

Supplemental Appendix 2

The 239 morphological characters used for present phylogenetic analysis are listed. The character list is built upon the three large datasets for Mesozoic birds: 13 characters from Chiappe (2002), 135 characters from Clarke *et al.* (2006), five characters from Wang *et al.* (2015), and 67 characters from Bell & Chiappe (2015). Characters 29, 30, 33, 37, 43, 71, 74, 95, 103, 111, 117, 133, 151, 152, 166, 175, 180, 197, 202, 205, 215, 227, 234, 235, and 236 in the present list have been modified from original description of previous studies. In addition, 19 new characters are included. The 33 characters are ordered.

Skull and mandible

1. Premaxillae: (0) unfused in adults, (1) partially or completely fused in adults. (Chiappe 2002)
2. Premaxillary teeth: (0) present, (1) absent. (Chiappe 2002)
3. Maxillary teeth: (0) present, (1) absent. (Chiappe 2002)
4. Dentary teeth: (0) present, (1) absent. (Chiappe 2002)
5. Dentaries: (0) joined proximally by ligaments, (1) joined by bone. (Clarke et al. 2006)
6. Facial margin: (0) primarily formed by the maxilla, with the maxillary process of the premaxillae restricted to the anterior tip, (1) maxillary process of the premaxillae extending half of facial margin, (2) maxillary process of the premaxillae extending more than half of facial margin. *Ordered* (Clarke et al. 2006)
7. Nasal [frontal] process of premaxillae: (0) short, does not approach frontal, (1) long, closely approaching frontal. (Chiappe 2002)
8. Frontal/parietal suture in adult: (0) open, (1) fused. (Clarke et al. 2006)
9. Basilar tubercle prominent, in marginal position: (0) present, (1) reduced or absent.

(Elzanowski and Galton 1991)

10. Glossopharyngeal foramen: (0) absent, (1) present. (Elzanowski and Galton 1991)
11. Vomer contacts premaxilla: (0) present, (1) absent. (Clarke et al. 2006)
12. Squamosal incorporated into the braincase, forming a zygomatic process: (0) absent, (1) present. (Chiappe, 2002)
13. Eustachian tubes ossified: (0) absent, (1) present. (Clarke et al. 2006)
14. Quadrate, pneumaticity: (0) absent, (1) present. (Chiappe 2002)
15. Orbital process of quadrate/ pterygoid articulation: (0) pterygoid broadly overlapping medial surface of orbital process (i.e., “pterygoid ramus”), (1) restricted to anteromedial edge of process. (Clarke et al. 2006)
16. Quadrate/pterygoid contact: (0) as a facet, variably with slight anteromedial projection cradling base, (1) condylar, with a well-projected tubercle on the quadrate. (Clarke et al. 2006)
17. Quadrate, well-developed tubercle on anterior surface of dorsal process of quadrate: (0) absent, (1) present. (Clarke et al. 2006)
18. Quadrate, quadratojugal articulation: (0) overlapping, (1) peg-and-socket. (Clarke et al. 2006)
19. Quadrate, dorsal process articulation: (0) with squamosal only, (1) with squamosal and prootic. (Clarke et al. 2006)
20. Quadrate, mandibular articulation: (0) bicondylar, (1) tricondylar articulation, additional posterior condyle or broad surface. (Clarke et al. 2006)
21. Meckel’s groove: (0) not completely covered by splenial, deep and conspicuous medially, (1) covered by splenial, not exposed medially. (Clarke et al. 2006)
22. Postorbital: (0) present, (1) absent. (Chiappe 2002)

23. Dentary strongly forked posteriorly: (0) unforked, or with a weakly developed dorsal ramus, (1) strongly forked with the dorsal and ventral rami approximately equal in posterior extent. (Clarke et al. 2006)
24. Splenial, anterior extent: (0) splenial stops well posterior to mandibular symphysis, (1) extending to mandibular symphysis, though noncontacting, (2) extending to proximal tip of mandible, contacting on midline. (Clarke et al. 2006)
25. Mandibular symphysis, anteroposteriorly extensive, flat to convex, dorsal-facing surface develop: (0) absent, concave, (1) flat surface developed. (Clarke et al. 2006)

Vertebral column and ribs

26. Cervical vertebrae: (0) variably dorsoventrally compressed, amphicoelous ('biconcave': flat to concave articular surfaces), (1) anterior surface heterocoelous (i.e. mediolaterally concave, dorsoventrally convex), posterior surface flat, (2) heterocoelous anterior (i.e. mediolaterally concave, dorsoventrally convex) and posterior (i.e. mediolaterally convex, dorsoventrally concave) surfaces. *Ordered* (Clarke et al. 2006)
27. Prominent (50% or more of the height of the centrum's cranial articular surface) ventral process of the cervicothoracic vertebrae: (0) absent, (1) present. (Chiappe 2002)
28. Thoracic vertebrae (with ribs articulating with the sternum), one or more with prominent hypapophyses: (0) absent, (1) present. (This character does not address the presence of hypapophyses on transitional vertebrae, or 'cervicothoracics', that do not have associated ribs that articulate with the sternum (e.g. Gauthier, 1986, Chiappe, 1996). In contrast, in Aves, well-developed hypapophyses are developed well into the thoracic series, on vertebrae with ribs articulating with the sternum). (Clarke et al. 2006)

