view and shows a ventral projection extending laterally (char. 55:1) dorsal to the ectocondyle. In posterior view, the quadrate head is conical and pointed (char. 39:1) and includes two very distinct condyles, an otic and squamosal capitula (char. 37:2). The quadrate ridge is strongly inclined laterally (char. 12:0), and the anterior margin of the pterygoid flange is parabolic (char. 71:2). In oviraptorids, the pterygoid contacts the quadrate on the medioventral side of the quadrate body (char. 58:1). The entocondyles has a limited extension on the posterior surface of the quadrate body (char. 28:0; char. 31:0), and the ventral margin of the mandibular articulation is "W-shaped" in posterior view (char. 20:2). Both ecto- and entocondyle are oval in ventral view (char. 25:0; char. 29:0) and the entocondyle does not protrude anteriorly (char. 30:0). Left (**3**) quadrate of *Daspletosaurus* jimmadseni (TMP 94.143.1) in lateral view (Currie, 2003). The dorsal quadratojugal contact shortly projects ventrally (char. 47:1), and the surface of the ventral quadratojugal contact is smooth (char. 51:1) and pierced by small foramina (char. 56:1). Left (**4**) quadrate of *Albertosaurus sarcophagus* (TMP 81.10.1) in posteromedial view (Currie, 2003). The quadrate head of *Albertosaurus* has two slightly differentiated condyles (char. 37:1), and the dorsal quadratojugal contact faces posterolaterally (char. 43:2). The quadrate ridge corresponds to a narrow crest (char. 11:0) bifurcating ventrally (char. 15:1) into two ridges separated by an oval concavity. The pterygoid flange is semi-oval (char. 71:3) with the anteriormost side inclined anteriorly (char. 72:1). There is a medial pneumatopore lacking of a septum (char. 94:1) in the posteroventral corner of the pterygoid flange, and this pneumatic opening is relatively small (char. 95:0). Ventral parts of the (**6**) right quadrate of *Majungasaurus crenatissimus* (FMNH PR 2100) in anterior view showing the deep anterior fossa (char. 90:1) lateral to the ventral part of the pterygoid flange. Right (**7**) quadrate of *Ilokelesia aguadagrandensis* (MCF-PVPH 35) in posterior view displaying a pronounced ridge on the lateroventral part of the quadrate body (char. 9:1), a lateral process terminating to the mandibular articulation ventrally (char. 80:1), and the ecto- and entocondyle extending moderately on the posterior surface of the quadrate (char. 31:1; char. 28:1). Ventral parts of (**8**) right quadrate of *Torvosaurus tanneri* (BYUVP 9246) and (**9**) left quadrate of *Afrovenator abakensis* (UC OBA1) in medial views. The quadrates of these two megalosaurids possess a medial foramen located within the posteroventral corner of the pterygoid flange (char. 68:1), as well as small fossa dorsal to the entocondyle (char. 87:1) that includes a second small foramen (fo2) in *Torvosaurus*. The pterygoid flange of both quadrates join the quadrate body just above the mandibular articulation without reaching it (char. 74:1). Right (**10–12**) quadrate of an indeterminate Spinosauridae (WDC-CSG uncatalogued) in (**10**) anterior, (**11**) ventral, and (**12**) posterior view, with details on (**10**-**11**) the mandibular articulation and (**12**) the quadrate ridge and quadrate foramen. The mandibular articulation of some spinosaurid display a deep concavity on the anterior surface of the ectocondyle (char. 26:2), a strongly sigmoid ectocondyle (char. 25:3), and an elliptical and moderately entocondyle (29:1) which does not protrude anteriorly (char. 30:0). The ridge of some spinosaurids also shows a small furrow on the posterior surface of the quadrate, medial to the quadrate foramen (char. 8:1), as well as a ventral projection of the dorsal quadratojugal contact (char. 47:1). Ventral part of right (**13–14**) quadrate of *Sinraptor dongi* (IVPP 10600) in posterior view, with details on (**14**) the ventral quadratojugal contact. There is a deep and strongly ventro-dorsally elongated posterior fossa (char. 89:2) centrally positioned on the posterior surface of the quadrate body and not leading to the quadrate foramen (char. 88:1) in *Sinraptor*. The ventral quadratojugal contact faces posterolaterally (char. 49:0) and there are radiating ridges on its surface (char. 51:0). Central part of (**15**) left quadrate of *Sinornithomimus dongi* (IVPP−V11797−31) in posterior view showing the well-delimited, ventrodorsally elongated (char. 89:2) and centrally positioned (char. 88:1) posterior fossa, as well as the small posterior pneumatopore (93:1) within the fossa, well dorsal to the quadrate foramen (char. 92:2). Posterior parts of (**16**) right quadrates of *Falcarius utahensis* (UMNH VP 16022) with details on the ventro-dorsally elongated, well-delimited posterior fossa (char. 89:2) surrounding the quadrate foramen (char. 88:2), as well as the elongated projection of the dorsal quadratojugal contact (char. 47:2). Right (**17**) quadrate of *Allosaurus* ‘*jimmadseni*’ (SMA 005/02) in posterior views showing the quadrate ridge groove (char. 16:1) passing through the rod-shaped quadrate ridge (char. 11:1). Left (**18**) quadrate of *Avimimus portensus* (cast of PIN 3907/1) in lateral view with the ventral part of the pterygoid flange projecting posteromedially (char. 58:1) to contact the basisphenoid.

Appendix 3: Character Scoring for Taxa

3.1 Datamatrix of quadrate based characters.

“?”–unknown; “[]”–polymorphic character state; “-”–inapplicable character.

nstates 5

xread

98 56

Eoraptor

?02100?000?1?0?00??0??????????????0???00?????00?1???0???0???0101000?????????

??000100???0-?0-------

Herrerasaurus

000110000010000001000010100[01]2011010?0000?????0001???[01]1??00010101000

011001001000000100000-00-------

Eodromaeus

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???100??0????????????00-------

Tawa

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00100???????00???0-------

Liliensternus

????3000?01011000??1????????001???0?1?

?0???1???01?00-------

Syntarsus

01010000000100000?010??0???1??1???100?10??1??0001???0???00??0111000???????

???00000100??10?0-------

Dilophosaurus

1101200000100000020000203201[12]01111?0000?10110?111120010000?101013020

2000201100000010?002200-------

Cryolophosaurus

10010000-

0100?001?0?0???????????????0??0??1??0011???1???001?0111100?00?02000?01------

10???0-------

Ceratosaurus

0101000000110000000101102001001011010100101000-11[01]101000-0111------

020010001100000010100-00-------

Noasaurus

????00?0?11100000?0001000000?1??0???010??????????????????0?????????02101000
10001??01?00??00-------

Masiakasaurus

01??100001110000000000010000?0011001?10?00??????-111101000-0??1------
0????2001?0010?0???0??00-------

Abelisaurus

?00100???11102000?010?00?0??0??0??0[01]0?0?????????1????????010???????00001
0101000???01??0??10-------

Ilokelesia

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122101000?0?????????0?????1????010?01??0??00-------

Carnotaurus

010200000111000000000010100010110010?0?00??0??1-?????100?-0?01------
?20011010000100110100-10-------

Aucasaurus

????0000001100000002010000?2012101?0010????????111200000???????????0?????0
????01??01???1000-------

Majungasaurus

00010000011100000000201010002011001000000001000-111201000-0101------
020012000100100010101010-------

Monolophosaurus

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??100011011100-00-------

Eustreptospondylus

11??10000110100001010020300?11?000?00100001100-010111100-0?01------
020010100001------000-00-------

Afrovenator

1101100000101000110000001012112100?0010?101100-010200100-0??1------
120010100001------010-00-------

Torvosaurus

11?1000000101000010100203111011000?00100101100-021201000-0??1------
1?????1?0??1------?10-00-------

Baryonyx

2???010100201000030000303211002100?00100111200101021110000??0111120020111200001------100-00-------

Suchomimus

2???01?000201000030000?2???1???????0000011110010101110010??01111200?????2?0??1------?00-00-------

Irritator

?020????????????????????????????????0200??1??0?11???????0??00101100???????????1------?????0-------

Spinosaurine morphotype I

2???010[01]00201[01]0[02]02000030311210[12][01]00?00[12]00111[02][02]01110[23]0110000??010111003011121 0001------100-00-------

Spinosaurine morphotype II

?????10100201?0??30000303201102000?????02?1[02]2?11132001000???01011000?????2?0??1------100-00-------

Allosaurus fragilis

10000000001020011101002210011110001101001001111010000000101001111100312200111 01------100-00-------

Allosaurus europaeus

?00000?00010???1??????????????????0?0??0??0??0101???0?0000100111110??1220001100011011102200-------

Allosaurus jimmadseni

10?010000010100111010022100111 1000?10100?00??1101???000010?001011100212?10101000110111 02200-------

Aerosteon

1???3000000001001110000201001111110?10101201001001310 0100-0??0011120021220010000 11121?000-01100--02

Sinraptor

000000000010100101020020100100100021010010101100010001001010011110003122011010001101 0001200-------

Acrocanthosaurus

10000000001000010202002030000010001201 00??1??0000???0???0010010120002122010?10001101100210120 2100?

Shaochilong

1???0?000010000002010020300120 1100?2010????????010200000?0?????????03122010000???????00??00-------

Giganotosaurus
1???000000100000020000202001211000?201002111000110001000000??02012000???
??1?0?0001?01?0021010-10000
Mapusaurus
1???0000001000000?000??0??0????????10100221100011020000?0?0??0101200021?21
1100000100110021010-11100
Ornitholestes
?101?00000112?0??10100101000201011????0??00?002???????0?10??0101??002122[
12]00??0000111???22?0-------
Bicentenaria
??01?00000112?0??1000020100100100l?????????????0101100001???01?1??00????22
0000???????10??00-------
Zuolong
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2100000000100l0022?0-------
Proceratosaurus
1?2030000010000000?000??????????????????0???????00???0???00?00211110?013??11
?001------000-00-------
Eotyrannus
?????00000100?0??10000101001110001????????110?00002001000???02??2?00?????1
?1??1------100-00-------
Xiongguanlong
1020000000102?0?01000010100100l0112?0100??2????10???010?00??0211220??????
?0?001------?00-?0-------
Alioramus
10003000000022100?0[01]00?0?001?0?1???0010021200112031001000 0?1010122001
1312201001------000-010-0-200
Albertosaurus
20013000000022100?0000???001??0???2?1?002120201003100l0100?1011122100131
22??001------100-010-10210
Daspletosaurus
200130000000221001000010000?10?0112?0100102001l?1010010110?10111?200013
?2201001------100-010-??200
Tyrannosaurus

2001300000002010010000100001001111201100232100100020010010 1?0111220001322201001------000-010-0-210

Garudimimus

002030000[01]110?000?010??????1??1??1000100??1??0001?20000000??02012100112?120??01------??12?121?????

