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Part A. Phylogenetic Analyses

1) Phylogenetic methods

To explore the phylogenetic position of *Entelognathus* and the impact of its characters on gnathostome phylogeny, we conducted phylogenetic analyses using a modified dataset with 253 characters and 75 taxa (Supplementary Figs 1-5). This dataset (hereafter referred to as the full dataset) is based on that of Davis *et al.* (2012), with revised codings for 29 of the original 138 characters, and with the addition of 115 characters and 15 taxa including *Entelognathus*.

In order to detect the impact of including *Entelognathus*, and the respective impact of revising codings for 29 characters, of adding 115 characters, and of adding 15 taxa (including *Entelognathus*), we conducted additional analyses using three different subsets of the full dataset (Supplementary Figs 6-8). Subset 1 (Supplementary Fig. 6) is the same as the dataset of Davis *et al*. (2012), with 138 characters and 60 taxa (61 counting *Entelognathus*). Subset 2 (Supplementary Fig. 7) is modified from the dataset of Davis *et al*. (2012), with revised codings for 29 characters out of the original 138 characters. Subset 3 (Supplementary Fig. 8) is based on the original dataset of Davis *et al*. (2012), with revised codings for 29 characters, and with 115 additional characters. The full dataset and the 3 subsets were run twice, first with, and then without, codings for *Entelognathus*.

The dataset of Davis *et al.* (2012) includes 2 outgroup taxa (jawless galeaspids and osteostracans) and 58 ingroup taxa (11 placoderms, 23 acanthodians, 13 conventionally defined chondrichthyans, and 11 osteichthyans). The 15 additional taxa in our full dataset include *Entelognathus* as well as the following 2 placoderms and 12 osteichthyans: *Parayunnaolepis* (Zhang *et al.* 2001, Zhu *et al.* 2012), *Sigaspis* (Goujet 1973), *Lophosteus* (Gross 1969, Gross 1971, Otto 1991, Burrow 1995, Schultze & Märss 2004, Botella *et al.* 2007), *Miguashaia* (Schultze 1973, Cloutier 1996, Forey 1998, Forey *et al.* 2000), *Moythomasia* (Gardiner 1984), *Powichthys* (Jessen 1975, Jessen 1980, Clément & Janvier 2004, Clément & Ahlberg 2010), *Osteolepis* (Westoll 1936, Thomson 1965, Jarvik 1980), *Osorioichthys* (Casier 1952, Casier 1954, Taverne 1997), *Styloichthys* (Zhu & Yu 2002, Zhu & Yu 2004), *Youngolepis* (Chang 1982, Chang 1991, Chang & Smith 1992, Chang 2004), *Diabolepis* (Chang & Yu 1984, Chang & Smith 1992, Chang 1995), *Kenichthys* (Chang & Zhu 1993, Chang & Yu 1997, Zhu & Ahlberg 2004), *Achoania* (Zhu *et al.* 2001, Zhu & Yu 2004), *Meemannia* (Zhu *et al.* 2006, Zhu *et al.* 2010).

The 115 additional characters in the full dataset (also in subset 3) are either characters taken from other analyses (e.g., Brazeau 2009, Zhu *et al.* 2009, Friedman & Brazeau 2010) or are newly formulated characters. Where appropriate, brief comments on modified character codings and newly formulated characters appear in the "Character List" section below.

The character data entry and formatting were performed in Mesquite (version 2.5) (Maddison & Maddison 2008). All characters were treated as unordered, and weighted equally. The dataset was subjected to the parsimony analysis in PAUP* (version 4.0b10) (Swofford 2003) following the algorithm used in Davis *et al*. (2012). Heuristic searches were initially run for 25 random sequence additions to estimate the length of the shortest tree (TS). The value TS+1 was then used as the "chuckscore" (the treescore at and above which a fixed number of trees were kept). A more comprehensive heuristic search was then run using 1,000 (full dataset and subset 3) or 10,000 (subsets 1 and 2) random sequence additions, keeping 500 trees greater than or equal to the chuckscore (CHUCKSCORE =TS+1, NCHUCK = 500) for each random addition replicate.

MacClade 4.0 (Maddison & Maddison 2000) was used to trace the character transformation in the selected cladogram, based on one of the 1117 most parsimonious trees from the analysis of the full dataset (Supplementary Fig. 3). Bremer decay indices (Fig. 6 and Supplementary Fig. 1a) were obtained using command files composed by TreeRot (Sorenson 1999) in conjunction with the heuristic search algorithm in PAUP*.

The full dataset was also subjected to Bayesian inference analysis (Supplementary Fig. 3) using MrBayes 3.1.2 (Huelsenbeck 2001, Ronquist & Huelsenbeck 2003). Galeaspida was set as the outgroup, and codings showing polymorphism were changed to "?". Priors were kept at their default settings for standard (= morphological) analyses. The analysis was run for $1*10^7$ generations. Samples were taken every $1*10^2$ generations, resulting in a total of $1*10^5$ samples for each of the parallel analyses. The first $2.5*10^4$ samples for each run, representing the "burn-in" period, were discarded. The 50% majority-rule consensus tree was computed for the sampled generations.

2) Phylogenetic results

Parsimony analysis using the full dataset, with Enteloganthus *(Supplementary Figs 1a, 2a, 3) and without* Enteloganthus *(Supplementary Figs 1b, 2b).*

The inclusion of *Entelognathus* to the full dataset brings significantly better resolution to the crown gnathostomes and the placoderms (including *Entelognathus*) on the gnathostome stem (Supplementary Fig. 1a). *Entelognathus* is positioned in a polychotomy with arthrodires (*Sigaspis*, *Buchanosteus*, *Dicksonosteus*, *Coccosteus* and *Cowralepis*), ptyctodonts (*Austroptyctodus*, *Rhamphodopsis*, *Campbellodus*) and crown gnathostomes (Supplementary Fig. 1a). The 50% majority-rule consensus of the 1117 most parsimonious trees (MPTs) from the analysis of the full dataset favours *Entelognathus* as the sister group of crown gnathostomes (Supplementary Fig. 2a). *Cowralepis* falls into the arthrodire clade instead of being placed among the ptyctodonts (cf. Davis *et al*. 2012, same as Supplementary Fig. 4b). All acanthodians are resolved as successive plesions leading up to the conventionally-defined chondrichthyans. The monophyly of the osteichthyans and the monophyly of the conventionally-defined chondrichthyans are supported. *Lophosteus* is resolved as the sister groups of the remaining osteichthyans, while the *Guiyu-Achoania-Psarolepis* clade is unresolved as stem-group sarcopterygians or stem-group osteichthyans.