29. Thoracic vertebrae, count: (0) 12 or more, (1) 11, (2) 10 to 8, (3) 7 or fewer. *Ordered* (modified from Clarke et al. 2006).
30. Thoracic vertebrae: (0) at least part of series with subround, central articular surfaces (e.g. amphicoelous/opisthocoelous) that lack the dorsoventral compression seen in heterocoelous vertebrae; (1) central articular surfaces are compressed dorsoventrally and lack the saddle-shaped, concave on one axis and convex on the other; (2) series completely heterocoelous. (modified from Clarke et al. 2006)
31. Thoracic vertebrae, parapophyses: (0) rostral to transverse processes, (1) directly ventral to transverse processes (close to midpoint of vertebrae). (Clarke et al. 2006)
32. Thoracic vertebrae, centra, length, and midpoint width: (0) approximately equal in length and midpoint width, (1) length markedly greater than midpoint width. (Clarke et al. 2006)
33. Thoracic vertebrae, lateral sides of the centra, lateral excavation: (0) excavation with a pronounced and sharply defined edge of the ventral margin, (1) excavation without a pronounced and sharply defined edge of the ventral margin, (2) not depressed or only slightly depressed. (modified from Clarke et al. 2006)
34. Thoracic vertebrae with ossified connective tissue bridging transverse processes: (0) absent, (1) present. (Clarke et al. 2006)
35. Notarium: (0) absent, (1) present. (Clarke et al. 2006)
36. Synsacrum: cranial articular surface of synsacrum: (0) flat or amphicoelous, (1) heterocoelous.
37. Sacral vertebrae, number ankylosed: (0) less than 7, (1) 7, (2) 8, (3) 9, (4) 10, (5) 11-14, (6) 15 or more. *Ordered* (modified from Clarke et al. 2006)
38. Sacral vertebrae, series of short vertebrae, number of fused vertebra that are positioned

- anterior to the anterior margin of the acetabulum: (0) two or three, (1) four or five, (2) six or more.
39. Sacrum shape (in lateral view): (0) straight, (1) slight convex curve (dorsal edge at peak of curve). (Bell & Chiappe 2015)
40. Degree of fusion of distal caudal vertebrae: (0) fusion absent, (1) few vertebrae partially ankylosed (intervening elements are well-discernable), (2) vertebrae completely fused into a pygostyle. *Ordered* (Wang et al. 2015)
41. Free caudal vertebrae, number: (0) more than 8, (1) 8 or less. (Clarke et al. 2006)
42. Free caudals, length of transverse processes: (0) subequal to width of centrum, (1) significantly shorter than centrum width. (Clarke et al. 2006)
43. Anterior free caudal vertebrae: (0) elongate pre/postzygapophyses, (1) pre- and postzygapophyses short or negligible. (modified from Clarke et al. 2006)
44. Fused distal caudals, morphology: (0) fused element length equal or greater than 4 free caudal vertebrae, (1) length less than 4 caudal vertebrae, (2) less than 2 caudal vertebrae in length. *Ordered* (Clarke et al. 2006)
45. Cranial end of pygostyle dorsally forked: (0) absent, (1) present. (Wang et al. 2015)
46. Ossified uncinat processes: (0) absent, (1) present and unfused to ribs, (2) fused to ribs. *Ordered* (Clarke et al. 2006)
47. Gastralria: (0) present, (1) absent. (Clarke et al. 2006)

Pectoral Girdle

48. Ossified sternal plates: (0) unfused, (1) fused, flat, (2) fused, with slightly raised midline ridge, (3) fused with projected carina. *Ordered* (Clarke et al. 2006)
49. Sternum, dorsal surface, pneumatic foramen (or foramina): (0) absent, (1) present.

(Clarke et al. 2006)

50. Sternum, pneumatic foramina in the depressions (loculi costalis, Baumel & Witmer, 1993) between rib articulations (processi articularis sternocostalis, Baumel & Witmer, 1993): (0) absent, (1) present. (Clarke et al. 2006)
51. Sternum, coracoidal sulci spacing on anterior edge: (0) widely separated mediolaterally, (1) adjacent, (2) crossed on midline. (Clarke et al. 2006)
52. Sternum, number of processes for articulation with the sternal ribs: (0) three, (1) four, (2) five, (3) six, (4) seven or more. *Ordered* (Clarke et al. 2006).
53. Sternum: raised, paired intermuscular ridges (linea intermuscularis, Baumel & Witmer, 1993) parallel to sternal midline: (0) absent, (1) present. (Clarke et al. 2006)
54. Furcula, hypocleideum: (0) absent, (1) a tubercle, (2) an elongate process. *Ordered* (Clarke et al. 2006).
55. Scapula and coracoid: (0) fused, (1) unfused. (Clarke et al. 2006)
56. Coracoid and scapula: (0) articulate through a wide, sutured articulation, (1) articulate through more localized facets. (Chiappe 2002)
57. Coracoid and scapula articulation, pit-shaped scapular cotyla developed on the coracoid, and coracoidal tubercle developed on the scapula ('ball and socket' articulation): (0) absent, (1) present. (modified from Clarke et al. 2006)
58. Coracoid and scapula, glenoid facet: (0) placed in the same plane, (1) forming a sharp angle. (Chiappe, 2002)
59. Coracoid and scapula, glenoid facet reduced: (0) absent, (1) present. (Bell & Chiappe 2015)
60. Scapula, posterior end: (0) wider or approximately the same width as proximal dorsoventral shaft width, (1) tapering distally. (Clarke et al. 2006)

