

Supplementary information to

**Extreme convergence of the body plans of a suchian (Archosauria) and
ornithomimid (Theropoda) dinosaurs.**

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1. Phylogenetic analysis
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1. Phylogenetic analysis

A modified version of Benton's (1999) phylogenetic analysis (see character list below) of basal archosaurs was used to test the relationships of *Effigia*. Parsimony analysis consisted of equally weighted heuristic searches with 100 random addition (RA) replicates and tree bisection and reconnection (TBR) branch-swapping run using PAUP* v4.0b10 (Swofford 2002). Nodal support was examined using nonparametric bootstrapping, with 1000 bootstrap replicates, TBR branch-swapping, and 10 RA sequences. Decay indices were calculated using TreeRot v2c (Sorenson 1999). A unique tree was recovered (20 taxa, 81 characters, characters weighted equally, unordered, tree length 156 steps, consistency index (CI) 0.5897, retention index (RI) 0.8320).

The phylogenetic analysis finds *Effigia* and *Shuvosaurus* well supported within Suchia. The fully developed crocodile-normal ankle and crocodylomorph-like pes clearly places *Effigia* more closely related to crocodiles than to birds. Therefore, most of the 'theropod-like' characters that *Effigia* exhibits are convergent with dinosaurs, theropods, and other clades within Theropoda (see below). The placement of *Effigia*

within Theropoda as a basal theropod requires the addition of twenty-seven steps and the placement sister to ornithomimids requires the addition of thirty steps.

2. Character list

1. Skull length: less (0) or more (1) than 50% of length of the presacral vertebral column [Sereno 1991, character 33]. (Benton 1999)
2. Subnarial fenestra or foramen between premaxilla and maxilla: absent (0), present (1) [Benton & Clark 1988; Juul 1994, character 37]. (Benton 1999)
3. Jugal-lacrimal articular relation: lacrimal overlaps jugal (0), jugal overlaps lacrimal (1) [Sereno & Novas 1993, character 16]. (Benton 1999)
4. Jugal posterior process, shape: tapering (0), forked (1) [Sereno & Novas 1993, character 17]. (Benton 1999)
5. Postfrontal: present (0), absent (1) [Gauthier 1986; Benton & Clark 1988; Juul 1994, character 16; Bennett 1996]. (Benton 1999)
6. Postorbital-jugal bar behind orbit: curved or straight. (0), 'stepped' (1) [Benton & Clark 1988; Juul 1994, character 38]. (Benton 1999)
7. Lower temporal fenestra shape: non-triangular (0), triangular and reduced in size (1) [Benton & Clark 1988; Juul 1994, character 31]. (Benton 1999)
8. Squamosal overhanging quadrate and quadratojugal laterally: absent I'O, present, and contacting the lower temporal fenestra dorsally (1), present, but excluded from the rim of the lower temporal fenestra by postorbital and quadratojugal (2) [Benton & Clark 1988; Juul 1994, character 74]. (Benton 1999)
9. Quadrate head in lateral aspect: hidden by squamosal (0), exposed (1) [Sereno & Novas 1992; Juul 1994, character 64]. (Benton 1999)
10. Pterygoid-ectopterygoid articular relation: ectopterygoid ventral (0), ectopterygoid dorsal (1) [Sereno & Novas 1993, character 12]. (Benton 1999)
11. Size of post-temporal opening: fenestra (0), foramen (1) [Sereno & Novas 1993, character 14]. (Benton 1999)
12. Parasphenoid rostrum: rodlike (0), a dorsovenirally expanded wedge (1) [Parrish 1993; Juul 1994, character 70]. (Benton 1999)
13. Palatal teeth (pterygoid, palatine, vomer): present (0), absent (1) [Benton & Clark 1988; Sereno 1991, character 1; Juul 1994, character 23]. (Benton 1999)
14. Intra-mandibular joint: absent or poorly developed (0), well developed (1) [Sereno & Novas 1993; Juul 1994, character 73]. (Benton 1999)
15. Centrum shape in presacrals 6-9 (or 10): subrectangular (0), parallelogram-shaped (1) [Gauthier 1986; Sereno 1991, character AA]. (Benton 1999)
16. Length of presacral centrum 8 divided by length of presacral centrum 18: less (0) or more (1) than 1.0 [Gauthier 1986; Juul 1994, character 65]. (Benton 1999)
17. Cervical ribs: slender (0), short and stout (1) [Gauthier 1986; Benton & Clark 1988; Juul 1994, character 26]. (Benton 1999)
18. Hyposphene—hypantrum accessory intervertebral articulations in trunk vertebrae: absent (0), present (1) [Gauthier 1986; Juul 1994, character 66]. (Benton 1999)
19. Number of sacral vertebrae: two (0), two plus an incipient third (1), three or more (2) [Gauthier 1986; Juul 1994, character 46]. (Benton 1999)
20. Accessory neural spine on mid-caudal vertebrae: absent (0), present (1) [Benton & Clark 1988; Sereno 1991, character 23; Juul 1994, character 34]. (Benton 1999)
21. Clavicle: present (0), rudimentary or absent (1) [Gauthier 1986; Sereno 1991, character 24]. (Benton 1999)
22. Interclavicle: present (0), absent (1) [Gauthier 1986; Juul 1994, character 44]. (Benton 1999)
23. Scapulocoracoid notch at anterior junction of scapula and coracoid: absent (0), present (1) [Parrish 1993, character 14]. (Benton 1999)
24. Forelimb-hindlimb length ratio: more than 0.55 (0), less than 0.55 (1) [Gauthier 1986; Sereno 1991, character BB; Juul 1994, character 45]. (Benton 1999)
25. Deltopectoral crest on humerus: rounded (0), subrectangular (1) [Sereno 1991, character 25; Juul 1994, character 51]. (Benton 1999)
26. Deltopectoral crest elongate and with apex situated at a point corresponding to less (0) or more (1) than 38 down the length of the humerus [Benton 1990; Juul 1994, character 59]. (Benton 1999)
27. Manual digit I (pollex-thumb): metacarpal I and ungual phalanx similar in size to those of manual digits II-V (0), metacarpal I robust and half or less the length of metacarpal II, first phalanx longer than metacarpal I or any other