Supplementary Figure 3 shows one of the 1117 MPTs from the analysis of the full dataset, with node numbers defining various clades. For characters and character states defining major clades, see pp. 46-51. For a summary of nodal synapomorphies in one of the 1117 MPTs from the full dataset, see pp. 51-53.

Among the 1117 MPTs from the analysis of the full dataset, 738 MPTs or 66% of 1117 MPTs assign *Entelognathus* as the sister group of crown gnathostomes (Supplementary Fig. 4a). In the remaining trees, ptyctodonts (66 MPTs or 6% of 1117 MPTs) and arthrodires-ptyctodonts-*Entelognathus* clade (313 MPTs or 28% of 1117 MPTs) are respectively recovered as the sister group of crown gnathostomes (Supplementary Fig. 4b, c).

When *Entelognathus* is excluded (Supplementary Fig. 1b), largely-unresolved acanthodian taxa form a polychotomy with the conventionally-defined chondrichthyans. The internal topology of osteichthyans collapses into a polychotomy, although the 9 rhipidistian taxa maintain their monophyly. On the gnathostome stem, the placoderm taxa are largely unresolved except for the ptyctodont clade (*Austroptyctodus*, *Rhamphodopsis*, *Campbellodus*) and the antiarch clade (*Bothriolepis*, *Pterichthyodes*).

Bayesian inference analysis using the full dataset (Supplementary Fig. 5)

Bayesian inference analysis (Supplementary Fig. 5) agrees with the parsimony analysis in placing all acanthodians in the stem segment of the chondrichthyan total group, in the internal topology of the conventionally-defined chondrichthyans, and in the position of *Lophosteus* as the sister group of the remaining osteichthyan taxa. However, Bayesian inference analysis (Supplementary Fig. 5) places *Sigaspis* and *Entelognathus* as two successive sister groups of osteichthyans. While the monophyly of the acanthodian-chondrichthyan branch is kept, the acanthodian taxa are poorly resolved. Seven placoderm taxa - the ptyctodont clade (*Austroptyctodus*, *Rhamphodopsis*, *Campbellodus*), *Cowralepis*, *Dicksonosteus*, *Buchanosteus* and *Coccosteus* - form a polychotomy with the acanthodian-chondrichthyan branch and the *Sigaspis*-*Entelognathus*-osteichthyan clade.

Parsimony analysis using subset 1, with Enteloganthus *(Supplementary Fig. 6a) and without* Enteloganthus *(Supplementary Fig. 6b)*

Entelognathus is placed within a paraphyletic array of placoderms, less crownward than the clade including *Cowralepis* (a phyllolepid) and three ptyctodont taxa (*Campbellodus*, *Austroptyctodus*, *Rhamphodopsis*). Compared to the dataset of Davis *et al.* (2012) (same as Supplementary Fig. 6b), the addition of *Enteloganthus* codings to the dataset significantly changes the internal topology of the gnathostome crown group (Supplementary Fig. 6a). Nine acanthodians (*Acanthodes*, *Ischnacanthus* etc.) are removed from stem osteichthyan positions, and another 9 acanthodians (*Climatius*, *Diplacanthus*, etc.) are removed from stem gnathostome positions. Thus, all the 23 acanthodian taxa fall into the acanthodian-chondrichthyan branch, collateral to the osteichthyan branch. In the stem segment of the acanthodian-chondrichthyan branch, the acanthodian taxa mostly form a polychotomy, although the *Ischnacanthus-Poracanthodes* clade and the clade including *Cassidiceps, Mesacanthus, Promesacanthus, Cheiracanthus, Acanthodes* and *Homalacanthus* remain intact. Most osteichthyans collapse into polytomies, while the internal topology of the conventionally-defined chondrichthyans remains intact.

Parsimony analysis using subset 2, with Enteloganthus *(Supplementary Fig. 7a) and without* Enteloganthus *(Supplementary Fig. 7b)*

The inclusion of *Enteloganthus* brings significantly better resolution to the internal topology of the gnathostome crown group (Supplementary Fig. 7a). All acanthodian taxa are recovered as stem chondrichthyans on the acanthodian-chrondrichthyan branch. *Entelognathus* is placed in a trichotomy with ptyctodonts and the gnathostome crown group.

Compared to the topology of Davis *et al*. (2012) (same as Supplementary Fig. 6b, without *Entelognathus*), the revised codings of 29 characters cause the collapse of the internal topology of the gnathostome crown group (Supplementary Fig. 7b). Acanthodian taxa collapse into a polychotomy with osteichthyans and chondrichthyans. Although the monophyly of osteichthyans and of conventionally-defined chondrichthyans remains intact, the osteichthyans collapse into a polychotomy. *Cowralepis* clusters with three arthrodire taxa (*Dicksonosteus*, *Buchanosteus* and *Coccosteus*), rather than with ptyctodonts as in the topology of Davis *et al*. (2012) (same as Supplementary Fig. 6b) - regardless whether *Entelognathus* is included. When *Entelognathus* is included (Supplementary Fig. 7a), *Lupopsyrus*, *Obtusacanthus*, *Kathemacanthus*, *Brochoadmones* and *Vernicomacanthus* form successive plesions leading up to the conventionally-defined chondrichthyans, similar to the strict consensus tree from Davis *et al.* (2012) (same as Supplementary Fig. 6b).