61. Scapula: (0) straight, (1) dorsoventrally curved. (Clarke et al. 2006)
62. Scapula, length: (0) shorter than humerus, (1) as long as or longer than the humerus.
(Clarke et al. 2006)
63. Scapula, acromion process: (0) projected anteriorly to surpass the articular surface for coracoid (facies articularis coracoidea, Baumel & Witmer, 1993), (1) projected less anteriorly than the articular surface for coracoid. (Clarke et al. 2006)
64. Scapula, acromion process: (0) straight, (1) laterally hooked tip. (Clarke et al. 2006)
65. Coracoid, procoracoid process: (0) absent, (1) present. (Clarke et al. 2006)
66. Coracoid: (0) trapezoidal, (1) strut-like, (2) blunt triangle with short neck. (Bell & Chiappe 2015)
67. Coracoid, lateral margin: (0) straight to slightly concave, (1) convex. (Clarke et al. 2006)
68. Coracoid, dorsal surface (= posterior surface of basal maniraptoran theropods): (0) strongly concave, (1) flat to convex. (Clarke et al. 2006)
69. Coracoid, pneumatized: (0) absent, (1) present. (Clarke et al. 2006)
70. Coracoid, pneumatic foramen: (0) proximal, (1) distal. (Clarke et al. 2006)
71. Coracoid, lateral process: (0) absent, (1) present, expanded laterally, (2) present as a hooked projection. (modified from Clarke et al. 2006)
72. Coracoid, ventral surface, lateral intermuscular line or ridge: (0) absent, (1) present.
(Clarke et al. 2006)
73. Coracoid, glenoid and scapular facets: (0) located near the proximal end of the coracoid, (1) displaced distally. (Bell & Chiappe 2015)
74. Coracoid, acrocoracoid: (0) absent, (1) present, straight, (2) present, hooked medially.
(modified from Clarke et al. 2006)
75. Coracoid, n. supracoracoideus passes through coracoid: (0) present, (1) absent. (Clarke

et al. 2006)

- 76. Coracoid, medial surface, area of the foramen n. supracoracoideus (when developed): (0) strongly depressed, (1) flat to convex. (Clarke et al. 2006)
- 77. Coracoid, sternocoracoidal facet: (0) thin, arched ridge, (1) thickened ridge along the sternal margin. (Bell & Chiappe 2015)
- 78. Coracoid, sternocoracoidal process on the sternal half of the coracoid: (0) absent, (1) present. (Bell & Chiappe 2015)

Pectoral limb

- 79. Humerus, shape: (0) robust, with large, expanded proximal and/or distal ends, (1) elongate or slender. (Bell & Chiappe, 2015)
- 80. Humerus and ulna, length: (0) humerus longer than ulna, (1) ulna and humerus approximately the same length, (2) ulna significantly longer than humerus. *Ordered* (Clarke et al. 2006)
- 81. Humerus, proximal end, head in anterior or posterior view: (0) strap-like, articular surface flat, no proximal midline convexity, (1) head domed proximally. (Clarke et al. 2006)
- 82. Humerus, proximal end, proximal projection: (0) dorsal edge projected farthest, (1) midline projected farthest. (Clarke et al. 2006)
- 83. Humerus, ventral tubercle: (0) projected ventrally, (1) projected caudally, separated from the humeral head by a deep capital incision. (Bell & Chiappe 2015)
- 84. Humerus, capital incisure: (0) an open groove, (1) closed by tubercle associated with a muscle insertion just distal to humeral head. (Clarke et al. 2006)
- 85. Humerus, anterior surface, well-developed fossa on midline making proximal articular

- surface appear v-shaped in proximal view: (0) absent, (1) present. (Clarke et al. 2006)
86. Humerus, 'transverse groove': (0) absent, (1) present, developed as a discreet, depressed scar on the proximal surface of the bicipital crest or as a slight transverse groove. (Clarke et al. 2006)
87. Humerus, deltopectoral crest: (0) projected dorsally (in line with the long axis of humeral head), (1) projected anteriorly. (Clarke et al. 2006)
88. Humerus, deltopectoral crest: (0) less than shaft width, (1) same width, (2) dorsoventral width greater than shaft width. *Ordered* (Clarke et al. 2006)
89. Humerus, deltopectoral crest, proximoposterior surface: (0) flat to convex, (1) concave. (Clarke et al. 2006)
90. Humerus, bicipital crest in anterior view, pit-shaped scar/fossa for muscular attachment on ventroproximal surface of crest: (0) absent, (1) present. (Clarke et al. 2006)
91. Humerus, proximal end, one or more pneumatic foramina: (0) absent, (1) present. (Clarke et al. 2006)
92. Humerus, well defined distal condyles: (0) present, (1) absent.
93. Humerus, distal condyles, remarkable intercondylar incision: (0) present, (1) absent.
94. Humerus, distal condyles: (0) developed distally, (1) developed on anterior surface of humerus. (Clarke et al. 2006)
95. Humerus, distal condyles: (0) subround, bulbous, (1) weakly defined, 'strap-like', (2) extremely reduced. (modified from Clarke et al. 2006)
96. Humerus, long axis of dorsal condyle: Humerus, long axis of dorsal condyle: (0) at low angle to humeral axis, proximodistally orientated, (1) at high angle to humeral axis, almost transversely orientated. (Clarke et al. 2006)

