**List of characters in Zhu Y. et al. (2022)**

*Skeletal tissues*

1. Tessellate prismatic calcified cartilage: (0) absent; (1) present.

Coates & Sequeira (2001a,b); Maisey (2001); Brazeau (2009); Davis et al. (2012), Character 1; Giles et al. (2015), Character 1; Choo et al. (2017), Character 1; King et al. (2017), Character 1; Castiello (2018), Character 1; Zhu Y. et al. (2022), Character 1.

1. Prismatic calcified cartilage: (0) single layered; (1) multi-layered.

Maisey (2001), Character 17; Pradel et al. (2011), Character 0; Giles et al. (2015), Character 2; Choo et al. (2017), Character 253; King et al. (2017), Character 2; Castiello (2018), Character 2; Zhu Y. et al. (2022), Character 2.

1. Extensive calcified cartilage: (0) absent; (1) present.

Coates et al. (2018), Character 4; Zhu Y. et al. (2022), Character 3.

1. Perichondral bone: (0) present; (1) absent.

Janvier (1996); Donoghue & Aldridge (2001); Brazeau (2009); Davis et al. (2012), Character 2; Choo et al. (2017), Character 2; King et al. (2017), Character 3; Castiello (2018), Character 3; Zhu Y. et al. (2022), Character 4.

1. Extensive endochondral ossification: (0) absent; (1) present.

Forey (1980); Gardiner (1984); Brazeau (2009); Davis et al. (2012), Character 3; Choo et al. (2017), Character 3; King et al. (2017), Character 4; Castiello (2018), Character 4; Zhu Y. et al. (2022), Character 5.

1. Three-layered exoskeleton: (0) absent; (1) present.

King et al. (2017), Character 6; Castiello (2018), Character 6; Zhu Y. et al. (2022), Character 6.

Score changed from 0 to 1 for *Anglaspis maccoulloughi* (Keating et al., 2015).

1. Cephalic dermoskeletal bone: (0) cellular; (1) acellular.

King et al. (2017), Character 7; Castiello (2018), Character 7; Zhu Y. et al. (2022), Character 7.

1. Perforated horizontal lamina in the sensory line canals and vascular system: (0) absent; (1) present.

King et al. (2017), Character 8; Castiello (2018), Character 8; Zhu Y. et al. (2022), Character 8.

1. Superficial glassy layer of dermal armour: (0) absent; (1) present.

King et al. (2017), Character 18; Castiello (2018), Character 18; Zhu Y. et al. (2022), Character 9.

1. Dentinous tissue: (0) absent; (1) present.

Donoghue & Aldridge (2001); Brazeau 2009; Davis et al. (2012), Character 4; Choo et al. (2017), Character 4; King et al. (2017), Character 10; Zhu Y. et al. (2021), Character 9; Castiello (2018), Character 10; Zhu Y. et al. (2022), Character 10.

1. Dentine kind: (0) mesodentine; (1) semidentine; (2) orthodentine.

Donoghue & Aldridge (2001); Brazeau 2009; Davis et al. (2012), Character 5; Choo et al. (2017), Character 5; King et al. (2017), Character 12; Castiello (2018), Character 12; Zhu Y. et al. (2022), Character 11.

1. Plicidentine: (0) absent; (1) simple or generalized polyplacodont.

Zhu *et al.* (2009, Character 152), and references therein; Zhu et al. (2013), Character 141; Giles et al. (2015), Character 86; Choo et al. (2017), Character 137; King et al. (2017), Character 343; Castiello (2018), Character 335; Zhu Y. et al. (2022), Character 12.

1. Enamel(oid) present on dermal bones and scales: (0) absent; (1) present.

Giles et al. (2015), Character 5; Choo et al. (2017), Character 254; King et al. (2017), Character 15; Castiello (2018), Character 15; Zhu Y. et al. (2022), Character 13.

1. Enamel: (0) single-layered; (1) multi-layered.

Giles et al. (2015), Character 6; Choo et al. (2017), Character 255; King et al. (2017), Character 16; Castiello (2018), Character 16; Zhu Y. et al. (2022), Character 14.

1. Enamel layers: (0) applied directly to one another (ganoine); (1) separated by layers of dentine.

Giles et al. (2015), Character 7; Choo et al. (2017), Character 256; King et al. (2017), Character 17; Castiello (2018), Character 17; Zhu Y. et al. (2022), Character 15.

1. Enamel(oid) on teeth: (0) absent; (1) present.

Giles et al. (2015), Character 79; Choo et al. (2017), Character 284; King et al. (2017), Character 365; Castiello (2018), Character 355; Zhu Y. et al. (2022), Character 16.

1. Cap of enameloid restricted to upper part of teeth (acrodin): (0) absent; (1) present.

Zhu *et al.* (2009, Character 151), Friedman & Brazeau (2010, Character 46), and

references therein; Zhu et al. (2013), Character 140; Giles et al. (2015), Character 80; Choo et al. (2017), Character 136; King et al. (2017), Character 342; Castiello (2018), Character 334; Zhu Y. et al. (2021), Character 78; Zhu Y. et al. (2022), Character 17.

1. Galeaspidin: (0) absent; (1) present.

King et al. (2017), Character 9; Castiello (2018), Character 9; Zhu Y. et al. (2022), Character 18.

1. Extensive pore canal network: (0) absent; (1) present.

Giles et al. (2015), Character 8; Choo et al. (2017), Character 257; King et al. (2017), Character 5; Castiello (2018), Character 5; Zhu Y. et al. (2022), Character 19.

1. Resorption and redeposition of odontodes: (0) lacking or partially developed; (1) developed.

Zhu et al. (2009, Character 148), and references therein; Zhu et al. (2013), Character 139; Choo et al. (2017), Character 157; King et al. (2017), Character 14; Castiello (2018), Character 14; Zhu Y. et al. (2022), Character 20.

1. Generations of odontodes: (0) buried; (1) areally growing; (2) resorbed.

Zhu Y. et al. (2021), Character 17; Zhu Y. et al. (2022), Character 21.

Score changed from 1 to – for Galeaspida, from 2 to – for *Eusthenopteron*.

1. Enamel and pore canals: (0) enamel absent from inner surface of pores; (1) enamel lines portions of pore canal.

Zhu Y. et al. (2021), Character 232; Zhu Y. et al. (2022), Character 22.

1. Relative size of cosmine pores: (0) small; (1) large.

King et al. (2017), Character 270; Castiello (2018), Character 264; Zhu Y. et al. (2022), Character 23.

1. Rostral tubuli: (0) absent; (1) present.

Zhu et al. (2009, Character 150), and references therein; Zhu et al. (2013), Character 142; Choo et al. (2017), Character 158; King et al. (2017), Character 67; Castiello (2018), Character 69; Zhu Y. et al. (2022), Character 24.

1. Bone cell lacunae in body scale bases: (0) present; (1) absent.

Giles et al. (2015), Character 11; Choo et al. (2017), Character 259. King et al. (2017), Character 11; Castiello (2018), Character 11; Zhu Y. et al. (2022), Character 25.

Score changed from 0 to 1 for Galeaspida.

1. Main dentinous tissue forming fin spine: (0) osteodentine; (1) orthodentine.

Giles et al. (2015), Character 12; Choo et al. (2017), Character 260; King et al. (2017), Character 13; Castiello (2018), Character 13; Zhu Y. et al. (2022), Character 26.

*Squamation & related structures*

1. Lepidotrichia or lepidotrichia-like scale alignment: (0) present; (1) absent.

Davis et al. (2012), Character 7; Choo et al. (2017), Character 6; Zhu Y. et al. (2022), Character 27.

1. Differentiated lepidotrichia: (0) absent; (1) present.

Giles et al. (2015), Character 14; Choo et al. (2017), Character 261; King et al. (2017), Character 469; Castiello (2018), Character 458; Zhu Y. et al. (2022), Character 28.

1. Epichordal lepidotrichia in caudal fin: (0) absent; (1) present.

Zhu *et al.* (2009, Character 142), and references therein; Zhu et al. (2013), Character 146; Giles et al. (2015), Character 236; Choo et al. (2017), Character 140; King et al. (2017), Character 470; Castiello (2018), Character 459; Zhu Y. et al. (2022), Character 29.

1. Barbed lepidotrichial segments: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 263; Zhu Y. et al. (2022), Character 30.

1. Fringing fulcra: (0) absent; (1) present.

Zhu et al. (2009, Character 151), Friedman & Brazeau (2010, Character 46), and references therein; Zhu et al. (2013), Character 145; Choo et al. (2017), Character 252; King et al. (2017), Character 467; Castiello (2018), Character 456; Zhu Y. et al. (2022), Character 31.

Taxa without lepidotrichia are coded as ‘logical impossibility’.

1. Scute-like ridge scales (basal fulcra): (0) absent; (1) present.

Giles et al. (2015), Character 27; Choo et al. (2017), Character 264; King et al. (2017), Character 471; Castiello (2018), Character 460; Zhu Y. et al. (2022), Character 32.

1. Flank scale alignment: (0) vertical rows; (1) oblique rows or hexagonal/rhombic packing; (2) disorganised.

Davis et al. (2012), Character 14; Choo et al. (2017), Character 13; King et al. (2017), Character 491; Castiello (2018), Character 481; Zhu Y. et al. (2022), Character 33.

1. Scales: (0) macromeric; (1) micromeric.

King et al. (2017), Character 496; Castiello (2018), Character 485; Zhu Y. et al. (2022), Character 34.

1. Body scale growth pattern: (0) monodontode (monocuspid); (1) polyodontode (multicuspid).

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 8; Choo et al. (2017), Character 7; Coates et al. (2018), Character 9; King et al. (2017), Character 485; Castiello (2018), Character 474; Zhu Y. et al. (2022), Character 35.

The coding of *Helodus* is changed from 1 to 0 (Coates et al., 2018).

1. Body scale growth concentric: (0) absent; (1) present.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 9; Choo et al. (2017), Character 8; King et al. (2017), Character 486; Castiello (2018), Character 475; Zhu Y. et al. (2022), Character 36.

1. Body scales with peg-and-socket articulation: (0) absent; (1) present.

Gardiner (1984); Coates (1999); Brazeau (2009); Davis et al. (2012), Character 10; Choo et al. (2017), Character 9; King et al. (2017), Character 487; Castiello (2018), Character 476; Zhu Y. et al. (2022), Character 37.

1. Peg on rhomboid scale: (0) longer than wide (narrow); (1) wider than long (broad).

Zhu *et al.* (2009, Character 139), and references therein; Zhu et al. (2013), Character 143; Giles et al. (2015), Character 19; Choo et al. (2017), Character 138; King et al. (2017), Character 492; Castiello (2018), Character 477; Zhu Y. et al. (2022), Character 38.

1. Body scale profile: (0) distinct crown and base demarcated by a constriction (neck); (1) flattened.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 11; Choo et al. (2017), Character 10; King et al. (2017), Character 488; Castiello (2018), Character 478; Zhu Y. et al. (2022), Character 39.

1. Body scales with bulging base: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 12; Choo et al. (2017), Character 11; King et al. (2017), Character 489; Castiello (2018), Character 479; Zhu Y. et al. (2022), Character 40.

1. Body scales with flattened base: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 13; Choo et al. (2017), Character 12; King et al. (2017), Character 490; Castiello (2018), Character 480; Zhu Y. et al. (2022), Character 41.

The character states in Brazeau (2009, Character 13) were reversed.

1. Relationship of crown and base of isolated trunk scale: (0) crown fully covering the base; (1) crown sitting on the bony base, with an exposed depressed field overlapped by adjacent scale in articulation.

Choo et al. (2017), Character 336; Zhu Y. et al. (2022), Character 42.

1. Profile of scales with constriction between crown and base: (0) neck similar in width to crown; (1) neck greatly constricted, resulting in anvil-like shape.

Giles et al. (2015), Character 22; Choo et al. (2017), Character 262; King et al. (2017), Character 494; Castiello (2018), Character 483; Zhu Y. et al. (2022), Character 43.

1. Body scales with basal canal or open basal vascular cavity (basal pores in scales): (0) absent; (1) present.

Choo et al. (2017), Character 263; Coates et al. (2018), Character 15; King et al. (2017), Character 495; Castiello (2018), Character 484; Zhu Y. et al. (2022), Character 44.

1. Neck canal: (0) absent; (1) present.

Coates et al. (2018), Character 16; Zhu Y. et al. (2022), Character 45.

1. Keel of scale: (0) absent; (1) present.

Cui et al. (2019), Character 343; Zhu Y. et al. (2022), Character 46.

1. Posterior ledge (or secondary keel) of scale: (0) absent; (1) weak; (2) developed.

Cui et al. (2019), Character 344; Zhu Y. et al. (2022), Character 47.

1. Anteroventral process of scale: (0) absent; (1) present.

Cui et al. (2019), Character 345; Zhu Y. et al. (2022), Character 48.

1. Ventral process of scale: (0) present; (1) absent.

Cui et al. (2019), Character 346; Zhu Y. et al. (2022), Character 49.

1. Anterodorsal process on scale: (0) absent; (1) present.

Zhu *et al.* (2009, Character 140), and references therein; Zhu et al. (2013), Character 144; Giles et al. (2015), Character 20; Choo et al. (2017), Character 139; King et al. (2017), Character 493; Castiello (2018), Character 482; Zhu Y. et al. (2022), Character 50.

1. Anterodorsal process and peg: (0) separated; (1) confluent.

Zhu Y. et al. (2022), Character 51.

1. Sensory line canal of body: (0) passes between or beneath scales; (1) passes over scales and/or is partially enclosed or surrounded by scales; (2) perforates and passes through scales.

Davis (2002); Friedman & Brazeau (2010); Davis et al. (2012), Character 15; Choo et al. (2017), Character 14; Coates et al. (2018), Character 17; Dearden et al. (2019), Character 17; King et al. (2017), Character 324; Castiello (2018), Character 316; Zhu Y. et al. (2022), Character 52.

1. Sensory line canal of head: (0) passes between or beneath scales; (1) passes over scales and/or is partially enclosed or surrounded by scales; (2) perforates and passes through scales.

Choo et al. (2017), Character 14; Coates et al. (2018), Character 17; Dearden et al. (2019), Character 18; Zhu Y. et al. (2022), Character 53.

1. Longitudinal scale alignment in fin webs: (0) present; (1) absent.

Zhu Y. et al. (2021), Character 13; King et al. (2017), Character 468; Castiello (2018), Character 457; Zhu Y. et al. (2022), Character 54.

1. Sensory line scales/plates on head: (0) unspecialized; (1) apposed growth; (2) paralleling canal; (3) semicylindrical C-shaped ring scales.

Zhu Y. et al. (2021), Character 59; Zhu Y. et al. (2022), Character 55.

*Cranial dermal skeleton*

1. Dermal ornamentation: (0) smooth; (1) parallel, vermiform ridges; (2) concentric ridges; (3) tuberculate.

Giles et al. (2015), Character 29; Choo et al. (2017), Character 265; King et al. (2017), Character 205; Castiello (2018), Character 204; Zhu Y. et al. (2022), Character 56.

1. Sensory line network: (0) preserved as open grooves; (1) pass through canals enclosed within dermal bones.

Davis et al. (2012), Character 16; Choo et al. (2017), Character 15; King et al. (2017), Character 283; Castiello (2018), Character 276; Zhu Y. et al. (2022), Character 57.

1. Sensory canals/grooves: (0) contained within the thickness of dermal bones; (1) contained in prominent ridges on visceral surface of bone.

Giles et al. (2015), Character 31; Choo et al. (2017), Character 266; King et al. (2017), Character 301; Castiello (2018), Character 292; Zhu Y. et al. (2022), Character 58.

1. Dermal skull roof: (0) includes large dermal plates; (1) consists of undifferentiated plates or tesserae; (2) include both large dermal plates and tesserae.

Davis et al. (2012), Character 18; Choo et al. (2017), Character 17; King et al. (2017), Character 151; Castiello (2018), Character 150; Zhu Y. et al. (2022), Character 59.

Score changed from 0 to 1 for *Kawichthys*.

1. Tesserae morphology: (0) large interlocking polygonal plates: (1) microsquamose, not larger than body tesserae.

Davis et al. (2012), Character 19; Choo et al. (2017), Character 18; King et al. (2017), Character 152; Castiello (2018), Character 151; Zhu Y. et al. (2022), Character 60.

1. Extent of dermatocranial cover: (0) complete; (1) incomplete (scale-free and elsewhere).

Brazeau (2009); Davis et al. (2012), Character 20; Choo et al. (2017), Character 19; King et al. (2017), Character 153; Castiello (2018), Character 152; Zhu Y. et al. (2022), Character 61.

1. Unpaired median skull roofing bone in contact with unpaired plate bearing pineal eminence or foramen: (0) absent; (1) present.

Castiello (2018), Character 189; Zhu Y. et al. (2022), Character 62.

1. Median rostral extension of the headshield: (0) absent; (1) present.

King et al. (2017), Character 218; Castiello (2018), Character 217; Zhu Y. et al. (2022), Character 63.

1. Lateral fields: (0) absent; (1) present.

King et al. (2017), Character 219; Castiello (2018), Character 218; Zhu Y. et al. (2022), Character 64.

1. Division of lateral fields: (0) absent; (1) divided once; (2) divided twice.

King et al. (2017), Character 220; Castiello (2018), Character 219; Zhu Y. et al. (2022), Character 65.

1. Lateral fields extend posterior to pectoral sinus: (0) absent; (1) present.

King et al. (2017), Character 221; Castiello (2018), Character 220; Zhu Y. et al. (2022), Character 66.

1. Lateral fields extend onto cornua: (0) absent; (1) present.

King et al. (2017), Character 222; Castiello (2018), Character 221; Zhu Y. et al. (2022), Character 67.

1. Median fields: (0) absent; (1) present.

King et al. (2017), Character 223; Castiello (2018), Character 222; Zhu Y. et al. (2022), Character 68.

1. Median field separation from pineal plate or foramen: (0) absent; (1) present.

King et al. (2017), Character 224; Castiello (2018), Character 223; Zhu Y. et al. (2022), Character 69.

1. Median dorsal opening: (0) absent; (1) present.

King et al. (2017), Character 226; Castiello (2018), Character 225; Zhu Y. et al. (2022), Character 70.

1. Cornual extensions: (0) absent; (1) present.

King et al. (2017), Character 229; Castiello (2018), Character 228; Zhu Y. et al. (2022), Character 71.

1. Corners: (0) absent; (1) present.

Castiello (2018), Character 229; Zhu Y. et al. (2022), Character 72.

1. Fused scale rows on posterior of headshield: (0) absent; (1) present.

King et al. (2017), Character 230; Castiello (2018), Character 230; Zhu Y. et al. (2022), Character 73.

1. Dorsal spinal process of headshield: (0) absent; (1) present.

King et al. (2017), Character 231; Castiello (2018), Character 231; Zhu Y. et al. (2022), Character 74.

1. Oralobranchial covering: (0) minute scales; (1) tesserae (2); dermal plates; (3) one or two massive dermal plates.

King et al. (2017), Character 232; Castiello (2018), Character 232; Zhu Y. et al. (2022), Character 75.

1. Shape of median dorsal opening: (0) transverse slit-like; (1) oval-like (2); slender longitudinal oval.

King et al. (2017), Character 233; Castiello (2018), Character 234; Zhu Y. et al. (2022), Character 76.

1. Spines on corners: (0) absent; (1) present.

King et al. (2017), Character 234; Castiello (2018), Character 233; Zhu Y. et al. (2022), Character 77.

1. Headshield enclosed posteriorly behind oralobranchial chamber: (0) no; (1) yes.

King et al. (2017), Character 235; Castiello (2018), Character 235; Zhu Y. et al. (2022), Character 78.

1. Enlarged tubercles form symmetrical pattern on posterior part of head shield: (0) absent; (1) present.

King et al. (2017), Character 236; Castiello (2018), Character 236; Zhu Y. et al. (2022), Character 79.

1. T-shaped rostral plate: (0) absent; (1) present.

King et al. (2017), Character 237; Castiello (2018), Character 237; Zhu Y. et al. (2022), Character 80.

1. Single median element carrying the central, middle and posterior pit line: (0) absent; (1) present.

King et al. (2017), Character 238; Castiello (2018), Character 238; Zhu Y. et al. (2022), Character 81.

1. Postnuchal plates: (0) absent; (1) present.

King et al. (2017), Character 239; Castiello (2018), Character 239; Zhu Y. et al. (2022), Character 82.

Score changed from 1 to 0 for *Eurycaraspis*, 1 to ? for *Paucipetalichthys*, ? to 0 for *Qilinyu* as for antiarchs.

1. Cutaneous sensory organ on suborbital plate: (0) absent; (1) present.

King et al. (2017), Character 240; Castiello (2018), Character 240; Zhu Y. et al. (2022), Character 83.

1. Cutaneous sensory organ on postsuborbital plate: (0) absent; (1) present.

King et al. (2017), Character 241; Castiello (2018), Character 241; Zhu Y. et al. (2022), Character 84.

1. Cutaneous sensory organ on skull roof posterior to orbits: (0) absent; (1) present.

King et al. (2017), Character 242; Castiello (2018), Character 242; Zhu Y. et al. (2022), Character 85.

1. Sclerotic ring incorporated into skull roof: (0) absent; (1) present.

King et al. (2017), Character 244; Castiello (2018), Character 243; Zhu Y. et al. (2022), Character 86.

1. Rostrocaudal groove on the inner surface of the premedian plate: (0) absent; (1) present.

King et al. (2017), Character 245; Castiello (2018), Character 244; Zhu Y. et al. (2022), Character 87.

1. Preorbital depression: (0) absent; (1) present.

King et al. (2017), Character 246; Castiello (2018), Character 245; Zhu Y. et al. (2022), Character 88.

1. Preorbital recess: (0) absent; (1) present.

Zhu et al. (2016), Character 342; King et al. (2017), Character 247; Castiello (2018), Character 246; Zhu Y. et al. (2021), Character 311; Zhu Y. et al. (2022), Character 89.

Score changed from 0 to 1 for *Minicrania lirouyii* (Zhu and Janvier, 1996).

1. Preorbital recess: (0) restricted to premedian plate; (1) extends onto lateral plates.

King et al. (2017), Character 248; Castiello (2018), Character 247; Zhu Y. et al. (2022), Character 90.

1. Submarginal articulation: (0) absent; (1) present.

King et al. (2017), Character 250; Castiello (2018), Character 249; Zhu Y. et al. (2022), Character 91.

