Deciduous dentition and dental eruption of Hyainailouroidea (Hyaenodonta, "Creodonta," Placentalia, Mammalia)

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APPENDIX 2.

Descriptions of the characters used in this analysis with the source of the character or comparable characters from other analyses

Appendix 2

Lower Dentition

Deciduous Lower Dentition

1) dP_3 paraconid height: paraconid indistinct (0); paraconid present lower than talonid (1); paraconid present and taller than talonid (2).
2) dP_4 paraconid height: lower than half protoconid height (0); half protoconid height or taller (1).
3) dP_4 metaconid height: lower than half paraconid height (0); half paraconid height or taller (1). (compare with Bastl et al. 2014; Character 12)
4) dP_4 talonid basin cusps: Entoconid and hypoconid present (0); Only hypoconid present (1). (compare with Bastl et al. 2014; Character 13)
5) dP_4 talonid length proportion: More than 1/3 length of entire tooth (0); less than 1/3 length of entire tooth (1).

Adult Lower Dentition

6) First mental foramen position: inferior to P_1 (0); inferior to P_2 (1). (Solé et al., 2014; Character 0)
7) Second mental foramen position: inferior to P_3 (0); inferior to P_4 (1). (Solé et al., 2014; Character 1)
8) P_1: present (0); absent (1). (Solé et al., 2014; Character 2)
9) P_1 root number: two roots (0); one root (1). (Polly, 1996; Character 13; Zack, 2011; Character 2; Solé et al., 2014; Character 2)
10) P_2 talonid mesiodistal length: absent to short (0); elongate with distinct inflection separating postprotocristid from talonid (1). (modified Polly, 1996; Character 3; Egi et al., 2005; Character 34; Solé et al., 2014; Character 5)
11) P_2 to P_3 relative mesiodistal length: P_2 shorter than P_3 (0); P_2 as long or longer than P_3 (1). (Egi et al., 2005; Character 29; Solé et al., 2014; Character 6)
12) P_3 inclination: perpendicular to horizontal ramus, tooth forms isosceles triangle in buccal view (0); tooth inclines distally, preprotocristid mesially convex (1).
13) P_3 buccolingual width relative to mesiodistal length: width 33% of length (0); width 50% of length (1); width more than 50% of length (2).
14) P_3 paraconid morphology: absent or small (0); developed with distinct postparacristid (1). (modified Polly, 1996; Character 6; Egi et al., 2005; Character 35; Solé et al., 2014; Character 7)
15) P_3 talonid mesiodistal length: short, cusp-like (0); long, distinct inflection separating postprotocristid from talonid (1). (modified Polly, 1996; Character 4; Egi et al., 2005; Character 37; Solé et al., 2014; Character 8)
16) P_3 entoconid: absent (0); present (1). (Solé et al., 2014; Character 9)
17) P_3 to P_4 relative mesiodistal length: P_3 shorter than P_4 (0); P_3 as long or longer than P_4 (1). (Egi et al., 2005; Character 31; Solé et al., 2014; Character 10)
18) P_4 inclination: perpendicular to horizontal ramus, tooth forms isosceles triangle in buccal view (0); tooth inclines distally, preprotocristid mesially convex (1).