97. Humerus, distal margin: (0) approximately perpendicular to long axis of humeral shaft, (1) ventrodistal margin projected significantly distal to dorsodistal margin, distal margin angling strongly ventrally (sometimes described as a well-projected flexor process). (Clarke et al. 2006)
98. Humerus, distal end, compressed anteroposteriorly and flared dorsoventrally: (0) absent, (1) present. (Clarke et al. 2006)
99. Humerus, brachial fossa: (0) absent, (1) present, developed as a flat scar or as a scar-impressed fossa. (Clarke et al. 2006)
100. Humerus, ventral condyle: (0) length of long axis of condyle less than the same measure of the dorsal condyle, (1) same or greater. (Clarke et al. 2006)
101. Humerus, demarcation of muscle origins (e.g. m. extensor metacarpi radialis in Aves) on the dorsal edge of the distal humerus: (0) no indication of origin as a scar, a pit, or a tubercle, (1) indication as a pit-shaped scar or as a variably projected scar-bearing tubercle or facet. (Clarke et al. 2006)
102. Humerus, distal end, posterior surface, groove for passage of m. scapulotriceps: (0) absent, (1) present. (Clarke et al. 2006)
103. Humerus, m. *humerothoracalis* groove: (0) absent or shallow, (1) present as a remarkable ventral depression contiguous with the olecranon fossa. (modified from Clarke et al. 2006)
104. Humerus, Bicipital crest: (0) present, (1) reduced or absent. (Bell & Chiappe 2015)
105. Humerus, well-developed olecranon fossa on the caudal face of the distal end of the humerus: (0) absent, (1) present. (Chiappe 2002)
106. Humerus in cranial view, ventral epicondyle extends: (0) to a similar extent as condyles, (1) epicondyles absent. (Bell & Chiappe 2015)

107. Ulna, distal end, dorsal condyle, dorsal trochlear surface developed as a semilunate ridge: (0) absent, (1) present. (Clarke et al. 2006)
108. Ulna, distal end, dorsal condyle, dorsal trochlear surface, extent along posterior margin: (0) less than transverse measure of dorsal trochlear surface, (1) approximately equal in extent. (Clarke et al. 2006)
109. Ulna, bicipital scar: (0) absent, (1) developed as a slightly raised scar, (2) developed as a conspicuous tubercle. (Clarke et al. 2006)
110. Ulna, brachial scar: (0) absent, (1) present. (Clarke et al. 2006)
111. Radius, muscle impression on ventro-posterior surface: (0) absent, (1) present. (modified from Clarke 2004)
112. Ulnare: (0) absent, (1) present. (Clarke et al. 2006)
113. Semilunate carpal and metacarpals: (0) no fusion, (1) incomplete proximal fusion, (2) complete proximal fusion, (3) complete proximal and distal fusion. *Ordered* (Clarke et al. 2006)
114. Semilunate carpal, position relative to metacarpal I: (0) over 1/2 or more of proximal surface, (1) over less than 1/2 proximal surface. *Ordered* (Clarke et al. 2006)
115. Metacarpal III, anteroposterior diameter as a percent of same dimension of metacarpal II: (0) approximately equal or greater than 50%, (1) less than 50%. (Clarke et al. 2006)
116. Metacarpal I, extensor process: (0) absent, (1) present as a small knob, (2) present as a well-developed process.
117. Metacarpal I, anterior surface: (0) roughly hourglass-shaped, (1) truncate-shaped, (2) rounded. (modified from Clarke et al. 2006)
118. Metacarpal I, distal articulation with phalanx I: (0) ginglymoid, (1) shelf. (Clarke et al.

2006)

- 119. Pisiform process: (0) absent, (1) present. (Clarke et al. 2006)
- 120. Carpometacarpus, ventral surface, supratrochlear fossa deeply excavating proximal surface of pisiform process: (0) absent, (1) present. (Clarke et al. 2006)
- 121. Intermetacarpal space (between metacarpals II and III): (0) reaches proximally as far as the distal end of metacarpal I, (1) terminates distal to end of metacarpal I. (Clarke et al. 2006)
- 122. Carpometacarpus, distal end, metacarpals II and III, articular surfaces for digits: (0) metacarpal II subequal or surpasses metacarpal III in distal extent, (1) metacarpal III extends further. (Clarke et al. 2006)
- 123. Intermetacarpal process or tubercle: (0) absent, (1) present as scar, (2) present as tubercle or flange. *Ordered* (Clarke et al. 2006)
- 124. Manual digit II, phalanx 1: (0) subcylindrical to subtriangular, (1) strongly dorsoventrally compressed, flat caudal surface. (Clarke et al. 2006)
- 125. Manual digit II, phalanges: (0) length of phalanx II- 1 less than or equal to that of II-2, (1) longer. (Clarke et al. 2006)

Pelvic Girdle

- 126. Pelvis, acetabular foramen, (0) large and completely open, (1) extremely reduced by ossification.
- 127. Small acetabulum, acetabulum: ilium length equal or less than 0.11: (0) absent, (1) present. (Bell & Chiappe 2015)
- 128. Ilium, ischium, pubis, proximal contact in adult: (0) unfused, (1) partial fusion (pubis not ankylosed), (2) completely fused. *Ordered* (Clarke et al. 2006)