- phalanx in the hand, lingual phalanx I much larger than other unguals (1) [Gauthier 1986; Benton 1990]. (Benton 1999)
28. Manual digits I-III: comparatively short with relatively blunt unguals on at least digits II and III (0), long penultimate phalanx with trenchant unguals on digits I-III (1) [Gauthier 1986; Juul 1994, character n69]. (Benton 1999)
29. Metacarpal III and IV bases: lie more or less in the same plane as the inner metacarpals (0), lie on palmar surfaces of manual digits III and IV respectively (1) [Gauthier 1986; Juul 1994, character 67]. (Benton 1999)
30. Manual digit IV: five (0), four (1), fewer than four (2) phalanges [Gauthier 1986; Benton & Clark 1988; Sereno 1993, character 10]. (Benton 1999)
31. Supra-acetabular crest on ilium: absent (0), present (1) character. [Gauthier 1986; Juul 1994, character 39]. (Benton 1999)
32. Brevis shelf on ventral surface of postacetabular part of ilium: absent (0), present (1) [Gauthier 1986; Juul 1994, character 47]
33. Acetabulum: laterally orientated (0), ventrally deflected (1), open ventrally (2) [Benton & Clark 1988; Juul 1994, character 36].
34. Acetabulum: imperforate (0), semi-perforated (1), extensively perforated (2) [Gauthier 1986; Juul 1994, character 60].
35. Acetabular antitrochanter on ilium and ischium: absent (0) present (1) [Sereno & Arcucci 1994a, character 12].
36. Pubis length: shorter than ischium (0), longer than ischium (1) [Benton & Clark 1988; Juul 1994, character 32].
37. Pubis length: less (0) or more (1) than three times width of acetabulum [Sereno 1991, character 13; Juul 1994, character 35].
38. Pubic acetabular margin, posterior portion: continuous with anterior portion (0), recessed (1) [Sereno 1991, character 14].
39. Pubic foot: absent (0), present with only a posterior expansion (1) or present with both an anterior and posterior expansion (2) [Gauthier 1986; Juul 1994, character 68].
40. Tibia-femur ratio: less than 1.0 (0), more than 1.0 (1) [Gauthier 1986; Sereno 1991, character 27; Juul 1994, character 48].
41. Femoral proximal head: rounded and not distinctly offset (0), subrectangular and distinctly offset (1) [Gauthier 1986; Juul 1994, character 61].
42. Femoral head articular surface: limited extent (0), extends under head (1) [Sereno & Arcucci 1994a, character 14].
43. Fossa trochanterica on femoral head: absent (0), present (1) [Novas 1996, character 7].
44. Femoral fourth trochanter: absent (0), moundlike (1), sharp (aliform) ridge (2) [Gauthier 1986; Benton & Clark 1988; Sereno 1991, character 35 (in part); Juul 1994, character 4; Bennett 1996, character 81].
45. Femoral lesser (anterior) trochanter: absent (0), weakly developed (1), a spike or crest (2) [Gauthier 1986; Novas 1992; Juul 1994, character 42].
46. Cnemial crest on tibia prominent: absent (0), present (1) [Benton & Clark 1988; Juul 1994, character 43].
47. Tibial distal end: unexpanded, or only slightly expanded, and rounded (0), transversely expanded, with a subrectangular end (1) [Gauthier 1986; Sereno 1991, p. 37].
48. Tibia with posterolateral flange, with receiving depression on dorsal aspect of astragalus: absent (0), present (1) [Novas 1992; Juul 1994, character 62].
49. Fibula and calcaneum shape: unreduced (0), fibula tapering and calcaneum reduced in size (1) [Gauthier 1986; Juul 1994, character 49].
50. Ventral astragalocalcaneal articular facet size: small (0), large (1) [Sereno 1991, character 11].
51. Astragalar tibial facet: concave (0), flexed/convex (1) [Sereno 1991, character 7; Juul 1994, character 28— wrongly given as 'fibular facet']
52. Ascending process of the astragalus on the anterior side of the tibia absent (0), height less than half the width of the astragalus (1), height more than half the width of the astragalus (2). 53. Astragalar posterior groove: present (0), absent (1). [Sereno 1991, character 28].
54. Astragalar anteromedial corner shape: obtuse (0), acute (1) [Sereno 1991, character CC; Juul 1994, character 55]
55. Calcaneal proximal articular face: convex or flat (0), concave (1) [Novas 1992; Juul 1994, character 63].
56. Calcaneal distal articular face: transverse width more character 47]. I'O) or less (1) than 35 of that of the astragalus [Sereno 1991, character DD; Juul 1994, character 56]
57. Calcaneal tuber: prominent (0), rudimentary or absent (1) [Gauthier 1986; Sereno 1991, character 29; Juul 1994, character 52].
58. Calcaneal tuber orientation: lateral (0), deflected more than 45° posterolaterally (1) [Sereno 1991, character 2; Juul 1994, character 24].
59. Calcaneal tuber shaft proportions; taller than broad (0), broader than tall (1) [Sereno 1991, character 9; Juul 1994, character 29].
60. Calcaneal tuber distal end: anteroposteriorly compressed (0), rounded (1) [Sereno 1991, character 10; Juul 1994, character 30].
61. Calcaneal tuber distal end, with dorsoventrally aligned median depression: absent (0), present (1) [Parrish 1993, character 21; Juul 1994, character 72].
62. Articular surfaces for fibula and distal tarsal IV on calcaneum: separated by a non-articular surface (0), continuous