19) P_4 paraconid morphology: present but poorly developed (0); paraconid well-developed (1); paraconid indistinct to absent (2). (modified Polly, 1996; Character 7; Solé et al., 2014; Character 11)
20) P_4 metaconid: absent (0); present, usually weakly developed or ridge-like (1). (modified Solé et al., 2014; Character 12)
21) P_4 entoconid: absent (0); present (1). (Solé et al., 2014; Character 14)
22) P_4 hypoconid height: short, less than 33% of protoconid height (0); tall, more than 33% protoconid height (1). (modified Solé et al., 2014; Character 16)
23) P_4 talonid basin: buccolingually compressed and shallow (0); buccolingually wide and deep (1); absent (2).
24) P_4 precingulid and postcingulid: absent (0); present (1). (modified Solé et al., 2014; Character 18)
25) P_4 relative height: mesiodistally longer than height (0); mesiodistally shorter than height (1); mesiodistal length and height subequal (2).
26) P_4 height relative to molars: shorter than all molars (0); taller than M_1 only (1); taller than M_2 (2).
27) P_5 presence: present (0); absent (1).
28) M_1 and M_2 entoconid morphology: well developed or bulbous (0); crestiform with visible apex (1); undifferentiated entocristid (2). (modified Zack, 2011; Charcter 23; Solé et al., 2014; Character 27)
29) M_1 and M_2 talonid depth: deep (0); shallow (1). (modified Zack, 2011; Character 25; Solé et al., 2014; Character 29)
30) M_2 entocristid in lingual view: parallels hypocristid (0); present, stops before metaconid (lower than hypocristid) (1); weak ridge or absent (2).
31) M_3 entocristid: parallels hypocristid (0); present, stops before metaconid (lower than hypocristid) (1); weak ridge or absent (2).
32) M_1 and M_2 talonid buccolingual width: narrow, less than 80% width of trigonid (0); wide, greater than 80% trigonid (1). (modified Solé et al., 2014; Character 28)
33) M_1 mesiodistal length relative to M_2: M_1 length subequal or longer than M_2 (0); M_1 length less than M_2 (1). (modified Zack, 2011; Character 26; Solé et al., 2014; Character 31)
34) M_1–M_3 trigonid height relative to talonid: trigonid tall on all molars, talonid less than 50% of trigonid height (0); trigonid low on all molars, talonid more than 50% of trigonid height (1); trigonid low on M_1 and M_2 (2). (modified Solé et al., 2014; Character 32)
35) M_3 postprotocristid distal trend in buccal view: slopes mesial to distal (0); perpendicular to alveolus (1); slopes distal to mesial (overhangs talonid) (2).
36) M_2 cristid obliqua orientation relative to mesiodistal axis: lingual to buccal trend (0); parallel to mesiodistal axis (1); buccal to lingual trend (2). (compare to Zack, 2011; Character 21)
37) M_2 and M_3 paraconid position relative to protoconid, angle defined relative to mesiodistal axis of mandible: directly mesial to protoconid,15 degrees (0); slightly lingual paraconid, 15.1 to 45 degree angle (1); strong lingual position, 45.1 to 60 degrees (2). *Ordered*
38) M_3 postparacristid mesial to distal trend: steep slope to preprotocristid ("V" shaped acute angle) (0); shallow slope to preprotocristid (forms right angle with preprotocristid) (1); forms obtuse angle with preprotocristid (2). *Ordered*
39) M_2 and M_3 paraconid height relative to protoconid: paraconid significantly shorter than protoconid (0); paraconid slightly shorter than protoconid (1); paraconid and protoconid subequal in height (2).