Sinornithomimus

0?21000??[01]110?000?000???????????????0?00??1???000???0?0?00??0201210?2???? ?2???01------??12?121?????

Shuvuuia

01210000001100000200002 02??0000101202?22??0?? 10?2???100?00?1031012003122101?000001012000-?0-------

Falcarius

1???1000011020000?0110201002002011?0010021102120102000000 0??011112003142111100001100?0022010-10000

Erlikosaurus

1010400001112?0001100020????00?1010?0??120132?001420000000?10211120?22421010000011001000-?0-------

Avimimus

101?100002-------

000001010001001 11??2??110110?021120110001?10??????0?122?11?011------100-00-------

Oviraptoridae

10[01]00010001000200000200000001000101202010101100000120101001 1102002[12]1011[02]01210001------000-0[01]0-[01]1000

Buitreraptor

1?2100100111 20000?010020?0?0000????00?0???1???001121000000??02112200?????????? 100000???0-?121?????

Bambiraptor

1021001001110000030130203000000 10023010?001000011010020000??0200?2000250200200000000?000-00-------

Tsaagan

202000100111000002013020300011000023010 11[14]100000101002000 0?0020022000250201100000010100 1000-------

Dromaeosaurus

```
10200010011100000030110?0??01010000200101101100021020000?01002012200215
01002000010011000-00-------
Troodontidae
1020001?0[01]110?000301101010010001012000?00?01?000001100100000?10[12]10?2?
03[12]2210?1?01------000-0[01]210--00
;
ccode + 0 2 3 10 17 19 22 28 61 65 68 73;
proc/;
```

3.2 Supermatrix of quadrate based characters combined with 6 other datasets.

The data file is available at DRYAD: xx.

Appendix 4: Results of the Cladistic Analysis

Cladistic analysis perform on the datamatrix of quadrate based characters.

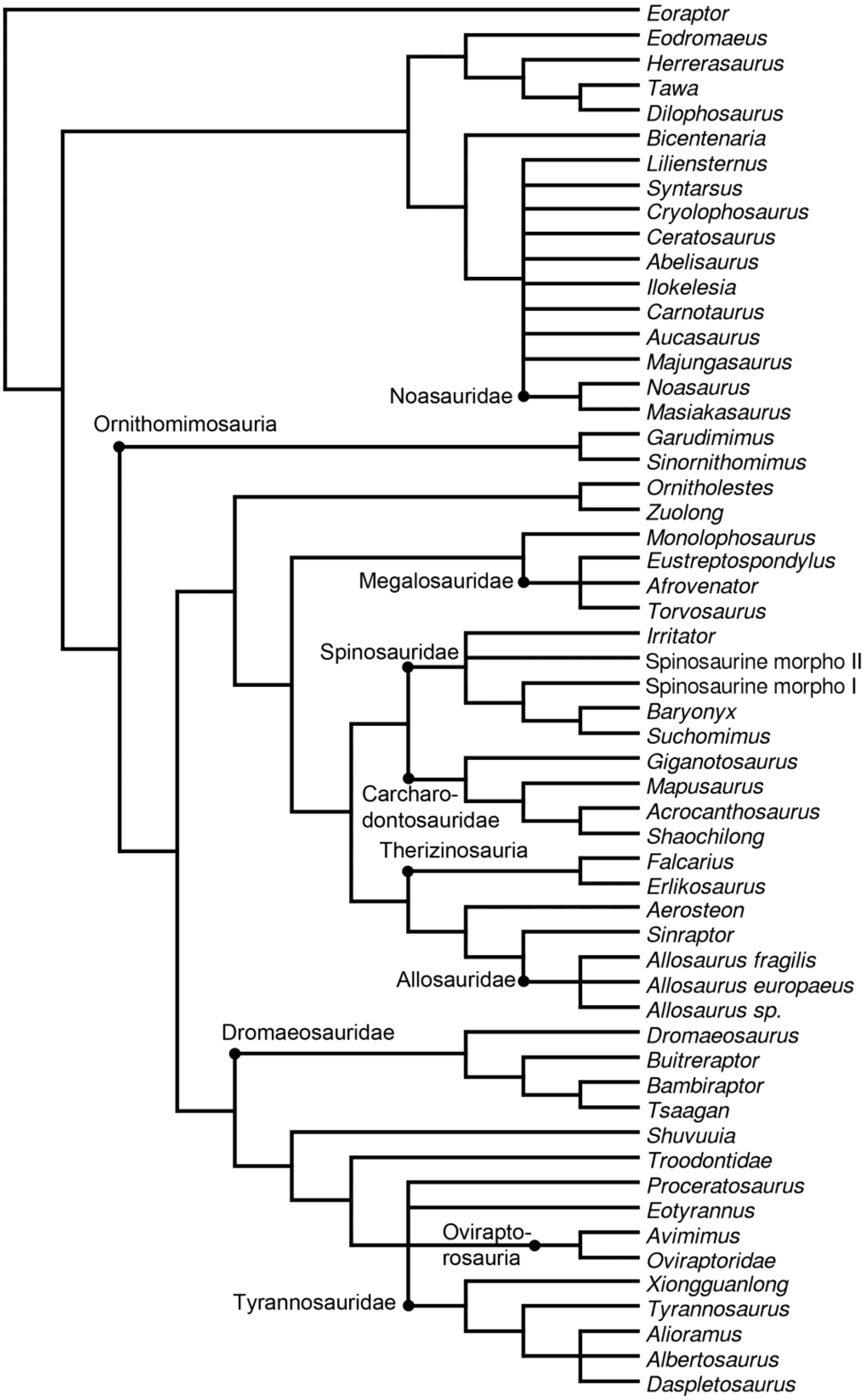

FIGURE S4. Strict consensus cladogram from 40 most parsimonious trees. Initial analysis was a New Technology Search using TNT v.1.1 of a datamatrix comprising 98 quadrate based characters combined with one outgroup (*Eoraptor lunensis*) and 55 nonavian theropod taxa. Tree length = 592 steps; CI = 0.271; RI = 0.536.

Cladistic analysis perform on the supermatrix.

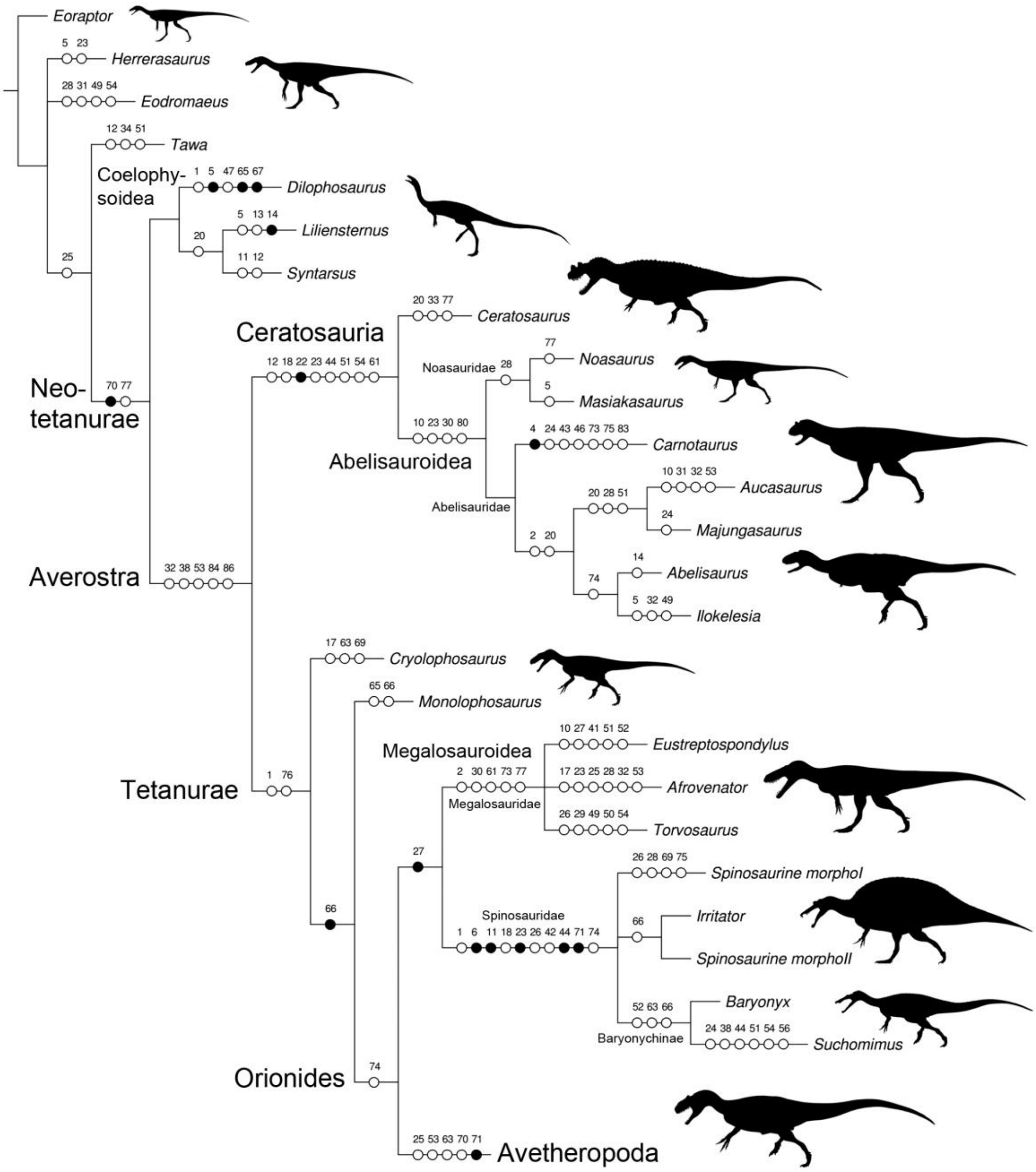

FIGURE S5A. Strict consensus cladogram of 36 most parsimonious trees. Initial analysis was a New Technology Search using TNT v.1.1 of a datamatrix comprising 98 quadrate based characters combined with six recent datasets on the whole skeleton (Choiniere, Xu, et al., 2010; Brusatte, Norell, et al., 2010; Martinez et al., 2011; Carrano et al., 2012; Pol and Rauhut, 2012) for one outgroup (*Eoraptor lunensis*) and 55 nonavian theropod taxa. Tree length = 3616 steps; CI = 0.562; RI = 0.631. The unambiguous and ambiguous dentition based synapomorphies are represented by black and white circles, respectively, and the character number associated with each synapomorphy is above the circles.