Parsimony analysis using subset 3, with Enteloganthus *(Supplementary Fig. 8a) and without* Enteloganthus *(Supplementary Fig. 8b)*

As in the case with subset 2 (Supplementary Fig. 7a), the inclusion of *Enteloganthus* makes the internal topology of the gnathostome crown group better resolved (Supplementary Fig. 8a). *Entelognathus* is positioned in a trichotomy with osteichthyans and the acanthodian-chondrichthyan branch. All acanthodian taxa are recovered as stem chondrichthyans on the acanthodian-chondrichthyan branch - regardless whether *Entelognathus* is included.

When compared to the strict consensus trees from subset 2 (Supplementary Fig. 7a, b), the addition of 115 characters does not drastically change the respective topologies of the strict consensus trees, except that the placoderm taxa become better resolved when *Entelognathus* is included (Supplementary Fig. 8a, b).

3) Taxa used in the most expanded dataset with principal sources of data (75 OUTs with 253 characters)

Outgroup (2 OTUs)

Osteostraci: Janvier 1981, Janvier 1985, Janvier *et al.* 2004.

Galeaspida: Halstead 1979, Janvier 1981, Wang 1991, Pan 1992, Gai *et al.* 2011.

Ingroup (73 OTUs)

Entelognathus: This paper.

Placoderms (13 out of 73 ingroup OTUs)

Parayunnanolepis: Zhang *et al.* 2001, Zhu *et al.* 2012a.

Bothriolepis: Young 1984, Young 1988, Janvier 1996, Arsenault *et al.* 2004, Downs & Donoghue 2009.

Pterichthyodes: Hemmings 1978, Hemmings & Rostron 1972.

Brindabellaspis: Young 1980, Young 1986, Burrow & Turner 1998, Burrow & Turner 1999, Goujet & Young 2004.

Macropetalichthys: Stensiö 1925, Gross 1935, Stensiö 1969, Denison 1978, Jarvik 1980.

Sigaspis: Goujet 1973.

Dicksonosteus: Goujet 1975, Goujet 1984.

Buchanosteus: Young 1979, Young *et al.* 2001.

Coccosteus: Stensiö 1963, Miles & Westoll 1968.

Cowralepis: Ritchie 2005, Carr *et al.* 2009.

Campbellodus: Miles & Young 1977, Long 1997.

Austroptyctodus: Miles & Young 1977, Long 1997, Trinajstic *et al.* 2012.

Rhamphodopsis: Watson 1938, Miles 1967, Miles & Young 1977, Long 1997.

Conventionally-defined chondrichthyans (13 out of 73 ingroup OTUs)

Pucapampella: Maisey 2001, Maisey & Anderson 2001, Maisey & Lane 2010.

Akmonistion: Coates *et al.* 1998, Coates & Sequeira 1998, Coates & Sequeira 2001a, Coates & Sequeira 2001b.

Doliodus: Miller *et al.* 2003, Maisey *et al.* 2009.

Cladodoides: Gross 1937, Gross 1938, Maisey 2005.

Hamiltonichthys: Maisey 1989a.

Cladoselache: Woodward & White 1938, Bendix-Almgreen 1975, Schaeffer 1981, Maisey 1989b, Maisey 2007.

Orthacanthus: Heidtke 1982, Heidtke 1998, Soler-Gijón 1999.

Tamiobatis: Romer 1964, Schaeffer 1981, Williams 1998.

Chondrenchely: Moy-Thomas 1936, Zangerl & Case 1973, Lund 1982.

Cobelodus: Zangerl & Case 1976, Maisey 2007.

Debeerius: Grogan & Lund 2000.

Onychoselache: Dick & Maisey 1980a, Dick & Maisey 1980b, Coates & Gess 2007.

Tristychius: Woodward 1924, Dick 1978, Coates & Gess 2007.

Acanthodians (23 out of 73 ingroup OTUs)

Diplacanthus: Watson 1937, Miles 1973a, Denison 1979, Gagnier & Wilson 1996a.

Climatius: Watson 1937, Ørvig 1967a, Miles 1973a, Miles 1973b.

Ptomacanthus: Miles 1973a, Miles 1973b, Brazeau 2009, Brazeau 2012.

Poracanthodes: Denison 1979, Valiukevicius 1992. (See note below)

Acanthodes: Miles 1968, Miles 1973a, Miles 1973b, Jarvik 1977, Denison 1979, Jarvik 1980, Heidtke 1993, Coates 1994, Coates & Davis 2010, Davis *et al*. 2012.

Tetanopsyrus: Gagnier & Wilson 1995, Gagnier *et al.* 1999, Hanke *et al.* 2001.

Kathemacanthus: Gagnier & Wilson 1996b, Hanke & Wilson 2010.

Parexus: Watson 1937, Miles 1973a.

Brachyacanthus: Watson 1937.

Gladiobranchus: Bernacsek & Dineley 1977, Hanke & Davis 2008.

Culmacanthus: Long 1983, Young 1989, Burrow & Young 2012.

Brochoadmones: Bernacsek & Dineley 1977, Gagnier & Wilson 1996b, Hanke & Wilson 2006.

Obtusacanthus: Hanke & Wilson 2004.

Euthacanthus: Watson 1937, Miles 1973a, Newman *et al.* 2011.

Ischnacanthus: Watson 1937, Miles 1973a, Hermus 2003.

Cassidiceps: Gagnier & Wilson 1996a.

Mesacanthus: Watson 1937, Miles 1973a.

Cheiracanthus: Watson 1937, Miles 1973a, Denison 1979.

Homalacanthus: Watson 1937, Gagnier 1996.

Promesacanthus: Hanke 2008.

Vernicomacanthus: Miles 1973a.

Rhadinacanthus: Traquair 1888, Miles 1973a.