129. Ilium/ischium, distal co-ossification to completely enclose the ilioischadic fenestra: (0) absent, (1) present. (Clarke et al. 2006)
130. Ischium: (0) forked (dorsal process present), (1) straight, no dorsal process. (Clarke et al. 2006)
131. Ischium, dorsal process: (0) does not contact ilium, (1) contacts ilium. (Clarke et al. 2006)
132. Ischium and pubis: (0) not subparallel, pubis directed nearly directly ventrally, (1) subparallel, pubis posteriorly directed. *Ordered* (modified from Clarke et al. 2006)
133. Laterally projected process on ischiadic peduncle (antitrochanter): (0) directly posterior to acetabulum, (1) posterodorsal to acetabulum, (2) dorsal to acetabulum. (modified from Clarke et al. 2006)
134. Preacetabular pectineal process (Baumel & Witmer, 1993): (0) absent, (1) present as a small flange, (2) present as a well-projected flange. *Ordered* (Clarke et al. 2006)
135. Preacetabular ilium: (0) approach on midline, open, or cartilaginous connection, (1) co-ossified, dorsal closure of 'iliosynsacral canals'. (Clarke et al. 2006)
136. Preacetabular ilium extends anterior to first sacral vertebrae: (0) no free ribs overlapped, (1) one or more ribs overlapped. (Clarke et al. 2006)
137. Length of preacetabular ilium approximately: (0) equal to, (1) 60%, (2) less than 40% the length of the post-acetabular ilium. *Ordered* (Bell & Chiappe 2015)
138. Postacetabular ilium: (0) dorsoventrally orientated, (1) mediolaterally orientated. (Clarke et al. 2006)
139. Postacetabular ilium, ventral surface, renal fossa developed: (0) absent, (1) present. (Clarke et al. 2006)
140. ilium, m.cuppodicus fossa as broad, mediolaterally orientated surface directly

- anteroventral to acetabulum: (0) present, (1) surface absent, insertion variably marked by a small entirely lateral fossa anterior to acetabulum. (Clarke et al. 2006)
141. Ischium, posterior demarcation of the obturator foramen: (0) absent, (1) present, developed as a small flange or raised scar contacting/fused with pubis and demarcating the obturator foramen distally. (Clarke et al. 2006)
142. Ischium, length relative to that of pubis: (0) 1/3 or greater total pubis length extends posterior to end of ishium, (1) less than 1/3 pubis extends further than end of ishium. (Clarke et al. 2006)
143. Pubis: (0) suboval in cross section, (1) compressed mediolaterally. (Clarke et al. 2006)
144. Pubes, distal contact: (0) contacting, variably coossified into symphysis, (1) noncontacting. (Clarke et al. 2006)
145. Distal end of pubis: (0) expanded, flared, (1) straight, subequal, in proportion with rest of pubis. (Clarke et al. 2006)
146. Pubic apron: (0) one-third or more the length of the pubis, (1) shorter or absent. (Bell & Chiappe 2015)

Pelvic limb

147. Femur, fossa for insertion of lig. capitis femoris: (0) absent, (1) present. (Clarke et al. 2006)
148. Femur, posterior trochanter: (0) present, developed as a slightly projected tubercle or flange, (1) hypertrophied, 'shelf-like' conformation (in combination with development of the trochanteric shelf, see Hutchinson, 2001), (2) absent. *Ordered* (Chiappe 1991)
149. Femur, lesser and greater trochanters: (0) separated by a notch, (1) fused to it, developed as a single trochanteric crest. (Clarke et al. 2006)

150. Femur, in proximal view, anterior margin of the trochanteric crest: (0) well developed and positioned anterior to the anterior margin of femoral head, (1) moderately developed and positioned at the same level with the anterior margin of femoral head, (2) less developed and positioned posteriorly to the anterior margin of the femoral head.
151. Femur: (0) ectocondylar tubercle and lateral condyle separated by deep notch, (1) prominent tibiofibular crest and lateral condyle separated by fibular trochlea. (modified from Clarke et al. 2006)
152. Femur, caudal view, distal condyles widely spaced, such that the popliteal fossa is bounde distally by intercondylar bridge: (0) absent, popliteal fossa open, (1) present. (modified from Bell & Chiappe 2015)
153. Femur, Fossa for the femoral origin of *m. tibialis cranialis*: (0) absent, (1) present. (Wang et al. 2015)
154. Femur, lateral margin of shaft (between trochanter and fibular condyle): (0) relatively straight, (1) slightly concave, (2) highly concave. (Bell & Chiappe 2015)
155. Femur in medial or lateral view, "hunched", thickened appearance along shaft: (0) absent, (1) present. (Bell & Chiappe 2015)
156. Femur, medial margin of shaft, tubercle for *m. iliofemoralis* and *m. caudofemoralis* (Zinoviev, 2011): (0) absent or faint, (1) well-defined.
157. Femur, intramuscular lines: (0) absent or faint, (1) well-developed, with high relief. (Bell & Chiappe, 2015)
158. Femur, trochanter and head: (0) nearly continuous or separated by a shallow notch, (1) separated by a deep notch. (Bell & Chiappe, 2015)
159. Femur: (0) neck absent, (1) head merges into neck without sharp margin, (2) head

forms distinct knob separated from neck. *Ordered* (Bell & Chiappe, 2015)