1. Prelateral plate: (0) absent; (1) present.

King et al. (2017), Character 251; Castiello (2018), Character 250; Zhu Y. et al. (2022), Character 92.

1. Posterior descending lamina of skull roof: (0) absent; (1) present.

King et al. (2017), Character 252; Castiello (2018), Character 251; Zhu Y. et al. (2022), Character 93.

1. Mesial lamina on the internal surface of marginal plate: (0) absent; (1) present.

King et al. (2017), Character 254; Castiello (2018), Character 252; Zhu Y. et al. (2022), Character 94.

1. Nostrils enclosed in dermal skull roof: (0) yes; (1) no.

King et al. (2017), Character 255; Castiello (2018), Character 253; Zhu Y. et al. (2022), Character 95.

1. Lacrimal: (0) absent; (1) present.

King et al. (2017), Character 257; Castiello (2018), Character 254; Zhu Y. et al. (2022), Character 96.

1. Pineal and rostral: (0) contact; (1) separated.

King et al. (2017), Character 258; Castiello (2018), Character 255; Zhu Y. et al. (2022), Character 97.

1. Snout region fragmented into mosaic of small plates: (0) no; (1) yes.

King et al. (2017), Character 259; Castiello (2018), Character 256; Zhu Y. et al. (2022), Character 98.

1. B-bone: (0) absent; (1) present.

King et al. (2017), Character 261; Castiello (2018), Character 258; Zhu Y. et al. (2022), Character 99.

1. Series of bones lateral to supratemporal (postmarginal plate in placoderms): (0) absent; (1) single bone; (2) two bones.

King et al. (2017), Character 263; Castiello (2018), Character 260; Zhu Y. et al. (2022), Character 100.

Score changed from 1 to 0 for *Romundina*.

1. Pore clusters: (0) absent; (1) present.

King et al. (2017), Character 267; Castiello (2018), Character 261; Zhu Y. et al. (2022), Character 101.

1. Prerostral plate: (0) absent; (1) present.

King et al. (2017), Character 269; Castiello (2018), Character 263; Zhu Y. et al. (2022), Character 102.

1. Interparietal: (0) absent; (1) present.

King et al. (2017), Character 271; Castiello (2018), Character 265; Zhu Y. et al. (2022), Character 103.

1. Supratemporal (marginal) in contact with postparietal (central): (0) absent; (1) present.

King et al. (2017), Character 273; Castiello (2018), Character 267; Zhu Y. et al. (2022), Character 104.

1. Supratemporal (marginal) contact with nasal (postnasal): (0) absent; (1) present.

King et al. (2017), Character 274; Castiello (2018), Character 268; Zhu Y. et al. (2022), Character 105.

1. Quadratojugal: (0) present; (1) absent.

King et al. (2017), Character 276; Castiello (2018), Character 270; Zhu Y. et al. (2022), Character 106.

*Buchanosteus* *confertituberculatus* is coded 1 (Young, 1979).

1. Accessory operculum: (0) absent; (1) present.

King et al. (2017), Character 278; Castiello (2018), Character 272; Zhu Y. et al. (2022), Character 107.

1. Dermal bone (sarcopterygian postorbital) between jugal (suborbital) and intertemporal (postorbital): (0) absent; (1) present.

King et al. (2017), Character 279; Castiello (2018), Character 273; Zhu Y. et al. (2022), Character 108.

1. Lacrimal notch: (0) absent; (1) present.

King et al. (2017), Character 280; Castiello (2018), Character 274; Zhu Y. et al. (2022), Character 109.

1. Orbital process of maxilla: (0) absent; (1) present.

King et al. (2017), Character 282; Castiello (2018), Character 275; Zhu Y. et al. (2022), Character 110.

1. Dermal cranial joint at level of sphenoid-otic junction: (0) absent; (1) present.

Zhu *et al.* (2009), Character 21; Zhu et al. (2013), Character 147; Giles et al. (2015), Character 46; Choo et al. (2017), Character 141; King et al. (2017), Character 170; Castiello (2018), Character 168; Zhu Y. et al. (2022), Character 111.

1. Posterior nostril: (0) associated with orbit; (1) not associated with orbit.

Zhu *et al.* (2009, Character 8), and references therein; Zhu et al. (2013), Character 152; Giles et al. (2015), Character 116; Choo et al. (2017), Character 142; King et al. (2017), Character 171; Castiello (2018), Character 169; Zhu Y. et al. (2022), Character 112.

1. Posterior nostril: (0) external; (1) palatal.

Choo et al. (2017), Character 332; Lu et al. (2017), Character 262; Zhu Y. et al. (2022), Character 113.

1. Posterior nostril in external position: (0) far from jaw margin; (1) at or close to jaw margin.

Zhu *et al.* (2009, Character 7), and references therein; Zhu et al. (2013), Character 153; Choo et al. (2017), Character 163; King et al. (2017), Character 181; Castiello (2018), Character 178; Zhu Y. et al. (2022), Character 114.

1. Choana: (0) absent; (1) present.

King et al. (2017), Character 260; Castiello (2018), Character 257; Zhu Y. et al. (2022), Character 115.

1. Lacrimal posteriorly enclosing posterior nostril: (0) absent; (1) present.

Zhu *et al.* (2009, Character 58), and references therein; Zhu et al. (2013), Character 172; Choo et al. (2017), Character 179; King et al. (2017), Character 194; Castiello (2018), Character 193; Zhu Y. et al. (2022), Character 116.

1. Premaxilla contributes to posterior nostril: (0) absent; (1) present.

King et al. (2017), Character 272; Castiello (2018), Character 266; Zhu Y. et al. (2022), Character 117.

1. Position of anterior nostril: (0) facial; (1) at oral margin.

Zhu Y. et al. (2021), Character 255; Zhu Y. et al. (2022), Character 118.

1. Number of nasals: (0) many; (1) one or two.

Zhu *et al.* (2009, Character 4), and references therein; Zhu et al. (2013), Character 149; Choo et al. (2017), Character 160; King et al. (2017), Character 178; Castiello (2018), Character 175; Zhu Y. et al. (2022), Character 119.

1. Mesial margin of nasal: (0) not notched; (1) notched.

Zhu *et al.* (2009, Character 3), and references therein; Zhu et al. (2013), Character 150; Choo et al. (2017), Character 161; King et al. (2017), Character 179; Castiello (2018), Character 176; Zhu Y. et al. (2022), Character 120.

The condition in placoderms is coded ‘unavailability’, although the ‘postnasal plate’ is likely to be equivalent of the nasal in osteichthyans.

The coding for *Cheirolepis* was changed to ‘1’, following Coates et al. (2018, Character 29). Unlike Coates et al. (2018), the coding for *Mimipiscis* and *Moythomasia* was retained as ‘1’.

1. Dermintermedial process: (0) absent; (1) present.

Zhu *et al.* (2009, Character 6), and references therein; Zhu et al. (2013), Character 151; Choo et al. (2017), Character 162; King et al. (2017), Character 180; Castiello (2018), Character 177; Zhu Y. et al. (2022), Character 121.

The process seems present in *Ligulalepis*. The presence should be a plesiomorphy for osteichthyans.

1. Extended preorbital region between eyes and nasal capsule: (0) absent; (1) present.

King et al. (2017), Character 22; Castiello (2018), Character 22; Zhu Y. et al. (2022), Character 122.

1. Orbit dorsal or facing dorsolaterally: (0) present; (1) absent.

Castiello (2018), Character 29; Zhu Y. et al. (2022), Character 123.

1. Orbits, surrounded laterally by endocranium: (0) absent; (1) partially surrounded; (2) surrounded.

Castiello (2018), Character 30; Zhu Y. et al. (2022), Character 124.

1. Supraorbital (sensu Cloutier and Ahlberg 1996, including posterior tectal of Jarvik): (0) absent; (1) present.

Zhu *et al.* (2009, Character 10), and references therein; Zhu et al. (2013), Character 154; Choo et al. (2017), Character 164; King et al. (2017), Character 182; Castiello (2018), Character 179; Zhu Y. et al. (2022), Character 125.

1. Number of supraorbitals: (0) one; (1) two; (2) many.

King et al. (2017), Character 262; Castiello (2018), Character 259; Zhu Y. et al. (2022), Character 126.

1. Supraorbital, preorbital and nasal: (0) unfused; (1) fused.

Zhu *et al.* (2009, Character 11), and references therein; Zhu et al. (2013), Character 155; Choo et al. (2017), Character 165; King et al. (2017), Character 183; Castiello (2018), Character 180; Zhu Y. et al. (2022), Character 127.

1. Tectal (sensu Cloutier and Ahlberg 1996, not counting the posterior tectal of Jarvik): (0) absent; (1) present.

Zhu *et al.* (2009, Character 15), and references therein; Zhu et al. (2013), Character 156; Choo et al. (2017), Character 166; King et al. (2017), Character 184; Castiello (2018), Character 18l; Zhu Y. et al. (2022), Character 128.

1. Pineal opening in braincase: (0) absent; (1) present.

King et al. (2017), Character 115; Castiello (2018), Character 116; Zhu Y. et al. (2022), Character 129.

1. Pineal opening perforation in dermal skull roof: (0) present; (1) absent.

Davis et al. (2012), Character 25; Choo et al. (2017), Character 24; King et al. (2017), Character 159; Castiello (2018), Character 117; Zhu Y. et al. (2022), Character 130.

1. Pineal eminence (in taxa lacking pineal foramen): (0) absent; (1) present.

Zhu Y. et al. (2021), Character 233; Zhu Y. et al. (2022), Character 131.

1. Location of pineal foramen/eminence: (0) level with posterior margin of orbits; (1) well posterior of orbits.

Zhu *et al.* (2009, Character 19), and references therein; Zhu et al. (2013), Character 158; Choo et al. (2017), Character 168; King et al. (2017), Character 186; Castiello (2018), Character 183; Zhu Y. et al. (2022), Character 132.

1. Opening in dermal skull roof for spiracular bounded by bones carrying otic canal: (0) absent; (1) present.

Choo et al. (2017), Character 327; Lu et al. (2017), Character 241; King et al. (2017), Character 188; Castiello (2018), Character 186; Zhu Y. et al. (2022), Character 133.

1. Dermal plate associated with pineal eminence or foramen: (0) contributes to orbital margin; (1) plate bordered laterally by skull roofing bones.

Giles et al. (2015), Character 42; Choo et al. (2017), Character 270; King et al. (2017), Character 208; Castiello (2018), Character 207; Zhu Y. et al. (2021), Character 41; Zhu Y. et al. (2022), Character 134.

Among taxa sampled in this analysis, osteostracans, antiarchs, *Brindabellaspis*, and *Romundina* bear pineal plates that contribute to the margin of the orbit, corresponding to state '0'. We consider taxa where the pineal foramen is bounded by rectilinear skull roofing bones but which lack separate pineal ossifications (e.g., *Mimipiscis*) as showing state '1'. Taxa lacking macromeric cranial skeletons are coded as inapplicable for this character. (Giles et al., 2015)

1. Skull roof with broad supraorbital vaults: (0) absent; (1) present.

Dennis and Miles, 1981, Character 16; Giles et al. (2015), Character 44; Choo et al. (2017), Character 271; King et al. (2017), Character 200; Castiello (2018), Character 208; Zhu Y. et al. (2021), Character 42; Zhu Y. et al. (2022), Character 135.

This character is contingent on the presence of a dermal skull roof composed of large plates. In coccosteomorph arthrodires, the dorsal surfaces of the orbits, comprising the preorbital and postorbital plates, are formed of broad, concave laminae. Similar vaults on the visceral surface of the dermal skull are absent in other placoderms and osteichthyans. (Giles et al., 2015)

1. Parietals (preorbitals of placoderms): (0) absent; (1) present.

Choo et al. (2017), Character 169; Clement et al. (2018), Character 279; Zhu Y. et al. (2022), Character 136.

1. Condition of parietals/preorbitals: (0) do not meet in midline; (1) meet in midline; (2) single midline bone.

Clement et al. (2018), Character 280; Zhu Y. et al. (2022), Character 137.

1. Parietals (preorbitals of placoderms) surround pineal foramen or eminence: (0) yes; (1) no.

King et al. (2017), Character 187; Castiello (2018), Character 184; Zhu Y. et al. (2022), Character 138.

1. Postparietals (centrals of placoderms): (0) absent; (1) present.

Clement et al. (2018), Character 277; Zhu Y. et al. (2022), Character 139.

1. Condition of postparietals/centrals: (0) do not meet in midline; (1) meet in midline; (2) single midline bone.

Clement et al. (2018), Character 278; Zhu Y. et al. (2022), Character 140.

1. Suture between paired skull roofing bones: (0) straight; (1) sinusoidal.

Miles & Dennis (1979), Character 6; Giles et al. (2015), Character 49; Choo et al. (2017), Character 274; King et al. (2017), Character 210; Castiello (2018), Character 209; Zhu Y. et al. (2022), Character 141.

1. Large unpaired median skull roofing bone anterior to the level of nasal capsules (premedian plate): (0) absent; (1) present.

Zhu et al. (2013), Character 148; Choo et al. (2017), Character 159; King et al. (2017), Character 177; Castiello (2018), Character 174; Zhu Y. et al. (2022), Character 142.

1. Position of premedian plate: (0) dorsal; (1) ventral.

Zhu Y. et al. (2022), Character 143.

1. Postnasal plate: (0) absent; (1) present.

Zhu et al. (2016), Character 341; Zhu Y. et al. (2021), Character 310; Zhu Y. et al. (2022), Character 144.

1. Postmarginal plate: (0) absent; (1) present.

Zhu et al. (2016), Character 346; Zhu Y. et al. (2021), Character 313; Zhu Y. et al. (2022), Character 145.

1. Obstantic margin of skull roof: (0) long; (1) short.

Zhu et al. (2016), Character 347; Zhu Y. et al. (2021), Character 314; Zhu Y. et al. (2022), Character 146.

1. Large unpaired median bone contributing to posterior margin of skull roof (nuchal plate): (0) absent; (1) present.

Zhu et al. (2013), Character 163; Choo et al. (2017), Character 172; Zhu Y. et al. (2022), Character 147.

1. Nuchal plate: (0) without orbital facets; (1) with orbital facets.

Castiello (2018), Character 248; Zhu Y. et al. (2022), Character 148.

1. Nuchal reaching or almost reaching orbital margin: (0) absent; (1) present.

Zhu et al. (2016), Character 345; Zhu Y. et al. (2021), Character 312; Zhu Y. et al. (2022), Character 149.

1. Paired pits on ventral surface of nuchal or median extrascapular plate: (0) absent; (1) present.

Miles & Dennis (1979), Character 10; Dennis & Miles (1981), Character 10); Giles et al. (2015), Character 51; Choo et al. (2017), Character 276; King et al. (2017), Character 212; Castiello (2018), Character 211; Zhu Y. et al. (2022), Character 150.

1. Contact of nuchal or centronuchal or median extrascapular plate with paired preorbital or parietal plates: (0) absent; (1) present.

Zhu et al. (2013), Character 164; Choo et al. (2017), Character 173; Zhu Y. et al. (2022), Character 151.

1. Number of marginal bones alongside paired median skull roofing bones over the otico-occipital division of braincase: (0) single; (1) two or more.

Zhu *et al.* (2009, Character 27), and references therein; Zhu et al. (2013), Character 161; Giles et al. (2015), Character 48; Choo et al. (2017), Character 143; King et al. (2017), Character 172; Castiello (2018), Character 170; Zhu Y. et al. (2021), Character 46; Zhu Y. et al. (2022), Character 152.

1. Lateral plate: (0) absent; (1) present.

Zhu et al. (2013), Character 157; Choo et al. (2017), Character 167; King et al. (2017), Character 185; Castiello (2018), Character 182; Zhu Y. et al. (2022), Character 153.

1. Paranuchal number: (0) one pair; (1) two pairs.

Zhu et al. (2013), Character 162; Choo et al. (2017), Character 171; King et al. (2017), Character 189; Castiello (2018), Character 187; Zhu Y. et al. (2022), Character 154.

1. Median paranuchal plate: (0) absent; (1) present.

Zhu Y. et al. (2022), Character 155.

We exclude the median paranuchal plate from the parachal series (Character 154), which runs along the main lateral line. Paired median paranuchals are present in some acanthothoracids, e.g., *Romundina*, *Arabosteus* (Olive et al., 2011) and *Sudaspis* (Vaškaninová and Ahlberg, 2017). (Zhu Y. et al., 2022)

1. Posterior process of the paranuchal plate behind the nuchal plate (dorsal face): (0) absent; (1) present.

Zhu et al. (2013), Character 165; Choo et al. (2017), Character 174; Zhu Y. et al. (2022), Character 156.

1. Medial processes of paranuchal wrapping posterolateral corners of nuchal plate: (0) absent; (1) present; (2) paranuchals precluded from nuchal by central or median paranuchal.

Giles et al. (2015), Character 50; Choo et al. (2017), Character 275; King et al. (2017), Character 211; Castiello (2018), Character 210; Zhu Y. et al. (2022), Character 157.

1. Posterior projection on posterior paranuchal plate: (0) absent; (1) present.

Castiello (2018), Character 188; Castiello (2018), Character 188; Zhu Y. et al. (2022), Character 158.

1. Canal-bearing bone of skull roof extends far past posterior margin of parietals: (0) no; (1) yes.

Choo et al. (2017), Character 325; Lu et al. (2017), Character 238; Castiello (2018), Character 185; Zhu Y. et al. (2022), Character 159.

1. Extratemporal: absent (0), present (1).

Zhu Y. et al. (2022), Character 160

1. Westoll-lines: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 237; King et al. (2017), Character 268; Castiello 2018 Character 262; Zhu Y. et al. (2022), Character 161.

1. Anteriorly directed adductor fossae between neurocranium and skull roof: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 250; Zhu Y. et al. (2022), Character 162.

1. Anterior pit line of dermal skull roof: (0) absent; (1) present.

Giles et al. (2015), Character 34; Choo et al. (2017), Character 267; King et al. (2017), Character 302; Castiello (2018), Character 293; Zhu Y. et al. (2022), Character 163.

1. Position of anterior pit-line: (0) on paired median skull roofing bones over the otico-occipital division of braincase; (1) on paired median skull roofing bones over the sphenoid division of braincase.

Zhu *et al.* (2009, Character 106), and references therein; Zhu et al. (2013), Character 184; Choo et al. (2017), Character 189; King et al. (2017), Character 287; Castiello (2018), Character 279; Zhu Y. et al. (2022), Character 164.

1. Middle and posterior pit-lines on postparietal: (0) posteriorly situated; (1) mesially situated.

Zhu *et al.* (2009, Character 107), and references therein; Zhu et al. (2013), Character 185; Choo et al. (2017), Character 190; King et al. (2017), Character 288; Castiello (2018), Character 280; Zhu Y. et al. (2022), Character 165.

1. Position of middle and posterior pit lines: (0) close to midline; (1) near the central portion of each postparietal.

Zhu *et al.* (2009, Character 108), and references therein; Zhu et al. (2013), Character 186; Choo et al. (2017), Character 191; King et al. (2017), Character 289; Castiello (2018), Character 281; Zhu Y. et al. (2022), Character 166.

1. Junction of posterior pitline and main lateral line: (0) far in front of posterior margin of skull roof; (1) close to posterior margin of skull roof.

Zhu et al. (2013), Character 166; Choo et al. (2017), Character 175; Zhu Y. et al. (2022), Character 167.

1. Ethmoid commissure: (0) absent; (1) present.

Castiello (2018), Character 311; Zhu Y. et al. (2022), Character 168.

1. Ethmoid commissure fused into midline canal: (0) absent; (1) present.

King et al. (2017), Character 320; Castiello (2018), Character 312; Zhu Y. et al. (2022), Character 169.

1. Course of ethmoid commissure: (0) middle portion through median rostral; (1) sutural course; (2) through bone center of premaxillary.

Zhu *et al.* (2009, Character 105), and references therein; Zhu et al. (2013), Character 183; Choo et al. (2017), Character 188; King et al. (2017), Character 286; Castiello (2018), Character 278; Zhu Y. et al. (2022), Character 170.

1. Infraorbital canal follows premaxillary suture: (0) no; (1) yes.

Choo et al. (2017), Character 198; King et al. (2017), Character 296; Castiello (2018), Character 287; Zhu Y. et al. (2022), Character 171.

1. Postmarginal canal: (0) absent; (1) present.

King et al. (2017), Character 315; Castiello (2018), Character 306; Zhu Y. et al. (2022), Character 172.

1. Postmarginal line issued from main lateral line: (0) on marginal or supratemporal; (1) on anterior paranuchal or tabular.

Zhu et al. (2016), Character 349; Zhu Y. et al. (2021), Character 315; Zhu Y. et al. (2022), Character 173.

1. Central sensory line: (0) absent; (1) present.

Zhu et al. (2016), Character 350; Zhu Y. et al. (2021), Character 316; King et al. (2017), Character 312; Castiello (2018), Character 303; Zhu Y. et al. (2022), Character 174.

1. Supraorbital sensory canals: (0) absent; (1) present.

King et al. (2017), Character 307; Castiello (2018), Character 299; Zhu Y. et al. (2022), Character 175.

1. Course of supraorbital canal: (0) between anterior and posterior nostrils; (1) anterior to both nostrils.

Zhu *et al.* (2009, Character 109), and references therein; Zhu et al. (2013), Character 187; Choo et al. (2017), Character 192; King et al. (2017), Character 290; Castiello (2018), Character 282; Zhu Y. et al. (2022), Character 176.

1. Course of supraorbital canal: (0) straight; (1) lyre-shaped.

Zhu *et al.* (2009, Character 110), and references therein; Zhu et al. (2013), Character 188; Choo et al. (2017), Character 193; King et al. (2017), Character 291; Castiello (2018), Character 283; Zhu Y. et al. (2022), Character 177.

1. Posterior end of supraorbital canal: (0) in postparietal (central); (1) in parietal (preorbital); (2) in intertemporal; (3) in nuchal plate; (4) in postpineal plate.

Zhu *et al.* (2009, Character 111), and references therein; Zhu et al. (2013), Character 189; Choo et al. (2017), Character 194; Zhu Y. et al. (2022), Character 178.

1. Posteriorly converging supraorbital canals: (0) absent; (1) present.

Zhu Y. et al. (2022), Character 179.

1. Supraorbital canals and posterior pitlines convergence: (0) absent; (1) converge without contact; (2) converge with contact.

Long et al. (2015), Character 256; Choo et al. (2017), Character 248; King et al. (2017), Character 300; Castiello (2018), Character 291; Zhu Y. et al. (2022), Character 180.