40) M_3 postparacristid to premetacristid in lingual view: postparacristid shorter than premetacristid (0); postparacristid subequal to premetacristid (1); postparacristid longer than premetacristid (2).
41) M_3 postparacristid length to preprotocristid in buccal view (carnassial blade proportions): postparacristid much shorter than preprotocristid (30%) (0); postparacristid half length of preprotocristid (1); postparacristid more than half preprotocristid length (2); subequal lengths (3).
42) M_2 and M_3 metaconid expression: connate and connects to paraconid base (0); connate, separated from paraconid (1); fold or ridge (2); absent (3). *Ordered*
43) M_1 metaconid: taller than paraconid (0); subequal to paraconid (1); shorter than paraconid or absent (2). *Ordered* (compare to Polly, 1996; Character 18)
44) M_2 metaconid: taller than paraconid (0); subequal to paraconid (1); shorter than paraconid or absent (2). *Ordered* (compare to Polly, 1996; Character 18)
45) M_3 metaconid: taller than paraconid (0); subequal to paraconid (1); shorter than paraconid or absent (2). *Ordered* (compare to Polly, 1996; Character 19)
46) M_2 mesiodistal length to M_3 length: M_2 shorter than M_3 (0); M_2 subequal to M_3 (1); M_2 longer than M_3 (2); M_3 absent (3). *Ordered* (compare to Zack, 2011; Character 30)
47) M_2 talonid mesiodistal length (% of total mesiodistal length): >40% (0); 40% to 30% (1); 29% to 21% (2); <20% (3). *Ordered*
48) M_3 talonid mesiodistal length (% of total mesiodistal length): >40% (0); 40% to 30% (1); 29% to 21% (2); <20% (3). *Ordered*
49) M_3 talonid: present, bears hypoconid and hypoconulid (0); present, only one distinct cusp (1); absent (2). *Ordered*
50) M_2 buccal talonid margin: steep slope distal to mesial (0); shallow slope distal to mesial (1); parallel to alveolus (2); slopes mesial to distal (3). *Ordered*
51) M_3 buccal talonid margin angle from highest point to lowest: steep slope distal to mesial (0); shallow slope distal to mesial (1); parallel to alveolus (2); slopes mesial to distal (3). *Ordered*
52) M_1–M_3 ectocingulid: weakly expressed to absent (0); distinct (1). (modified Solé et al., 2014; Character 34)
53) M_1–M_3 postcingulid: absent (0); present (1). (modified Solé et al., 2014; Character 35)
54) M_1–M_3 ectocingulid to postcingulid connection: separated (0); fused (1). (modified Solé et al., 2014; Character 36)
55) M_3 talonid buccolingual width relative to M_2 talonid width: equal (0); narrower (1).
56) Mandible inflection anterior to angular process (Solé et al., 2015): present (0); absent (1).
57) Angular process morphology: distinct process with medial inflection (0); gently curved process in line with mandibular corpus (1); ventral inflection (2).
58) Mandibular condyle position: superior to M_3 alveolus (0); directly distal to M_3 alveolus (1); inferior to M_3 alveolus (2).
59) Coronoid process shape: tall, anterior and posterior slopes similar (0); tall, posterior slope concave (1); low, rounded (2).
60) Anterior coronoid angle relative to horizontal ramus: near vertical, 90 to 100 degrees (0); slight posterior inclination, 100 to 110 degrees (1); strong posterior inclination, greater than 110 degrees (2).
61) Masseteric fossa depth: deeply excavated with strong anterior angle, inferior margin well-defined (0); rounded anterior margin, little inferior definition (1); deep fossa but poorly defined inferior margin (2).

Upper Dentition

Deciduous Upper Dentition

62) dP^3 parastyle mesiodistal length: more than half metastyle length (0); less than half metastyle length (1).
63) dP^3 metacone-paracone fusion: metacone distinct cusp (premetacrista slopes to metacone apex; See *Pterodon dasyuroides*) (0); metacone fused to paracone (premetacrista sub-horizontal; See *Apterodon*) (1).
64) dP^3 paracone morphology: pre- and postparacrista similar in slope (apex isosceles triangle in buccal view) (0); preparacrista distally inclined (apex closer to right triangle in buccal view) (1).
65) dP^3 metastyle notch: Small inflection between postmetacrista and metastyle (0); deep notch between postmetacrista and metastyle (1).
66) dP^3 Protocone prominence: mesiodistal length shorter than buccolingual width (narrow) (0); mesiodistal length equal to or longer than buccolingual width (wide) (1). (modified from Bastl et al. 2014; Character 2)
67) dP^3 lingual cingulum: present (distinct lingual connection between parastyle and protocone) (0); absent (faint or no connection between parastyle and protocone) (1). (modified from Bastl et al. 2014; Character 4)
68) dP^4 main cusp height: paracone taller than metacone (0); Paracone subequal to metacone (1); Paracone shorter than metacone (2). *Ordered* (Modified from Bastl et al., 2014; Character 6)
69) dP^4 protocone orientation: Protocone projects mesially to parastyle margin (0); Protocone projects lingually and does not align with parastyle (1).
70) dP^4 ectoflexus: Deep and distinct inflection between metacone and metastyle (0); Indistinct or shallow inflection between metacone and metastyle (1).