Lupopsyrus: Bernacsek & Dineley 1977, Hanke & Davis 2012.

Osteichthyans (23 out of 73 ingroup OTUs)

Lophosteus: Gross 1969, Gross 1971, Otto 1991, Burrow 1995, Schultze & Märss 2004, Botella *et al.* 2007.

Dialipina: Schultze 1968, Schultze 1992, Schultze & Cumbaa 2001.

Ligulalepis: Schultze 1968, Burrow 1994, Basden *et al.* 2000, Basden & Young 2001.

Meemannia: Zhu *et al.* 2006, Zhu *et al.* 2010.

Cheirolepis: Ørvig 1967b, Pearson & Westoll 1979, Pearson 1982, Arratia & Cloutier 1996, Arratia & Cloutier 2004.

Howqualepis: Long 1988.

Mimipiscis: Gardiner 1984a, Choo 2011.

Moythomasia: Gardiner 1984a.

Osorioichthys: Casier 1954, Taverne 1997.

Psarolepis: Zhu & Schultze 1997, Yu 1998, Zhu *et al.* 1999, Qu *et al.* 2010, Zhu *et al.* 2012b, Qu *et al.* 2013.

Guiyu: Zhu *et al.* 2009, Qiao & Zhu 2010, Zhu *et al.* 2012b.

Achoania: Zhu *et al.* 2001, Zhu & Yu 2004.

Onychodus: Jessen 1966, Andrews *et al.* 2006.

Miguashaia: Schultze 1973, Cloutier 1996, Forey 1998, Forey *et al.* 2000.

Porolepis: Jarvik 1972, Clément 2004.

Styloichthys: Zhu & Yu 2002, Zhu & Yu 2004.

Youngolepis: Chang 1982, Chang 1991, Chang & Smith 1992, Chang 2004.

Diabolepis: Chang & Yu 1984, Chang 1995.

Powichthys: Jessen 1975, Jessen 1980, Clément & Janvier 2004, Clément & Ahlberg 2010.

Kenichthys: Chang & Zhu 1993, Chang & Yu 1997, Zhu & Ahlberg 2004.

Gogonasus: Long *et al.* 1997, Long *et al.* 2006, Holland & Long 2009, Holland 2013.

Osteolepis: Westoll 1936, Thomson 1965, Jarvik 1980.

Eusthenopteron: Jarvik 1944, Jarvik 1954, Jarvik 1980.

Note regarding *Poracanthodes*: Mainly based on scale traits, Vergoossen (1997, 1999) divided the genus *Poracanthodes* into three genera, *Poracanthodes* (type species *P. punctatus* Brotzen, 1934), *Radioporacanthodes* (type species *Poracanthodes porosus* Brotzen, 1934), and *Zemlyacanthus* (type species *Poracanthodes menneri* Valiukevicius, 1992), within the family Poracanthodidae. In addition to these three species, a Chinese porosiform species (*Poracanthodes qujingensis* Wang & Wang, 1989) was also referred to *Poracanthodes*. In general, these four species share the similar scale morpology and histology (i.e., highly specialized pore-canal network), as distinguishable from other ischnacanthid acanthodians. While some authors adopted *Zemlyacanthus menneri* (Burrow *et al*. 1999, Long *et al*. 2004), others maintained the usage of *Poracanthodes menneri* (Blom 1999, Brazeau 2009, Davis *et al*. 2012). Considering the uncertain status of *Zemlyacanthus*, we choose to use a broad definition of *Poracanthodes*, which includes *P. puctatus*, *P. porosus*, *P. menneri*, and *P. qujingensis*.

4) Character list.

Characters 1-138 (full dataset and subsets 1-3) are adopted from Davis *et al.* (2012). Characters 139-253 (full dataset and subset 3) are newly added characters, which are listed in sequenced categories similar to those in Brazeau (2009) and Davis *et al.* (2012).

1. Tessellate prismatic calcified cartilage: absent (0); present (1).
   Schaeffer (1981, Character 1), Coates & Sequeira (2001a, Character 1), Coates & Sequeira (2001b, Character 1), Maisey (2001, Character 1), Brazeau (2009, Character 1), Davis *et al.* (2012, Character 1).

2. Perichondral bone: present (0); absent (1).
   Brazeau (2009, Character 2), Davis *et al.* (2012, Character 2).
   We code the presence of perichondral bone in *Bothriolepis* based on Young (1984, pl.54), although *Bothriolepis* bears no perichondrally ossified neurocranium (Downs & Donoghue 2009). *Pterichthyodes* is coded as "?" because no endoskeletal remains are revealed (Hemmings & Rostron 1972, Hemmings 1978).

3. Extensive endochondral ossification: absent (0); present (1).
   Forey (1980), Gardiner (1984a), Zhu *et al.* (2009, Character 30), Brazeau (2009, Character 3), Friedman & Brazeau (2010, Character 27), Davis *et al.* (2012, Character 3), and references therein.
   Dialipina is coded as "?" due to missing data (Schultze & Cumbaa 2001).

4. Dentine: absent (0); present (1).
   Brazeau (2009, Character 4), Davis *et al.* (2012, Character 4).

5. Type of dentine: mesodentine (0); semidentine (1); orthodentine (2).
   Brazeau (2009, Character 5), Davis *et al.* (2012, Character 5).
   The coding for *Brindabellaspis* is changed from "0" to "1" according to Burrow & Turner (1998). *Psarolepis* is coded as "2" according to Zhu *et al.* (2006), and Qu *et al.* (2013)

6. Cosmine: absent (0); present (1).
   Cloutier & Ahlberg (1996, Character 1), Zhu & Schultze (2001, Character 203), Schultze & Cumbaa (2001, Character 105), Zhu *et al.* (2001, Character 148), Zhu & Yu (2002, Character 148), Brazeau (2009, Character 6), Davis *et al.* (2012, Character 6)

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

Brazeau (2009, Character 7), Friedman & Brazeau (2010, Character 21), Davis *et al.* (2012, Character 7).
The coding for *Gogonasus* is changed from "1" to "0" (Holland 2013).