160. Femur, caudal view, flattened surface of head (where the fovea for the capital ligament is located) directed: (0) medially, (1) proximo-medially. (Bell & Chiappe, 2015)
161. Femur, cranial view, trochanter extends proximally: (0) similar extent, (1) further, (2) less far than head (when femur aligned along axis between notch between head and trochanter and intercondylar sulcus). (Bell & Chiappe, 2015)
162. Femur, lateral view, margin of trochanter: (0) smooth, flattened surface, (1) lumpy, irregular surface, (2) sharp ridge with highly irregular margin. (Bell & Chiappe, 2015)
163. Femur, patellar groove: (0) absent, (1) extends smoothly onto the distal shaft as a broad shallow groove, (2) divided from the remainder of the shaft by a slight ridge, giving it a 'pocketed' appearance. *Ordered* (Bell & Chiappe, 2015)
164. Femur, medial condyle in caudal view: (0) sub-circular or oval, (1) kidney bean shaped. (Bell & Chiappe, 2015)
165. Femur, lateral condyle: (0) similar distal extent as medial, (1) extends distally past medial. (Bell & Chiappe, 2015)
166. Femur, laterally projected fibular trochlea: (0) absent, (1) shelf-like projection. (modified from Clarke et al. 2006)
167. Femur, distal view, depressed medial margin of medial condyle: (0) faint or absent, (1) present.
168. Femur, in distal view, lateral surface of fibular condyle: (0) smooth, (1) remarkably concave.
169. Femur, face of fibular condyle oriented: (0) caudally or slightly laterally, (1) nearly entirely laterally. (Bell & Chiappe, 2015)
170. Femur, lateral view, lateral condyle: (0) merges smoothly into shaft, (1) constricts into

neck before widening at shaft. (Bell & Chiappe, 2015)

171. Femur, width / length ratio of proximal end: (0) less than 0.30, (1) between 0.31 and 0.44, (2) more than 0.45.
172. Femur, width / length ratio of distal end: (0) less than 0.25, (1) between 0.25 and 0.41, (2) more than 0.41.
173. Patella in medial view, foramen for *m. ambiens*: (0) located cranially, (1) located at around the center.
174. Patella shape: (0) roughly pyramidal, (1) craniocaudally compressed, nearly flat and highly elongated. (Bell & Chiappe, 2015)
175. Tibiotarsus, proximal articular surface: (0) both medial and lateral cotylae are flat, (1) lateral cotyla is tilted laterally, (2) both medial and lateral cotylae are strongly tilted laterally. (modified from Bell & Chiappe 2015)
176. Tibiotarsus, proximal articular surface, central depression between cotylae: (0) absent, (1) present. (Bell & Chiappe 2015)
177. Tibiotarsus, proximal view, lateral incision (incisura lateralis, Baumel and Witmer, 1993): (0) shallow, (1) remarkably deep.
178. Calcaneum and astragalus: (0) unfused to each other or tibia in adult, (1) fused to each other, unfused to tibia, (2) complete fused to each other and tibia. *Ordered* (Clarke et al. 2006)
179. Tibiotarsus, cnemial crest(s): (0) lateral crest only, (1) lateral and anterior crests developed. (Clarke et al. 2006)
180. Tibiotarsus, medial view, roughened triangular surface covers proximo-cranial portion of shaft and cnemial expansion: (0) absent, (1) faint, (2) well-developed and bounded by a diagonal ridge. (modified from Bell & Chiappe, 2015)

181. Tibiotarsus, in anterior view, lateral margin of lateral cnemial crest: (0) well-flared laterally, hiding the lateral cotyla, (1) slightly flared laterally, not hiding the lateral cotyla.
182. Tibiotarsus, cnemial crests on cranial surface of cnemial expansion: (0) asymmetric, medial crest forms sharp angle distal to the slight flare of lateral crest, (1) fairly symmetric, medial and lateral crests both curve outward slightly, (2) asymmetric, medial crest projects cranially, lateral has sharp angle. (Bell & Chiappe, 2015)
183. Tibiotarsus, caudal view, lateral border of lateral cotylae: (0) smooth bulge, (1) abrupt lip outward from shaft. (Bell & Chiappe, 2015)
184. Tibiotarsus, fibular crest extends approximately: (0) over half-way, (1) half-way down shaft, (2) restricted to upper 1/3 of shaft. (Bell & Chiappe, 2015)
185. Tibiotarsus, distal fibular crest is interrupted by a transverse groove extending across the lateral border of the tibial shaft: (0) absent, (1) present. (Bell & Chiappe, 2015)
186. Tibia/tarsal formed condyles, extensor canal: (0) absent, (1) an emarginate groove, (2) groove bridged by an ossified supratendinal bridge. *Ordered* (Clarke et al. 2006)
187. Tibia/tarsal formed condyles, *tuberositas retinacula extensoris* (Baumel & Witmer, 1993) indicated by short medial ridge or tubercle proximal to the condyles close to the midline and a more proximal second ridge on the medial edge: (0) absent, (1) present. (Clarke et al. 2006)
188. Tibia/tarsal formed condyles, mediolateral widths: (0) medial condyle wider, (1) approximately equal, (2) lateral condyle wider. *Ordered* (Clarke et al. 2006)
189. Tibiotarsus, cranial view, medial condyle: (0) similar length to, (1) shorter than lateral condyle. (Bell & Chiappe, 2015)
190. Tibia, extension of articular surface for distal tarsals/tarsometatarsus: (0) no posterior

extension of trochlear surface, or restricted to distal-most edge of posterior surface, (1) well-developed posterior extension, sulcus cartilaginis tibialis of Aves (Baumel & Witmer, 1993), distinct surface extending up the posterior surface of the tibiotarsus, (2) with well-developed, posteriorly projecting, medial and lateral crests. *Ordered* (Clarke et al. 2006)