Adult Upper Dentition

71) Upper incisor count: 4 or more (0); 3 or fewer (1).
72) Lateral-most upper incisor: incisiform, similar to mesial incisor (0); caniniform (1).
73) P^3 lobe of the protocone: absent (0); present but small (1); protocone well-developed, individuated (2). (modified Polly, 1996; Charcter 9; Egi et al., 2005; Character 4; Solé et al., 2014; Character 39)
74) P^3 root number: two roots (0); three roots (1). (Solé et al., 2014; Character 40)
75) P^3 contact with P^4 parastyle: P^3 contacts or aligned with P^4 parastyle (0); P^3 framed by P^4 parastyle (1).
76) P^4 parastyle: distinct (0); very reduced to absent (1). (modified Egi et al., 2005; Character 8; Zack, 2011; Character 34; Solé et al., 2014; Character 41)
77) P^4 protocone alignment: transversely aligned with paracone (0); mesially shifted relative to paracone (1). (Zack, 2011; Character 36; Solé et al., 2014; Character 42)
78) P^4 protocone morphology: bulbous and distinct from paracone (0); weak separation from paracone, shelf to cingulum-like (1). (modified Polly, 1996; Character 10; Egi et al., 2005; Character 6/7; Solé et al., 2014; Character 43)

79) P^4 metastylar blade (=postmetacrista): short (0); elongate (1). (modified Egi et al., 2005; Character 9; Zack, 2011; Character 35; Solé et al., 2014; Character 45)
80) P^4 metastyle contact with M^1: P^4 metastyle braced buccally by M^1 parastyle (0); P^4 metastyle contacts mesial aspect of M^1 parastyle (1).
81) M^1 and M^2 metastyle blade curvature: straight with carnassial notch (0); postmetacrista arcuate, no carnassial notch (1). (Zack, 2011; Character 42; Solé et al., 2014; Character 46)
82) M^1 and M^2 metastyle blade length: short, carnassial blade shorter than postmetacrista (0); intermediate, subequal to slightly longer than postmetacrista (1); elongate, greater than 1.5x length of postmetacrista (2). *Ordered* (Egi et al., 2005; Character 21; Solé et al., 2014; Character 47)
83) M^1 mesiodistal length relative to M^2: M^1 subequal or longer than M^2 (0); M^1 shorter than M^2 (1). (modified Solé et al., 2014; Character 50)
84) M^1 and M^2 premetaconule crista: present (0); absent (1). (modified Solé et al., 2014; Character 51)
85) M^1 and M^2 conules: metaconule and paraconule present (0); only paraconule present (1); metaconule and paraconule absent (2) (modified Solé et al., 2014; Character 53)
86) M^1 and M^2 precingulum and postcingulum: absent (0); present (1). (modified from Polly, 1996; Character 20; Egi et al., 2005; Character 26; Solé et al., 2014; Character 54)
87) M^1 and M^2 precingulum and postcingulum connection: separated (0); fused lingually (1). (Solé et al., 2014; Character 55)
88) M^1 and M^2 protocone morphology: Triangular, mesial and distal margins angled (0); parallel mesial and distal margins (1). (modified Egi et al., 2005; Character 14)
89) M^1 and M^2 protocone position relative to paracone and metacone: centered (0); mesially shifted (1). (modified Egi et al., 2005; Character 15; Solé et al., 2014; Character 56)
90) M^1 and M^2 metacone mesiodistal length relative to paracone: shorter (0); subequal (1); longer (2). (modified Egi et al., 2005; Character 12)
91) M^1 and M^2 metacone coronal cross section: circular (0); ovoid, slightly compressed buccolingually (1); ellipsoid, strong buccolingual compression (2).
92) M^2 paracone compression: conical, rounded base (0); ovoid (slight buccolingual compression) (1); ellipsoid (strong buccolingual compression) (2).
93) M^1 and M^2 paracone and metacone separation: separated to base (0); fused between base and half of height (1); almost completely fused (2). *Ordered* (modified Polly, 1996; Character 28; Egi et al., 2005; Character 10; Zack, 2011; Character 40)
94) M^1 and M^2 paracone height: paracone taller than metacone (0); paracone as tall as metacone (1); paracone shorter than metacone (2). *Ordered* (modified Egi et al., 2005; Character 11; Zack, 2011; Character 41; Solé et al., 2014; Character 48)
95) M^1 and M^2 protocone height: shorter than paracone/metacone separation (0); same height as paracone/metacone separation (1); subequal to paracone/metacone apices (2). (compare to Zack, 2011; Character 49)
96) M^2 parastyle: absent (0); present and shelf-like (1); present and distinct cusp (2). (modified Egi et al., 2005; Character 19)
97) M^1 parastyle compared to M^2: M^1 parastyle relatively shorter than M^2 parastyle (0); parastyle on M^1 and M^2 similar (1).
98) M^1 and M^2 buccal cingulum: absent (0); weak ridge along metastyle base (1); prominent shelf forms shallow basin between metastyle and cingulum (2). (modified Egi et al., 2005; Character 16/17)