8. Body scale growth pattern: monodontode (0); polyodontode (1).
Brazeau (2009, Character 8), Davis *et al.* (2012, Character 8).

9. Body scale growth concentric: absent (0); present (1).
Brazeau (2009, Character 9), Davis *et al.* (2012, Character 9).

10. Body scales with peg-and-socket articulation: absent (0); present (1).
Brazeau (2009, Character 10), Zhu *et al.* (2009, Character 138), Friedman & Brazeau (2010, Character 24), Davis *et al.* (2012, Character 10), and references therein.
Psarolepis is coded as "1" according to Qu *et al.* (2013). Galeaspida (Zhu *et al.* 2012c) and *Doliodus* (Miller *et al.* 2003) are coded as "0".

11. Body scale profile: distinct crown and base demarcated by a constriction (neck) (0); flattened (1).
Brazeau (2009, Character 11), Davis *et al.* (2012, Character 11).

12. Body scales with bulging base: absent (0); present (1).
Brazeau (2009, Character 12), Davis *et al.* (2012, Character 12).

13. Body scales with flattened base: absent (0); present (1).
Brazeau (2009, Character 13), Davis *et al.* (2012, Character 12).
Brazeau (2009) and Davis *et al.* (2012) stated "present (0), absent (1)". This was an obvious clerical error, as shown by their actual codings in the data matrix. Here we reverse the description of the character states without actually affecting the codings in the data matrix.

14. Flank scale alignment: vertical rows (0); oblique rows or hexagonal/rhombic packing (1); disorganised (2).
Brazeau (2009, Character 15), Davis *et al.* (2012, Character 14).

15. Sensory line canal passes between or beneath scales (0); passes over scales and/or is partially enclosed or surrounded by scales (1); perforates and passes through scales (2).
Brazeau (2009, Character 16), Friedman & Brazeau (2010, Character 36), Davis *et al.* (2012, Character 15).
Psarolepis is coded as "2" based on Qu *et al.* (2010), Qu *et al.* (2013).

16. Sensory line network preserved as open grooves (sulci) in dermal bones (0);

sensory lines pass through canals enclosed within dermal bones (1).
Brazeau (2009, Character 40), Davis *et al.* (2012, Character 16).

17. Jugal portion of infraorbital canal joins supramaxillary canal: present (0); absent (1).
Friedman (2007, Character 49), Brazeau (2009, Character 18), Zhu *et al.* (2009, Character 117), Friedman & Brazeau (2010, Character 45), Davis *et al.* (2012, Character 17), and references therein.

18. Dermal skull roof includes large dermal plates (0); consists of undifferentiated plates or tesserae (1).
Brazeau (2009, Character 19), Davis *et al.* (2012, Character 18), and references therein.
Brazeau (2009) defined tesserae of skull roof as "flat-based, plate-like head coverings that are differentiated from the body scales, but do not form a distinct pattern as the dermal skull roof of placoderms or osteichthyans". Accordingly, the coding for galeaspids (Brazeau 2009) was corrected from "0" to "1", as in osteostracans.

19. Tessera morphology: large interlocking polygonal plates (0); microsquamose, not larger than body squamation (1).
Brazeau (2009, Character 20), Davis *et al.* (2012, Character 19).
This character is applicable only to those taxa where the dermal skull roof comprises exclusively of tesserae. Taxa with large dermal plates are coded as "-" (logical impossibility).

20. Extent of dermatocranial cover: complete (0); incomplete (scale-free cheek and elsewhere) (1).
Brazeau (2009, Character 21), Davis *et al.* (2012, Character 20).
As ptyctodonts normally contain scattered scales in association with articulated specimens (Long 1997: p.534), we are not in a position to confirm the naked cheek condition in these taxa. The cheek condition in ptyctodonts is likely to be similar to *Macropetalichthys*. Consequently, we code "?" (instead of "1") for Character 20 in three ptyctodont taxa, similar to the coding for *Macropetalichthys*.

21. Endolymphatic ducts open in dermal skull roof: present (0); absent (1).
Brazeau (2009, Character 22), Davis *et al.* (2012, Character 21).

22. Endolymphatic ducts with oblique course through dermal skull bones: absent (0); present (1).
Brazeau (2009, Character 23), Davis *et al.* (2012, Character 22).

23. Series of paired median skull roofing bones that meet at the dorsal midline of the skull (rectilinear skull roof pattern): absent (0); present (1).

Brazeau (2009, Character 24), Davis *et al.* (2012, Character 23).

24. Consolidated cheek plates: absent (0); present (1).
Brazeau (2009, Character 25), Davis *et al.* (2012, Character 24).
Macropetalichthys (Stensiö 1925, 1969) and ptyctodonts are coded as "0". Those taxa with incomplete dermatocranial cover (state 1 of Character 20) are coded 'inapplicability'.

25. Pineal opening perforation in dermal skull roof: present (0); absent (1).
Friedman (2007, Character 19), Brazeau (2009, Character 26), Zhu *et al.* (2009, Character 21), Davis *et al.* (2012, Character 25), and references therein.

26. Enlarged postorbital tessera separate from orbital series: absent (0); present (1).
Brazeau (2009, Character 30), Davis *et al.* (2012, Character 26).

27. Bony hyoidean gill-cover series (branchiostegals): absent (0); present (1).
Brazeau (2009, Character 31), Friedman & Brazeau (2010, Character 18), Davis *et al.* (2012, Character 27).
Campbellodus is coded as "0" based on an almost complete individual (Long 1997: WAM 86.9.672).

28. Branchiostegal plate series along ventral margin of lower jaw: absent (0); present (1).
Brazeau (2009, Character 32), Davis *et al.* (2012, Character 28), and references therein.