The character “median commissure between supraorbital sensory lines: (0) absent; (1) present” (Choo et al., 2017, Character 272; Giles et al., 2015c, Character 45) is deleted due to its overlap with the current state 2. (Zhu Y. et al., 2022)

1. Contact between otic and supraorbital canals: (0) not in contact; (1) in contact.

Zhu *et al.* (2009, Character 112), and references therein; Zhu et al. (2013), Character 190; Choo et al. (2017), Character 195; King et al. (2017), Character 293; Castiello (2018), Character 284; Zhu Y. et al. (2022), Character 181.

1. Contact of supraorbital and infraorbital canals: (0) in contact rostrally; (1) not in contact rostrally.

Zhu *et al.* (2009, Character 113), and references therein; Zhu et al. (2013), Character 191; Choo et al. (2017), Character 196; King et al. (2017), Character 294; Castiello (2018), Character 285; Zhu Y. et al. (2022), Character 182.

1. Otic canal: (0) runs through skull roof; (1) follows edge of skull roof.

Zhu *et al.* (2009, Character 114), and references therein; Zhu et al. (2013), Character 192; Choo et al. (2017), Character 197; King et al. (2017), Character 295; Castiello (2018), Character 286; Zhu Y. et al. (2022), Character 183.

1. Otic canal extends through postparietals (central): (0) absent; (1) present.

Cloutier & Ahlberg (1996), Character 101; Zhu & Schultze (2001) Character 47; Zhu & Yu (2001), Character 37; Zhu & Yu (2002), Character 37; Friedman (2007), Character 40; Giles et al. (2015), Character 47; Choo et al. (2017), Character 273; King et al. (2017), Character 303; Castiello (2018), Character 294; Zhu Y. et al. (2022), Character 184.

1. Jugal portion of infraorbital canal joins supramaxillary canal: (0) present; (1) absent.

Davis et al. (2012), Character 17; Choo et al. (2017), Character 16; King et al. (2017), Character 284; Castiello (2018), Character 277; Zhu Y. et al. (2022), Character 185.

1. Infra-orbital sensory line: (0) crosses lateral field; (1) does not cross lateral field.

Castiello (2018), Character 295; King et al. (2017), Character 304; Zhu Y. et al. (2022), Character 186.

1. Festooned pattern of sensory canals: (0) absent; (1) present.

King et al. (2017), Character 305; Castiello (2018), Character 296; Zhu Y. et al. (2022), Character 187.

1. Median transverse canals: (0) two or more; (1) one; (2) absent.

Castiello (2018), Character 297; Zhu and Gai (2006), Character 30; Zhu Y. et al. (2022), Character 188.

We added the third state (“absent”) to describe the condition in jawed vertebrates. (Zhu Y. et al., 2022)

1. Multiply branched sensory canal system associated with the posterior end of the supraorbital canal: (0) absent; (1) present.

King et al. (2017), Character 306; Castiello (2018), Character 298; Zhu Y. et al. (2022), Character 189.

In the present dataset, the character is only present in *Wenshanaspis*.

1. Branching end of lateral transverse canals: (0) absent; (1) present.

King et al. (2017), Character 308; Castiello (2018), Character 300; Zhu Y. et al. (2022), Character 190.

In the present dataset, the character is only present in *Wenshanaspis*.

1. Median dorsal canal: (0) absent; (1) present.

King et al. (2017), Character 310; Castiello (2018), Character 301; Zhu Y. et al. (2022), Character 191.

Score changed from 0/1 to 1 for *Eugaleaspis changi*; 0 to ? for *Shuyu zhejiangensis*.

1. Infraorbital and otic sensory line grooves run along mesial margin of marginal plate: (0) no; (1) yes.

King et al. (2017), Character 311; Castiello (2018), Character 302; Zhu Y. et al. (2022), Character 192.

1. Semicircular pit line: (0) absent; (1) present.

King et al. (2017), Character 313; Castiello (2018), Character 304; Zhu Y. et al. (2022), Character 193.

In the present dataset, the character is only present in *Bothriolepis*.

1. Horizontal sensory line canal on cheek: (0) absent; (1) present.

King et al. (2017), Character 314; Castiello (2018), Character 305; Zhu Y. et al. (2022), Character 194.

1. Preopercular canal: (0) absent; (1) present.

King et al. (2017), Character 316; Castiello (2018), Character 307; Zhu Y. et al. (2022), Character 195.

1. Preopercular canal meets otic canal: (0) absent; (1) present.

King et al. (2017), Character 317; Castiello (2018), Character 308; Zhu Y. et al. (2022), Character 196.

1. Supraoral canal: (0) absent; (1) present.

King et al. (2017), Character 318; Castiello (2018), Character 309; Zhu Y. et al. (2022), Character 197.

1. Extension of otic canal beyond infraorbital canal ("P" canal): (0) absent; (1) present.

King et al. (2017), Character 319; Castiello (2018), Character 310; Zhu Y. et al. (2022), Character 198.

1. Posterior pitline and postmarginal canal in contact: (0) absent; (1) present.

King et al. (2017), Character 321; Castiello (2018), Character 313; Zhu Y. et al. (2022), Character 199.

In the present dataset, the character is only present in *Entelognathus*.

1. Supraorbital canal joins infraorbital canal: (0) anterior to supraoral canal; (1) posterior to supraoral canal.

King et al. (2017), Character 322; Castiello (2018), Character 314; Zhu Y. et al. (2022), Character 200.

1. Sensory line commissure across extrascapular bones (nuchal and paranuchal): (0) absent; (1) present.

King et al. (2017), Character 323; Castiello (2018), Character 315; Zhu Y. et al. (2022), Character 201.

1. Sensory canal or pit-line associated with maxilla: (0) absent; (1) present.

Zhu *et al.* (2009, Character 116), and references therein; Zhu et al. (2013), Character 192; Choo et al. (2017), Character 199; King et al. (2017), Character 297; Castiello (2018), Character 288; Zhu Y. et al. (2022), Character 202.

1. Endolymphatic ducts open in dermal skull roof: (0) present; (1) absent.

Janvier (1996); Brazeau (2009); Davis et al. (2012), Character 21; Choo et al. (2017), Character 20; King et al. (2017), Character 154; Castiello (2018), Character 153; Zhu Y. et al. (2022), Character 203.

1. External endolymphatic duct openings’ location in relation to median field: (0) internal; (1) external.

Castiello (2018), Character 224; Zhu Y. et al. (2022), Character 204.

1. Endolymphatic ducts with oblique course through dermal skull bones: (0) absent; (1) present.

Goujet & Young (1995); Brazeau (2009); Davis et al. (2012), Character 22; Choo et al. (2017), Character 21; King et al. (2017), Character 155; Castiello (2018), Character 154; Zhu Y. et al. (2022), Character 205.

1. Endolymphatic duct relationship to median skull roof bone (i.e. nuchal plate): (0) within median bone; (1) on bones flanking the median bone (e.g. paranuchals).

Giles et al. (2015), Character 40; Choo et al. (2017), Character 269; King et al. (2017), Character 207; Castiello (2018), Character 206; Zhu Y. et al. (2022), Character 206.

1. Sclerotic ring: (0) absent; (1) present.

Burrow et al. (2011); Giles et al. (2015), Character 52; Choo et al. (2017), Character 277; King et al. (2017), Character 213; Castiello (2018), Character 212; Zhu Y. et al. (2022), Character 207.

1. Number of sclerotic plates: (0) four or less; (1) more than four.

Zhu *et al.* (2009, Character 57), and references therein; Zhu et al. (2013), Character 170; Choo et al. (2017), Character 241; King et al. (2017), Character 204; Castiello (2018), Character 203; Zhu Y. et al. (2022), Character 208.

1. Number of extrascapulars: (0) uneven; (1) paired.

Zhu *et al.* (2009, Character 29), and references therein; Zhu et al. (2013), Character 167; Choo et al. (2017), Character 176; King et al. (2017), Character 191; Castiello (2018), Character 190; Zhu Y. et al. (2022), Character 209.

1. Number of paired extrascapulars: (0) one pair; (1) two pairs.

King et al. (2017), Character 277; Castiello (2018), Character 271; Zhu Y. et al. (2022), Character 210.

1. Consolidated cheek plates: (0) absent; (1) present.

Davis (2002); Brazeau (2009); Davis et al. (2012), Character 24; Choo et al. (2017), Character 23; King et al. (2017), Character 157; Castiello (2018), Character 156; Zhu Y. et al. (2022), Character 211.

1. Foramina (similar to infradentary foramina) on cheek bones: (0) absent; (1) present.

Zhu *et al.* (2009, Character 56), and references therein; Zhu et al. (2013), Character 171; Choo et al. (2017), Character 178; King et al. (2017), Character 193; Castiello (2018), Character 192; Zhu Y. et al. (2022), Character 212.

1. Most posterior major bone of cheek bearing preopercular canal (preopercular) extending forward, close to orbit: (0) absent; (1) present.

Zhu *et al.* (2009, Character 59), and references therein; Zhu et al. (2013), Character 173; Choo et al. (2017), Character 180; King et al. (2017), Character 195; Castiello (2018), Character 194; Zhu Y. et al. (2022), Character 213.

1. Number of cheek bones bearing preopercular canal posterior to jugal: (0) one; (1) two.

Zhu *et al.* (2009, Character 60), and references therein; Zhu et al. (2013), Character 174; Choo et al. (2017), Character 181; King et al. (2017), Character 196; Castiello (2018), Character 195; Zhu Y. et al. (2022), Character 214.

1. Bone bearing both quadratojugal pit-line and preopercular canal: (0) absent; (1) present.

Zhu *et al.* (2009, Character 61), and references therein; Zhu et al. (2013), Character 175; Choo et al. (2017), Character 182; King et al. (2017), Character 197; Castiello (2018), Character 196; Zhu Y. et al. (2022), Character 215.

1. Anterior portion of preopercular canal: (0) present; (1) absent.

Zhu *et al.* (2009, Character 118), and references therein; Zhu et al. (2013), Character 195; Choo et al. (2017), Character 200; Zhu Y. et al. (2022), Character 216.

1. Vertical canal associated with preopercular/suborbital canal: (0) absent; (1) present.

Giles et al. (2015), Character 57; Choo et al. (2017), Character 258; Zhu Y. et al. (2022), Character 217.

1. Cheek plate: (0) undivided; (1) divided (i.e., squamosal and preopercular).

Giles et al. (2015), Character 54; Choo et al. (2017), Character 278; King et al. (2017), Character 214; Castiello (2018), Character 213; Zhu Y. et al. (2021), Character 52; Zhu Y. et al. (2022), Character 218.

This character is contingent on the presence of a consolidated dermal cheek. This character reflects whether the canal-bearing dermal cheek (preorpercular or suborbital equivalent) is composed of one or multiple bones. State '0' is apparent in actinopterygians, *Guiyu*, *Psarolepis* (preopercular), *Entelognathus* and other placoderms. (Giles et al., 2015)

1. Subsquamosals in taxa with divided cheek: (0) absent; (1) present.

Zhu & Schultze (2001), Character 64; Zhu & Yu (2001), Character 48; Zhu & Yu (2002), Character 48; Friedman (2007), Character 43; Giles et al. (2015), Character 55; Choo et al. (2017), Character 279; King et al. (2017), Character 215; Castiello (2018), Character 214; Zhu Y. et al. (2021), Character 53; Zhu Y. et al. (2022), Character 219.

1. Preopercular shape: (0) rhombic; (1) bar-shaped.

Zhu et al. (2001), Character 54; Zhu & Yu (2001), Character 54; Friedman (2007), Character 48; Giles et al. (2015), Character 56; Choo et al. (2017), Character 280; King et al. (2017), Character 216; Castiello (2018), Character 215; Zhu Y. et al. (2021), Character 54; Zhu Y. et al. (2022), Character 220.

This character applies only to the subset of sarcopterygians with subdivided cheek plates. In onychodonts (Andrews et al., 2006), porolepiforms (Jarvik, 1972), and coelacanths (Forey, 1998), the preopercular assumes a plate-like morphology. By contrast, tetrapodomorphs bear a bar-shaped preopercular bone (Jarvik, 1980; Long et al., 1997). (Giles et al., 2015)

1. Preoperculosubmandibular: (0) absent; (1) present.

Choo et al. (2017), Character 328; Lu et al. (2017), Character 244; Zhu Y. et al. (2022), Character 221.

1. Dermohyal: (0) absent; (1) present.

Zhu *et al.* (2009, Character 62), and references therein; Zhu et al. (2013), Character 176; Choo et al. (2017), Character 183; King et al. (2017), Character 198; Castiello (2018), Character 197; Zhu Y. et al. (2022), Character 222.

Gardiner and Schaeffer (1989, ch.A2) and Coates (1998, ch.A2) defined this character as a dermohyal covering the head of the hyomandibular which notches the supratemporal or the dermosphenotic (Cloutier and Arratia, 2004).

1. Enlarged postorbital tesserae separated from orbital series: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 26; Choo et al. (2017), Character 25; King et al. (2017), Character 159; Castiello (2018), Character 157; Zhu Y. et al. (2022), Character 223.

1. Bony hyoidean gill-cover series (branchiostegals): (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Davis et al. (2012), Character 27; Choo et al. (2017), Character 26; King et al. (2017), Character 160; Castiello (2018), Character 158; Zhu Y. et al. (2022), Character 224.

1. Branchiostegal plate series along ventral margin of lower jaw: (0) absent; (1) present.

Davis (2002); Hanke and Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 28; Choo et al. (2017), Character 27; King et al. (2017), Character 161; Castiello (2018), Character 159; Zhu Y. et al. (2022), Character 225.

1. Branchiostegal ossifications: (0) plate-like; (1) narrow and ribbon-like.

Hanke and Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 29; Choo et al. (2017), Character 28; King et al. (2017), Character 162; Castiello (2018), Character 160; Zhu Y. et al. (2022), Character 226.

1. Branchiostegal ossifications: (0) ornamented; (1) unornamented.

Brazeau (2009); Davis et al. (2012), Character 30; Choo et al. (2017), Character 29; King et al. (2017), Character 163; Castiello (2018), Character 161; Zhu Y. et al. (2022), Character 227.

1. Imbricated branchiostegal ossifications: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 31; Choo et al. (2017), Character 30; King et al. (2017), Character 164; Castiello (2018), Character 162; Zhu Y. et al. (2022), Character 228.

1. Opercular flap/gill slits: (0) complete or partial; (1) separate gill covers and gill slits.

Hanke and Wilson (2004); Davis et al. (2012), Character 32; Choo et al. (2017), Character 31. Dearden et al. (2019), Character 73; King et al. (2017), Character 165; Castiello (2018), Character 163; Zhu Y. et al. (2022), Character 229.

1. Opercular (submarginal) ossification: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 33; Choo et al. (2017), Character 32; Zhu Y. et al. (2022), Character 230.

1. Shape of opercular (submarginal) ossification: (0) broad plate that tapers towards its proximal end; (1) narrow, rod-shaped.

Brazeau (2009); Davis et al. (2012), Character 34; Choo et al. (2017), Character 33; King et al. (2017), Character 166; Castiello (2018), Character 164; Zhu Y. et al. (2022), Character 231.

1. Ventral lamina of opercular (submarginal) ossification: (0) absent; (1) present.

Zhu et al. (2016), Character 355; Zhu Y. et al. (2021), Character 317; Zhu Y. et al. (2022), Character 232.

1. Ventral lamina of suborbital (jugal): (0) absent; (1) present.

Zhu et al. (2016), Character 356) Zhu Y. et al. (2021), Character 318; Zhu Y. et al. (2022), Character 233.

1. Notch in anterior margin of jugal: (0) absent; (1) present.

King et al. (2017), Character 275; Castiello (2018), Character 269; Zhu Y. et al. (2022), Character 234.

1. Anterodorsal process of opercular (submarginal) ossification attaching onto skull: (0) absent; (1) present.

Zhu et al. (2016), Character 357; Zhu Y. et al. (2021), Character 319; Zhu Y. et al. (2022), Character 235.

1. Subopercular ossification: (0) absent; (1) present.

Coates et al. (2018), Character 58; Zhu Y. et al. (2022), Character 236.

1. Lateral gular plates: (0) absent; (1) present.

Gardiner (1984); Brazeau (2009); Davis et al. (2012), Character 35; Choo et al. (2017), Character 34; King et al. (2017), Character 167; Castiello (2018), Character 165; Zhu Y. et al. (2022), Character 237.

1. Size of lateral gular plates: (0) extending most of length of the lower jaw; (1) restricted to the anterior third of the jaw (no longer than the width of three or four branchiostegals.

Coates (1999); Brazeau (2009); Davis et al. (2012), Character 36; Choo et al. (2017), Character 35; King et al. (2017), Character 168; Castiello (2018), Character 166; Zhu Y. et al. (2022), Character 238.

1. Median gular: (0) present; (1) absent.

Zhu *et al.* (2009, Character 102), and references therein; Zhu et al. (2013), Character 196; Giles et al. (2015), Character 67; Choo et al. (2017), Character 135; King et al. (2017), Character 169; Castiello (2018), Character 167; Zhu Y. et al. (2022), Character 239.

*Dentition, dermal jaw & tooth-bearing bones*

1. Oral dermal tubercles borne on jaw cartilages: (0) absent; (1) present.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 39; Choo et al. (2017), Character 38; King et al. (2017), Character 327; Castiello (2018), Character 319; Zhu Y. et al. (2022), Character 240.

1. Oral dermal tubercles patterned in organised rows (teeth): (0) absent; (1) present.

Zhu Y. et al. (2021), Character 76; Zhu Y. et al. (2022), Character 241.

1. Teeth ankylosed to dermal bones: (0) absent; (1) present.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 43; Choo et al. (2017), Character 42; King et al. (2017), Character 331; Castiello (2018), Character 323; Zhu Y. et al. (2022), Character 242.

1. Dermal jaw plates on biting surface of jaw cartilages: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 44; Choo et al. (2017), Character 43; King et al. (2017), Character 332; Castiello (2018), Character 324; Zhu Y. et al. (2022), Character 243.

1. Large dermal plates forming outer dental arcade: (0) only with denticles; (1) with large monolinear tooth row.

Zhu *et al.* (2009, Character 74), and references therein; Zhu et al. (2013), Character 198; Choo et al. (2017), Character 202; King et al. (2017), Character 202; Castiello (2018), Character 201; Zhu Y. et al. (2022), Character 244.

1. Dermal plates on mesial (lingual) surfaces of Meckel’s cartilage and palatoquadrate: (0) absent; (1) present.

Zhu et al. (2013), Character 213; Choo et al. (2017), Character 215; King et al. (2017), Character 358; Castiello (2018), Character 350; Zhu Y. et al. (2022), Character 245.

1. Gnathal plates mesial to and/or above (or below) jaw cartilage: (0) absent; (1) present.

Coates et al. (2018), Character 90; Zhu Y. et al. (2022), Character 246.

1. Deep, high supragnathal bone with durophagous occlusal surface: (0) absent; (1) present.

Long et al. (2015), Character 257; Choo et al. (2017), Character 249; Castiello (2018), Character 354. King et al. (2017), Character 364; Zhu Y. et al. (2022), Character 247.

1. Posterior supragnathal with vertical pipe-like ridges: (0) absent; (1) present.

King et al. (2017), Character 373; Castiello (2018), Character 362; Zhu Y. et al. (2022), Character 248.

1. Strongly curved infragnathals with wide flat non-biting region: (0) absent; (1) present.

King et al. (2017), Character 374; Castiello (2018), Character 363; Zhu Y. et al. (2022), Character 249.

1. Number of fang pairs on ectopterygoid: (0) none; (1) one; (2) two.

King et al. (2017), Character 376; Castiello (2018), Character 365; Zhu Y. et al. (2022), Character 250.

1. Enlarged anterior tooth on premaxilla: (0) absent; (1) present.

King et al. (2017), Character 379; Castiello (2018), Character 368; Zhu Y. et al. (2022), Character 251.

1. Number of tooth rows on outer dental arcade: (0) single row; (1) two rows, with large teeth lingually and small teeth labially.

Lu et al. (2012), Character 123; King et al. (2017), Character 380; Castiello (2018), Character 369; Zhu Y. et al. (2022), Character 252.

1. Number of infradentaries: (0) one; (1) two; (2) more than 2.

King et al. (2017), Character 381; Castiello (2018), Character 370; Zhu Y. et al. (2022), Character 253.

1. Number of fang pairs on posterior coronoid: (0) none; (1) one; (2) two.

King et al. (2017), Character 383; Castiello (2018), Character 372; Zhu Y. et al. (2022), Character 254.

1. Teeth radial rows on prearticular: (0) absent; (1) present.

King et al. (2017), Character 384; Castiello (2018), Character 373; Zhu Y. et al. (2022), Character 255.

1. ’Symplectic’ articulation: (0) absent; (1) present.

King et al. (2017), Character 388; Castiello (2018), Character 376; Zhu Y. et al. (2022), Character 256.

1. Processus ascendens of palatoquadrate: (0) absent; (1) present.

King et al. (2017), Character 389; Castiello (2018), Character 377; Zhu Y. et al. (2022), Character 257.

1. Grooved, curved upper toothplates attached to median labial element: (0) absent; (1) present.

King et al. (2017), Character 390; Castiello (2018), Character 378; Zhu Y. et al. (2022), Character 258.

1. Two divergent processes extending from anterior of palatoquadrate: (0) absent; (1) present.

King et al. (2017), Character 391; Castiello (2018), Character 379; Zhu Y. et al. (2022), Character 259.

1. Extramandibular dentition: (0) absent; (1) present.

King et al. (2017), Character 392; Castiello (2018), Character 380; Zhu Y. et al. (2022), Character 260.

1. Bilateral series of labial cartilages: (0) absent; (1) present.

King et al. (2017), Character 393; Castiello (2018), Character 381; Zhu Y. et al. (2022), Character 261.

1. Maxilla and premaxilla sensu lato (upper gnathal plates lateral to jaw cartilage): (0) absent; (1) present.

Coates et al. (2018), Character 92; Zhu Y. et al. (2022), Character 262.

1. Maxilla and premaxilla sensu stricto (upper gnathal plates lateral to jaw cartilage without palatal lamina): (0) absent; (1) present.

Coates et al. (2018), Character 93; Zhu Y. et al. (2022), Character 263.

1. Tooth-bearing median rostral: (0) absent; (1) present.

Zhu *et al.* (2009, Character 75), and references therein; Zhu et al. (2013), Character 199; Choo et al. (2017), Character 203; King et al. (2017), Character 346; Castiello (2018), Character 337; Zhu Y. et al. (2022), Character 264.