191. Tibiotarsus, distal-most mediolateral width: (0) wider than mid-point of shaft, giving distal profile a weakly developed triangular form, (1) approximately equal to shaft width, no distal expansion of whole shaft, although condyles may be variably splayed mediolaterally. (Clarke et al. 2006)
192. Tibiotarsus, cranial view, intercondylar sulcus: (0) symmetric, (1) asymmetric, medial margin steeper than lateral margin. (Bell & Chiappe, 2015)
193. Tibiotarsus, cranial view, intercondylar sulcus: (0) slightly, (1) deeply indented. (Bell & Chiappe, 2015)
194. Tibiotarsus, groove runs along caudal surface of shaft adjacent to fibular crest: (0) faint or absent, (1) well-developed. (Bell & Chiappe, 2015)
195. Tibiotarsus, distal shaft: (0) symmetric, medial and lateral condyles evenly expanded on either side of shaft, (1) medial condyle more expanded than lateral, distal end flares slightly medially from the midline of the shaft. (Bell & Chiappe, 2015)
196. Tibiotarsus, lateral view, lateral condyle: (0) roughly circular, (1) j-shaped, (2) half-circle. (Bell & Chiappe, 2015)
197. Tibiotarsus, distal view, intercondylar incision: (0) excavated by a notch, (1) broad and shallow, (2) deep with sloped sides. (modified from Bell & Chiappe, 2015)
198. Tibiotarsus, distal view, lateral condyle cranio-caudally: (0) similar length to, (1) longer than, (2) shorter than medial condyle. (Bell & Chiappe 2015)

- 199.** Tibiotarsus, cranial margin as it approaches proximal end: (0) continues in a smooth curve, widening slightly, (1) bulges cranially. (Bell & Chiappe 2015)
- 200.** Fibula: (0) reaches tarsal joint articulating into distinct socket formed between the proximal tarsals and the tibia, (1) reduced in length, does not reach tarsal joint. (Clarke et al. 2006)
- 201.** Fibula, proximal end: (0) prominently excavated by a medial fossa, (1) nearly flat. (Wang et al. 2015)
- 202.** Distal tarsals and metatarsals, fusion: (0) distal tarsals fuse to metatarsals, (1) distal tarsals fuse to metatarsals and proximal metatarsals co-ossify, (2) extremely distal fusion (Martin, 1983; Cracraft, 1986). *Ordered* (modified from Clarke et al. 2006)
- 203.** Metatarsal V: (0) present, (1) absent. (Clarke et al. 2006)
- 204.** Metatarsal III: (0) proximally in plane with II and IV, (1) proximally displaced plantarly, relative to metatarsals II and IV. (Clarke et al. 2006)
- 205.** Tarsometatarsus, plantar view, projected surface or grooves on hypotarsus area: (0) flat, unprojected surface, (1) projected without distinct crest and groove, (2) projectcted with distinct two crests and one groove, (3) projected with at least one groove enclosed by bone posteriorly, (4) projected with four crests and three grooves. (modified from Clark et al. 2006)
- 206.** Tarsometatarsus, dorsal view, proximal vascular foramen (foramina): (0) absent, (1) one, between metatarsals III and IV, (2) two. *Ordered* (Clarke et al. 2006)
- 207.** Tarsometatarsus, plantar view, proximal vascular foramen (foramina): (0) absent, (1) one perforated foramen, (2) two perforated foramens.
- 208.** Tarsometatarsus, intercotylar eminence: (0) absent, (1) low relief, (2) high relief. (Bell & Chiappe, 2015)

- 209.** Tarsometatarsus, intercotylar eminence: (0) absent, (1) projects symmetrically from articular surface, (2) projects asymmetrically, such that it tilts laterally in dorsal view. (Bell & Chiappe, 2015)
- 210.** Metatarsal I: (0) straight, (1) curved or distally deflected but not twisted, ventral surface convex 'J shaped', (2) deflected and twisted such that the ventromedial surface is concave proximal to trochlear surface for phalanx I. *Ordered* (Clarke et al. 2006)
- 211.** Metatarsal II tubercle (associated with the insertion of the tendon of the *m. tibialis cranialis* in Aves): (0) absent, (1) present, on approximately the center of the proximodorsal surface of metatarsal II, (2) present, developed on lateral surface of metatarsal II, at contact with metatarsal III or on lateral edge of metatarsal III. *Ordered* (Clarke et al. 2006)
- 212.** Metatarsal II, distal plantar surface, fossa for metatarsal I (fossa metatarsi I, Baumel and Witmer, 1993): (0) absent, (1) shallow notch, (2) conspicuous ovoid fossa. *Ordered* (Clarke et al. 2006)
- 213.** Metatarsal II, articular surface for first phalanx: (0) ginglymoid, (1) rounded. (Clarke et al. 2006)
- 214.** Tarsometatarsus, distal extent of trochlea IV: (0) not as far as, (1) to a similar level as, (2) slightly further than, (3) or markedly further than trochlea III. *Ordered* (Bell & Chiappe 2015)
- 215.** Tarsometatarsus, distal extent of metatarsal II relative to metatarsal IV: (0) distal edge of metatarsal II extends farther than the base of metatarsal IV trochlea, (1) distal edge of metatarsal II does not reach the base of metatarsal IV trochlea. (modified from Clarke et al. 2006)
- 216.** Metatarsals, relative mediolateral width at mid shaft: (0) metatarsal IV approximately

the same width as metatarsals II and III, (1) metatarsal IV narrower than metatarsal II and metatarsal III, (2) metatarsal IV greater in width than either metatarsal II or III. (Clarke et al. 2006)