29. Branchiostegal ossifications plate-like (0); narrow and ribbon-like (1).
Brazeau (2009, Character 33), Davis *et al.* (2012, Character 29), and references therein.

30. Branchiostegal ossifications ornamented (0); unornamented (1).
Brazeau (2009, Character 34), Davis *et al.* (2012, Character 30).

31. Imbricated branchiostegal ossifications: absent (0); present (1).
Brazeau (2009, Character 35), Davis *et al.* (2012, Character 31).

32. Opercular cover of branchial chamber complete or partial (0); separate gill covers and gill slits (1).
Davis *et al.* (2012, Character 32).

33. Opercular (submarginal) ossification: absent (0); present (1).
Brazeau (2009, Character 36), Davis *et al.* (2012, Character 33).

34. Shape of opercular (submarginal) ossification: broad plate that tapers towards its

proximal end (0); narrow, rod-shaped (1).
Brazeau (2009, Character 37), Davis *et al.* (2012, Character 34).
The coding for *Campbellodus* is changed from “1” to “0” based on its more ovate shape (Miles & Young 1977: fig.10, Long 1997: fig.5), in contrast to a long, narrow submarginal in *Austroptyctodus* and *Rhamphodopsis* (Young 1986: p.50).

35. Gular plates: absent (0); present (1).
Brazeau (2009, Character 38), Davis *et al.* (2012, Character 35).

36. Size of lateral gular plates: extending most of length of the lower jaw (0); restricted to the anterior third of the jaw (no longer than the width of three or four branchiostegals) (1).
Brazeau (2009, Character 39), Zhu *et al.* (2009, Character 103), Friedman & Brazeau (2010, Character 74), Davis *et al.* (2012, Character 36), and references therein.

37. Basihyal: present (0); absent, hyoid arch articulates directly with basibranchial (1).
Davis *et al.* (2012, Character 37).

38. Interhyal: absent (0); present (1).
Davis *et al.* (2012, Character 38).

39. Oral dermal tubercles borne on jaw cartilages: absent (0); present (1).
Brazeau (2009, Character 41), Davis *et al.* (2012, Character 39).

40. Tooth whorls: absent (0); present (1).
Brazeau (2009, Character 43), Davis *et al.* (2012, Character 40).
The coding for *Guiyu* is changed from “0” to “1” (Zhu *et al.* 2009, fig. 4g), similar to that for *Psarolepis*.

41. Bases of tooth whorls: single, continuous plate (0); some or all whorls consist of separate tooth units (1).
Brazeau (2009, Character 44), Davis *et al.* (2012, Character 41)

42. Enlarged adsymphysial tooth whorl: absent (0); present (1).
Brazeau (2009, Character 45), Davis *et al.* (2012, Character 42).
The coding for *Guiyu* is changed from “0” to “1” (Zhu *et al.* 2009, fig. 4g), similar to that for *Psarolepis*. *Dicksonosteus* is coded as “0” (Goujet 1984).

43. Teeth ankylosed to dermal bones: absent (0); present (1).
Brazeau (2009, Character 46), Davis *et al.* (2012, Character 43).

44. Dermal jaw plates on biting surface of jaw cartilages: absent (0); present (1).
Brazeau (2009, Character 48), Davis *et al.* (2012, Character 44).

We follow Brazeau (2009, Character 48) in referring "primarily to large dermal plates borne directly on the jaw cartilages, including the gnathal plates of placoderms, the dentigerous bones of ischnacanthids, and the palatine/coronoid series of osteichthyans". *Psarolepis* is coded as "1" (Yu 1998).

45. Maxillary and dentary tooth-bearing bones: absent (0); present (1).
Brazeau (2009, Character 45), Zhu *et al.* (2009, Character 73), Davis *et al.* (2012, Character 45).
This character can be re-formulated as "large dermal plates forming outer arcade of biting edge". Dermal bones forming outer arcade of biting edge include premaxilla, maxilla, and dentary in osteichthyans. We follow Brazeau (2009) in using a composite character to avoid inflated support caused by correlated or overlapping characters.

46. Large otic process of the palatoquadrate: absent (0); present (1).
Brazeau (2009, Character 49), Davis *et al.* (2012, Character 46), and references therein.
Poracanthodes is code as "1" (Valiukevicius 1992).

47. Insertion area for jaw adductor muscles on palatoquadrate: ventral or medial (0); lateral (1).
Brazeau (2009, Character 50), Davis *et al.* (2012, Character 47).
Doliodus is coded as "1" (Maisey *et al.* 2009). *Buchanosteus* is coded as "1" based on Young (1979). *Campbellodus* and *Austroptyctodus* were coded as "0" in Brazeau (2009) and as "1" in Davis *et al.* (2012). The metapterygoid portion of palatoquadrate is usually the place for the attachment of the adductor mandibulae muscle. The palatoquadrate of ptyctodonts is very specialized with its metapterygoid not sandwiched between the quadrate and the autopalatine (Miles & Young 1977: fig. 28, Trinajstic *et al.* 2012, *contra* Long 1997: metapterygoid interpreted as the "nasal ossification of neurocranium"). Davis *et al.* (2012) suggested the lateral recess of the quadrate in *Campbellodus* and *Austroptyctodus* receives the adductor mandibulae muscle. However, the "V-shaped cavity" of *Austroptyctodus* Miles & Young (1977, fig. 25b) may also represent the fossa for adductor mandibulae muscle. Long (1997, fig.11) suggested that the fossa for adductor mandibulae muscle in *Campbelllodus* is located below the medial ridge of the quadratopterygoid and mesially directed. Considering all these uncertainties, we code "?" for *Campbellodus* and *Austroptyctodus*.

48. Oblique ridge or groove along medial face of palatoquadrate: absent (0); present (1).
Brazeau (2009, Character 52), Davis *et al.* (2012, Character 48).