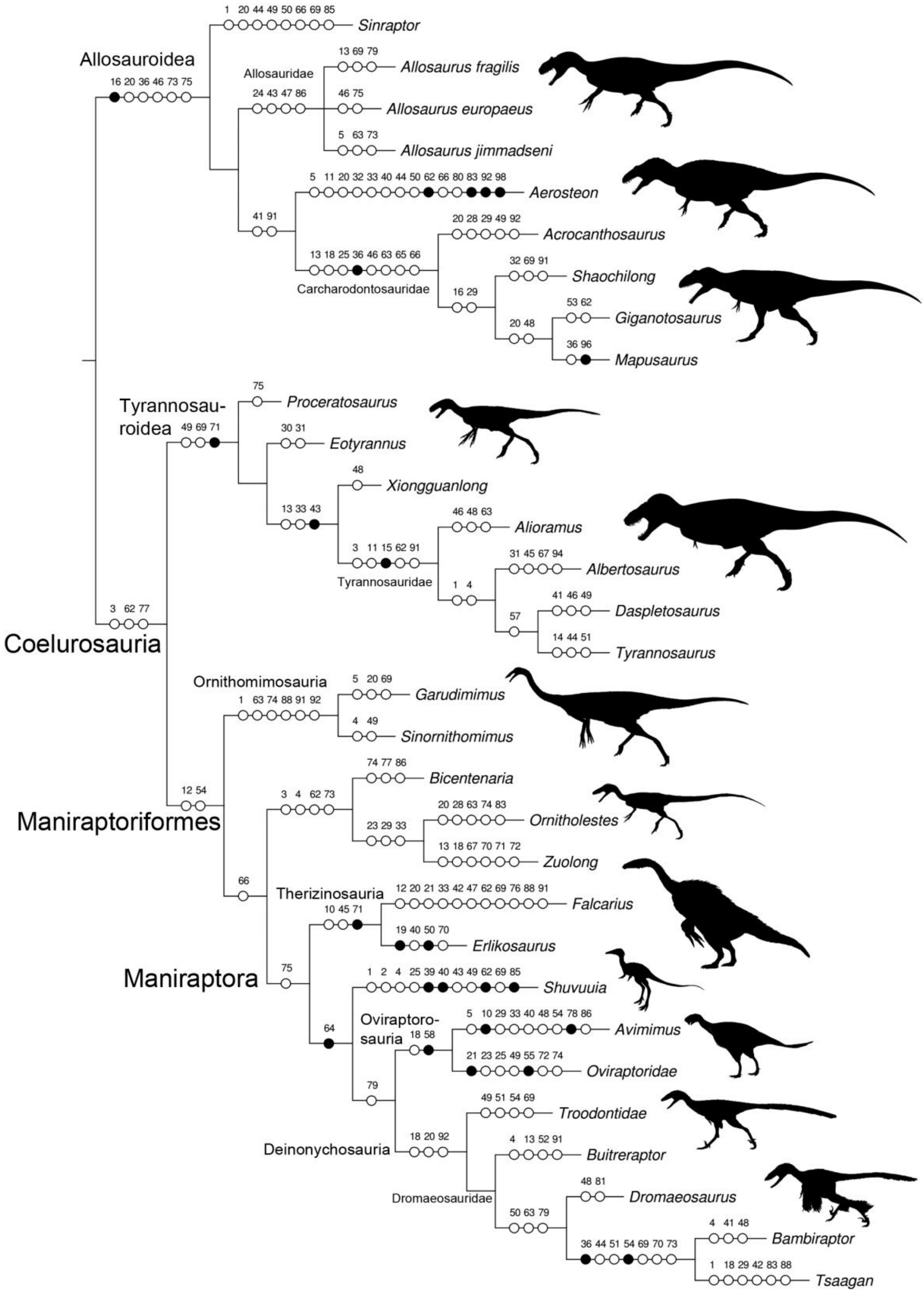

FIGURE S5B. (Continued.)

Attribution of silhouettes for Figures 1, 2, S4, and S5A-B.

All the theropod silhouettes in figures 1, 2, S4, and S5A-B have been downloaded from Phylopic.org. All images are under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License unless stated otherwise.

- Basalmost Theropoda (*Eoraptor* and *Herrerasaurus*): Scott Hartman
- Coelophysoidea: Funkmonk (Public Domain)
- Ceratosauridae: Scott Hartman
- Noasauridae: Scott Hartman
- Abelisauridae (two silhouettes): Scott Hartman
- Basal Megalosauroidea: Scott Hartman
- Megalosauridae: Scott Hartman
- Spinosaurinae: Scott Hartman
- Baryonychinae: Scott Hartman
- Avetheropoda/Allosauridae: Scott Hartman
- Carcharodontosauridae (two silhouettes): Scott Hartman
- Basal Tyrannosauroidea: Scott Hartman
- Tyrannosauridae: Scott Hartman
- Ornithomimosauria: Scott Hartman
- Unnamed clade (compsognathid): Scott Hartman
- Therizinosauria: Funkmonk (Public Domain)
- *Shuvuuia*: Funkmonk (Public Domain)
- Oviraptorosauria: Scott Hartman
- Troodontidae: Scott Hartman
- Dromaeosauridae: Scott Hartman & Funkmonk (Public Domain)

Appendix 5: Illustration of Landmarks for the Phylogenetic Morphometric Analysis

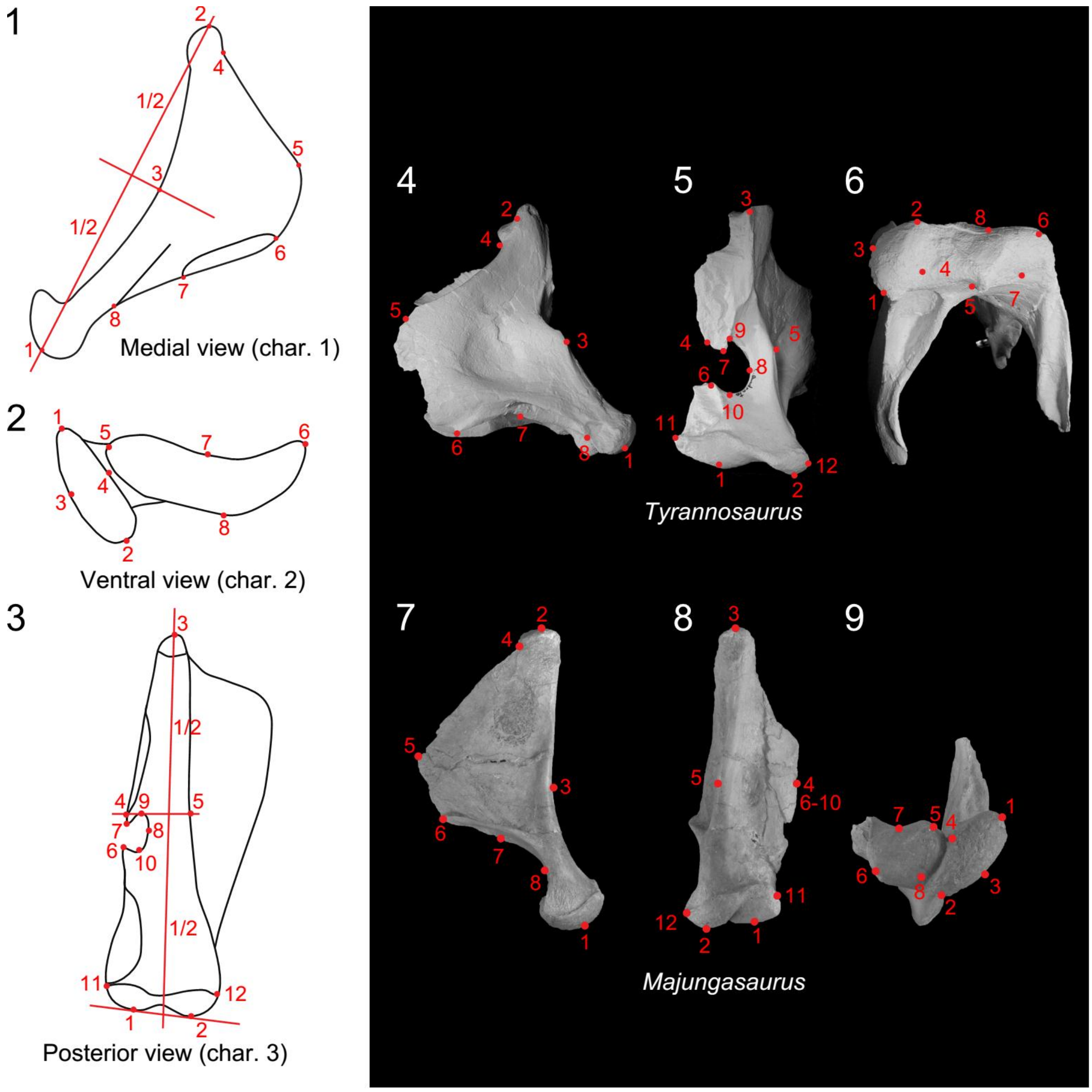

FIGURE S6. Phylogenetic morphometrics landmark locations and examples. Hypothetical quadrate in (**1**) medial view, (**2**) ventral view, and (**3**) posterior view. The resulting landmark configurations correspond to characters 1, 2, and 3, respectively. *Tyrannosaurus* quadrate in (**4**) medial, (**5**) posterior, and (**6**) ventral views and the corresponding landmark locations on each view forming therefore a landmark configuration thus, character. *Majungasaurus* quadrate in (**7**) medial, (**8**) posterior, and (**9**) ventral views. The absence of a quadrate foramen implies a specific organization of landmarks 4, 6-10 in character 3 (figure 8).