1. Premaxillae with inturned symphysial processes: (0) absent; (1) present.

Zhu *et al.* (2009, Character 76), and references therein; Zhu et al. (2013), Character 177; Choo et al. (2017), Character 184; King et al. (2017), Character 199; Castiello (2018), Character 198; Zhu Y. et al. (2022), Character 265.

1. Premaxilla forming part of orbit: (0) absent; (1) present.

Zhu *et al.* (2009, Character 77), and references therein; Zhu et al. (2013), Character 178; Choo et al. (2017), Character 185; King et al. (2017), Character 200; Castiello (2018), Character 199; Zhu Y. et al. (2022), Character 266.

1. Premaxilla: (0) extends under orbit; (1) restricted anterior to orbit.

Giles et al. (2015), Character 89; Choo et al. (2017), Character 286; King et al. (2017), Character 217; Castiello (2018), Character 216; Zhu Y. et al. (2022), Character 267.

1. Preorbital process of premaxilla: (0) absent; (1) present.

Zhu *et al.* (2009, Character 78), and references therein; Zhu et al. (2013), Character 179; Choo et al. (2017), Character 186; Zhu Y. et al. (2022), Character 268.

1. Ventral margin of maxilla: (0) straight; (1) curved.

Zhu *et al.* (2009, Character 80), and references therein; Zhu et al. (2013), Character 181; Choo et al. (2017), Character 187; King et al. (2017), Character 201; Castiello (2018), Character 200; Zhu Y. et al. (2022), Character 269.

1. Posterior expansion of maxilla (maxilla cleaver-shaped): (0) present; (1) absent.

Zhu *et al.* (2009, Character 79), and references therein; Zhu et al. (2013), Character 180; Giles et al. (2015), Character 90; Choo et al. (2017), Character 145; King et al. (2017), Character 175; Castiello (2018), Character 172; Zhu Y. et al. (2022), Character 270.

1. Contribution by maxilla to posterior margin of cheek: (0) present; (1) absent.

Zhu *et al.* (2009, Character 81), and references therein; Zhu et al. (2013), Character 182; Giles et al. (2015), Character 59; Choo et al. (2017), Character 146; King et al. (2017), Character 176; Castiello (2018), Character 173; Zhu Y. et al. (2022), Character 271.

1. Dentary marginal bone of mouth: (0) absent; (1) present.

Coates et al. (2018), Character 91. Zhu Y. et al. (2021), Character 354; Zhu Y. et al. (2022), Character 272.

1. Teeth of dentary: (0) reaching anterior end of dentary; (1) not reaching anterior end.

Zhu *et al.* (2009, Character 87), and references therein; Zhu et al. (2013), Character 200; Choo et al. (2017), Character 204; Zhu Y. et al. (2022), Character 273.

1. Pair of tooth plates (anterior supragnathals or vomers) on ethmoidal plate: (0) absent; (1) present.

Giles et al. (2015), Character 91; Choo et al. (2017), Character 287; King et al. (2017), Character 367; Castiello (2018), Character 357; Zhu Y. et al. (2022), Character 274.

1. Fused anterior supragnathals: (0) absent; (1) present.

Castiello (2018), Character 361; King et al. (2017), Character 372; Castiello (2018), Character 361; Zhu Y. et al. (2022), Character 275.

1. Vomerine fangs: (0) absent; (1) present.

Zhu *et al.* (2009, Character 63), and references therein; Zhu et al. (2013), Character 235; Choo et al. (2017), Character 225; King et al. (2017), Character 360; Castiello (2018), Character 352; Zhu Y. et al. (2022), Character 276.

1. Vomeral area with grooves and raised areas: (0) absent; (1) present.

Zhu *et al.* (2009, Character 64), and references therein; Zhu et al. (2013), Character 236; Choo et al. (2017), Character 226; King et al. (2017), Character 71; Castiello (2018), Character 73; Zhu Y. et al. (2022), Character 277.

1. Posterior process of vomers: (0) absent; (1) present.

King et al. (2017), Character 375; Castiello (2018), Character 364; Zhu Y. et al. (2022), Character 278.

1. Median dermal bone of palate (parasphenoid): (0) absent; (1) present.

Gardiner (1984); Brazeau (2009); Davis et al. (2012), Character 55; Choo et al. (2017), Character 54; King et al. (2017), Character 131; Castiello (2018), Character 130; Zhu Y. et al. (2022), Character 279.

1. Buccohypophysial canal in parasphenoid: (0) single; (1) paired.

Giles et al. (2015), Character 114; Choo et al. (2017), Character 292; King et al. (2017), Character 74; Castiello (2018), Character 76; Zhu Y. et al. (2022), Character 280.

1. Ascending process of parasphenoid: (0) absent; (1) present.

Zhu *et al.* (2009, Character 67), and references therein; Zhu et al. (2013), Character 239; Giles et al. (2015), Character 113; Choo et al. (2017), Character 154; King et al. (2017), Character 132; Castiello (2018), Character 131; Zhu Y. et al. (2022), Character 281.

1. Shape of parasphenoid denticulated field: (0) broad rhomboid or lozenge-shaped; (1) broad, splint-shaped; (2) slender, splint-shaped.

Friedman (2007, Character 168), Zhu *et al.* (2009, Character 68), and references therein; Zhu et al. (2013), Character 240; Giles et al. (2015), Character 111; Choo et al. (2017), Character 155; King et al. (2017), Character 133; Castiello (2018), Character 132; Zhu Y. et al. (2022), Character 282.

1. Parasphenoid denticulated field with multifid anterior margin: (0) absent; (1) present.

Friedman (2007, Character 167), Zhu et al. (2009, Character 69), and references therein; Zhu et al. (2013), Character 241; Giles et al. (2015), Character 112; Choo et al. (2017), Character 156; King et al. (2017), Character 134; Castiello (2018), Character 133; Zhu Y. et al. (2022), Character 283.

1. Parasphenoid: (0) protruding forward into ethmoid region of endocranium; (1) behind ethmoid region.

Zhu *et al.* (2009, Character 65), and references therein; Zhu et al. (2013), Character 237; Choo et al. (2017), Character 227; King et al. (2017), Character 135; Castiello (2018), Character 134; Zhu Y. et al. (2022), Character 284.

1. Posterior of parasphenoid: (0) restricted to ethmosphenoid region; (1) extends to otic region.

Zhu Y. et al. (2021), Character 261; Zhu Y. et al. (2022), Character 285.

1. Denticulated field of parasphenoid: (0) without spiracular groove; (1) with spiracular groove.

Friedman (2007, Character 82), Zhu et al. (2009, Character 66), and references therein; Zhu et al. (2013), Character 238; Choo et al. (2017), Character 228; King et al. (2017), Character 136; Castiello (2018), Character 135; Zhu Y. et al. (2022), Character 286.

1. Parasphenoid denticle field with anteriorly divergent lateral margins: (0) absent; (1) present.

Zhu *et al.* (2009, Character 70), and references therein; Zhu et al. (2013), Character 242; Choo et al. (2017), Character 229; Zhu Y. et al. (2022), Character 287.

1. Parasphenoid denticle field: (0) terminates at or anterior to level of foramina for internal carotid arteries; (1) extends posterior to foramina for internal carotid arteries.

Zhu *et al.* (2009, Character 71), and references therein; Zhu et al. (2013), Character 243; Choo et al. (2017), Character 230; King et al. (2017), Character 137; Castiello (2018), Character 136; Zhu Y. et al. (2022), Character 288.

1. Anterior portion of parasphenoid (pre-buccohypophyseal foramen) of greater length than posterior portion (post-foramen): (0) absent; (1) present.

Coates et al. (2018), Character 99; Zhu Y. et al. (2022), Character 289.

1. Coronoids: (0) present, (1) absent.

King et al. (2017), Character 382; Castiello (2018), Character 371; Zhu Y. et al. (2022), Character 290.

1. Number of coronoids: (0) more than three; (1) three.

Lu *et al.* (2012), Character 145; Zhu et al. (2013), Character 201; Giles et al. (2015), Character 106; Choo et al. (2017), Character 147; King et al. (2017), Character 344; Castiello (2018), Character 336; Zhu Y. et al. (2022), Character 291.

1. Fangs of coronoids (sensu stricto): (0) absent; (1) present.

Zhu *et al.* (2009, Character 94), and references therein; Zhu et al. (2013), Character 202; Giles et al. (2015), Character 94; Choo et al. (2017), Character 148; King et al. (2017), Character 345; Castiello (2018), Character 337; Zhu Y. et al. (2022), Character 292.

1. Dentition on coronoids: (0) broad marginal ‘tooth ﬁeld’; (1) narrow or single marginal tooth row.

Zhu et al. (2001), Zhu and Yu (2002), Character 70; Friedman (2007), Character 58; Zhu et al., 2009, Character 95; Zhu et al. (2013), Character 203; King et al. (2017), Character 348; Castiello (2018), Character 340; Zhu Y. et al. (2022), Character 293.

1. Posterior coronoid: (0) similar to anterior coronoids; (1) forms expanded coronoid process.

Zhu Y. et al. (2021), Character 247; Zhu Y. et al. (2022), Character 294.

1. Infradentary: (0) absent; (1) present.

Zhu et al. (2013), Character 204; Choo et al. (2017), Character 206; King et al. (2017), Character 349; Castiello (2018), Character 341; Zhu Y. et al. (2022), Character 295.

1. Extent of infradentaries: (0) along much of ventral margin of dentary; (1) restricted to posterior half of dentary.

Giles et al. (2015), Character 93; Choo et al. (2017), Character 288; King et al. (2017), Character 368; Castiello (2018), Character 358; Zhu Y. et al. (2022), Character 296.

1. Infradentary foramen and groove: (0) present; (1) absent.

Zhu *et al.* (2009, Character 85), and references therein; Zhu et al. (2013), Character 205; Choo et al. (2017), Character 207; Coates et al. (2018), Character 95; King et al. (2017), Character 350; Castiello (2018), Character 342; Zhu Y. et al. (2022), Character 297.

1. Large ventromesially directed flange of symphysial region of mandible: (0) absent; (1) present.

Zhu *et al.* (2009, Character 83), and references therein; Zhu et al. (2013), Character 206; Choo et al. (2017), Character 208; King et al. (2017), Character 351; Castiello (2018), Character 343; Zhu Y. et al. (2022), Character 298.

1. Extensive flange composed of prearticular and Meckelian bone that extends beyond ventral edge of outer dermal series: (0) absent; (1) present.

Choo et al. (2017), Character 330; King et al. (2017), Character 352; Lu et al. (2017), Character 252; Castiello (2018), Character 344; Zhu Y. et al. (2022), Character 299.

1. Strong ascending flexion of symphysial region of mandible: (0) absent; (1) present.

Zhu *et al.* (2009, Character 82), and references therein; Zhu et al. (2013), Character 208; Choo et al. (2017), Character 210; King et al. (2017), Character 353; Castiello (2018), Character 345; Zhu Y. et al. (2022), Character 300.

1. Parasymphysial plate: (0) detachable tooth whorl; (1) long with posterior corner, sutured to coronoid, denticulated or with tooth row; (2) absent.

Zhu *et al.* (2009, Character 91), and references therein; Zhu et al. (2013), Character 209; Choo et al. (2017), Character 211; King et al. (2017), Character 354; Castiello (2018), Character 346; Zhu Y. et al. (2022), Character 301.

1. Anterior end of prearticular: (0) far from jaw symphysis; (1) near jaw symphysis.

Zhu *et al.* (2009, Character 96), and references therein; Zhu et al. (2013), Character 210; Choo et al. (2017), Character 212; King et al. (2017), Character 355; Castiello (2018), Character 347; Zhu Y. et al. (2022), Character 302.

1. Prearticular - dentary contact: (0) present; (1) absent.

Zhu *et al.* (2009, Character 98), and references therein; Zhu et al. (2013), Character 211; Choo et al. (2017), Character 213; King et al. (2017), Character 356; Castiello (2018), Character 348; Zhu Y. et al. (2022), Character 303.

1. Number of dermopalatines: (0) one; (1) two; (2) more than 2

Castiello (2018), Character 367. King et al. (2017), Character 378. Zhu Y. et al. (2021), Character 252; Zhu Y. et al. (2022), Character 304.

1. Entopterygoids: (0) separated; (1) contact along midline.

Zhu Y. et al. (2021), Character 253; Zhu Y. et al. (2022), Character 305.

1. Proportions of entopterygoid: (0) anterior end level with processus ascendens; (1) anterior end considerably anterior to processus ascendens.

Castiello (2018), Character 366; Zhu Y. et al. (2022), Character 306.

1. Course of mandibular canal: (0) passing through dentary; (1) not passing through dentary.

Zhu *et al.* (2009, Character 120), and references therein; Zhu et al. (2013), Character 218; Choo et al. (2017), Character 218; Coates et al. (2018), Character 94; King et al. (2017), Character 299; Castiello (2018), Character 290; Zhu Y. et al. (2022), Character 307.

1. Pharyngeal teeth or denticles: (0) absent; (1) present.

Coates et al. (2018), Character 78; Zhu Y. et al. (2022), Character 308.

1. Lingual torus: (0) absent; (1) present.

Coates et al. (2018), Character 81; Zhu Y. et al. (2022), Character 309.

1. Basolabial shelf: (0) absent; (1) present.

Coates et al. (2018), Character 82; Zhu Y. et al. (2022), Character 310.

1. Tooth whorls: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 40; Choo et al. (2017), Character 39; King et al. (2017), Character 328; Castiello (2018), Character 320; Zhu Y. et al. (2022), Character 311.

1. Distribution of tooth whorls: (0) upper and lower jaws; (1) lower jaws only; (2) upper jaws only.

Giles et al. (2015), Character 84; Choo et al. (2017), Character 285; King et al. (2017), Character 366; Castiello (2018), Character 356; Zhu Y. et al. (2022), Character 312.

1. Bases of tooth whorls: (0) single, continuous plate; (1) some or all whorls consist of separate tooth units.

Brazeau (2009); Davis et al. (2012), Character 41; Choo et al. (2017), Character 40; King et al. (2017), Character 329; Castiello (2018), Character 321; Zhu Y. et al. (2022), Character 313.

1. Enlarged adsymphysial tooth whorl: (0) absent; (1) present.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 42; Choo et al. (2017), Character 41; King et al. (2017), Character 330; Castiello (2018), Character 322; Zhu Y. et al. (2022), Character 314.

1. Tooth families/whorls: (0) restricted to symphysial region; (1) distributed along jaw margin.

Coates et al. (2018), Character 83; Zhu Y. et al. (2022), Character 315.

1. Number of tooth families/whorls per jaw ramus: (0) 15 or fewer; (1) 20 or more.

Coates et al. (2018), Character 84; Zhu Y. et al. (2022), Character 316.

1. Tooth families/whorls: (0) continuous; (1) discontinuous.

Zhu Y. et al. (2022), Character 317.

1. Toothplates consolidated into one to three large posterior plates, and one to three smaller anterior tooth plates, occupying each quadrant of the jaw: (0) absent; (1) present.

Coates et al. (2018), Character 86; Zhu Y. et al. (2022), Character 318.

Score changed from 0 (Coates et al., 2018) to - for *Austroptyctodus*, *Campbellodus* and *Rhamphodopsis*.

1. Toothplate complement restricted to two pairs in the upper jaw and a single pair in the lower jaw: (0) absent; (1) present.

Coates et al. (2018), Character 87; Zhu Y. et al. (2022), Character 319.

Score changed from 0 (Coates et al., 2018) to - for *Austroptyctodus*, *Campbellodus* and *Rhamphodopsis*.

1. Length of dentary: (0) constitutes a majority of jaw length; (1) half the length of jaw or less.

Zhu Y. et al. (2021), Character 242; Zhu Y. et al. (2022), Character 320.

1. Labial pit: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 243; King et al. (2017), Character 385; Castiello (2018), Character 374; Zhu Y. et al. (2022), Character 321.

1. Prearticular symphysis: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 244; Zhu Y. et al. (2022), Character 322.

1. Retroarticular process: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 248; King et al. (2017), Character 386; Castiello (2018), Character 375; Zhu Y. et al. (2022), Character 323.

*Mandibular arch*

1. Mandibular arch (jaws): (0) absent; (1) present.

Dupret et al. (2014), Character 254; Choo et al. (2017), Character 246; Zhu Y. et al. (2022), Character 324.

1. Position of mandibular arch articulations: (0) terminal; (1) subterminal.

Zhu Y. et al. (2021), Character 93; Zhu Y. et al. (2022), Character 325.

1. Palatoquadrate relationship to dermal cheek bones: (0) articulation narrow and restricted; (1) broad articulation.

Zhu Y. et al. (2021), Character 97; Zhu Y. et al. (2022), Character 326.

1. Articulation between neurocranium and palatoquadrate posterodorsal to orbit (suprapterygoid articulation): (0) absent; (1) present.

Zhu Y. et al. (2021), Character 144; Zhu Y. et al. (2022), Character 327.

1. Articulation surface of the palatoquadrate with the postorbital (suprapteryoid) process: (0) directed anteriorly; (1) laterally; (2) dorsally.

Coates et al. (2018), Character 107; Zhu Y. et al. (2022), Character 328.

1. Large otic process of the palatoquadrate: (0) absent; (1) present.

Coates & Sequeira (2001a); Davis (2002); Brazeau (2009); Davis et al. (2012), Character 46; Choo et al. (2017), Character 45; King et al. (2017), Character 334; Castiello (2018), Character 326; Zhu Y. et al. (2022), Character 329.

1. Laterally extending palatoquadrate: (0) absent; (1) present.

Zhu et al. (2016), Character 327; Zhu Y. et al. (2021), Character 308; Zhu Y. et al. (2022), Character 330.

1. Insertion area for jaw adductor muscles on palatoquadrate: (0) ventral; (1) lateral.

Janvier (1996); Brazeau (2009); Davis et al. (2012), Character 47; Choo et al. (2017), Character 46; King et al. (2017), Character 335; Castiello (2018), Character 327; Zhu Y. et al. (2022), Character 331.

1. Oblique ridge or groove along medial face of palatoquadrate: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 48; Choo et al. (2017), Character 47; King et al. (2017), Character 336; Castiello (2018), Character 328; Zhu Y. et al. (2022), Character 332.

1. Fenestration of palatoquadrate at basipterygoid articulation: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 49; Choo et al. (2017), Character 48; King et al. (2017), Character 337; Castiello (2018), Character 329; Zhu Y. et al. (2022), Character 333.

1. Perforate or fenestrate anterodorsal (metapterygoid) portion of palatoquadrate: (0) absent; (1) present.

Davis (2002); Brazeau (2009); Davis et al. (2012), Character 50; Choo et al. (2017), Character 49; King et al. (2017), Character 338; Castiello (2018), Character 330; Zhu Y. et al. (2022), Character 334.

1. Metapterygoid with developed medial ventral protrusion: (0) absent; (1) present.

Zhu et al. (2013), Character 216; Choo et al. (2017), Character 244; King et al. (2017), Character 362; Castiello (2018), Character 353; Zhu Y. et al. (2022), Character 335.

1. Autopalatine and quadrate: (0) comineralized; (1) separate mineralizations.

Giles et al. (2015), Character 97; Choo et al. (2017), Character 290; King et al. (2017), Character 370; Castiello (2018), Character 359; Zhu Y. et al. (2022), Character 336.

1. Palatoquadrate fused with neurocranium: (0) absent; (1) present.

Giles et al. (2015), Character 101; Choo et al. (2017), Character 291; King et al. (2017), Character 371; Castiello (2018), Character 360; Zhu Y. et al. (2022), Character 337.

1. Contact between palatoquadrate and dermal cheek bones: (0) continuous contact of metapterygoid and autopalatine; (1) metapterygoid and autopalatine contacts separated by gap between commissural lamina of palatoquadrate and cheek bones.

Zhu et al. (2013), Character 215; Choo et al. (2017), Character 243; Zhu Y. et al. (2022), Character 338.

1. Position of upper mandibular arch cartilage (and associated cheek plate where present): (0) entirely suborbital; (1) with a postorbital extension.

Giles et al. (2015), Character 95; Choo et al. (2017), Character 289; Zhu Y. et al. (2022), Character 339.

1. Scalloped oral margin on Meckel’s cartilage and palatoquadrate: (0) absent; (1) present.

Coates et al. (2018), Character 113; Zhu Y. et al. (2022), Character 340.

1. Mandibular symphysis fused: (0) absent; (1) present.

Coates et al. (2018), Character 114; Zhu Y. et al. (2022), Character 341.

1. Pronounced dorsal process on Meckelian bone or cartilage: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 51; Choo et al. (2017), Character 50; King et al. (2017), Character 339; Castiello (2018), Character 331; Zhu Y. et al. (2022), Character 342.

1. Meckelian bone exposed immediately anterior to first coronoid: (0) yes; (1) no.

Zhu *et al.* (2009, Character 99), and references therein; Zhu et al. (2013), Character 212; Choo et al. (2017), Character 214; King et al. (2017), Character 357; Castiello (2018), Character 349; Zhu Y. et al. (2022), Character 343.

1. Preglenoid process: (0) absent; (1) present.

Davis et al. (2012), Character 52; Choo et al. (2017), Character 51; King et al. (2017), Character 340; Castiello (2018), Character 332; Zhu Y. et al. (2022), Character 344.

1. Biconcave glenoid on lower jaw: (0) absent; (1) present.

Friedman & Brazeau (2010, Character 17); Zhu et al. (2013), Character 214; Choo et al. (2017), Character 216; King et al. (2017), Character 359; Castiello (2018), Character 351; Zhu Y. et al. (2022), Character 345.

1. Jaw articulation located on rearmost extremity of mandible: (0) absent; (1) present.

Davis et al. (2012), Character 53; Choo et al. (2017), Character 52; King et al. (2017), Character 341; Castiello (2018), Character 333; Zhu Y. et al. (2022), Character 346.

*Hyoid and gill arches*

1. Foramen in hyomandibular: (0) absent; (1) present.

Zhu *et al.* (2009, Character 100), and references therein; Zhu et al. (2013), Character 197; Choo et al. (2017), Character 201; King et al. (2017), Character 142; Castiello (2018), Character 141; Zhu Y. et al. (2022), Character 347.

1. Interhyal: (0) absent; (1) present.

Davis et al. (2012), Character 38; Choo et al. (2017), Character 37; King et al. (2017), Character 141; Castiello (2018), Character 140; Zhu Y. et al. (2022), Character 348.