49. Fenestration of palatoquadrate at basipterygoid articulation: absent (0); present (1).
Brazeau (2009, Character 53), Zhu *et al.* (2009, Character 72), Friedman &

Brazeau (2010, Character 44), Davis *et al.* (2012, Character 49), and references therein.
Onychodus is coded as "0" (Andrews *et al.* 2006).

50. Perforate or fenestrate anterodorsal (metapterygoid) portion of palatoquadrate: absent (0); present (1).
Brazeau (2009, Character 54), Davis *et al.* (2012, Character 50), and references therein.

51. Pronounced dorsal process on Meckelian bone or cartilage: absent (0); present (1).
Brazeau (2009, Character 55), Davis *et al.* (2012, Character 51), and references therein.

52. Preglenoid process: absent (0); present (1).
Davis *et al.* (2012, Character 52).
Onychodus and *Psarolepis* are coded as "0" (Yu 1998, Andrews *et al.* 2006).

53. Jaw articulation located on rearmost extremity of mandible: absent (0); present (1).
Davis *et al.* (2012, Character 53).

54. Precerebral fontanelle: absent (0); present (1).
Brazeau (2009, Character 58), Davis *et al.* (2012, Character 54), and references therein.

55. Median dermal bone of palate (parasphenoid): absent (0); present (1).
Brazeau (2009, Character 57), Davis *et al.* (2012, Character 55), and references therein.
Young (1986, p.47) suggested the presence of the parasphenoid in the antiarch *Bothriolepis*, based on personal communication with R. S. Miles. Dennis-Bryan (1995, p.135) also mentioned the presence of the parasphenoid in *Bothriolepis*. Here we code two antiarch genera (*Bothriolepis* and *Pterichthyodes*) as "?".

56. Nasal opening(s): dorsal, placed between orbits (0); ventral and anterior to orbit (1).
Brazeau (2009, Character 59), Davis *et al.* (2012, Character 56), and references therein.

57. Olfactory tracts: short, with olfactory capsules situated close to telencephalon cavity (0); elongate and tubular (much longer than wide) (1).
Brazeau (2009, Character 60), Friedman & Brazeau (2010, Character 10), Davis *et al.* (2012, Character 57).
The short canals for olfactory tracts exist in *Psarolepis* (IVPP V11490.2) and *Achoania* (IVPP V11114) as shown by the high-resolution CT scanning (personal observation). Brazeau (2009) and Davis *et al.* (2012) coded "1" for *Onychodus*. Since the available evidence (Andrews *et al.* 2006) does not indicate whether

Onychodus has a short canal like *Ligulalepis* and *Psarolepis* or a long canal like other crown osteichthyans, we revise its coding from “1” to “?”.

58. Prominent pre-orbital rostral expansion of the neurocranium: present (0); absent (1).
Brazeau (2009, Character 61), Davis *et al.* (2012, Character 58).

59. Pronounced subpituitary keel: absent (0); present (1).
Brazeau (2009, Character 62), Davis *et al.* (2012, Character 59), and references therein.

60. Position of myodome for superior oblique eye muscles: posterior and dorsal to foramen for optic nerve (N. II) (0); anterior and dorsal to foramen (1).
Brazeau (2009, Character 63), Davis *et al.* (2012, Character 60), and references therein.

61. Endoskeletal intracranial joint: absent (0); present (1).
Friedman (2007, Character 86), Brazeau (2009, Character 64), Zhu *et al.* (2009, Character 42), Friedman & Brazeau (2010, Character 28), Davis *et al.* (2012, Character 61), and references therein.

62. Spiracular groove on basicranial surface: absent (0); present (1).
Brazeau (2009, Character 65), Friedman & Brazeau (2010, Character 3), Davis *et al.* (2012, Character 62), and references therein.

63. Spiracular groove on lateral commissure: absent (0); present (1).
Davis *et al.* (2012, Character 63).

64. Subpituitary fenestra: absent (0); present (1).
Brazeau (2009, Character 66), Davis *et al.* (2012, Character 64), and references therein.

65. Supraorbital shelf broad with convex lateral margin: absent (0); present (1).
Coates & Sequeira (1998, Character 17), Brazeau (2009, Character 67), Davis *et al.* (2012, Character 65).

66. Orbit dorsal or facing dorsolaterally, surrounded laterally by endocranium: present (0); absent (1).
Brazeau (2009, Character 68), Davis *et al.* (2012, Character 66).

67. Extended prehypophysial portion of sphenoid: absent (0); present (1).
Brazeau (2009, Character 69), Davis *et al.* (2012, Character 67).

68. Narrow interorbital septum: absent (0); present (1).

Friedman (2007, Character 174), Brazeau (2009, Character 70), Zhu *et al.* (2009, Character 32), Friedman & Brazeau (2010, Character 39), Davis *et al.* (2012, Character 68)
Guiyu is coded as "0" (Zhu *et al.* 2009, Qiao & Zhu 2010).

69. The main trunk of facial nerve (N. VII): elongate and passes anterolaterally through orbital floor (0); stout, divides within otic capsule at the level of the postorbital process (1).
Brazeau (2009, Character 71), Davis *et al.* (2012, Character 69).

70. Hyoid ramus of facial nerve (N. VII) exits through posterior jugular opening: absent (0); present (1).
Friedman (2007, Character 179), Brazeau (2009, Character 72), Zhu *et al.* (2009, Character 47), Friedman & Brazeau (2010, Character 9), Davis *et al.* (2012, Character 70).

71. Glossopharyngeal nerve (N. IX) exit: foramen situated posteroventral to otic capsule and anterior to metotic fissure (0); through metotic fissure (1).
Brazeau (2009, Character 73), Davis *et al.* (2012, Character 71).

72. Short otico-occipital region of braincase: absent (0); present (1).
Brazeau (2009, Character 74), Davis *et al.* (2012, Character 72).

73. Ethmoid region elongate with dorsoventrally deep lateral walls: absent (0); present (1).
Davis *et al.* (2012, Character 73).