Appendix 6: Files of the Phylogenetic Morphometric Analysis

Quadrate in medial view

xread

1 23

& [landmark 2d]

Tawa -0.393379,-0.363027 0.030871,0.494995 -0.099922,0.034209 0.095770,0.410704 0.240327,0.055161 0.252247,-0.155153 0.042896,-0.250473 -0.168809,-0.226416

Acrocanthosaurus -0.347851,-0.372605 0.064049,0.454228 -0.129651,0.030656 0.086559,0.377745 0.332817,0.076521 0.268293,-0.091671 -0.031051,-0.179041 -0.243165,-0.295832

Aerosteon -0.330502,-0.339433 0.006116,0.542885 -0.082190,0.078341 0.073417,0.440501 0.248078,-0.021938 0.214597,-0.213055 0.033620,-0.237495 -0.163136,-0.249806

Afrovenator -0.317782,-0.409878 0.044241,0.488695 -0.155718,0.053133 0.091950,0.427828 0.324932,-0.021360 0.202490,-0.133618 0.002617,-0.169229 -0.192729,-0.235572

Allosaurus_fragilis -0.373657,-0.423068 0.099659,0.446464 -0.128198,0.008971 0.135785,0.392038 0.277109,0.165119 0.185009,-0.114792 0.002690,-0.212743 -0.198396,-0.261989

Bambiraptor -0.278910,-0.318253 -0.043199,0.574985 -0.106330,0.109591 0.008940,0.494961 0.298554,-0.211952 0.242902,-0.243588 0.035657,-0.193141 -0.157613,-0.212604

Baryonyx -0.325118,-0.332576 0.038011,0.483921 -0.089595,0.056640 0.108911,0.421752 0.344402,0.182231 0.081729,-0.230561 -0.000108,-0.302492 -0.158233,-0.278915

Allosaurus_jimmadseni. -0.383948,-0.387309 0.083620,0.426610 -0.162140,0.029601 0.093109,0.376991 0.332825,0.133744 0.239706,-0.085431 -0.003290,-0.249564 -0.199882,-0.244642

Ceratosaurus_dentisulcatus -0.406391,-0.423291 0.076669,0.444680 -0.159697,-0.001862 0.113533,0.387656 0.300400,0.061212 0.242128,-0.075908 0.034870,-0.135694 -0.201512,-0.256792

Ceratosaurus_magnicornis -0.377604,-0.383236 0.059158,0.422494 -0.139449,0.015676 0.108359,0.363167 0.345451,0.096021 0.276476,-0.048708 -0.006060,-0.165918 -0.266330,-0.299496

Dilophosaurus -0.430510,-0.368257 0.058452,0.399213 -0.193359,0.026841 0.095194,0.351027 0.331982,0.082015 0.327973,-0.032344 ? -0.242083,-0.277175

Eustreptospondylus -0.333681,-0.389891 0.050350,0.490386 -0.134473,0.048712 0.108051,0.420804 0.289401,-0.006978 0.214875,-0.107432 0.004566,-0.163626 -0.199089,-0.291974

Falcarius -0.292259,-0.372774 0.089411,0.508849 -0.100318,0.064938 0.104489,0.466756 0.250721,0.029336 0.124453,-0.103134 -0.005458,-0.300058 -0.171040,-0.293914

Giganotosaurus -0.439289,-0.425809 0.096641,0.431695 -0.176710,0.000314 0.144277,0.337092 ? ? ? -0.240508,-0.297850

Majungasaurus -0.317048,-0.394642 0.040925,0.500737 -0.122645,0.047431 0.092083,0.434958 0.311627,0.004114 0.179358,-0.168037 0.005615,-0.172104 -0.189915,-0.252455

Masiakasaurus -0.330711,-0.386602 0.090842,0.460793 -0.167200,0.039820 0.111380,0.411775 ? ? ? -0.194187,-0.252939

Oviraptoridae -0.348556,-0.341898 0.053853,0.455543 -0.152191,0.061371 0.124301,0.339907 0.259494,0.122775 0.309898,-0.105011 0.055531,-0.207009 -0.302332,-0.325678

Shaochilong -0.327703,-0.397807 0.079713,0.505791 -0.099231,0.045422 0.129980,0.416180 0.262057,0.112648 0.129885,-0.165009 -0.010664,-0.226369 -0.164038,-0.290855

Sinraptor -0.320705,-0.372504 0.058710,0.493063 -0.106836,0.047984 0.100197,0.447441 0.271319,0.061080 0.185202,-0.186872 -0.019947,-0.212228 -0.167940,-0.277964

Spinosaurinae_morphoI -0.316729,-0.355880 0.103613,0.474022 -0.063714,0.035556 0.101397,0.443775 0.314260,0.230764 0.041325,-0.219714 -0.021927,-0.303130 -0.158224,-0.305392

Torvosaurus -0.417646,-0.454881 0.118029,0.463426 -0.119705,-0.028078 0.165537,0.397299 ? ? ? -0.226565,-0.308099

Tsaagan -0.293354,-0.316888 -0.016823,0.536914 -0.116529,0.101890 0.020909,0.504520 0.273643,-0.182841 0.269108,-0.192841 0.032114,-0.220458 -0.169069,-0.230296

Tyrannosaurus -0.336384,-0.303823 0.014658,0.472741 -0.118755,0.053683 0.059230,0.398866 0.358495,0.125098 0.222479,-0.255952 0.009612,-0.217283 -0.209333,-0.273330

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Tawa 0.023888,-0.274110 0.210722,-0.265792 -0.133421,0.752203 -
0.110409,0.215758 0.071896,0.249426 -0.058885,-0.094335 -0.056505,-0.003903 -
0.029194,-0.037576 -0.040803,0.002815 -0.045755,-0.076486 -0.062606,-0.240083
0.231071,-0.227917
Acrocanthosaurus 0.012428,-0.290145 0.246361,-0.277328 -0.088901,0.680540 -
0.183063,0.181942 0.080680,0.204930 -0.055772,-0.026106 -0.067918,0.007360 -
0.040582,0.010029 -0.058635,0.017817 -0.055809,-0.026026 -0.081889,-0.270151
0.293099,-0.212862
Aerosteon 0.028165,-0.336047 0.271439,-0.295344 -0.107656,0.580106 -
0.169869,0.096919 0.117138,0.138522 -0.129006,0.057858 -0.128935,0.058828
0.008523,0.079085 -0.076058,0.139378 -0.035399,-0.020055 -0.120749,-0.262117
0.342407,-0.237134
Afrovenator 0.066015,-0.343904 0.245400,-0.352224 -0.163238,0.566721 -
0.080950,0.102022 0.080088,0.137411 -0.080740,0.099694 -0.080608,0.101508 -
0.079766,0.100868 -0.080335,0.101912 -0.080593,0.099883 -0.020021,-0.300222
0.274748,-0.313669
Allosaurus_fragilis 0.011834,-0.349177 0.277691,-0.325771 -0.141951,0.569229 -
0.142640,0.174572 0.051994,0.208544 -0.062744,0.030465 -0.067773,0.047959 -
0.035040,0.053709 -0.057911,0.091325 -0.037666,0.013405 -0.107392,-0.242491
0.311598,-0.271770
Bambiraptor 0.024545,-0.286390 0.275900,-0.220804 -0.035558,0.641438 -
0.161154,0.166439 0.155973,0.189613 -0.172090,-0.193351 -0.155566,0.143320
0.011165,0.011265 -0.072573,0.113052 -0.053830,-0.113844 -0.134530,-0.285027
0.317718,-0.165712
Baryonyx -0.013952,-0.324187 0.311699,-0.284159 -0.149628,0.570796 -
0.053273,0.128242 0.068642,0.142662 -0.102209,-0.025183 -0.071956,0.132243 -
0.036914,0.052039 -0.062471,0.140155 -0.057069,-0.021334 -0.183773,-0.269628
0.350903,-0.241645

Allosaurus_jimmadseni. 0.012501,-0.342776 0.263913,-0.321825 -0.142172,0.574733 -0.098343,0.115041 0.071511,0.140566 -0.059500,0.023154 -0.092918,0.111760 -0.042234,0.080813 -0.082256,0.129302 -0.048105,0.020529 -0.108312,-0.286174 0.325917,-0.245122

Ceratosaurus_dentisulcatus 0.073402,-0.357246 0.239552,-0.330516 -0.120229,0.594176 -0.087696,0.089953 0.094634,0.132326 -0.087297,0.087952 -0.087205,0.089216 -0.086619,0.088770 -0.087015,0.089497 -0.086879,0.088020 -0.039769,-0.328490 0.275120,-0.243657

Ceratosaurus_magnicornis 0.057922,-0.357020 0.247213,-0.330440 -0.135307,0.574643 -0.084150,0.098644 0.075522,0.130620 -0.083696,0.096367 -0.083591,0.097805 -0.082924,0.097297 -0.083375,0.098125 -0.083220,0.096444 -0.028917,-0.322061 0.284523,-0.280423

Dilophosaurus -0.002188,-0.332170 0.229958,-0.333839 -0.221817,0.613796 -0.155836,0.126101 0.068178,0.172541 -0.034463,0.037218 -0.036321,0.041590 0.015733,0.100735 -0.016178,0.073015 0.002026,0.052457 -0.123175,-0.277568 0.274083,-0.273876