99) M^2 ectoflexus: strong, strong indentation (0); weak, slight curve (1); absent, straight (2). (modified Egi et al., 2005; Character 18)
100) Ectoflexus depth on M^1 and M^2: M^1 ectoflexus shallower than M^2 (0); same relative depth between M^1 and M^2 (1); M^2 lacks metastyle (no ectoflexus) (2). *Ordered* (compare to Zack, 2011; Character 52)
101) M^3 metacone: present (0); absent (1). (modified Polly, 1996; Character 15; Zack, 2011; Character 53; Solé et al., 2014; Character 58)

Cranial Characters

102) Nuchal crest morphology: medial to lateral trend from apex to mastoid (0); dorsolateral margin tapers medially with thin connection to exoccipital (1); lateral margins trend medially, very weak ridge connects to exoccipital (2). *Ordered* (modified Polly, 1996; Character 35)
103) Facial wing of the lacrimal: extensive (larger than orbit diameter) (0); moderate (slightly longer than orbit diameter) (1); reduced (shorter than orbit diameter) (2). (modified Polly, 1996; Character 36)
104) Foramen rotundum size: slightly larger than foramen ovale (0); much larger than foramen ovale (1). (Polly, 1996; Character 39)
105) Palatal rugosity or torus at distal margin of palate: well-expressed (0); smooth (1).
106) Zygomatic arch contact: short contact between zygomatic and squamosal (0); extensive contact between zygomatic and squamosal (1).
107) Superior squamosal morphology: superior and inferior margins parallel (0); torsion along superior margin (1).
108) Foramen ovale orientation: anterior orientation (0); palatal orientation (1).
109) Exoccipital condyle position: tall, lateral placement around foramen magnum (0); ventral placement around foramen magnum (1).
110) Notch between occipital condyles: ring-like with no rostral excavation (0); rounded indentation with condyles meeting medially below foramen magnum (1); deep excavation with occipital "processes" following notch (2).
111) Postmandibular process: vertical orientation (0); strong anterior curvature (1).
112) Posterior orbital process: present, strong expression (0); present, weak with frontal "peaked" (1); absent (2).
113) Frontal furrow: absent or indistinct (0); present and well-defined (1).
114) Palatine and pterygoid medial contact: parallel posterior to palatine torus (0); palatines trend medially or partially fuse (1); fused entire extent of palatines (2).
115) Pterygoid size: broad, ventral projection anteriorly extensive (0); short anterior extent, trends medially (1).
116) Frontoparietal suture in dorsal view: steep constriction (0); gentle curvature (1).
117) Lateral expansion of the mastoid process (Solé et al., 2015): projects to midpoint of mandibular fossa (0); projects beyond mandibular fossa (1).
118) Mastoid/paroccipital process: short tubercle (0); well-defined, prong-like process (1).
119) Process at maxilla/jugal suture (Solé et al., 2015): present (0); absent (1).
120) Squamosal constriction in dorsal view: present, squamosal does not extend laterally (0); absent, squamosal expanded laterally (1).