1. Hypohyal: (0) absent; (1) present.

Giles et al. (2015), Character 75; Choo et al. (2017), Character 282; King et al. (2017), Character 144; Castiello (2018), Character 143; Zhu Y. et al. (2022), Character 349.

1. Disposition of the interbranchial ridges of the oralobranchial chamber roof: (0) oligobranchiate; (1) orthobranchiate; (2) nectaspidoform.

King et al. (2017), Character 146; Castiello (2018), Character 145; Zhu Y. et al. (2022), Character 350.

1. Number of branchial fossae: (0) 5-7; (1) 9-17; (2) more than 20.

King et al. (2017), Character 147; Castiello (2018), Character 146; Zhu Y. et al. (2022), Character 351.

1. Basibranchial elements: (0) unpaired; (1) paired.

King et al. (2017), Character 148; Castiello (2018), Character 147; Zhu Y. et al. (2022), Character 352.

1. Sublingual rod: (0) absent; (1) present.

King et al. (2017), Character 149; Castiello (2018), Character 148; Zhu Y. et al. (2022), Character 353.

1. Dense array of hyoid arch rays covers gill area: (0) absent; (1) present.

King et al. (2017), Character 150; Castiello (2018), Character 149; Zhu Y. et al. (2022), Character 354.

1. Endoskeletal urohyal: (0) absent; (1) present.

Giles et al. (2015), Character 76; Choo et al. (2017), Character 283; King et al. (2017), Character 145; Castiello (2018), Character 144; Zhu Y. et al. (2022), Character 355.

1. Urohyal shape (vertical plate): (0) absent; (1) present.

Choo et al. (2017), Character 329; Lu et al. (2017), Character 246; Zhu Y. et al. (2022), Character 356.

1. Basihyal: (0) absent; (1) present.

Choo et al. (2017), Character 36; King et al. (2017), Character 140; Castiello (2018), Character 139; Zhu Y. et al. (2022), Character 357.

1. Ceratohyal smooth with posterior, lateral fossa: (0) absent; (1) present.

Coates et al. (2018), Character 69; Zhu Y. et al. (2022), Character 358.

1. Anterior most unpaired element of branchial skeleton contacted by: (0) one branchial arch only; (1) two or more branchial arches.

Pradel et al. (2014); Choo et al. (2017), Character 36; Coates et al. (2018), Character 71; Dearden et al. (2019), Character 73; Zhu Y. et al. (2022), Character 359.

This character formulation (Dearsen et al., 2019) is modified from Coates et al. (2018): Basihyal absent/present.

1. Multiple unpaired branchial mineralisations: (0) absent; (1) present.

Dearden et al. (2019), Character 74; Zhu Y. et al. (2022), Character 360.

1. Posterior two ventral branchial arches:0 separate; (1) articulate ventrally.

Dearden et al. (2019), Character 80; Zhu Y. et al. (2022), Character 361.

1. Posterior two dorsal branchial arches: (0) separate; (1) articulate dorsally.

Dearden et al. (2019), Character 81; Zhu Y. et al. (2022), Character 362.

1. Gill arches: (0) largely restricted to region under braincase; (1) extend far posterior to braincase.

Giles et al. (2015), Character 72; Choo et al. (2017), Character 281; King et al. (2017), Character 143; Castiello (2018), Character 142; Zhu Y. et al. (2022), Character 363.

1. Gill skeleton extends posteriorly beyond occiput: (0) absent; (1) present.

Coates et al. (2018), Character 66. Dearden et al. (2019), Character 67; Zhu Y. et al. (2022), Character 364.

1. First branchial arch meets neurocranium: (0) ventral to otic region; (1) posterior to otic region.

Dearden et al. (2019), Character 68; Zhu Y. et al. (2021), Character 355; Zhu Y. et al. (2022), Character 365.

1. Separate supra- and infra-pharyngobranchials: (0) absent; (1) present.

Coates et al. (2018), Character 72; Zhu Y. et al. (2022), Character 366.

1. Pharyngobranchial orientation: (0) directed anteriorly; (1) posteriorly.

Coates et al. (2018), Character 73; Zhu Y. et al. (2022), Character 367.

1. Posteriormost branchial arch bears epibranchial unit: (0) absent; (1) present.

Coates et al. (2018), Character 74; Zhu Y. et al. (2022), Character 368.

1. Epibranchials bear posterior flange: (0) absent; (1) present.

Coates et al. (2018), Character 75; Zhu Y. et al. (2022), Character 369.

1. Hypobranchial orientation: (0) directed anteriorly; (1) hypobranchials of second and more posterior gill arches directed posteriorly.

Coates et al. (2018), Character 76; Zhu Y. et al. (2022), Character 370.

*Neurocranium*

1. Endoskeletal intracranial joint: (0) absent; (1) present.

Janvier (1996), and references therein; Davis et al. (2012), Character 61; Choo et al. (2017), Character 60; King et al. (2017), Character 25; Castiello (2018), Character 25; Zhu Y. et al. (2022), Character 371.

1. Discrete division of the ethmoid and more posterior braincase at the level of the optic tract canal (optic fissue): (0) absent; (1) present.

Choo et al. (2017), Character 247; Zhu Y. et al. (2021), Character 118; King et al. (2017), Character 73; Castiello (2018), Character 75; Zhu Y. et al. (2022), Character 372.

1. Ventral cranial fissure: (0) absent; (1) present.

Janvier (1996); Coates & Sequeira (2001); Maisey (2001); Davis (2002); Brazeau (2009), Character 92; Davis et al. (2012), Character 96; Giles et al. (2015), Character 168; Choo et al. (2017), Character 92. King et al. (2017), Character 54; Castiello (2018), Character 55; Zhu Y. et al. (2022), Character 373.

Davis et al. (2012): Coding for *Homalacanthus* adopted from Brazeau (2009); see also Gagnier (1996). Unexpectedly, in the context of a holocephalan chondrocranium, there is evidence of a ventral fissure in *Chondrenchelys*, visible in the basicranium of NMS 2002.68.1.

1. Metotic (otic-occipital) fissure: (0) absent; (1) present.

Schaeffer (1981); Janvier (1996); Coates & Sequeira (1998); Maisey (2001); Davis (2002); Brazeau (2009) ), Character 93; Davis et al. (2012), Character 97; Choo et al. (2017), Character 93. King et al. (2017), Character 55; Castiello (2018), Character 56; Zhu Y. et al. (2022), Character 374.

1. External nasal opening: (0) single median; (1) paired.

Castiello (2018), Character 226; Zhu Y. et al. (2022), Character 375.

1. Nasal opening(s): (0) dorsal, placed between orbits; (1) ventral and anterior to orbits.

Friedman (2007); Brazeau (2009); Davis et al. (2012), Character 56; Choo et al. (2017), Character 55. King et al. (2017), Character 20; Castiello (2018), Character 20; Zhu Y. et al. (2022), Character 376.

1. Nasohypophyseal opening shape: (0) unconstructed; (1) constriction between nasal and hypophysial divisions; (2) split into nasal and hypophysial divisions.

Castiello (2018), Character 227; Zhu Y. et al. (2022), Character 377.

1. Endoskeletal lamina (postnasal wall) separating posterior nostril and orbit: (0) absent; (1) present.

Clement et al. (2018), Character 281; Zhu Y. et al. (2022), Character 378.

1. Orbitonasal lamina dorsoventrally deep: (0) absent; (1) present.

Coates et al. (2018), Character 122; Zhu Y. et al. (2022), Character 379.

1. Size of profundus canal in postnasal wall: (0) small; (1) large.

Choo et al. (2017), Character 333; Lu et al. (2017), Character 265; Zhu Y. et al. (2022), Character 380.

1. Three large pores (in addition to nostrils) associated with each side of ethmoid: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 257; Zhu Y. et al. (2022), Character 381.

1. Ventral face of nasal capsule in taxa with mineralized ethmoid: (0) complete; (1) fenestra ventrolateralis; (2) entire floor unmineralized.

Choo et al. (2017), Character 172; Zhu Y. et al. (2021), Character 258; Zhu Y. et al. (2022), Character 382.

1. Fenestra ventrolateralis: (0) absent; (1) present; (2) common ventral fenestra for anterior and posterior nostrils.

Zhu *et al.* (2009, Character 34), and references therein; Zhu et al. (2013), Character 220; Choo et al. (2017), Character 219; Zhu Y. et al. (2022), Character 383.

1. Precerebral fontanelle: (0) absent; (1) present.

Schaeffer (1981); Coates & Sequeira (1998, 2001); Maisey (2001); Brazeau (2009); Davis et al. (2012), Character 54; Choo et al. (2017), Character 53. King et al. (2017), Character 19; Castiello (2018), Character 19; Zhu Y. et al. (2022), Character 384.

1. Olfactory tracts: (0) short, with olfactory capsules situated close to telencephalon cavity; (1) elongate and tubular (much longer than wide).

Zhu *et al*. (2009); Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 57; Choo et al. (2017), Character 56. King et al. (2017), Character 21; Castiello (2018), Character 21; Zhu Y. et al. (2022), Character 385.

1. Olfactory tracts: (0) parallel or near-parallel; (1) significantly diverged.

Zhu Y. et al. (2021), Character 342; Zhu Y. et al. (2022), Character 386.

1. Prominent pre-orbital rostral expansion of the neurocranium: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 58; Choo et al. (2017), Character 57; Zhu Y. et al. (2022), Character 387.

The coding of *Ramirosuarezia* is changed from 0 to 1.

1. Ethmoid region elongate with dorsoventrally deep lateral walls: (0) absent; (1) present.

Davis et al. (2012), Character 73; Choo et al. (2017), Character 72. King et al. (2017), Character 36; Castiello (2018), Character 36; Zhu Y. et al. (2022), Character 388.

1. Ethmoid articulation for palatoquadrate: (0) placed on postnasal wall; (1) extends posteriorly to the level of N.II.

Zhu *et al.* (2009, Character 35), and references therein; Zhu et al. (2013), Character 221; Choo et al. (2017), Character 242; King et al. (2017), Character 72; Castiello (2018), Character 74; Zhu Y. et al. (2022), Character 389.

1. Internasal vacuities or pits: (0) absent; (1) present.

Lu et al. (2016), Character 49; Coates et al. (2018), Character 116; Zhu Y. et al. (2022), Character 390.

1. Morphology of internasal vacuities: (0) undifferentiated or anterior palatal fossa; (1) shallow, paired pits with strong midline ridge; (2) deep, peer-shaped pits.

Zhu *et al.* (2009, Character 33), and references therein; Zhu et al. (2013), Character 219; Lu et al. (2016), Character 49; Choo et al. (2017), Character 245; Zhu Y. et al. (2022), Character 391.

1. Basicranial morphology: (0) platybasic; (1) tropibasic.

Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 74; Choo et al. (2017), Character 73; Zhu Y. et al. (2022), Character 392.

1. Narrow interorbital septum: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 68; Choo et al. (2017), Character 67. King et al. (2017), Character 32; Castiello (2018), Character 32; Zhu Y. et al. (2022), Character 393.

1. Optic lobes: (0) narrower than cerebellum; (1) same width or wider than cerebellum.

Lu et al. (2017), Character 271; Zhu Y. et al. (2022), Character 394.

1. Space for forebrain and (at least) proximal portion of olfactory tracts narrow and elongate, extending between orbits: (0) absent; (1) present.

Coates et al. (2018), Character 118. Zhu Y. et al. (2021), Character 347; Zhu Y. et al. (2022), Character 395.

1. Rostral bar: (0) absent; (1) present.

Coates et al. (2018), Character 120; Zhu Y. et al. (2022), Character 396.

1. Anteriormost articulation for the mandibular arch: (0) located anterior to the nasal capsules, terminal; (1) immediately below or posterior to nasal capsules, subterminal.

Zhu et al. (2016), Character 326; Coates et al. (2018), Character 123; Zhu Y. et al. (2021), Character 307; Zhu Y. et al. (2022), Character 397.

1. Palatobasal (or orbital) articulation: (0) posterior to the optic foramen; (1) anterior to the optic foramen, grooved, and overlapped by process or flange of palatoquadrate; (2) anterior to optic foramen, smooth, and overlaps or flanks articular surface on palatoquadrate.

Coates et al. (2018), Character 124; Zhu Y. et al. (2022), Character 398.

1. Close association of pineal organ and nasal cavities: (0) absent; (1) present.

Zhu et al. (2016), Character 328; Zhu Y. et al. (2021), Character 309; Zhu Y. et al. (2022), Character 399.

1. Trochlear nerve foramen anterior to optic nerve foramen: (0) absent; (1) present.

Coates et al. (2018), Character 126; Zhu Y. et al. (2021), Character 349; Zhu Y. et al. (2022), Character 400.

1. Pronounced sub-ethmoidal keel: (0) absent; (1) present.

Schaeffer (1981); Coates & Sequeira (1998); Brazeau (2009); Davis et al. (2012), Character 59; Choo et al. (2017), Character 58; King et al. (2017), Character 23; Castiello (2018), Character 23; Zhu Y. et al. (2022), Character 401.

1. Eyestalk or unfinished area on neurocranial wall for eyestalk: (0) absent; (1) present.

Zhu *et al.* (2009, Character 36), and references therein; Zhu et al. (2013), Character 222; Giles et al. (2015), Character 131; Choo et al. (2017), Character 149; King et al. (2017), Character 62; Castiello (2018), Character 63; Zhu Y. et al. (2022), Character 402.

1. Eye stalk position: (0) positioned laterally on the orbital wall; (1) positioned ventrally on the subocular shelf wall.

Castiello (2018), Character 64; Zhu Y. et al. (2022), Character 403.

1. Position of myodome for superior oblique eye muscles: (0) posterior and dorsal to foramen for nerve II; (1) anterior and dorsal to foramen.

Young (1986); Coates & Sequeira (2001a); Brazeau (2009); Davis et al. (2012), Character 60; Choo et al. (2017), Character 59; King et al. (2017), Character 24; Castiello (2018), Character 24; Zhu Y. et al. (2022), Character 404.

1. Orbit directed mostly laterally and free of flanking endocranial cartilage or bone: (0) absent; (1) present.

Coates et al. (2018), Character 128; Zhu Y. et al. (2022), Character 405.

1. Orbit dorsal or facing dorsolaterally, surrounded laterally by endocranium: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 66; Choo et al. (2017), Character 65; Zhu Y. et al. (2022), Character 406.

1. Orbit larger than otic capsule: (0) absent; (1) present.

Coates et al. (2018), Character 142; Zhu Y. et al. (2022), Character 407.

1. Paired pineal and parapineal tracts: (0) absent; (1) present.

Choo et al. (2017), Character 334; Lu et al. (2017), Character 266; Zhu Y. et al. (2022), Character 408.

1. Endoskeletal spiracular canal: (0) open; (1) partial enclosure or spiracular bar; (2) complete enclosure in canal.

Choo et al. (2017), Character 335; Lu et al. (2017), Character 268; Zhu Y. et al. (2022), Character 409.

1. Developed postorbital cavity: (0) absent; (1) present.

Zhu et al. (2013), Character 223; Choo et al. (2017), Character 220; Zhu Y. et al. (2022), Character 410.

1. Unconstricted cranial notochord: (0) absent; (1) present.

Zhu *et al.* (2009, Character 40), and references therein; Zhu et al. (2013), Character 225; Choo et al. (2017), Character 221; King et al. (2017), Character 68; Castiello (2018), Character 70; Zhu Y. et al. (2022), Character 411.

1. Descending process of sphenoid (with its posterior extremity lacking periostegeal lining): (0) absent; (1) present.

Zhu *et al.* (2009, Character 41), and references therein; Zhu et al. (2013), Character 226; Choo et al. (2017), Character 222; King et al. (2017), Character 69; Castiello (2018), Character 71; Zhu Y. et al. (2022), Character 412.

1. Opercular suspension on braincase: (0) absent; (1) present.

Brazeau (2009, Character 91); Zhu et al. (2013), Character 229; Choo et al. (2017), Character 224; King et al. (2017), Character 70; Castiello (2018), Character 72; Zhu Y. et al. (2022), Character 413.

1. Ophthalmic foramen in anterodorsal extremity of orbit communicates with cranial interior: (0) absent; (1) present.

Coates et al. (2018), Character 132; Zhu Y. et al. (2022), Character 414.

1. Internal carotids: (0) entering single or paired openings in the basicranium from a posterolateral angle; (1) entering basicranial opening(s) head-on from an extreme, lateral angle; (2) absent.

Coates et al. (2018), Character 137; Zhu Y. et al. (2022), Character 415.

Internal carotids converging almost head-on toward the midline (Schaeffer, 1981; Maisey, 1983) is shared by *Synechodus* and Recent elasmobranchs (Maisey, 1985).

1. Entrance of internal carotids: (0) through separate openings flanking the hypophyseal opening or recess; (1) through a common opening at the central midline of the basicranium.

Schaeffer (1981); Coates & Sequeira (1998); Brazeau (2009); Davis et al. (2012), Character 78; Choo et al. (2017), Character 78; King et al. (2017), Character 41; Castiello (2018), Character 41; Zhu Y. et al. (2022), Character 416.

1. Postorbital process: (0) absent; (1) present.

Giles et al. (2015), Character 132; Choo et al. (2017), Character 295; Coates et al. (2018), Character 165; King et al. (2017), Character 77; Castiello (2018), Character 79; Zhu Y. et al. (2021), Character 129; Zhu Y. et al. (2022), Character 417.

Here we define the postorbital process as a dorsally positioned process at the rear margin of the orbit. The postorbital process is known by a variety of names in different groups: suprapterygoid process (sarcopterygians: Jarvik 1980); supraorbital process (placoderms: Stensio 1969; Jarvik 1980); postorbital pila (in part; identified in some early sarcopterygians and Entelegnathus, where a bridge encloses the jugular vein: Yu 1998; Zhu et al. 2013); lateral commissure (in part; identified in early actinopterygians and *Ligulalepis*; Zhu et al. 2013). Rudimentary postorbital processes are present in the rhenanid Jagorina (Stensio 1969: fig. 90) and the porolepiforms *Porolepis* and *Glyptolepis* (Jarvik 1972: figs 20-21). Taxa in which the orbit is completely enclosed by the neurocranium (e.g., Macropetalichthys) or where the palatoquadrate is fused to the neurocranium (e.g., Helodus) are coded as uncertain for this character. (Giles et al., 2015)

1. Elongated distance between postorbital process and the articulation for hyomandibular: (0) absent; (1) present.

Zhu Y. et al. (2022), Character 418.

1. Postorbital process articulates with palatoquadrate: (0) absent; (1) present.

Schaeffer (1981); Coates & Sequeira (1998); Maisey (2001a); Davis et al. (2012), Character 81; Choo et al. (2017), Character 80; King et al. (2017), Character 43; Castiello (2018), Character 43; Zhu Y. et al. (2022), Character 419.

1. Postorbital process and arcade: (0) short and deep - width not more than maximum braincase width (excluding arcade); (1) process and arcade wide - width exceeds maximum width of braincase, and anteroposteriorly narrow; (2) process and arcade massive; (3) arcade forms postorbital pillar.

Coates et al. (2018), Character 144; Zhu Y. et al. (2021), Character 345; Zhu Y. et al. (2022), Character 420.

1. Postorbital process downturned, with anhedral angle relative to basicranium: (0) absent; (1) present.

Coates et al. (2018), Character 145; Zhu Y. et al. (2022), Character 421.

1. Canal for jugular in postorbital process: (0) absent; (1) present.

Giles et al. (2015), Character 133; Choo et al. (2017), Character 296; King et al. (2017), Character 78; Castiello (2018), Character 80; Zhu Y. et al. (2022), Character 422.

1. Jugular canal diameter: (0) small; (1) large; (2) canal absent.

Coates et al. (2018), Character 146; Zhu Y. et al. (2022), Character 423.

1. Jugular canal: (0) long (invested in otic region along length of skeletal labyrinth); (1) short (restricted to region anterior of skeletal labyrinth); (2) absent (jugular vein uninvested in otic region).

Giles et al. (2015), Character 126; Choo et al. (2017), Character 294; King et al. (2017), Character 76; Castiello (2018), Character 78; Zhu Y. et al. (2022), Character 424.

This character is modified from DFC characters 76 and 93. In part, this character describes patterns of variation among transverse otic processes that bear the hyomandibular facet (see characters 125 and 164). Transverse otic processes that lack a canal for the jugular are characteristic of many chondrichthyans (e.g. *Tamiobatis*, *Xenacanthus*). In cases where taxa lack a jugular canal and have a posteriorly positioned transverse otic process, this structure is typically called a lateral otic process (e.g. Schaeffer 1981: figs. 6, 21; Coates & Sequeira 1998: fig. 6). This character is composed as a compound because there are no further dependent characters. Mathematically, this should be equivalent to atomizing and using inapplicability. (Giles et al., 2015)

1. Canal, likely for trigeminal nerve (V) mandibular ramus, passes through the postorbital process from proximal dorsal entry to distal and ventral exit: (0) absent; (1) present.

Coates et al. (2018), Character 147; Zhu Y. et al. (2022), Character 425.

1. Postorbital process expanded anteroposteriorly: (0) absent; (1) present.

Coates et al. (2018), Character 148; Zhu Y. et al. (2022), Character 426.

1. C-bout notch separates postorbital process from supraotic shelf: (0) absent; (1) present.

Coates et al. (2018), Character 152; Zhu Y. et al. (2022), Character 427.

1. Series of perforations for innervation of supraorbital sensory canal in supraorbital shelf: (0) absent; (1) present.

Giles et al. (2015), Character 134; Choo et al. (2017), Character 297; King et al. (2017), Character 79; Castiello (2018), Character 81; Zhu Y. et al. (2022), Character 428.

This character is coded as inapplicable in taxa lacking well-developed supraorbital shelves. (Giles et al., 2015)

1. Spiracular groove on basicranial surface: (0) absent; (1) present.

Davis et al. (2012), Character 62; Choo et al. (2017), Character 61; King et al. (2017), Character 26; Castiello (2018), Character 26; Zhu Y. et al. (2022), Character 429.

1. Spiracular groove on lateral commissure: (0) absent; (1) present.

Davis et al. (2012), Character 63; Choo et al. (2017), Character 62; King et al. (2017), Character 27; Castiello (2018), Character 27; Zhu Y. et al. (2022), Character 430.

1. Subpituitary fenestra: (0) absent; (1) present.

Goujet & Young (1995); Brazeau (2009); Davis et al. (2012), Character 64; Choo et al. (2017), Character 63; King et al. (2017), Character 28; Castiello (2018), Character 94; Zhu Y. et al. (2022), Character 431.