Eustreptospondylus 0.057959,-0.368416 0.280762,-0.295216 -0.090014,0.586647 -0.092720,0.089099 0.075689,0.118685 -0.093365,0.087360 -0.093275,0.088600 -0.092699,0.088162 -0.093088,0.088876 -0.092955,0.087427 -0.058366,-0.323634 0.292073,-0.247591

Falcarius -0.010253,-0.355998 0.243283,-0.314837 -0.192219,0.586555 -0.082378,0.122856 0.066754,0.153862 -0.029976,-0.042204 -0.073795,0.113959 -0.014088,0.039623 -0.069091,0.274199 -0.018107,-0.030247 -0.090292,-0.290814 0.270161,-0.256956

Giganotosaurus 0.002003,-0.311181 0.237612,-0.296558 -0.121036,0.645278 -0.121227,0.155161 0.051534,0.181855 -0.054496,-0.007695 -0.062975,0.051402 -0.048461,0.027187 -0.057640,0.052169 -0.050132,-0.000909 -0.104438,-0.274855 0.329254,-0.221854

Majungasaurus 0.099024,-0.339532 0.272242,-0.316177 -0.042762,0.577528 -0.127056,0.085753 0.120598,0.133298 -0.126932,0.082461 -0.126762,0.084793 -0.125680,0.083970 -0.126411,0.085313 -0.126160,0.082587 0.002510,-0.294227 0.307389,-0.265767

Masiakasaurus 0.091113,-0.327294 0.253669,-0.292511 -0.005101,0.596734 -0.140255,0.073489 0.158005,0.162417 -0.140895,0.067911 -0.140658,0.071143 -

0.139159,0.070002 -0.140172,0.071863 -0.139824,0.068085 0.033314,-0.320626
0.309962,-0.241212
Oviraptoridae -0.025136,-0.310625 0.193592,-0.255300 -0.130330,0.634953 -
0.066994,0.171316 0.105996,0.195535 -0.112837,-0.123470 -0.065468,0.136367 -
0.046556,0.025949 -0.054251,0.138879 -0.086676,-0.078925 -0.039911,-0.306165
0.328570,-0.228515
Shaochilong 0.017622,-0.343527 0.276639,-0.300141 -0.143293,0.606636 -
0.081323,0.115986 0.056261,0.139048 -0.051471,0.032257 -0.069160,0.093674 -
0.060194,0.060931 -0.068159,0.093084 -0.051749,0.029716 -0.131637,-0.289280
0.306463,-0.238384
Sinraptor 0.015004,-0.336593 0.188983,-0.323739 -0.196693,0.650400 -
0.123755,0.144438 0.018799,0.176253 -0.065233,0.043940 0.003597,0.020437 -
0.001774,0.070966 -0.015648,0.104658 -0.021597,0.029946 -0.053620,-0.320158
0.251937,-0.260547
Spinosaurinae_morphoI 0.014599,-0.304523 0.287253,-0.275502 -0.084159,0.643305 -
0.118931,0.154071 0.096792,0.176022 -0.104744,-0.065452 -0.092440,0.059253 -
0.036257,0.012202 -0.067604,0.081091 -0.078858,-0.065362 -0.159020,-0.231238
0.343368,-0.183867
Torvosaurus 0.066384,-0.312031 0.310572,-0.350556 -0.120196,0.527992 -
0.100853,0.096682 0.091892,0.130708 -0.100235,0.093577 -0.100091,0.095538 -
0.100106,0.095016 -0.100721,0.096145 -0.100510,0.093853 -0.095361,-0.254839
0.349225,-0.312085
Tsaagan -0.021163,-0.326065 0.236268,-0.230804 -0.127302,0.645777 -
0.070085,0.161908 0.122438,0.175539 -0.121135,-0.159638 -0.080653,0.184843 -
0.007217,-0.002548 -0.039114,0.111327 -0.055292,-0.114945 -0.171108,-0.287916
0.334363,-0.157478
Tyrannosaurus -0.004194,-0.320605 0.294005,-0.265460 -0.114374,0.613546 -
0.167962,0.128312 0.078535,0.155846 -0.108608,-0.043052 -0.069656,0.085598
0.029187,0.050303 -0.072327,0.131975 -0.018494,-0.054362 -0.168194,-0.264560
0.322081,-0.217541
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Tawa -0.464489,0.116176 -0.023970,-0.232866 -0.318547,-0.168238 - 0.158595,0.048151 -0.124170,0.213977 0.596220,-0.028899 0.301808,0.121968 0.191744,-0.070269

Acrocanthosaurus -0.432153,0.123473 -0.032635,-0.208255 -0.302894,-0.138827 - 0.176459,0.048779 -0.193505,0.170150 0.644601,-0.034614 0.277339,0.126262 0.215706,-0.086967

Aerosteon -0.494234,0.143456 0.011661,-0.214962 -0.321330,-0.153061 - 0.177685,0.035283 -0.117259,0.157430 0.569638,-0.061088 0.303482,0.164450 0.225727,-0.071508

Afrovenator -0.518297,0.204136 0.049576,-0.291341 -0.345897,-0.189691 - 0.163377,0.056306 -0.118179,0.161330 0.576952,-0.013944 0.255974,-0.077890 0.263248,0.151094

Allosaurus_fragilis -0.458156,0.130333 0.002849,-0.177182 -0.326445,-0.145232 - 0.203823,0.029355 -0.090362,0.168071 0.634774,0.002972 0.280282,0.147470 0.160881,-0.155787

Bambiraptor -0.422093,0.160801 -0.036247,-0.156368 -0.319435,-0.131978 - 0.172433,0.048943 -0.218974,0.150053 0.667119,0.083687 0.272167,0.002342 0.229897,-0.157481

Baryonyx -0.389248,0.127314 -0.075976,-0.220962 -0.313834,-0.131841 - 0.159977,0.015696 -0.260645,0.234471 0.598531,0.021290 0.318131,0.076945 0.283019,-0.122913

Allosaurus_jimmadseni -0.497871,0.135941 0.064919,-0.229350 -0.320044,-0.176788 - 0.163265,0.069501 -0.103574,0.206528 0.568997,-0.058819 0.284870,0.164846 0.165969,-0.111858

Ceratosaurus_dentisulcatus -0.438566,0.226949 0.070832,-0.311251 -0.321897,- 0.201864 -0.104747,0.001422 -0.193434,0.239815 0.557789,-0.044235 0.259861,0.172292 0.170161,-0.083128

Ceratosaurus_magnicornis -0.418052,0.234891 0.026183,-0.316629 -0.353723,- 0.203537 -0.117064,0.006618 -0.129073,0.224423 0.555172,0.065259 0.285554,0.126580 0.151003,-0.137605

Dilophosaurus -0.439368,0.146150 -0.031261,-0.233712 -0.287253,-0.138233 - 0.180410,0.022163 -0.181168,0.222383 0.610898,0.016447 0.287771,0.086566 0.220791,-0.121765

Eustreptospondylus -0.455742,0.201997 -0.027289,-0.244244 -0.296984,-0.131572 -0.159681,0.053811 -0.188417,0.155885 0.600698,0.096668 0.279211,0.015790 0.248204,-0.148333

Falcarius -0.421929,0.058159 -0.162755,-0.225253 -0.414150,-0.244350 -0.214662,0.024311 0.073116,0.226813 0.521634,-0.016482 0.384042,0.207239 0.234703,-0.030436

Giganotosaurus -0.524450,0.138561 0.019481,-0.177997 -0.310622,-0.119446 -0.197408,0.059989 -0.107774,0.136560 0.581747,0.017456 0.319724,0.068951 0.219301,-0.124075

Majungasaurus -0.492128,0.211120 0.041819,-0.321744 -0.348417,-0.194278 -0.105881,0.049621 -0.033734,0.199570 0.501004,0.006431 0.249403,0.252058 0.187934,-0.202779

Masiakasaurus -0.535751,0.194571 0.100893,-0.277631 -0.330561,-0.295874 -0.129582,0.093324 -0.020571,0.237944 0.480331,-0.080462 0.310916,0.190240 0.124325,-0.062112

Oviraptoridae -0.523617,0.160491 0.025144,-0.355843 -0.399898,-0.280510 -0.060073,0.065909 0.051864,0.253321 0.445016,-0.047314 0.342087,0.227737 0.119477,-0.023791

Shaochilong -0.455568,0.174560 0.045420,-0.199899 -0.302979,-0.136574 -0.188634,0.048861 -0.191284,0.186538 0.613706,0.033727 0.266961,0.057411 0.212377,-0.164624

Sinraptor -0.492616,0.113184 -0.015966,-0.242545 -0.338943,-0.162879 -0.142788,0.036502 -0.053343,0.203982 0.565829,-0.032094 0.307480,0.192839 0.170346,-0.108989

Spinosaurinae_MorphoI -0.445947,0.152836 -0.047449,-0.200774 -0.331024,-0.135508 -0.175562,0.032535 -0.136129,0.171821 0.621545,0.077712 0.284126,0.041544 0.230441,-0.140167

Torvosaurus -0.487335,0.157126 -0.017826,-0.221727 -0.337676,-0.135715 -0.152719,0.062997 -0.103433,0.137419 0.584630,0.041485 0.280290,0.102202 0.234069,-0.143787

Tsaagan -0.506605,0.186508 -0.029755,-0.211724 -0.298369,-0.107450 -0.191987,0.077072 -0.112285,0.109430 0.588528,0.129073 0.296071,-0.001390 0.254402,-0.181519

Tyrannosaurus -0.420497,0.121775 -0.155857,-0.246915 -0.403823,-0.190452 -0.196052,0.002755 0.027429,0.165579 0.537503,0.048744 0.348481,0.186010 0.262816,-0.087496

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Tawa -0.393379,-0.363027 0.030871,0.494995 -0.099922,0.034209 0.095770,0.410704 0.240327,0.055161 0.252247,-0.155153 0.042896,-0.250473 -0.168809,-0.226416

Acrocanthosaurus -0.347851,-0.372605 0.064049,0.454228 -0.129651,0.030656 0.086559,0.377745 0.332817,0.076521 0.268293,-0.091671 -0.031051,-0.179041 -0.243165,-0.295832