- 217.** Tarsometatarsus, distal vascular foramen: (0) simple, with one exit, (1) forked, two exits (plantar and distal) between metatarsals III and IV. (Clarke et al. 2006)
- 218.** Tarsometatarsus, closed distal vascular foramen: (0) absent, (1) present.
- 219.** Tarsometatarsus, lateral view, proximal surface of lateral cotyla: (0) flat and perpendicular to long axis of shaft, (1) slopes distally at dorsal margin. (Bell & Chiappe 2015)
- 220.** Tarsometatarsus, dorsal view, articular surface forms a plane positioned, relative to the long axis of the shaft: (0) roughly perpendicular, (1) angled, medial cotyla further proximal than lateral. (Bell & Chiappe 2015)
- 221.** Tarsometatarsus, medial and plantar views: proximal plantar margin of metatarsal II possesses a flange: (0) absent, (1) slight, (2) enlarged or bulbous. *Ordered* (Bell and Chiappe 2015)
- 222.** Tarsometatarsus, medial view, shaft of metatarsal II: (0) nearly straight, (1) slightly curved, (2) dramatically curved into an s-shape. (Bell & Chiappe 2015)
- 223.** Tarsometatarsus, lateral view, round depression on proximal-most face of metatarsal IV: (0) weakly developed, (1) well-developed. (Bell & Chiappe, 2015)
- 224.** Tarsometatarsus, plantar-medial view, medial margin of metatarsal II: (0) rounded edge, (1) sharp ridge. (Bell & Chiappe 2015)
- 225.** Tarsometatarsus, plantar view, trochlea of metatarsal II: (0) fairly straight, (1) angles medially. (Bell & Chiappe 2015)
- 226.** Tarsometatarsus, shaft twisted laterally, when the distal end is in dorsal view, the

proximal end is in: (0) dorsal view (no minimal twisting), (1) dorso-lateral view. (Bell & Chiappe 2015)

- 227.** Distal metatarsus, trochlea in distal view: (0) aligned in a single plane, (1) metatarsal trochlea II and IV roughly aligned in a single plane, III displaced dorsally in respect to II and IV, (2) metatarsal trochlea II strongly displaced plantarly in respect to III and IV. (modified from Wang et al. 2015)
- 228.** Tarsometatarsus, distal view: (0) the dorsal edge of metatarsal trochlear III is dorsal to that of trochlear IV, (1) the dorsal edges of metatarsal trochleae III and IV are approximately equal, (2) the dorsal edge of metatarsal trochlear IV is dorsal to that of trochlear III.
- 229.** Tarsometatarsus, dorsal view, grooves separating metatarsals: (0) absent - metatarsals unfused along shaft, (1) absent - seam or crack only, (2) prominent - deep groove between metatarsals III and IV along entire length of shaft. (Bell & Chiappe, 2015)
- 230.** Tarsometatarsus, ridge on the dorsal surface of metatarsal IV: (0) absent, (1) extends to midshaft, (2) extends to trochlea. (Bell & Chiappe, 2015)
- 231.** Tarsometatarsus, lateral view, metatarsal IV shaft: (0) tapers evenly to distal end, (1) widest at midshaft, tapers at both proximal and distal ends. (Bell & Chiappe 2015)
- 232.** Tarsometatarsus, lateral view, shaft: (0) bowed, (1) straight. (Bell & Chiappe 2015)
- 233.** Tarsometatarsus, comparative metatarsal trochlear width: (0) metatarsal trochlea III is wider than II and IV, (1) metatarsals III and IV wider than II, IV is approximately as wide as III, (2) metatarsal trochlea IV remarkably wider than II and III.
- 234.** Tarsometatarsus, plantar view, intertrochlear incision between III and IV: (0) absent, metatarsals unfused, (1) wedge-shaped, (2) enclosed oval or tear-drop shape with

rounded proximal end. (modified from Bell and Chiappe 2015)

- 235.** Tarsometatarsus, distal view, articular ridges on metatarsal trochlea II: (0) aligned and roughly parallel, (1) angled toward each other dorsally, forming a triangular shape for the trochlea. (modified from Bell & Chiappe 2015)
- 236.** Digit IV phalanges in distal view: (0) the medial and lateral trochleae lie parallel and are about the same size, (1) medial trochlea greatly enlarged and the lateral trochlea reduced to a rounded peg. (modified from Bell & Chiappe 2015)
- 237.** Phalanx 1 of digit IV: (0) elongate, (1) robust, with a squat, shortened appearance. (Bell & Chiappe 2015)
- 238.** Phalanx I of Digit IV, ventral groove: (0) absent, (1) present. (Bell & Chiappe 2015)
- 239.** Phalanx I of Digit IV, ventral surface of phalanx: (0) smooth, (1) possesses a high flange. (Bell & Chiappe 2015)