- (1) [Serenó 1991, character 3; Juul 1994, character 25].
63. Hemicylindrical Calcaneal condyle: absent (0), present (1) [Serenó 1991, character 8; Juul 1994, character 27].
64. Distal tarsal 4: transverse width broader (0) or subequal (1) to distal tarsal 3 [Serenó 1991, character 30; Juul 1994, character 53].
65. Distal tarsal 4, size of articular facet for metatarsal V: more (0) or less (1) than half of lateral surface of distal tarsal 4 [Serenó 1991, character EE].
66. Metatarsus configuration: metatarsals diverging from ankle (0), compact metatarsus, with metatarsals I-IV tightly bunched [Benton & Clark 1988; Serenó 1991, character 31; Juul 1994, character 50].
67. Metatarsal midshaft diameters: I and V subequal or greater than II-IV (0), I and V less than II-IV (1) [Serenó 1991, character GG; Juul 1994, character 58].
68. Metatarsal I length, relative to length of metatarsal III: 50-75% (0), 85% or more (1) [Serenó 1991, character 36].
69. Metatarsals II-IV: shorter (0) or longer (1) than 50% of tibial length [Serenó 1991, character 32; Juul 1994, character 54].
70. Metatarsal V, 'hooked' proximal end: present (0), absent, and articular face for distal tarsal 4 subparallel to shaft axis (1) [Serenó 1991, character FF; Juul 1994, character 57].
71. Phalanges on pedal digit V: four (0), three (1), two (2), one (3), none (4) [Gauthier 1986; Benton & Clark 1988; Juul 1994, characters 40, 41 and 71].
72. Dorsal body osteoderms: absent (0), present as a single median row (1), a paramedian pair per cervicodorsal vertebra (2), more than one paramedian pair per cervico-dorsal vertebra (3) [Gauthier 1986; Benton & Clark 1988; Serenó 1991, character 12 (in part); Juul 1994, character 15].
73. Edentulous premaxilla absent (0) or present (1).
74. Edentulous maxilla absent (0) or present (1).
75. Posterior process of the premaxilla less than the length of the premaxilla (0) or greater than the length of the premaxilla (1).
76. Deep parabasisphenoid/basisphenoid recess absent (0) or present (1).
77. Mandibular fenestra less than half the length of the mandible (0) or greater than half the length of the mandible (1).
78. Presence of maxillary fenestra absent (0) or present (1) (Gauthier 1986)
79. Pleurocoels on cervical vertebrae absent (0), present as one pair (1) or present as two pairs (2). (Gauthier 1986)
80. Distal scapula expanded (0) or strap-like (1). (Gauthier 1986)
81. Metacarpal IV present (0) or absent (1). (Gauthier 1986)