1. Supraorbital shelf broad with convex lateral margin: (0) absent; (1) present.

Coates & Sequeira (1998); Brazeau (2009); Davis et al. (2012), Character 65; Choo et al. (2017), Character 64; King et al. (2017), Character 29; Castiello (2018), Character 28; Zhu Y. et al. (2022), Character 432.

1. Nerve VIII bifurcates before entering the labyrinth cavity: (0) bifurcates; (1) does not bifurcate.

Zhu Y. et al. (2021), Character 341; Zhu Y. et al. (2022), Character 433.

1. Prehypophysial diencephalon: (0) the prehypophysial ventral “step” is absent or insignificantly captured by endocast, the ventral aspect of telencephalon is continuous with the anterior boundary of the hypophysial recess; (1) significant prehypophysial diencephalon, indicated by a “step” between the optic nerve canal marking the start of the diencephalon, and the anterior boundary of the hypophysial recess.

Zhu Y. et al. (2021), Character 343; Zhu Y. et al. (2022), Character 434.

1. Otic or pre-vagus section of myelencephalon: (0) long, longer than metencephalon; (1) short, shorter than metencephalon.

Zhu Y. et al. (2021), Character 344; Zhu Y. et al. (2022), Character 435.

1. Extended prehypophysial portion of sphenoid: (0) absent; (1) present.

Davis et al. (2012), Character 67; Choo et al. (2017), Character 66. King et al. (2017), Character 31; Castiello (2018), Character 31; Zhu Y. et al. (2022), Character 436.

1. Main trunk of facial nerve: (0) elongate and passes anterolaterally through orbital floor; (1) stout and divides within otic capsule at the level of the postorbital process.

Brazeau (2009); Davis et al. (2012), Character 69; Choo et al. (2017), Character 68; Zhu Y. et al. (2022), Character 437.

1. Hyoid ramus of facial nerve exits through posterior jugular opening: (0) absent; (1) present.

Friedman (2007); Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 70; Choo et al. (2017), Character 69; King et al. (2017), Character 33; Castiello (2018), Character 33; Zhu Y. et al. (2022), Character 438.

1. Ascending basisphenoid pillar pierced by common internal carotid: (0) absent; (1) present.

Miles (1973b); Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 75; Choo et al. (2017), Character 74; King et al. (2017), Character 38; Castiello (2018), Character 38; Zhu Y. et al. (2022), Character 439.

1. Canal for efferent pseudobranchial artery within basicranial cartilage: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 79; Choo et al. (2017), Character 75; King et al. (2017), Character 39; Castiello (2018), Character 39; Zhu Y. et al. (2022), Character 440.

1. Position of basal/basipterygoid articulation: (0) same anteroposterior level as hypophysial opening; (1) anterior to hypophysial opening.

Brazeau (2009); Davis et al. (2012), Character 80; Choo et al. (2017), Character 79; King et al. (2017), Character 42; Castiello (2018), Character 42; Zhu Y. et al. (2022), Character 441.

1. Basipterygoid process (basal articulation) with vertically oriented component: (0) absent; (1) present.

Davis et al. (2012), Character 83; Choo et al. (2017), Character 82; King et al. (2017), Character 45; Castiello (2018), Character 45; Zhu Y. et al. (2022), Character 442.

1. Expanded articular area anterior to basipterygoid process: (0) absent; (1) present.

King et al. (2017), Character 103; Castiello (2018), Character 104; Zhu Y. et al. (2022), Character 443.

1. Pituitary vein canal: (0) dorsal to level of basipterygoid process; (1) flanked posteriorly by basipterygoid process.

Davis et al. (2012), Character 84; Choo et al. (2017), Character 83; King et al. (2017), Character 46; Castiello (2018), Character 46; Zhu Y. et al. (2022), Character 444.

1. Pituitary vein canal: (0) discontinuous, enters the cranial cavity; (1) discontinuous, enters hypophysial recess; (2) continuous transverse vein.

Clement et al. (2018), Character 282; Zhu Y. et al. (2022), Character 445.

1. Pituitary vein in a transverse canal connecting the orbit: (0) absent; (1) present.

Castiello (2018), Character 93; Zhu Y. et al. (2022), Character 446.

1. Short otico-occipital region of braincase: (0) absent; (1) present.

Schaeffer (1981); Coates & Sequeira (1998, 2001); Maisey (2001); Brazeau (2009); Davis et al. (2012), Character 72; Choo et al. (2017), Character 71; King et al. (2017), Character 35; Castiello (2018), Character 35; Zhu Y. et al. (2022), Character 447.

1. Position of hyomandibula articulation on neurocranium: (0) absent; (1) present.

Coates & Sequeira (2001); Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 95; Choo et al. (2017), Character 76; Zhu Y. et al. (2022), Character 448.

1. Articulation facet with hyomandibular: (0) single-headed; (1) double-headed.

Zhu *et al.* (2009, Character 44) and references therein; Zhu et al. (2013), Character 227; Giles et al. (2015), Character 155; Choo et al. (2017), Character 150; King et al. (2017), Character 63; Castiello (2018), Character 65; Zhu Y. et al. (2022), Character 449.

1. Position of hyomandibula articulation on neurocranium: (0) below or anterior to orbit, on ventrolateral angle of braincase; (1) on otic capsule, posterior to orbit.

Zhu Y. et al. (2021), Character 157; Zhu Y. et al. (2022), Character 450.

1. Position of hyomandibula articulation relative to structure of skeletal labyrinth: (0) anterior or lateral to skeletal labyrinth; (1) at level of posterior semicircular canal.

Zhu Y. et al. (2021), Character 158; Zhu Y. et al. (2022), Character 451.

1. Hyomandibula articulates with neurocranium beneath otic shelf: (0) absent; (1) present.

Coates et al. (2018), Character 162; Zhu Y. et al. (2022), Character 452.

1. Hyoid arch articulation: (0) on lateral commissure; (1) on otic capsule wall.

Brazeau (2009, Character 90), Zhu et al. (2009, Character 45), and references therein, Friedman & Brazeau (2010, Character 8); Zhu et al. (2013), Character 228; Choo et al. (2017), Character 223; Zhu Y. et al. (2022), Character 453.

1. Relative position of jugular groove and hyomandibular articulation: (0) hyomandibula dorsal or same level (i.e. on bridge); (1) jugular vein passing dorsal or lateral to hyomandibula.

Choo et al. (2017), Character 324; Zhu Y. et al. (2022), Character 454.

1. Hyomandibular facets where they straddle the jugular vein: (0) narrowly separated; (1) widely separated.

King et al. (2017), Character 104; Castiello (2018), Character 105; Zhu Y. et al. (2022), Character 455.

1. Hypophyseal chamber: (0) projects posteroventrally; (1) projects ventrally or anteroventrally.

Zhu Y. et al. (2021), Character 266; Zhu Y. et al. (2022), Character 456.

1. Cuccullaris fossa (trapezius fossa): (0) open posteriorly; (1) constrained posteriorly.

Zhu et al. (2016), Character 324; Zhu Y. et al. (2021), Character 306; Zhu Y. et al. (2022), Character 457.

1. Cranial cavity and labyrinth: (0) widely spaced; (1) closely spaced.

Lu et al. (2017), Character 273; Zhu Y. et al. (2022), Character 458.

1. Labyrinth cavity: (0) separated from the main neurocranial cavity by a cartilaginous or ossified capsular wall; (1) skeletal capsular wall absent.

Schaeffer (1981); Davis et al. (2012), Character 82; Choo et al. (2017), Character 81; King et al. (2017), Character 44; Castiello (2018), Character 44; Zhu Y. et al. (2022), Character 459.

1. External (horizontal) semicircular canal: (0) absent; (1) present.

Janvier (1996); Davis et al. (2012), Character 85; Choo et al. (2017), Character 84; King et al. (2017), Character 47; Castiello (2018), Character 47; Zhu Y. et al. (2022), Character 460.

1. External (horizontal) semicircular canal: (0) joins the vestibular region dorsal to posterior ampulla; (1) joins level with posterior ampulla.

Davis et al. (2012), Character 87; Choo et al. (2017), Character 86; King et al. (2017), Character 49; Castiello (2018), Character 49; Zhu Y. et al. (2022), Character 461.

1. Horizontal semicircular canal in dorsal view: (0) medial to path of jugular vein; (1) dorsal to jugular vein.

Giles et al. (2015), Character 154; Choo et al. (2017), Character 299; King et al. (2017), Character 81; Castiello (2018), Character 83; Zhu Y. et al. (2022), Character 462.

This character captures the variable relationship between the course of the jugular vein and the horizontal semicircular canal. In placoderms, the jugular canal extends lateral to the horizontal canal in dorsal view, whereas most crown gnathostomes show a contrasting condition where the vein is overlapped by the canal. Galeaspids and osteostracans are lack a horizontal canal, and are coded as inapplicable for this character. (Giles et al., 2015)

1. Crus commune connecting anterior and posterior semicircular canals: (0) present; (1) absent.

Coates et al. (2018), Character 180; Zhu Y. et al. (2021), Character 279; Zhu Y. et al. (2022), Character 463.

1. Crus commune of anterior and posterior semicircular canals: (0) dorsal to endocranial roof; (1) ventral to endocranial roof.

Lu et al. (2017), Character 272; Zhu Y. et al. (2022), Character 464.

1. Angle of external semicircular canal: in lateral view, straight line projected through canal intersects anterior ampulla, external ampullae, and base of foramen magnum: (0) absent; (1) present.

Coates et al. (2017; Character 101); Coates et al. (2018), Character 177; Zhu Y. et al. (2021), Character 350; Zhu Y. et al. (2022), Character 465.

1. Left and right external semicircular canals approach or meet the posterodorsal midine of the hindbrain roof: (0) absent; (1) present.

Coates et al. (2018), Character 178; Zhu Y. et al. (2021), Character 351; Zhu Y. et al. (2022), Character 466.

1. Preampullary portion of posterior semicircular canal: (0) absent; (1) present.

Maisey (2001), Character 17; Coates et al. (2018), Character 179; Zhu Y. et al. (2021), Character 332; Zhu Y. et al. (2022), Character 467.

1. Sinus superior: (0) absent or indistinguishable from union of anterior and posterior canals with saccular chamber; (1) present.

Davis et al. (2012), Character 86; Choo et al. (2017), Character 85; King et al. (2017), Character 41; Castiello (2018), Character 41; Zhu Y. et al. (2021), Character 331; Zhu Y. et al. (2022), Character 468.

1. Supraotic cavity: (0) absent; (1) present.

Lu et al. (2017), Character 275; Zhu Y. et al. (2022), Character 469.

1. Lateral cranial canal: (0) absent; (1) present.

Zhu *et al.* (2009, Character 55), and references therein; Zhu et al. (2013), Character 233; Giles et al. (2015), Character 155; Choo et al. (2017), Character 152; King et al. (2017), Character 64; Castiello (2018), Character 66; Zhu Y. et al. (2022), Character 470.

1. Subcircular endolymphatic foramen: (0) absent; (1) present.

Coates et al. (2018), Character 185; Zhu Y. et al. (2022), Character 471.

1. External opening for endolymphatic ducts anterior to crus commune: (0) absent; (1) present.

Coates et al. (2018), Character 186; Zhu Y. et al. (2021), Character 352; Zhu Y. et al. (2022), Character 472.

1. Endolymphatic ducts: (0) posteriodorsally angled tubes; (1) tubes oriented vertically through median endolymphatic fossa.

Schaeffer (1981); Coates & Sequeira (1998, 2001); Davis (2002); Brazeau (2009); Davis et al. (2012), Character 92; Choo et al. (2017), Character 91; Zhu Y. et al. (2022), Character 473.

1. Ampullary ends of anterior semicircular canal and external semicircular canal: (0) separated by the bulbous utricular chamber; (1) join before entering utricular chamber.

Maisey (2001), Character 25; Zhu Y. et al. (2021), Character 333; Zhu Y. et al. (2022), Character 474.

1. Orientation of saccular cavity in anterior view: (0) flat inclined; (1) steeply inclined or vertical.

Zhu Y. et al. (2021), Character 334; Zhu Y. et al. (2022), Character 475.

1. Sacculus position: (0) restricted ventral to external semicircular canal; (1) extends dorsal to semicircular canal.

Zhu Y. et al. (2021), Character 335; Zhu Y. et al. (2022), Character 476.

1. Vestibular cavity of the bony labyrinth shape: (0) drum-shaped; (1) irregularly shaped.

Zhu Y. et al. (2021), Character 336; Zhu Y. et al. (2022), Character 477.

1. Endolymphatic complex shape: (0) simple and tube-like; (1) differentiated into distinctive sections.

Zhu Y. et al. (2021), Character 337; Zhu Y. et al. (2022), Character 478.

1. Endolymphatic complex position: (0) lateral to the otic cartilaginous wall, close to inner ear; (1) mesial to the cartilaginous wall, close to brain cavity.

Zhu Y. et al. (2021), Character 338; Zhu Y. et al. (2022), Character 479.

1. Endolymphatic duct distal direction in lateral view: (0) posteriorly directed; (1) vertically directed.

Zhu Y. et al. (2021), Character 339; Zhu Y. et al. (2022), Character 480.

1. Endolymphatic duct distal direction in coronal view: (0) parallelled directed; (1) mesially directed; (2) laterally directed.

Zhu Y. et al. (2021), Character 340; Zhu Y. et al. (2022), Character 481.

1. Endolymphatic fossa: (0) absent; (1) present.

Coates et al. (2018), Character 190; Zhu Y. et al. (2022), Character 482.

1. Endolymphatic sacs: (0) absent; (1) present; (2) medially oriented endolymphatic fossae; (3) laterally oriented endolymphatic fossae.

Castiello (2018), Character 54; Zhu Y. et al. (2022), Character 483.

1. Endolymphatic fossa elongate (slot-shaped), dividing dorsal otic ridge along midline: (0) absent; (1) present.

Coates et al. (2018), Character 191; Zhu Y. et al. (2022), Character 484.

1. Perilymphatic fenestra within the endolymphatic fossa: (0) absent; (1) present.

Coates et al. (2018), Character 192; King et al. (2017), Character 119; Castiello (2018), Character 121; Zhu Y. et al. (2021), Character 353; Zhu Y. et al. (2022), Character 485.

1. Trigemino-facial recess: (0) absent; (1) present.

Davis et al. (2012), Character 88; Choo et al. (2017), Character 87; Zhu Y. et al. (2022), Character 486.

1. Posterior dorsal fontanelle: (0) absent; (1) present.

Schaeffer (1981); Coates & Sequeira (1998); Davis et al. (2012), Character 89; Choo et al. (2017), Character 88; King et al. (2017), Character 50; Castiello (2018), Character 50; Zhu Y. et al. (2022), Character 487.

1. Shape of posterior dorsal fontanelle: (0) approximately as long as broad; (1) much longer than wide, slot-shaped.

Coates & Sequeira (2001); Brazeau (2009); Davis et al. (2012), Character 90; Choo et al. (2017), Character 89. King et al. (2017), Character 51; Castiello (2018), Character 51; Zhu Y. et al. (2022), Character 488.

1. Posterior dorsal fontanelle: (0) connected to persistent otico-occipital fissure; (1) separated from the fissure by posterior tectum.

Coates et al. (2018), Character 184; Zhu Y. et al. (2022), Character 489.

1. Course of hyoid ramus of facial nerve (N. VII) relative to jugular canal: (0) traverses jugular canal, with separate exit in otic region; (1) intersects jugular canal, with exit through posterior jugular foramen.

Zhu Y. et al. (2021), Character 135; Zhu Y. et al. (2022), Character 490.

1. Relationship of cranial endocavity to basisphenoid: (0) endocavity occupies full depth of sphenoid; (1) enodcavity dorsally restricted.

King et al. (2017), Character 37; Castiello (2018), Character 37; Zhu Y. et al. (2021), Character 137; Zhu Y. et al. (2022), Character 491.

1. Supraotic shelf broad: (0) absent; (1) present.

Coates et al. (2018), Character 187; Zhu Y. et al. (2022), Character 492.

1. Dorsal otic ridge: (0) absent; (1) present.

Davis et al. (2012), Character 91; Choo et al. (2017), Character 90; King et al. (2017), Character 52; Castiello (2018), Character 52; Zhu Y. et al. (2021), Character 155; Zhu Y. et al. (2022), Character 493.

1. Dorsal otic ridge forms a crest posteriorly: (0) absent; (1) present.

Coates et al. (2018), Character 189; King et al. (2017), Character 118; Castiello (2018), Character 120; Zhu Y. et al. (2022), Character 494.

1. Vestibular fontanelle: (0) absent; (1) present.

Brazeau (2009); Friedman & Brazeau (2010); Davis et al. (2012), Character 98; Choo et al. (2017), Character 94; King et al. (2017), Character 56; Castiello (2018), Character 57; Zhu Y. et al. (2022), Character 495.

1. Hypotic lamina (and dorsally directed glossopharyngeal canal): (0) absent; (1) present.

Schaeffer (1981); Maisey (2001); Brazeau (2009); Davis et al. (2012), Character 103; Choo et al. (2017), Character 99; King et al. (2017), Character 61; Castiello (2018), Character 62; Zhu Y. et al. (2022), Character 496.

1. Basicranial fenestra: (0) absent; (1) present.

Zhu *et al.* (2009, Character 52), and references therein; Zhu et al. (2013), Character 231; Choo et al. (2017), Character 151; King et al. (2017), Character 64; Castiello (2018), Character 66; Zhu Y. et al. (2022), Character 497. Giles et al. (2015), Character 169

1. Channel for dorsal aorta and/or lateral dorsal aortae: (0) passes through basicranium: 1 external to basicranium.

Coates et al. (2018), Character 201; Choo et al. (2017), Character 77; King et al. (2017), Character 40; Castiello (2018), Character 40; Zhu Y. et al. (2022), Character 498.

*Ellopetalichthys* is coded as “0” (Castiello et al., 2020).

1. Dorsal aorta divides into lateral dorsal aortae: (0) posterior to occipital level; (1) anterior to level of the occiput.

Coates et al. (2018), Character 202; Choo et al. (2017), Character 153; King et al. (2017), Character 66; Castiello (2018), Character 68; Zhu Y. et al. (2022), Character 499.

1. Transverse otic process: (0) present; (1) absent.

Schaeffer (1981); Coates & Sequeira (1998); Giles et al. (2015), Character 125; Choo et al. (2017), Character 293; King et al. (2017), Character 75; Castiello (2018), Character 77; Zhu Y. et al. (2022), Character 500.

This character refers to the presence of a transverse wall or process of the otic region that supports the hyomandibular articulation. Such a structure is present in many placoderms (the anterior postorbital process of traditional nomenclature), chondrichthyans (the lateral otic process), and osteichthyans (the lateral commisure sensu lato). There is some variability in the structure (pierced by jugular canal versus imperforate) and location (level with the anterior or posterior of the otic capsule) of transverse otic processes among early gnathostomes. We describe these patterns of variability in characters 126 and 164. (Giles et al., 2015)

1. Subcranial ridges: (0) absent; (1) present.

Giles et al. (2015), Character 141; Choo et al. (2017), Character 298; King et al. (2017), Character 80; Castiello (2018), Character 82; Zhu Y. et al. (2022), Character 501.

Subcranial ridges were first described in *Doliodus* by Maisey et al. (2009). These ridges extend along the ventrolateral corner of the basicranium from the level of the hypophysis up to the hyomandibular articulation. These ridges have not previously been recognized in other early gnathostomes prior to our observations in *Janusiscus*. It is apparent from our revised comparative anatomy of early gnathostome braincases that subcranial ridges are present in the braincase referred to *Ligulalepis*, where they are manifest as downturned margins of the ventral surface of the sphenoid (Basden & Young, 2001), and *Mimipiscis* (Gardiner, 1984: fig. 50), where they greatly reduced in length. (Giles et al., 2015)

1. Synotic tectum: (0) absent; (1) present.

Coates & Sequeira (1998), Character 9; Giles et al. (2015), Character 159; Choo et al. (2017), Character 300; King et al. (2017), Character 82; Castiello (2018), Character 84; Zhu Y. et al. (2022), Character 502.

1. Shape of median dorsal ridge anterior to endolymphatic fossa: (0) developed as a squared-off ridge or otherwise ungrooved; (1) bears a midline groove.

Coates & Sequeira (1999), Character 11), Coates & Sequeira (2001a), Character 75; Coates & Sequeira (2001b), Character 9; Maisey (2001), Character 9; Giles et al. (2015), Character 161; Choo et al. (2017), Character 301; King et al. (2017), Character 83; Castiello (2018), Character 85; Zhu Y. et al. (2022), Character 503.

1. Medial recess of the posteroventral mydome: (0) absent; (1) present.

King et al. (2017), Character 89; Castiello (2018), Character 91; Zhu Y. et al. (2022), Character 504.

1. Abducens, trigeminal nerves and pituitary vein: (0) opening via different foramina on the orbital wall; (1) sharing the same foramen on the orbital wall.

Castiello (2018), Character 92; Zhu Y. et al. (2022), Character 505.

1. Number of "sel" canals: (0) five; (1) less than 5.

King et al. (2017), Character 91; Castiello (2018), Character 95; Zhu Y. et al. (2022), Character 506.

1. ’sel’ 1 canal bifurcation: (0) between orbit and field; (1) adjacent to lateral field; (2) adjacent to orbit.

King et al. (2017), Character 92; Castiello (2018), Character 96; Zhu Y. et al. (2022), Character 507.

1. Marginal vein: (0) absent; (1) present.

King et al. (2017), Character 92; Castiello (2018), Character 97; Zhu Y. et al. (2022), Character 508.

1. Profundus nerve: (0) emerges from the cranial cavity separately from the trigeminal nerve; (1) emerges together with the trigeminal nerve.

Young (1980); King et al. (2017), Character 94; Castiello (2018), Character 98; Zhu Y. et al. (2022), Character 509.

1. Transverse otic process: (0) not extending in front of orbits; (1) extending in front of orbits.

King et al. (2017), Character 95; Castiello (2018), Character 99; Zhu Y. et al. (2022), Character 510.

1. Nasal capsules in anterolateral corners of orbit: (0) no; (1) yes.

King et al. (2017), Character 96; Castiello (2018), Character 100; Zhu Y. et al. (2022), Character 511.

1. Vagal process: (0) forked; (1) unforked.

King et al. (2017), Character 97; Castiello (2018), Character 101; Zhu Y. et al. (2022), Character 512.