Aerosteon -0.330502,-0.339433 0.006116,0.542885 -0.082190,0.078341 0.073417,0.440501 0.248078,-0.021938 0.214597,-0.213055 0.033620,-0.237495 -0.163136,-0.249806

Afrovenator -0.317782,-0.409878 0.044241,0.488695 -0.155718,0.053133 0.091950,0.427828 0.324932,-0.021360 0.202490,-0.133618 0.002617,-0.169229 -0.192729,-0.235572

Allosaurus_fragilis -0.373657,-0.423068 0.099659,0.446464 -0.128198,0.008971 0.135785,0.392038 0.277109,0.165119 0.185009,-0.114792 0.002690,-0.212743 -0.198396,-0.261989

Bambiraptor -0.278910,-0.318253 -0.043199,0.574985 -0.106330,0.109591 0.008940,0.494961 0.298554,-0.211952 0.242902,-0.243588 0.035657,-0.193141 -0.157613,-0.212604

Baryonyx -0.325118,-0.332576 0.038011,0.483921 -0.089595,0.056640 0.108911,0.421752 0.344402,0.182231 0.081729,-0.230561 -0.000108,-0.302492 -0.158233,-0.278915

Allosaurus_jimmadseni -0.383948,-0.387309 0.083620,0.426610 -0.162140,0.029601 0.093109,0.376991 0.332825,0.133744 0.239706,-0.085431 -0.003290,-0.249564 -0.199882,-0.244642

Ceratosaurus_dentisulcatus -0.406391,-0.423291 0.076669,0.444680 -0.159697,-0.001862 0.113533,0.387656 0.300400,0.061212 0.242128,-0.075908 0.034870,-0.135694 -0.201512,-0.256792

Ceratosaurus_magnicornis -0.377604,-0.383236 0.059158,0.422494 -0.139449,0.015676 0.108359,0.363167 0.345451,0.096021 0.276476,-0.048708 -0.006060,-0.165918 -0.266330,-0.299496

Dilophosaurus -0.430510,-0.368257 0.058452,0.399213 -0.193359,0.026841 0.095194,0.351027 0.331982,0.082015 0.327973,-0.032344 ? -0.242083,-0.277175

Eustreptospondylus -0.333681,-0.389891 0.050350,0.490386 -0.134473,0.048712 0.108051,0.420804 0.289401,-0.006978 0.214875,-0.107432 0.004566,-0.163626 -0.199089,-0.291974

Falcarius -0.292259,-0.372774 0.089411,0.508849 -0.100318,0.064938 0.104489,0.466756 0.250721,0.029336 0.124453,-0.103134 -0.005458,-0.300058 -0.171040,-0.293914

Giganotosaurus -0.439289,-0.425809 0.096641,0.431695 -0.176710,0.000314 0.144277,0.337092 ? ? ? -0.240508,-0.297850

Majungasaurus -0.317048,-0.394642 0.040925,0.500737 -0.122645,0.047431 0.092083,0.434958 0.311627,0.004114 0.179358,-0.168037 0.005615,-0.172104 -0.189915,-0.252455

Masiakasaurus -0.330711,-0.386602 0.090842,0.460793 -0.167200,0.039820 0.111380,0.411775 ? ? ? -0.194187,-0.252939

Oviraptoridae -0.348556,-0.341898 0.053853,0.455543 -0.152191,0.061371 0.124301,0.339907 0.259494,0.122775 0.309898,-0.105011 0.055531,-0.207009 -0.302332,-0.325678

Shaochilong -0.327703,-0.397807 0.079713,0.505791 -0.099231,0.045422 0.129980,0.416180 0.262057,0.112648 0.129885,-0.165009 -0.010664,-0.226369 -0.164038,-0.290855

Sinraptor -0.320705,-0.372504 0.058710,0.493063 -0.106836,0.047984 0.100197,0.447441 0.271319,0.061080 0.185202,-0.186872 -0.019947,-0.212228 -0.167940,-0.277964

Spinosaurinae_morphoI -0.316729,-0.355880 0.103613,0.474022 -0.063714,0.035556 0.101397,0.443775 0.314260,0.230764 0.041325,-0.219714 -0.021927,-0.303130 -0.158224,-0.305392

Torvosaurus -0.417646,-0.454881 0.118029,0.463426 -0.119705,-0.028078 0.165537,0.397299 ? ? ? -0.226565,-0.308099

Tsaagan -0.293354,-0.316888 -0.016823,0.536914 -0.116529,0.101890 0.020909,0.504520 0.273643,-0.182841 0.269108,-0.192841 0.032114,-0.220458 -0.169069,-0.230296

Tyrannosaurus -0.336384,-0.303823 0.014658,0.472741 -0.118755,0.053683 0.059230,0.398866 0.358495,0.125098 0.222479,-0.255952 0.009612,-0.217283 -0.209333,-0.273330

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Tawa -0.464489,0.116176 -0.023970,-0.232866 -0.318547,-0.168238 -0.158595,0.048151 -0.124170,0.213977 0.596220,-0.028899 0.301808,0.121968 0.191744,-0.070269

Acrocanthosaurus -0.432153,0.123473 -0.032635,-0.208255 -0.302894,-0.138827 -0.176459,0.048779 -0.193505,0.170150 0.644601,-0.034614 0.277339,0.126262 0.215706,-0.086967

Aerosteon -0.494234,0.143456 0.011661,-0.214962 -0.321330,-0.153061 -0.177685,0.035283 -0.117259,0.157430 0.569638,-0.061088 0.303482,0.164450 0.225727,-0.071508

Afrovenator -0.518297,0.204136 0.049576,-0.291341 -0.345897,-0.189691 -0.163377,0.056306 -0.118179,0.161330 0.576952,-0.013944 0.255974,-0.077890 0.263248,0.151094

Allosaurus_fragilis -0.458156,0.130333 0.002849,-0.177182 -0.326445,-0.145232 -0.203823,0.029355 -0.090362,0.168071 0.634774,0.002972 0.280282,0.147470 0.160881,-0.155787

Bambiraptor -0.422093,0.160801 -0.036247,-0.156368 -0.319435,-0.131978 -0.172433,0.048943 -0.218974,0.150053 0.667119,0.083687 0.272167,0.002342 0.229897,-0.157481

Baryonyx -0.389248,0.127314 -0.075976,-0.220962 -0.313834,-0.131841 -0.159977,0.015696 -0.260645,0.234471 0.598531,0.021290 0.318131,0.076945 0.283019,-0.122913

Allosaurus_jimmadseni -0.497871,0.135941 0.064919,-0.229350 -0.320044,-0.176788 -0.163265,0.069501 -0.103574,0.206528 0.568997,-0.058819 0.284870,0.164846 0.165969,-0.111858

Ceratosaurus_dentisulcatus -0.438566,0.226949 0.070832,-0.311251 -0.321897,-0.201864 -0.104747,0.001422 -0.193434,0.239815 0.557789,-0.044235 0.259861,0.172292 0.170161,-0.083128

Ceratosaurus_magnicornis -0.418052,0.234891 0.026183,-0.316629 -0.353723,-0.203537 -0.117064,0.006618 -0.129073,0.224423 0.555172,0.065259 0.285554,0.126580 0.151003,-0.137605

Dilophosaurus -0.439368,0.146150 -0.031261,-0.233712 -0.287253,-0.138233 -0.180410,0.022163 -0.181168,0.222383 0.610898,0.016447 0.287771,0.086566 0.220791,-0.121765

Eustreptospondylus -0.455742,0.201997 -0.027289,-0.244244 -0.296984,-0.131572 -0.159681,0.053811 -0.188417,0.155885 0.600698,0.096668 0.279211,0.015790 0.248204,-0.148333

Falcarius -0.421929,0.058159 -0.162755,-0.225253 -0.414150,-0.244350 -0.214662,0.024311 0.073116,0.226813 0.521634,-0.016482 0.384042,0.207239 0.234703,-0.030436

Giganotosaurus -0.524450,0.138561 0.019481,-0.177997 -0.310622,-0.119446 -0.197408,0.059989 -0.107774,0.136560 0.581747,0.017456 0.319724,0.068951 0.219301,-0.124075

Majungasaurus -0.492128,0.211120 0.041819,-0.321744 -0.348417,-0.194278 -0.105881,0.049621 -0.033734,0.199570 0.501004,0.006431 0.249403,0.252058 0.187934,-0.202779

Masiakasaurus -0.535751,0.194571 0.100893,-0.277631 -0.330561,-0.295874 -0.129582,0.093324 -0.020571,0.237944 0.480331,-0.080462 0.310916,0.190240 0.124325,-0.062112

Oviraptoridae -0.523617,0.160491 0.025144,-0.355843 -0.399898,-0.280510 -0.060073,0.065909 0.051864,0.253321 0.445016,-0.047314 0.342087,0.227737 0.119477,-0.023791

Shaochilong -0.455568,0.174560 0.045420,-0.199899 -0.302979,-0.136574 -0.188634,0.048861 -0.191284,0.186538 0.613706,0.033727 0.266961,0.057411 0.212377,-0.164624

Sinraptor -0.492616,0.113184 -0.015966,-0.242545 -0.338943,-0.162879 -0.142788,0.036502 -0.053343,0.203982 0.565829,-0.032094 0.307480,0.192839 0.170346,-0.108989

Spinosaurinae_morphoI -0.445947,0.152836 -0.047449,-0.200774 -0.331024,-0.135508 -0.175562,0.032535 -0.136129,0.171821 0.621545,0.077712 0.284126,0.041544 0.230441,-0.140167

Torvosaurus -0.487335,0.157126 -0.017826,-0.221727 -0.337676,-0.135715 -0.152719,0.062997 -0.103433,0.137419 0.584630,0.041485 0.280290,0.102202 0.234069,-0.143787

Tsaagan -0.506605,0.186508 -0.029755,-0.211724 -0.298369,-0.107450 -0.191987,0.077072 -0.112285,0.109430 0.588528,0.129073 0.296071,-0.001390 0.254402,-0.181519

Tyrannosaurus -0.420497,0.121775 -0.155857,-0.246915 -0.403823,-0.190452 -0.196052,0.002755 0.027429,0.165579 0.537503,0.048744 0.348481,0.186010 0.262816,-0.087496