3. Data Matrix

Euparkeria

00000000000000000000000000000?0000000000000100000000000000000000000012
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Proterochampsidae

00001000001000000000?00000000?00000000000001000000000000000000000000041
000000000

Parasuchia

100000000001000010000010000001000000000000010000011000000111011000000002
000000000

Ornithosuchidae

00000000000010000020000000000?10010111000002211100?000000111011000000012
000000000

Stagonolepididae

0000001000001001?0000010000002001001010000000010001000000111111000000002
0000?0000

Postosuchus

010001120011100010000110000000101101111000010000011000000111111001100011
000000000

Crocodylomorpha

000010010011100010010010000000001101110?00010000001000000111111000010022
000000000

Pterosauria

1000000000001001002011001001010000000001000000001?0010001?000?0101011020
000000??0

Lagerpeton

0???0????????????0????????????000000001100200001?0011011????10111101140????
??0??

Marasuchus

0????????????110000???110????1001110001011210001?0011011100010111101140??
???0??

Gallimimus

0111100011101111012011011111121102111011111221111?021111110001011110114?
110101111

Sauropodomorpha

0111100011101011012011011110121102111001111221110?011111110001011110113?
000000100

Ornithischia

0000100011101011002011011100021102111001111221111?011101110001011110114?
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Effigia

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1110000

Shuvosaurus

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1111000?

Arizonasaurus

0?00?1?00?0001??02?001??????101101111?00010????????????????????????00000
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Lotosaurus

0?0001000?0010101?2000?000?0?1101101110000020000011000000111111??00000?01
1??10000

Saurosuchus

010001000000100?1100001000000?101001111000010000011000000111111000000002
001000000

Tyrannosaurus

0111100011101111012011011111121102111011111221111?021111110001011110114?
000101111

Coelophysis

0111100011101111012011011111121102111011111221111?011111110001011110114?
000100200

References:

Benton, M.J. *Scleromochlus taylori* and the origin of dinosaurs and pterosaurs.

Philos. Trans. R. Soc. London. Bio. Sci. **1388**, 1423-1446 (1999).

Benton, M.J. & Clark, J.M. Archosaur phylogeny and the relationship of the

Crocodylia. In *The Phylogeny and Classification of the Tetrapods, 1: Amphibians,*

Reptiles, Birds (ed Benton, M.J.) 295-338 (Clarendon Press, Oxford, 1988).

Gauthier, J.A. 1986. Saurischian monophyly and the origin of birds. *Mem.*

California Academy Sci. **8**, 1-55 (1986).

Juul, L. The phylogeny of basal archosaurs. *Palaeontologia Africana* **31**, 1-31 (1994).

Novas, F.E. Phylogenetic relationships of the basal dinosaurs, the Herrerasauridae.

Palaeont. **35**, 51-62 (1992).

Parrish, J.M. Phylogeny of the Crocodylotarsi, with reference to archosaurian and

crurotarsan monophyly. *J. Vert. Paleont.* **13**, 287-308 (1993).

Sereno, P.C. Basal archosaurs: phylogenetic relationships and functional

implications. *J. Vert. Paleont.* (Suppl.) **11**, 1-51 (1991).

- Sereno, P.C. & Arcucci, A.B. Dinosaurian precursors from the Middle Triassic of Argentina: *Marasuchus lilloensis*, gen. nov. *J. Vert. Paleont.* **14**, 53-73 (1994).
- Sereno, P.C. & Novas, F.E. The skull and neck of the basal theropod *Herrerasaurus ischigualastensis*, *J. Vert. Paleont.* **13**, 451-476 (1993).
- Sorenson, M.D. *TreeRot*, version 2. Boston, MA: Boston University (1999).
- Swofford, D.L. *PAUP** (*Phylogenetic Analysis Using Parsimony and Other Methods*), Version 4.10b. Sunderland, MA: Sinauer Associates, Inc (2000).