1. Rostral processes: (0) absent; (1) present.

King et al. (2017), Character 99; Castiello (2018), Character 102; Zhu Y. et al. (2022), Character 513.

1. Median rostral dorsal process of the braincase: (0) absent; (1) present.

King et al. (2017), Character 100; Castiello (2018), Character 103; Zhu Y. et al. (2022), Character 514.

1. Posttemporal fossae: (0) absent; (1) present.

King et al. (2017), Character 106; Castiello (2018), Character 106; Zhu Y. et al. (2022), Character 515.

1. Rostral organ: (0) absent; (1) present.

King et al. (2017), Character 107; Castiello (2018), Character 107; Zhu Y. et al. (2022), Character 516.

1. Prespiracular dental plate: (0) absent; (1) present.

King et al. (2017), Character 108; Castiello (2018), Character 108; Zhu Y. et al. (2022), Character 517.

1. Suprapterygoid process: (0) absent; (1) present.

King et al. (2017), Character 109; Castiello (2018), Character 109; Zhu Y. et al. (2022), Character 518.

1. Processus supraorbitalis lateralis: (0) absent; (1) present.

King et al. (2017), Character 110; Castiello (2018), Character 110; Zhu Y. et al. (2022), Character 519.

1. Anterolateral fenestra in roof of otoccipital: (0) absent; (1) present.

King et al. (2017), Character 111; Castiello (2018), Character 111; Zhu Y. et al. (2022), Character 520.

1. Ventral cranial fissure connects with vestibular fontanelles: (0) absent; (1) present.

King et al. (2017), Character 112; Castiello (2018), Character 112; Zhu Y. et al. (2022), Character 521.

1. Bar across spiracular groove: (0) absent; (1) present.

King et al. (2017), Character 113; Castiello (2018), Character 113; Zhu Y. et al. (2022), Character 522.

1. Hypophysial opening in braincase: (0) absent; (1) present.

King et al. (2017), Character 114; Castiello (2018), Character 114; Zhu Y. et al. (2022), Character 523.

1. Hypophysial organ projection: (0) anterior (1) anteroventral (2) posteroventral

Castiello (2018), Character 115; Zhu Y. et al. (2022), Character 524.

1. Ventral rounded processes on preotic part of braincase: (0) absent; (1) present.

King et al. (2017), Character 116; Castiello (2018), Character 118; Zhu Y. et al. (2022), Character 525.

1. Notochord short, ending at the occipital cotylus: (0) absent; (1) present.

King et al. (2017), Character 120; Castiello (2018), Character 122; Zhu Y. et al. (2022), Character 526.

1. Accessory processes extend from ventral surface of nasal capsule: (0) absent; (1) present.

King et al. (2017), Character 124; Castiello (2018), Character 123; Zhu Y. et al. (2022), Character 527.

1. Internal carotid meets efferent pseudobranchial in orbit: (0) absent; (1) present.

King et al. (2017), Character 125; Castiello (2018), Character 124; Zhu Y. et al. (2022), Character 528.

1. Jugular vein passes through cranioquadrate passage: (0) absent; (1) present.

King et al. (2017), Character 126; Castiello (2018), Character 125; Zhu Y. et al. (2022), Character 529.

1. Anterior margin of ventral fissure: (0) straight; (1) sinusoidal.

King et al. (2017), Character 126; Castiello (2018), Character 126; Zhu Y. et al. (2022), Character 530.

1. Bulbous otic and auxiliary condyles for palatoquadrate articulation: (0) absent; (1) present.

King et al. (2017), Character 128; Castiello (2018), Character 127; Zhu Y. et al. (2022), Character 531.

1. Basal fenestra opening into floor of orbit: (0) absent; (1) present.

King et al. (2017), Character 129; Castiello (2018), Character 128; Zhu Y. et al. (2022), Character 532.

1. Nasal sacs: (0) unpaired; (1) paired.

King et al. (2017), Character 130; Castiello (2018), Character 129; Zhu Y. et al. (2022), Character 533.

1. 4 carotid foramina in parasphenoid: (0) absent; (1) present.

King et al. (2017), Character 138; Castiello (2018), Character 137; Zhu Y. et al. (2022), Character 534.

1. Parotic dental plates: (0) absent; (1) present.

King et al. (2017), Character 139; Castiello (2018), Character 138; Zhu Y. et al. (2022), Character 535.

1. Branchial ridges: (0) present; (1) reduced to vagal process; 2 absent (articulation made with bare cranial wall).

Giles et al. (2015), Character 166; Choo et al. (2017), Character 302; King et al. (2017), Character 84; Castiello (2018), Character 86; Zhu Y. et al. (2022), Character 536.

Here we define the vagal process as a lateral extension (or extensions) of the posterior otic region that are associated with foramina for branche of the vagus (X) nerve and bear facets for the branchial arches. They can also pierced by the jugular canal. Vagal processes are well developed in placoderms (e.g. *Dicksonosteus*; Goujet 1984: fig 6). A complete account of vagal processes is provided above in section 3 ('Lateral Processes of Early Gnathostome Neurocrania'). (Giles et al., 2015)

1. Periotic process: (0) absent; (1) present.

Coates et al. (2018), Character 156; King et al. (2017), Character 117; Castiello (2018), Character 119; Zhu Y. et al. (2022), Character 537.

1. Sub-otic occipital fossa: (0) absent; (1) present.

Coates et al. (2018), Character 163; Zhu Y. et al. (2022), Character 538.

1. Postotic process: (0) absent; (1) present.

Coates et al. (2018), Character 165; Zhu Y. et al. (2022), Character 539.

1. Otic capsule extends posterolaterally relative to occipital arch: (0) absent; (1) present.

Coates et al. (2018), Character 166; Zhu Y. et al. (2022), Character 540.

1. Otic capsules: (0) widely separated; (1) approaching dorsal midline.

Coates et al. (2018), Character 167; Zhu Y. et al. (2022), Character 541.

1. Otic capsules project anteriorly between postorbital processes: (0) absent; (1) present.

Coates et al. (2018), Character 168; Zhu Y. et al. (2022), Character 542.

1. Endocranial roof anterior to otic capsules domelike, smoothly convex dorsally and anteriorly: (0) absent; (1) present.

Coates et al. (2018), Character 169; Zhu Y. et al. (2022), Character 543.

1. Roof of skeletal cavity for cerebellum and mesencephalon significantly higher than dorsal-most level of semicircular canals: (0) absent; (1) present.

Coates et al. (2018), Character 170; Zhu Y. et al. (2022), Character 544.

1. Roof of the endocranial space for telencephalon and olfactory tracts offset ventrally relative to level of mesencephalon: (0) absent; (1) present.

Coates et al. (2018), Character 171. Zhu Y. et al. (2021), Character 348; Zhu Y. et al. (2022), Character 545.

1. Double octaval nerve foramina in chondrified mesial wall of otic capsule: (0) absent; (1) present.

Coates et al. (2018), Character 173; Zhu Y. et al. (2022), Character 546.

1. Glossopharyngeal nerve exit: (0) foramen situated posteroventral to otic capsule and anterior to metotic fissure; (1) through metotic fissure.

Schaeffer (1981); Coates &Sequeira (1998, 2001); Brazeau (2009); Davis et al. (2012), Character 71; Choo et al. (2017), Character 70. King et al. (2017), Character 34; Castiello (2018), Character 34; Zhu Y. et al. (2022), Character 547.

1. Glossopharyngeal and vagus nerves share common exit from neurocranium: (0) absent; (1) present.

Coates et al. (2018), Character 199; Zhu Y. et al. (2022), Character 548.

1. Ventral portion of occipital arch wedged between rear of otic capsules: (0) absent; (1) present.

Coates et al. (2018), Character 203; King et al. (2017), Character 57; Castiello (2018), Character 58; Zhu Y. et al. (2022), Character 549.

1. Dorsal portion of occipital arch wedged between otic capsules: (0) absent; (1) present.

Choo et al. (2017), Character 95; Coates et al. (2018), Character 204; King et al. (2017), Character 57; Castiello (2018), Character 58; Zhu Y. et al. (2022), Character 550.

1. Craniospinal process ("supravagal process" in Stensio): (0) absent; (1) present.

Giles et al. (2015), Character 167; Choo et al. (2017), Character 303; King et al. (2017), Character 85; Castiello (2018), Character 87; Zhu Y. et al. (2022), Character 551.

The craniospinal process forms the posterolateral corner of the braincase and is often involved with or supports the cranio-thoracic joint. A complete account of the craniospinal process is provided above in section 3 ('Lateral Processes of Early Gnathostome Neurocrania'). (Giles et al., 2015)

1. Parachordal shape: (0) forming a broad, flat surface as wide as the otic capsules; (1) mediolaterally constricted relative to the otic capsules.

Brazeau (2009); Davis et al. (2012), Character 102; Choo et al. (2017), Character 98; King et al. (2017), Character 60; Castiello (2018), Character 61; Zhu Y. et al. (2022), Character 552.

1. Ventral notch between parachordals: (0) absent; (1) present or entirely unfused.

Brazeau (2009); Davis et al. (2012), Character 101; Choo et al. (2017), Character 97; King et al. (2017), Character 59; Castiello (2018), Character 60; Zhu Y. et al. (2022), Character 553.

1. Stalk-shaped parachordal/occipital region: (0) absent; (1) present.

Giles et al. (2015), Character 176; Choo et al. (2017), Character 304; King et al. (2017), Character 86; Castiello (2018), Character 88; Zhu Y. et al. (2022), Character 554.

In petalichthyids such as *Macropetalichthys*, the occiput is flanked by large cucullaris fossae, resulting in a very elongage and narrow occipital region (Stensiö, 1969; Young, 1978). Although the endocranium of *Lunaspis* is not known in any external preparations, the stalked occiput is clearly visible in a radiograph prepared by W. Stürmer (SMF WS 10825) of an isolated skull from the Hunsrück Slate. (Giles et al., 2015)

1. Size of aperture to notochordal canal: (0) much smaller than foramen magnum; (1) as large, or larger, than foramen magnum.

Giles et al. (2015), Character 178; Choo et al. (2017), Character 306; King et al. (2017), Character 88; Castiello (2018), Character 90; Zhu Y. et al. (2022), Character 555.

1. Spino-occipital nerve foramina: (0) two or more, aligned horizontally; (1) one or two, dorsoventrally offset.

Schaeffer (1981); Coates & Sequeira (1998); Brazeau (2009); Davis et al. (2012), Character 100; Choo et al. (2017), Character 96; Zhu Y. et al. (2022), Character 556.

1. Occipital crest anteroposteriorly elongate, and extends from the roof of the posterior tectum: (0) absent; (1) present.

Coates et al. (2018), Character 205; Zhu Y. et al. (2022), Character 557.

1. Paired occipital condyles: (0) absent; (1) present.

Choo et al. (2017), Character 305; Coates et al. (2018), Character 206; King et al. (2017), Character 87; Castiello (2018), Character 89; Zhu Y. et al. (2022), Character 558.

*Axial and appendicular skeleton*

1. Macromeric dermal shoulder girdle: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 104; Choo et al. (2017), Character 100; King et al. (2017), Character 421; Castiello (2018), Character 410; Zhu Y. et al. (2022), Character 559.

1. Dermal neck-joint between paired main-lateral-line-bearing bones of skull and shoulder girdle: (0) absent; (1) present.

Young (2010, Character 15); Zhu et al. (2013), Character 168; Choo et al. (2017), Character 177; King et al. (2017), Character 192; Castiello (2018), Character 191; Zhu Y. et al. (2022), Character 560.

1. Dorsal articular lamina on trunk armour: (0) absent; (1) present.

Zhu et al. (2019), Character 3; Zhu Y. et al. (2021), Character 356; Zhu Y. et al. (2022), Character 561.

1. Cranial fossa receiving the ventral articular lamina of the trunk: (0) absent; (1) present.

Zhu et al. (2019), Character 4; Zhu Y. et al. (2021), Character 357; Zhu Y. et al. (2022), Character 562.

1. Trunk ventral articular lamina develops into flange or condyle: (0) absent, continuous along the articular lamina of the anterior dorsolateral plate; (1) present, the articular lamina develops into distinctive flange or condyle.

Zhu et al. (2019), Character 5; Zhu Y. et al. (2021), Character 358; Zhu Y. et al. (2022), Character 563.

1. Rotatory contact of the articulation: (0) absent; (1) present.

Zhu et al. (2019), Character 8; Zhu Y. et al. (2021), Character 359; Zhu Y. et al. (2022), Character 564.

1. Lateral ridges on skull roof laterally defines the articulation: (0) absent; (1) present.

Zhu et al. (2019), Character 8; Zhu Y. et al. (2021), Character 360; Zhu Y. et al. (2022), Character 565.

1. Dermal shoulder girdle composition: (0) ventral and dorsal (scapular) components; (1) ventral components only.

Brazeau (2009); Davis et al. (2012), Character 105; Choo et al. (2017), Character 101; King et al. (2017), Character 422; Castiello (2018), Character 411; Zhu Y. et al. (2022), Character 566.

1. Dermal shoulder girdle forming a complete ring around the trunk: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 106; Choo et al. (2017), Character 102; King et al. (2017), Character 423; Castiello (2018), Character 412; Zhu Y. et al. (2022), Character 567.

1. Pectoral fenestra completely encircled by dermal shoulder armour: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 107; Choo et al. (2017), Character 103; King et al. (2017), Character 424; Castiello (2018), Character 413; Zhu Y. et al. (2022), Character 568.

1. Median dorsal plate: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 108; Choo et al. (2017), Character 104; King et al. (2017), Character 425; Castiello (2018), Character 414; Zhu Y. et al. (2022), Character 569.

1. Pronounced internal crista (keel) on median dorsal surface of shoulder girdle: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 109; Choo et al. (2017), Character 105; King et al. (2017), Character 426; Castiello (2018), Character 415; Zhu Y. et al. (2022), Character 570.

1. Anterior median dorsal plate: (0) absent; (1) present.

Zhu et al. (2016), Character 358; Zhu Y. et al. (2021), Character 320; Zhu Y. et al. (2022), Character 571.

1. Anterior margin of unpaired anterior median dorsal plate: (0) broad; (1) pointed.

Zhu et al. (2016), Character 362; Zhu Y. et al. (2021), Character 322; Zhu Y. et al. (2022), Character 572.

1. Anterior median dorsal plate (MD1) relative to posterior median dorsal plate (MD2) in length: (0) MD1 shorter than MD2; (1) MD1 longer than MD2.

Zhu et al. (2016), Character 36; Zhu Y. et al. (2021), Character 321; Zhu Y. et al. (2022), Character 573.

1. Anterior lateral plate: (0) absent; (1) present.

Zhu et al. (2016), Character 363; Zhu Y. et al. (2021), Character 323; Zhu Y. et al. (2022), Character 574.

1. Postbranchial lamina of trunk armour: (0) lateral; (1) internal.

Zhu et al. (2016), Character 364; Zhu Y. et al. (2021), Character 324; Zhu Y. et al. (2022), Character 575.

1. Crista internalis of dermal shoulder girdle: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 183; Zhu Y. et al. (2022), Character 576.

1. Anteroventral plate: (0) absent; (1) present.

Zhu et al. (2016), Character 365; Zhu Y. et al. (2021), Character 325; Zhu Y. et al. (2022), Character 577.

1. Number of median ventral plates: (0) two; (1) one.

Zhu et al. (2016), Character 366; Zhu Y. et al. (2021), Character 326; Zhu Y. et al. (2022), Character 578.

1. Interolateral plate: (0) paired; (1) fused (unpaired semilunar plate).

Zhu et al. (2016), Character 367; Zhu Y. et al. (2021), Character 327; Zhu Y. et al. (2022), Character 579.

1. Anterior ventrolateral plates of both sides: (0) in contact; (1) separated.

Zhu et al. (2016), Character 368; Zhu Y. et al. (2021), Character 328; Zhu Y. et al. (2022), Character 580.

1. Brachial process: (0) absent; (1) present.

Zhu et al. (2016), Character 369; Zhu Y. et al. (2021), Character 329; Zhu Y. et al. (2022), Character 581.

1. Presupracleithrum: (0) absent; (1) present.

Zhu et al. (2009, Character 121), and references therein; Zhu et al. (2013), Character 244; Choo et al. (2017), Character 231; King et al. (2017), Character 203; Castiello (2018), Character 202; Zhu Y. et al. (2022), Character 582.

1. Anocleithrum: (0) element developed as postcleithrum; (1) element developed as anocleithrum sensu stricto.

Zhu et al. (2009, Character 122), and references therein; Zhu et al. (2013), Character 245; Choo et al. (2017), Character 232; King et al. (2017), Character 430; Castiello (2018), Character 419; Zhu Y. et al. (2022), Character 583.

1. Dorsal cleithrum (AL of the Placodermi), ventral cleithrum (AVL of the Placodermi) and pectoral spine (SP of the Placodermi): (0) not fused; (1) fused.

Zhu et al. (2009, Character 122), and references therein; Zhu et al. (2013), Character 246; Choo et al. (2017), Character 234; King et al. (2017), Character 431; Castiello (2018), Character 420; Zhu Y. et al. (2022), Character 584.

1. Shape of dorsal blade of dermal shoulder girdle: (0) spatulate; (1) pointed.

Cloutier & Ahlberg (1996), Character 115; Schultze & Cumbaa (2001), Character 94; Zhu & Schultze (2001), Character 164; Zhu et al. (2001), Character 122; Zhu & Yu (2002), Character 122; Cloutier & Arratia (2004), Character 148; Zhu et al. (2006), Character 96; Friedman (2007), Character 107; Zhu et al. (2009), Character 124; Giles et al. (2015), Character 183; Choo et al. (2017), Character 307; King et al. (2017), Character 435; Castiello (2018), Character 424; Zhu Y. et al. (2022), Character 585.

1. Posterior dorsolateral plate or equivalent: (0) absent; (1) present.

Giles et al. (2015), Character 187; Choo et al. (2017), Character 308; King et al. (2017), Character 436; Castiello (2018), Character 425; Zhu Y. et al. (2022), Character 586.

1. Relationship of clavicle to cleithrum: (0) ascending process of clavicle overlapping cleithrum laterally; (1) ascending process of clavicle wrapping round anterior edge of cleithrum, overlapping it both laterally and mesially.

Zhu et al. (2009, Character 126), and references therein; Zhu et al. (2013), Character 247; Choo et al. (2017), Character 235; King et al. (2017), Character 432; Castiello (2018), Character 421; Zhu Y. et al. (2022), Character 587.

1. Paired fins relation to cephalic shield: (0) continuous;(1) delimited at pectoral sinus.

Castiello (2018), Character 383; Zhu Y. et al. (2022), Character 588.

1. Intromittent organ for internal fertilization (’claspers’): (0) absent; (1) present.

King et al. (2017), Character 395; Castiello (2018), Character 385; Zhu Y. et al. (2022), Character 589.

1. Entepicondyle on humerus: (0) present; (1) absent.

King et al. (2017), Character 418; Castiello (2018), Character 407; Zhu Y. et al. (2022), Character 590.

1. PL and PDL overlap: (0) simple; (1) insertion.

King et al. (2017), Character 437; Castiello (2018), Character 426; Zhu Y. et al. (2022), Character 591.

1. Left and right posterior dorsolateral plates contact below the median dorsal plate: (0) absent; (1) present.

King et al. (2017), Character 438; Castiello (2018), Character 427; Zhu Y. et al. (2022), Character 592.

1. PDL plate visible externally: (0) present; (1) absent.

King et al. (2017), Character 439; Castiello (2018), Character 428; Zhu Y. et al. (2022), Character 593.

The original character state formulation was incorrect by comparison to their codings in the data set.

1. Posteriorly produced spine on MD plate: (0) absent; (1) present.

King et al. (2017), Character 440; Castiello (2018), Character 429; Zhu Y. et al. (2022), Character 594.

1. Joint in macromeric armoured pectoral fin: (0) absent; (1) present.

King et al. (2017), Character 441; Castiello (2018), Character 430; Zhu Y. et al. (2022), Character 595.

1. Cd1 (first dorsal central) and Cd2 (second dorsal central) plates: (0) in contact; (1) separated.

King et al. (2017), Character 442; Castiello (2018), Character 431; Zhu Y. et al. (2022), Character 596.

1. Clavicles/interolateral plates: (0) large plates, comparable in size to cleithrum; (1) paired small semilunar plates; (2) unpaired semilunar plates.

King et al. (2017), Character 443; Castiello (2018), Character 432; Zhu Y. et al. (2022), Character 597.

1. Chang’s apparatus: (0) absent; (1) present.

King et al. (2017), Character 444; Castiello (2018), Character 433; Zhu Y. et al. (2022), Character 598.

1. Number of median dorsal plates: (0) one; (1) two; (2) three.

King et al. (2017), Character 445; Castiello (2018), Character 434; Zhu Y. et al. (2022), Character 599.

1. Anocleithrum sensu stricto: (0) exposed; (1) subdermal.

King et al. (2017), Character 446; Castiello (2018), Character 435; Zhu Y. et al. (2022), Character 600.

1. Median ventral trunk plates: (0) absent; (1) present.

King et al. (2017), Character 447; Castiello (2018), Character 436; Zhu Y. et al. (2022), Character 601.

1. Extracleithrum: (0) absent; (1) present.

King et al. (2017), Character 448; Castiello (2018), Character 437; Zhu Y. et al. (2022), Character 602.

1. Pectoral fin spine small (bivalve-like): (0) absent; (1) present.

Castiello (2018), Character 438. King et al. (2017), Character 449; Zhu Y. et al. (2022), Character 603.

1. Dorsal branch of main lateral line canal on posterior dorsolateral plate: (0) present; (1) absent.

King et al. (2017), Character 325; Castiello (2018), Character 317; Zhu Y. et al. (2022), Character 604.

The original character state formulation was incorrect by comparison to their codings in the data set.

1. Sharp downward bend in posterior dorsolateral plate sensory line: (0) absent; (1) present.

King et al. (2017), Character 326; Castiello (2018), Character 318; Zhu Y. et al. (2022), Character 605.

1. Horizontal caudal lobe: (0) absent; (1) present.

King et al. (2017), Character 451; Castiello (2018), Character 440; Zhu Y. et al. (2022), Character 606.

1. Triphycercal tail: (0) absent; (1) present.

King et al. (2017), Character 4521; Castiello (2018), Character 441; Zhu Y. et al. (2022), Character 607.

1. Spine-brush complex: (0) absent; (1) present.

King et al. (2017), Character 479; Castiello (2018), Character 468; Zhu Y. et al. (2022), Character 608.