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Tawa 0.023888,-0.274110 0.210722,-0.265792 -0.133421,0.752203 -0.110409,0.215758 0.071896,0.249426 -0.058885,-0.094335 -0.056505,-0.003903 -0.029194,-0.037576 -0.040803,0.002815 -0.045755,-0.076486 -0.062606,-0.240083 0.231071,-0.227917

Acrocanthosaurus 0.012428,-0.290145 0.246361,-0.277328 -0.088901,0.680540 -0.183063,0.181942 0.080680,0.204930 -0.055772,-0.026106 -0.067918,0.007360 -0.040582,0.010029 -0.058635,0.017817 -0.055809,-0.026026 -0.081889,-0.270151 0.293099,-0.212862

Aerosteon 0.028165,-0.336047 0.271439,-0.295344 -0.107656,0.580106 -0.169869,0.096919 0.117138,0.138522 -0.129006,0.057858 -0.128935,0.058828 0.008523,0.079085 -0.076058,0.139378 -0.035399,-0.020055 -0.120749,-0.262117 0.342407,-0.237134

Afrovenator 0.066015,-0.343904 0.245400,-0.352224 -0.163238,0.566721 -0.080950,0.102022 0.080088,0.137411 -0.080740,0.099694 -0.080608,0.101508 -0.079766,0.100868 -0.080335,0.101912 -0.080593,0.099883 -0.020021,-0.300222 0.274748,-0.313669

Allosaurus_fragilis 0.011834,-0.349177 0.277691,-0.325771 -0.141951,0.569229 -0.142640,0.174572 0.051994,0.208544 -0.062744,0.030465 -0.067773,0.047959 -0.035040,0.053709 -0.057911,0.091325 -0.037666,0.013405 -0.107392,-0.242491 0.311598,-0.271770

Bambiraptor 0.024545,-0.286390 0.275900,-0.220804 -0.035558,0.641438 -0.161154,0.166439 0.155973,0.189613 -0.172090,-0.193351 -0.155566,0.143320 0.011165,0.011265 -0.072573,0.113052 -0.053830,-0.113844 -0.134530,-0.285027 0.317718,-0.165712

Baryonyx -0.013952,-0.324187 0.311699,-0.284159 -0.149628,0.570796 -0.053273,0.128242 0.068642,0.142662 -0.102209,-0.025183 -0.071956,0.132243 -

0.036914,0.052039 -0.062471,0.140155 -0.057069,-0.021334 -0.183773,-0.269628 0.350903,-0.241645

Allosaurus_jimmadseni 0.012501,-0.342776 0.263913,-0.321825 -0.142172,0.574733 -0.098343,0.115041 0.071511,0.140566 -0.059500,0.023154 -0.092918,0.111760 -0.042234,0.080813 -0.082256,0.129302 -0.048105,0.020529 -0.108312,-0.286174 0.325917,-0.245122

Ceratosaurus_dentisulcatus 0.073402,-0.357246 0.239552,-0.330516 -0.120229,0.594176 -0.087696,0.089953 0.094634,0.132326 -0.087297,0.087952 -0.087205,0.089216 -0.086619,0.088770 -0.087015,0.089497 -0.086879,0.088020 -0.039769,-0.328490 0.275120,-0.243657

Ceratosaurus_magnicornis 0.057922,-0.357020 0.247213,-0.330440 -0.135307,0.574643 -0.084150,0.098644 0.075522,0.130620 -0.083696,0.096367 -0.083591,0.097805 -0.082924,0.097297 -0.083375,0.098125 -0.083220,0.096444 -0.028917,-0.322061 0.284523,-0.280423

Dilophosaurus -0.002188,-0.332170 0.229958,-0.333839 -0.221817,0.613796 -0.155836,0.126101 0.068178,0.172541 -0.034463,0.037218 -0.036321,0.041590 0.015733,0.100735 -0.016178,0.073015 0.002026,0.052457 -0.123175,-0.277568 0.274083,-0.273876

Eustreptospondylus 0.057959,-0.368416 0.280762,-0.295216 -0.090014,0.586647 -0.092720,0.089099 0.075689,0.118685 -0.093365,0.087360 -0.093275,0.088600 -0.092699,0.088162 -0.093088,0.088876 -0.092955,0.087427 -0.058366,-0.323634 0.292073,-0.247591

Falcarius -0.010253,-0.355998 0.243283,-0.314837 -0.192219,0.586555 -0.082378,0.122856 0.066754,0.153862 -0.029976,-0.042204 -0.073795,0.113959 -0.014088,0.039623 -0.069091,0.274199 -0.018107,-0.030247 -0.090292,-0.290814 0.270161,-0.256956

Giganotosaurus 0.002003,-0.311181 0.237612,-0.296558 -0.121036,0.645278 -0.121227,0.155161 0.051534,0.181855 -0.054496,-0.007695 -0.062975,0.051402 -0.048461,0.027187 -0.057640,0.052169 -0.050132,-0.000909 -0.104438,-0.274855 0.329254,-0.221854

Majungasaurus 0.099024,-0.339532 0.272242,-0.316177 -0.042762,0.577528 -0.127056,0.085753 0.120598,0.133298 -0.126932,0.082461 -0.126762,0.084793 -0.125680,0.083970 -0.126411,0.085313 -0.126160,0.082587 0.002510,-0.294227 0.307389,-0.265767

Masiakasaurus 0.091113,-0.327294 0.253669,-0.292511 -0.005101,0.596734 -0.140255,0.073489 0.158005,0.162417 -0.140895,0.067911 -0.140658,0.071143 -0.139159,0.070002 -0.140172,0.071863 -0.139824,0.068085 0.033314,-0.320626 0.309962,-0.241212
Oviraptoridae -0.025136,-0.310625 0.193592,-0.255300 -0.130330,0.634953 -0.066994,0.171316 0.105996,0.195535 -0.112837,-0.123470 -0.065468,0.136367 -0.046556,0.025949 -0.054251,0.138879 -0.086676,-0.078925 -0.039911,-0.306165 0.328570,-0.228515
Shaochilong 0.017622,-0.343527 0.276639,-0.300141 -0.143293,0.606636 -0.081323,0.115986 0.056261,0.139048 -0.051471,0.032257 -0.069160,0.093674 -0.060194,0.060931 -0.068159,0.093084 -0.051749,0.029716 -0.131637,-0.289280 0.306463,-0.238384
Sinraptor 0.015004,-0.336593 0.188983,-0.323739 -0.196693,0.650400 -0.123755,0.144438 0.018799,0.176253 -0.065233,0.043940 0.003597,0.020437 -0.001774,0.070966 -0.015648,0.104658 -0.021597,0.029946 -0.053620,-0.320158 0.251937,-0.260547
Spinosaurinae_morphoI 0.014599,-0.304523 0.287253,-0.275502 -0.084159,0.643305 -0.118931,0.154071 0.096792,0.176022 -0.104744,-0.065452 -0.092440,0.059253 -0.036257,0.012202 -0.067604,0.081091 -0.078858,-0.065362 -0.159020,-0.231238 0.343368,-0.183867
Torvosaurus 0.066384,-0.312031 0.310572,-0.350556 -0.120196,0.527992 -0.100853,0.096682 0.091892,0.130708 -0.100235,0.093577 -0.100091,0.095538 -0.100106,0.095016 -0.100721,0.096145 -0.100510,0.093853 -0.095361,-0.254839 0.349225,-0.312085
Tsaagan -0.021163,-0.326065 0.236268,-0.230804 -0.127302,0.645777 -0.070085,0.161908 0.122438,0.175539 -0.121135,-0.159638 -0.080653,0.184843 -0.007217,-0.002548 -0.039114,0.111327 -0.055292,-0.114945 -0.171108,-0.287916 0.334363,-0.157478
Tyrannosaurus -0.004194,-0.320605 0.294005,-0.265460 -0.114374,0.613546 -0.167962,0.128312 0.078535,0.155846 -0.108608,-0.043052 -0.069656,0.085598 0.029187,0.050303 -0.072327,0.131975 -0.018494,-0.054362 -0.168194,-0.264560 0.322081,-0.217541
;