121) Squamosal ventral projection: same transverse plane as petrosal (0); ventral to petrosal (1).
122) Posterior braincase: broad lateral expansion (0); narrow (1).
123) Subarcuate fossa morphology (Polly, 1996): cup-shaped (see *Pterodon*) (0); shallow and horseshoe-shaped (see *Hyaenodon*) (1).
124) Bridge of the stylomastoid foramen primitivum: absent or slender (0); robust (1); roofed over with secondary stylomastoid foramen (2). (Polly, 1996; Character 40)
125) Mastoid sinus lateral to foramen stylomastoid primitivum: absent (0); present (1). (Polly, 1996; Character 41)
126) Ridge of bone dividing posterior petrosal sinus from foramen stylomastoid primitivum (Polly, 1996): present (0); reduced to absent (1). (Polly, 1996; Character 42)
127) Posterior petrosal sinus: absent (0); small (1); greatly inflated (2). (Polly, 1996; character 43)

Postcrania

Humerus

128) Humerus cross-section above brachial flange: triangular (0); rounded (1). (Polly, 1996; Character 44)
129) Brachial flange expression: medium (0); enlarged (1); reduced (2). (Polly, 1996; Character 47)
130) Entepicondylar foramen: present, rounded (0); present, elongate (1); absent (2).
131) Medial epicondyle: large (bulbous) (0); reduced (elongate) (1).
132) Capitulum morphology: rounded, clearly separated (0); cylindrical (1).
133) Greater tubercle of the humerus: prominent, taller than humeral head (0); subequal to height of humeral head (1).

Ulna

134) Proximal trochlear notch orientation: lateral position on shaft (0); medial position on shaft (1).
135) Radial notch orientation: curved and faces laterally (0); flattened and faces anteriorly (1). (Polly, 1996; Character 47)
136) Olecranon process length: longer than trochlear notch (0); subequal or shorter than trochlear notch (1).
137) Olecranon process orientation: projects medially (0); projects ventrally (1).

Femur

138) Third trochanter of femur: large (0); small (1). (modified Polly, 1996; Character 50)

Astragalus

139) Astragalar foramen: large (0); reduced (0). (Polly, 1996; Character 51)
140) Astragalar condyles divided by: shallow depression (0); well-defined fossa or groove (1)

141) Astragalar condyle orientation: oblique relative to astragalar neck (0); parallel to astragalar neck (1).
142) Astragalar head relative to condyles: horizontal orientation (0); slight vertical orientation (1). (Polly, 1996; Character 53)
143) Sustentacular facet connection to astraglar head: clearly separated from astragalar head (0); grades into articulation of astragalar head (1).
144) Sustentacular facet position on astragalar neck: plantar astragalar neck (0); medial astragalar neck (1).

Calcaneum

145) Peroneal tubercle: distinct and separated from cuboid facet (0); part of a flange that grades to cuboid facet (1).
146) Cuboid facet inclination: perpendicular to calcaneal neck (0); plantar inclination (1).
147) Calcaneal neck trend: dorsal and plantar margins parallel (0); tapers proximally to calcaneal tuberosity (1).
148) Astragalar facet angle: oblique orientation to calcaneal neck (0); parallels calcaneal neck (1). (modified Polly, 1996; Character 58)

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