1. Series of median hexagonal scutes anterior to first dorsal fin: (0) absent; (1) present.

King et al. (2017), Character 480; Castiello (2018), Character 469; Zhu Y. et al. (2022), Character 609.

1. Intermediate spines with finlets: (0) absent; (1) present.

King et al. (2017), Character 481; Castiello (2018), Character 470; Zhu Y. et al. (2022), Character 610.

1. Median ventral prepectoral spine: (0) absent; (1) present.

King et al. (2017), Character 482; Castiello (2018), Character 471; Zhu Y. et al. (2022), Character 611.

1. Prepectoral spines form "necklace": (0) absent; (1) present.

King et al. (2017), Character 483; Castiello (2018), Character 472; Zhu Y. et al. (2022), Character 612.

1. Longitudinal rows of enlarged keeled scutes: (0) absent; (1) present.

King et al. (2017), Character 484; Castiello (2018), Character 473; Zhu Y. et al. (2022), Character 613.

1. Endoskeletal supports in pectoral fin: (0) multiple elements articulating with girdle; (1) single element ("humerus") articulating with girdle.

Zhu *et al.* (2009, Character 130), and references therein; Zhu et al. (2013), Character 250; Giles et al. (2015), Character 201; Choo et al. (2017), Character 233; King et al. (2017), Character 409; Castiello (2018), Character 398; Zhu Y. et al. (2022), Character 614.

1. Triradiate scapulocoracoid: (0) absent; (1) present.

Zhu *et al.* (2009, Character 128), and references therein; Zhu et al. (2013), Character 248; Choo et al. (2017), Character 236; King et al. (2017), Character 410; Castiello (2018), Character 399; Zhu Y. et al. (2022), Character 615.

1. Flange on trailing edge of scapulocoracoid: (0) absent; (1) present.

Davis (2002); Brazeau (2009); Davis et al. (2012), Character 113; Choo et al. (2017), Character 109; King et al. (2017), Character 401; Castiello (2018), Character 390; Zhu Y. et al. (2022), Character 616.

1. Horizontal plate of scapulocoracoid: (0) absent; (1) present.

King et al. (2017), Character 419; Castiello (2018), Character 408; Zhu Y. et al. (2022), Character 617.

1. Subscapular foramen: (0) absent; (1) present.

Zhu *et al.* (2009, Character 129), and references therein; Zhu et al. (2013), Character 249; Choo et al. (2017), Character 237; King et al. (2017), Character 411; Castiello (2018), Character 400; Zhu Y. et al. (2022), Character 618.

1. Scapular process of shoulder endoskeleton: (0) absent; (1) present.

Coates & Sequeira (2001); Zhu & Schultze (2001); Davis (2002); Brazeau (2009); Davis et al. (2012), Character 110; Choo et al. (2017), Character 106; King et al. (2017), Character 398; Castiello (2018), Character 387; Zhu Y. et al. (2022), Character 619.

1. Scapular process with posterodorsal angle: (0) absent; (1) present.

Coates & Sequeira (2001); Davis et al. (2012), Character 114; Choo et al. (2017), Character 110; King et al. (2017), Character 402; Castiello (2018), Character 391; Zhu Y. et al. (2022), Character 620.

1. Scapular infundibulum: (0) absent; (1) present.

Giles et al. (2015), Character 190; Choo et al. (2017), Character 309; King et al. (2017), Character 413; Castiello (2018), Character 402; Zhu Y. et al. (2022), Character 621.

This character refers to the dermal opening for the scapulocoracoid. In antiarchs, the scapula is situated within an infundibulum, rather than a fenestration.

1. Ventral margin of separate scapular ossification: (0) horizontal; (1) deeply angled.

Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 111; Choo et al. (2017), Character 107; King et al. (2017), Character 399; Castiello (2018), Character 388; Zhu Y. et al. (2022), Character 622.

1. Cross sectional shape of scapular process: (0) flattened or strongly ovate; (1) subcircular.

Davis (2002); Brazeau (2009); Davis et al. (2012), Character 112; Choo et al. (2017), Character 108; King et al. (2017), Character 400; Castiello (2018), Character 389; Zhu Y. et al. (2022), Character 623.

1. Endoskeletal postbranchial lamina on scapular process: (0) present; (1) absent.

Brazeau (2009); Davis et al. (2012), Character 115; Choo et al. (2017), Character 111; King et al. (2017), Character 403; Castiello (2018), Character 392; Zhu Y. et al. (2022), Character 624.

1. Mineralisation of internal surface of scapular blade: (0) mineralised all around; (1) unmineralised on internal face forming a hemicylindrical cross-section.

Brazeau (2009); Davis et al. (2012), Character 116; Choo et al. (2017), Character 112; King et al. (2017), Character 404; Castiello (2018), Character 393; Zhu Y. et al. (2022), Character 625.

1. Coracoid process: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 117; Choo et al. (2017), Character 113; King et al. (2017), Character 405; Castiello (2018), Character 394; Zhu Y. et al. (2022), Character 626.

1. Procoracoid mineralisation: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 118; Choo et al. (2017), Character 114; King et al. (2017), Character 406; Castiello (2018), Character 395; Zhu Y. et al. (2022), Character 627.

1. Paired (pectoral) fins: (0) absent; (1) present.

Castiello (2018), Character 382; Zhu Y. et al. (2022), Character 628.

1. Pectoral fins covered in macromeric dermal armour: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 124; Choo et al. (2017), Character 120; Zhu Y. et al. (2022), Character 629.

1. Armoured pectoral appendage: (0) unjointed; (1) jointed.

Zhu et al. (2016), Character 371; Zhu Y. et al. (2021), Character 330; Zhu Y. et al. (2022), Character 630.

1. Pectoral fin base has large, hemispherical dermal component: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 125; Choo et al. (2017), Character 121; King et al. (2017), Character 427; Castiello (2018), Character 416; Zhu Y. et al. (2022), Character 631.

1. Pectoral fin articulation: (0) monobasal; (1) dibasal; 2 three or more basals.

Choo et al. (2017), Character 310; King et al. (2017), Character 414; Coates et al. (2018), Character 227; Castiello (2018), Character 403; Zhu Y. et al. (2022), Character 632.

1. Fin base articulation on scapulocoracoid: (0) deeper than wide (stenobasal); (1) wider than deep (eurybasal).

Choo et al. (2017), Character 115; King et al. (2017), Character 407; Castiello (2018), Character 396; Zhu Y. et al. (2022), Character 633.

1. Number of mesomeres in metapterygial axis: (0) five or fewer; (1) seven or more.

Cloutier & Ahlberg (1996), Character 123; Zhu & Schultze (2001), Character 180; Zhu & Yu (2001), Character 132; Zhu & Yu (2002), Character 132; Friedman (2007), Character 115; Giles et al. (2015), Character 204; Choo et al. (2017), Character 311; King et al. (2017), Character 415; Castiello (2018), Character 404; Zhu Y. et al. (2022), Character 634.

1. Biserial pectoral fin endoskeleton: (0) absent; (1) present.

Giles et al. (2015), Character 205; Choo et al. (2017), Character 312; King et al. (2017), Character 416; Castiello (2018), Character 405; Zhu Y. et al. (2022), Character 635.

1. Filamentous extension of pectoral fin from axillary region: (0) absent; (1) present.

Giles et al. (2015), Character 207; Choo et al. (2017), Character 313; King et al. (2017), Character 417; Castiello (2018), Character 406; Zhu Y. et al. (2022), Character 636.

1. Metapterygium pectinate subtriangular plate or bar supporting numerous (six or more) radials along distal edge: (0) absent; (1) present.

Coates et al. (2018), Character 228; Zhu Y. et al. (2022), Character 637.

1. Metapterygial whip: (0) absent; (1) present.

Coates et al. (2018), Character 229; Zhu Y. et al. (2022), Character 638.

1. Pectoral propterygium: (0) absent; (1) present.

Zhu *et al.* (2009, Character 131), and references therein; Zhu et al. (2013), Character 251; Choo et al. (2017), Character 238; King et al. (2017), Character 412; Castiello (2018), Character 401; Zhu Y. et al. (2022), Character 639.

1. Perforate propterygium: (0) absent; (1) present.

Rosen *et al.* (1981); Patterson (1982); Davis et al. (2012), Character 120; Choo et al. (2017), Character 116; King et al. (2017), Character 408; Castiello (2018), Character 397; Zhu Y. et al. (2022), Character 640.

1. Distal articulation of propterygium: (0) with fin rays; (1) with a second enlarged element; (2) no articulation.

King et al. (2017), Character 420; Castiello (2018), Character 409; Zhu Y. et al. (2022), Character 641.

1. Pelvic fins: (0) absent; (1) present.

Janvier (1996); Davis et al. (2012), Character 121; Choo et al. (2017), Character 117; King et al. (2017), Character 394; Castiello (2018), Character 384; Zhu Y. et al. (2022), Character 642.

1. Pelvic girdle with substantial dermal component: (0) yes; (1) no.

Zhu *et al.* (2012b); Zhu et al. (2013), Character 252; Choo et al. (2017), Character 239; King et al. (2017), Character 433; Castiello (2018), Character 422; Zhu Y. et al. (2022), Character 643.

1. Dermal pelvic clasper ossifications: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 123; Choo et al. (2017), Character 119; King et al. (2017), Character 396; Castiello (2018), Character 386; Zhu Y. et al. (2022), Character 644.

1. Pelvic fin: (0) monobasal; (1) polybasal.

Lu et al. (2017), Character 278; Zhu Y. et al. (2022), Character 645.

1. Intromittent organ containing bone, not associated with pelvic fins: (0) absent; (1) present.

Janvier (1996); Davis et al. (2012), Character 122; Choo et al. (2017), Character 118; Zhu Y. et al. (2022), Character 646.

1. Intromittent organ with one large J-shaped element: (0) absent; (1) present.

Long et al., (2015), Character 258; Choo et al. (2017), Character 250; Zhu Y. et al. (2022), Character 647.

1. Intromittent organ ('clasper') consisting entirely of cartilage, formed from distal part of pelvic fin: (0) absent; (1) present.

Long et al., (2015), Character 259; Choo et al. (2017), Character 251; Zhu Y. et al. (2022), Character 648.

1. Pelvic girdle with fused puboischiadic bar: (0) absent; (1) present.

Coates et al. (2018), Character 233; Zhu Y. et al. (2022), Character 649.

1. Mixipterygial/mixopterygial claspers: (0) absent; (1) present.

Coates et al. (2018), Character 234; Zhu Y. et al. (2022), Character 650.

1. Pre-pelvic clasper or tenaculum: (0) absent; (1) present.

Coates et al. (2018), Character 236; Zhu Y. et al. (2022), Character 651.

1. Number of dorsal fins, if present: (0) one; (1) two.

Coates & Sequeira (2001); Brazeau (2009); Davis et al. (2012), Character 136; Choo et al. (2017), Character 132; King et al. (2017), Character 450; Castiello (2018), Character 439; Zhu Y. et al. (2022), Character 652.

1. Posterior dorsal fin shape: (0) base approximately as broad as tall, not broader than all of other median fins; (1) base much longer than the height of the fin, substantially longer than any of the other dorsal fins.

Giles et al. (2015), Character 229; Choo et al. (2017), Character 320; King et al. (2017), Character 476; Castiello (2018), Character 465; Zhu Y. et al. (2022), Character 653.

This is admittedly a compound character. This owes to the problems of rendering ratio-scale continuous characters as a discrete character. Our conceptualisation of this character is intended to capture the distinctively broad or ribbon-shaped second dorsal fins that are differentiated from any of the other median fins, and the generalized triangular shape of many gnathostomes and their relatives. In taxa possessing only a single dorsal fin, we have scored taxa where we think the observed fin is equivalent to a posterior dorsal fin. This is based on the postition of the posterior dorsal fin behind or at the level of the posterior limit of the posterior wall of the body cavity (as indicated by the position of the pelvic girdle and/or anal fin, or evidence of the body cavity present as an infill). We have reinterpreted the vertebral column of *Cowralepis*, arguing that Ritchie's (2005) reconstruction inverts the dorsoventral orientation. Ritchie's sub-haemal spines are here interpreted as dorsal or caudal fin radials. This is evidenced by the fact that the series bearing these epi-spinal elements continues under the dermal shoulder armour, while the opposing series terminates at the level of the pelvic fins (based on AMF9764, Ritchie, 2005, fig. 16 A, B). This also better explains the direction of the gentle sigmoid bend seen in several specimens (Ritchie, 2005, figs.16B, 17A, C). In photographs of specimen AMF103767 (Ritchie, 2005, fig. 1A-D, the orientation of the collapsed vertebral column can be observed. In the specimen showing the dorsal surface, the chordal surface the series lacking the accessory elements is observed, suggesting this was their ventral surface rather than dorsal. (Giles et al., 2015)

1. Basal plate in dorsal fin: (0) absent; (1) present.

Friedman & Brazeau (2010), Character 42; Giles et al. (2015), Character 230; Choo et al. (2017), Character 321; King et al. (2017), Character 477; Castiello (2018), Character 466; Zhu Y. et al. (2022), Character 654.

1. Branching radial structure articulating with dorsal fin basal plate: (0) absent; (1) present.

Giles et al. (2015), Character 231; Choo et al. (2017), Character 322; King et al. (2017), Character 456; Castiello (2018), Character 445; Zhu Y. et al. (2022), Character 655.

1. Branching radials in paired fins: (0) absent; (1) present.

Zhu Y. et al. (2021), Character 197; Zhu Y. et al. (2022), Character 656.

1. Posterior or pelvic-level dorsal fin with calcified base plate: (0) absent; (1) present.

Coates et al. (2018), Character 241; Zhu Y. et al. (2022), Character 657.

1. Posterior dorsal fin with delta-shaped cartilage: (0) absent; (1) present.

Coates et al. (2018), Character 242; Zhu Y. et al. (2022), Character 658.

1. Anal fin: (0) absent; (1) present.

Coates & Sequeira (2001); Brazeau (2009); Davis et al. (2012), Character 137; Choo et al. (2017), Character 133; King et al. (2017), Character 466; Castiello (2018), Character 455; Zhu Y. et al. (2022), Character 659.

1. Basal plate in anal fin: (0) absent; (1) present.

Friedman & Brazeau (2010), Character 42; Giles et al. (2015), Character 233; Choo et al. (2017), Character 323; King et al. (2017), Character 478; Castiello (2018), Character 467; Zhu Y. et al. (2022), Character 660.

1. Anal fin base narrow, posteriormost proximal segments radials broad: (0) absent; (1) present.

Coates et al. (2018), Character 245; Zhu Y. et al. (2022), Character 661.

1. Caudal radials: (0) extend beyond level of body wall and deep into hypochordal lobe; (1) restricted to axial lobe.

Davis et al. (2012), Character 138; Choo et al. (2017), Character 134; King et al. (2017), Character 453; Castiello (2018), Character 442; Zhu Y. et al. (2022), Character 662.

1. Series of thoracic supraneurals: (0) absent; (1) present.

Cloutier & Ahlberg (1996), Character 137; Ahlberg & Johanson (1998), Character 99; Zhu & Ahlberg (2004), Character 99; Zhu & Yu (2001), Character 142; Zhu & Yu (2001), Character 142; Friedman (2007), Character 125; Giles et al. (2015), Character 227; Choo et al. (2017), Character 319; King et al. (2017), Character 455; Castiello (2018), Character 444; Zhu Y. et al. (2022), Character 663.

1. Supraneurals in axial lobe of caudal fin: (0) absent; (1) present.

Giles et al. (2015), Character 235; Choo et al. (2017), Character 314; King et al. (2017), Character 454; Castiello (2018), Character 443; Zhu Y. et al. (2022), Character 664.

1. Caudal neural and/or supraneural spines or radials: (0) short; (1) long, expanded, and supporting high aspect-ratio (lunate) tail with notochord extending to posterodorsal extremity; (2) notochord terminates pre-caudal extremity, neural and heamal radial lengths near symmetrical and support epichordal and hypochordal lobes respectively.

Coates et al. (2018), Character 247; Zhu Y. et al. (2022), Character 665.

1. Synarcual: (0) absent; (1) present.

Brazeau (2009); Davis et al. (2012), Character 135; Choo et al. (2017), Character 131; King et al. (2017), Character 465; Castiello (2018), Character 454; Zhu Y. et al. (2022), Character 666.

1. Calcified vertebral centra: (0) absent; (1) present.

Coates et al. (2018), Character 207; Zhu Y. et al. (2022), Character 667.

1. Chordacentra: (0) absent; (1) present.

Coates et al. (2018), Character 208; Zhu Y. et al. (2022), Character 668.

1. Chordacentra polyspondylous and consist of narrow closely packed rings: (0) absent; (1) present.

Coates et al. (2018), Character 209; Zhu Y. et al. (2022), Character 669.

1. Brush complex of bilaterally distributed calcified tubes flanking or embedded in calcified cartilage core: (0) absent; (1) present.

Coates et al. (2018), Character 240; Zhu Y. et al. (2022), Character 670.

*Spines: fins, cranial and elsewhere*

1. Dorsal fin spine: (0) absent; (1) present.

Zhu *et al*. (2001); Zhu & Yu (2002); Friedman (2007); Brazeau (2009); Davis et al. (2012), Character 126; Choo et al. (2017), Character 122; King et al. (2017), Character 457; Castiello (2018), Character 446; Zhu Y. et al. (2022), Character 671.

1. Dorsal fin spine at anterior (pectoral level) location only: (0) absent; (1) present.

Coates et al. (2018), Character 249; Zhu Y. et al. (2022), Character 672.

1. Anal fin spine: (0) absent; (1) present.

Maisey (1986); Davis (2002); Brazeau (2009); Davis et al. (2012), Character 127; Choo et al. (2017), Character 123; King et al. (2017), Character 458; Castiello (2018), Character 447; Zhu Y. et al. (2022), Character 673.

1. Pectoral fin spine: (0) absent; (1) present.

Davis et al. (2012), Character 128; Choo et al. (2017), Character 124; King et al. (2017), Character 429; Castiello (2018), Character 418; Zhu Y. et al. (2022), Character 674.

1. Pelvic fin spine: (0) absent; (1) present.

Zhu et al. (2013), Character 253; Choo et al. (2017), Character 240; King et al. (2017), Character 434; Castiello (2018), Character 423; Zhu Y. et al. (2022), Character 675.

1. Median fin spine insertion: (0) shallow, not greatly deeper than dermal bones / scales; (1) deep.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 129; Choo et al. (2017), Character 125; King et al. (2017), Character 459; Castiello (2018), Character 448; Zhu Y. et al. (2022), Character 676.

1. Intermediate fin spines: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 130; Choo et al. (2017), Character 126; King et al. (2017), Character 460; Castiello (2018), Character 449; Zhu Y. et al. (2022), Character 677.

1. Intermediate spines when present: (0) one pair; (1) multiple pairs.

Giles et al. (2015), Character 219; Choo et al. (2017), Character 316; King et al. (2017), Character 473; Castiello (2018), Character 462; Zhu Y. et al. (2022), Character 678.

1. Prepectoral fin spines: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 131; Choo et al. (2017), Character 127; King et al. (2017), Character 461; Castiello (2018), Character 450; Zhu Y. et al. (2022), Character 679.

1. Anteriormost intermediate spine associated with shoulder girdle: (0) absent; (1) present.

Coates et al. (2018), Character 256. Dearden et al. (2019), Character 261; Zhu Y. et al. (2022), Character 680.

1. Cephalic spines: (0) absent; (1) present.

Choo et al. (2017), Character 268; Coates et al. (2018), Character 262; King et al. (2017), Character 206; Castiello (2018), Character 205; Zhu Y. et al. (2022), Character 681.

1. Pectoral fin spine with denticles along posterior surface: (0) absent; (1) present.

Coates et al. (2018), Character 254; Zhu Y. et al. (2022), Character 682.

1. Fin spines with ridges: (0) absent; (1) present.

Davis (2002); Brazeau (2009); Davis et al. (2012), Character 132; Choo et al. (2017), Character 128; King et al. (2017), Character 462; Castiello (2018), Character 451; Zhu Y. et al. (2022), Character 683.

1. Fin spines with nodes: (0) absent; (1) present.

Davis (2002); Hanke & Wilson (2004); Brazeau (2009); Davis et al. (2012), Character 133; Choo et al. (2017), Character 129; King et al. (2017), Character 463; Castiello (2018), Character 452; Zhu Y. et al. (2022), Character 684.

1. Fin spines with rows of large retrorse denticles: (0) absent; (1) present.

Davis et al. (2012), Character 134; Choo et al. (2017), Character 130; King et al. (2017), Character 464; Castiello (2018), Character 453; Zhu Y. et al. (2022), Character 685.

1. Fin spines (dorsal) with rows of large denticles: (0) absent; (1) on posterior surface; (2) on lateral surface.

Coates et al. (2018), Character 261; Zhu Y. et al. (2022), Character 686.

1. Fin spine cross-section: (0) round or horseshoe shaped; (1) flat-sided, with rectangular profile.

Giles et al. (2015), Character 218; Choo et al. (2017), Character 315; King et al. (2017), Character 472; Castiello (2018), Character 461; Zhu Y. et al. (2022), Character 687.

Early gnathostome fin spines have at least two distinctive profiles in cross-section. Generally, the profile is gently curving or parabolic. Taxa such as acanthodids and ischnacanthids exhibit a condition in which the cross-section is more rectangular, and the sides of the spine are flatter and closer to parallel (Denison, 1979; Gagnier & Wilson, 1996). (Giles et al., 2015)

1. Expanded spine rib on leading edge of spine: (0) absent; (1) present.

Giles et al. (2015), Character 224; Choo et al. (2017), Character 317; King et al. (2017), Character 474; Castiello (2018), Character 463; Zhu Y. et al. (2022), Character 688.

This character is common to acanthodids and their proximal relations. It is variably present in *Kathemacanthus*. (Giles et al., 2015)

1. Spine ridges: (0) converging at the distal apex of the spine; (1) converging on leading edge of spine.

Giles et al. (2015), Character 225; Choo et al. (2017), Character 318; King et al. (2017), Character 475; Castiello (2018), Character 464; Zhu Y. et al. (2022), Character 689.

1. Dorsal fin spine cross section: (0) horseshoe shaped; (1) flat sided, with rectangular profile; (2) subcircular.

Coates et al. (2018), Character 250; Zhu Y. et al. (2022), Character 690.

1. Anterior dorsal fin spine leading edge concave in lateral view: (0) absent; (1) present.

Coates et al. (2018), Character 251; Zhu Y. et al. (2022), Character 691.