Appendix 7: Results of the Phylogenetic Morphometric Analysis

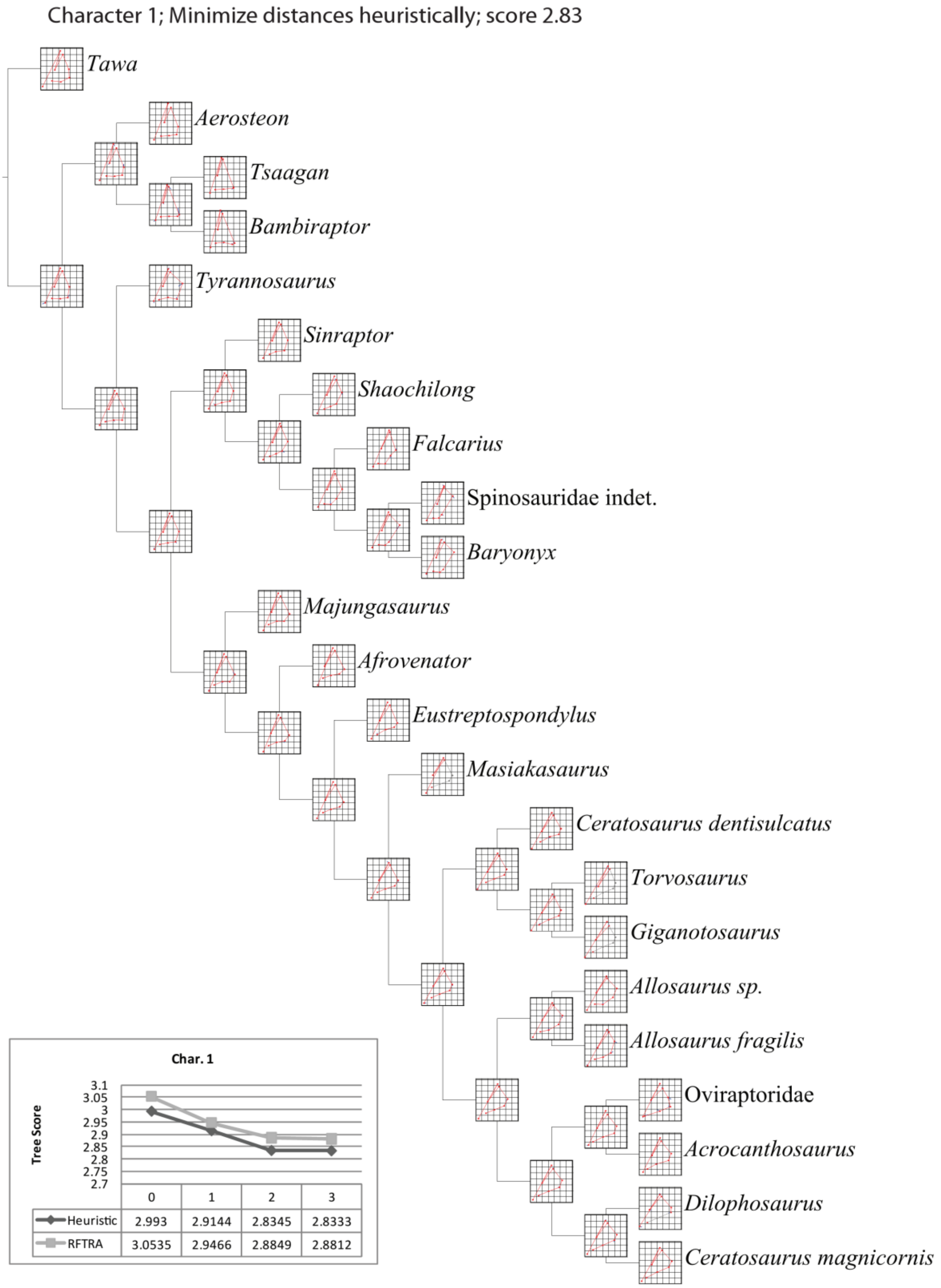

FIGURE S7. Quadrate in medial view (char.1) phylogenetic morphometrics results. The graphic shows on the y axis the tree score versus the level of thoroughness of the analysis (x axis), level 3 being more thorough.

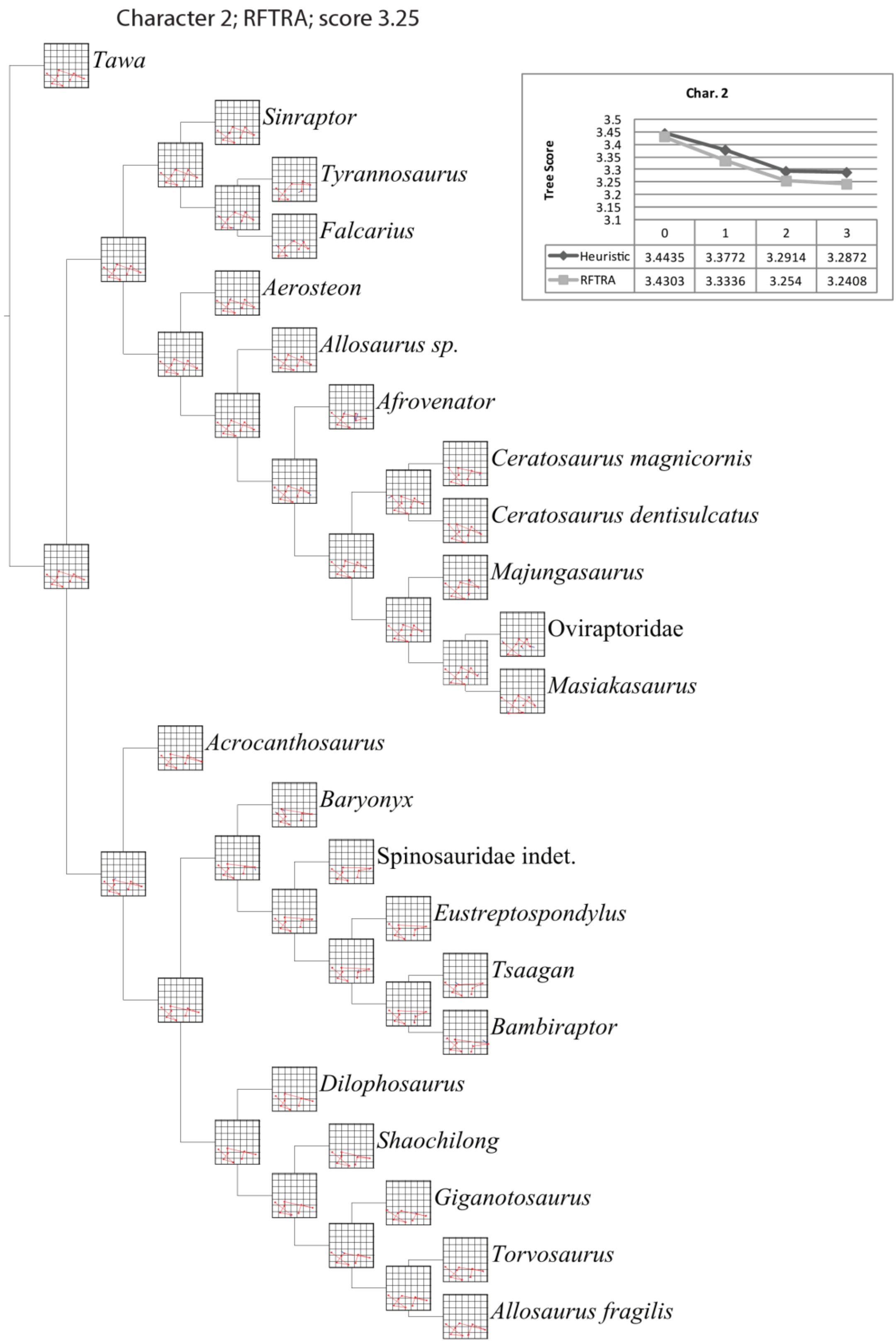

FIGURE S8. Phylogenetic morphometrics results of the quadrate in ventral view (char. 2). The graphic shows on the y axis the tree score versus the level of thoroughness of the analysis (x axis), level 3 being more thorough.

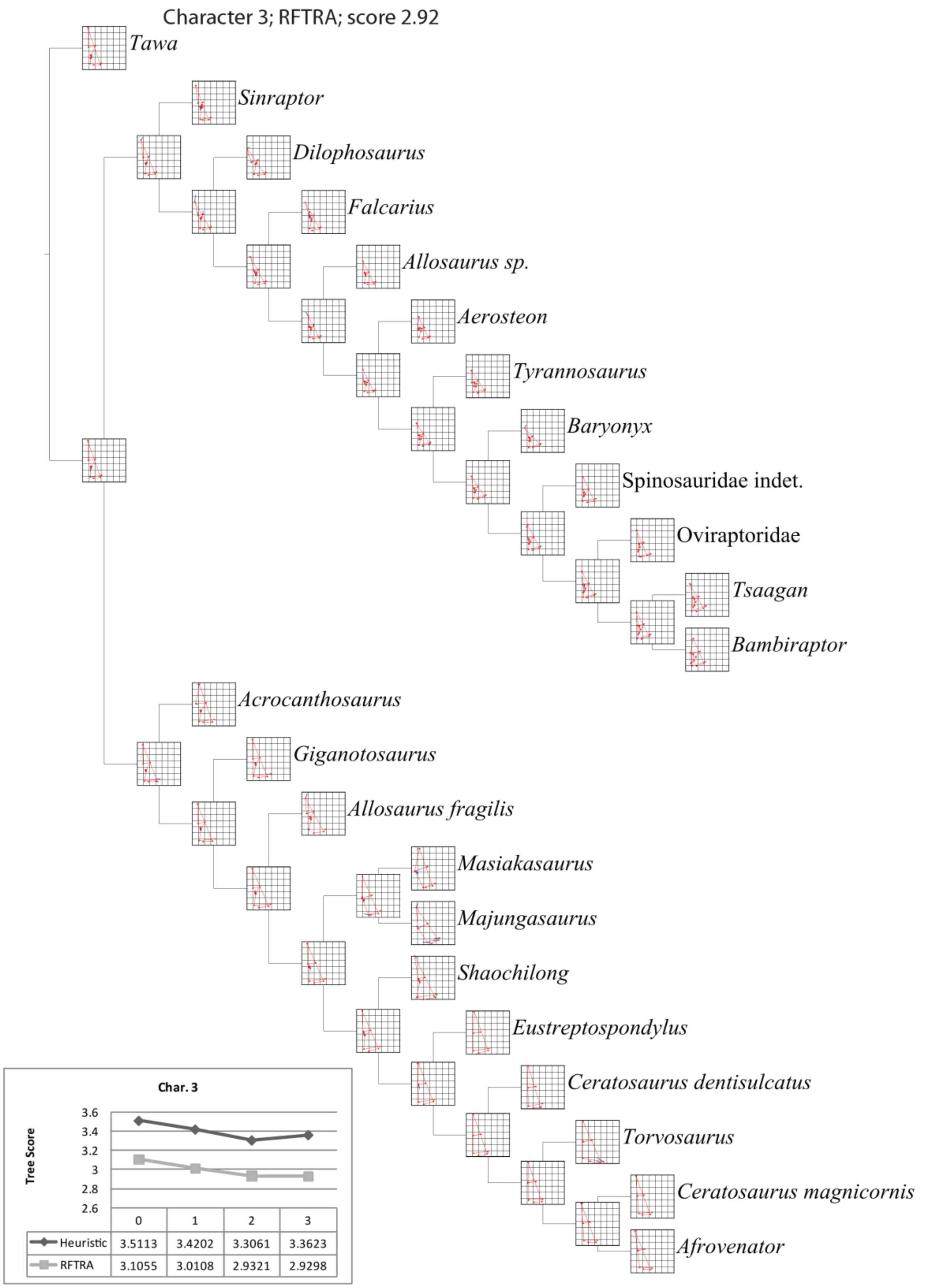

FIGURE S9. Phylogenetic morphometrics results of the quadrate in posterior view (char. 3). The graphic shows on the y axis the tree score versus the level of thoroughness of the analysis (x axis), level 3 being more thorough.