74. Basicranial morphology: platybasic (0); tropibasic (1).
Brazeau (2009, Character 75), Friedman & Brazeau (2010, Character 1), Davis *et al.* (2012, Character 74).

75. Ascending basisphenoid pillar pierced by common internal carotid: absent (0); present (1).
Brazeau (2009, Character 76), Davis *et al.* (2012, Character 75), and references therein.

76. Jugular vein: invested in otic capsule wall posterior to the postorbital process (0); lateral wall of jugular canal incomplete or absent (1).
Brazeau (2009, Character 77), Davis *et al.* (2012, Character 76).

77. Canal for lateral dorsal aorta within basicranial cartilage: absent (0); present (1).
Friedman (2007, Character 183), Brazeau (2009, Character 78), Zhu *et al.* (2009, Character 51), Davis *et al.* (2012, Character 77).

78. Entrance of internal carotids: through separate openings flanking the hypophyseal opening or recess (0); through a common opening at the midline of the basicranium (1).
Brazeau (2009, Character 79), Davis *et al.* (2012, Character 78).
Porolepis was coded as "1" by Brazeau (2009) or "?" by Davis *et al.* (2012). As shown in Jarvik (1972, pl. 7-1), the condition for the internal carotid entrances in *Porolepis* is the same as that in *Glyptolepis* (1972, fig. 92A), where two separate openings are present for the entrances of internal carotids. The similar condition is also present in *Youngolepis* (Chang 1982). Thus, we code the *Porolepis*, as well as *Psarolepis* and *Guiyu*, as "0". The coding for *Onychodus* is based on Andrews *et al.* (2006, fig.55).

79. Canal for efferent pseudobranchial artery within basicranial cartilage: absent (0); present (1).
Brazeau (2009, Character 80), Davis *et al.* (2012, Character 79).

80. Position of basal/basipterygoid articulation: same anteroposterior level as hypophysial opening (0); anterior to hypophysial opening (1).
Brazeau (2009, Character 81), Davis *et al.* (2012, Character 80).

81. Postorbital process articulates with palatoquadrate: absent (0); present (1).
Davis *et al.* (2012, Character 81), and references therein.

82. Labyrinth cavity separated from the main neurocranial cavity by a cartilaginous or ossified capsular wall (0); skeletal capsular wall absent (1).
Davis *et al.* (2012, Character 82).
Austroptyctodus was coded as "?" as we consider that the presence or absence of a capular wall, either cartilaginous or ossified, in this taxon (Davis *et al*. 2012) is not definitive based on available fossil data (e.g. Trinajstic *et al*. 2012).

83. Basipterygoid process (basal articulation) with vertically oriented component: absent (0); present (1).
Davis *et al.* (2012, Character 83).

84. Pituitary vein canal dorsal to level of basipterygoid process (0); flanked posteriorly by basipterygoid process (1).
Davis *et al.* (2012, Character 84).

85. External (horizontal) semicircular canal: absent (0); present (1).
Davis *et al.* (2012, Character 85).

86. Sinus superior: absent or indistinguishable from union of anterior and posterior canals with saccular chamber (0); present (1).
Davis *et al.* (2012, Character 86).

87. External (horizontal) semicircular canal: joins the vestibular region dorsal to posterior ampulla (0); joins the vestibular region levelling with posterior ampulla (1).
    Davis *et al.* (2012, Character 87).

88. Trigemino-facial recess: absent (0); present (1).
    Davis *et al.* (2012, Character 88).

89. Posterior dorsal fontanelle: absent (0); present (1).
    Brazeau (2009, Character 85), Davis *et al.* (2012, Character 89), and references therein.

90. Shape of posterior dorsal fontanelle: approximately as long as broad (0); much longer than wide, slot-shaped (1).
    Coates & Sequeira (1998, Character 10), Brazeau (2009, Character 86), Davis *et al.* (2012, Character 90).

91. Dorsal ridge: absent (0); present (1).
    Davis *et al.* (2012, Character 91), and references therein.

92. Endolymphatic ducts: posteriodorsally angled tubes (0); tubes oriented vertically through median endolymphatic fossa (1).
    Brazeau (2009, Character 87), Davis *et al.* (2012, Character 92), and references therein.
    Cowralepis is coded as "0" based on Ritchie (2005: fig. 7F, G).

93. Lateral otic process: absent (0); present (1).
    Brazeau (2009, Character 88), Davis *et al.* (2012, Character 93), and references therein.

94. Process forming part or complete wall of jugular groove or canal projecting from otic capsule wall: absent (0); present (1).
    Davis *et al.* (2012, Character 94).

95. Position of hyomandibula articulation on neurocranium: below or anterior to orbit, on ventrolateral angle of braincase (0); posterior to orbit (1).
    Brazeau (2009, Character 89), Friedman & Brazeau (2010), Davis *et al.* (2012, Character 95).

96. Ventral cranial fissure: absent (0); present (1).
    Brazeau (2009, Character 92), Davis *et al.* (2012, Character 96), and references therein.

97. Metotic (otico-occipital) fissure: absent (0); present (1).
    Brazeau (2009, Character 93), Davis *et al.* (2012, Character 97), and references therein.

98. Vestibular fontanelle: absent (0); present (1).
    Brazeau (2009, Character 96), Zhu *et al.* (2009, Character 48), Friedman & Brazeau (2010, Character 5), Davis *et al.* (2012, Character 98).

99. Occipital arch wedged in between otic capsules: absent (0); present (1).
    Brazeau (2009, Character 94), Davis *et al.* (2012, Character 99), and references therein.

100. Spino-occipital nerve foramina: two or more, aligned horizontally (0); one or two, aligned dorsoventrally (1).
    Brazeau (2009, Character 95), Davis *et al.* (2012, Character 100), and references therein.

101. Ventral notch between parachordals: absent (0); present or entirely unfused (1).
    Brazeau (2009, Character 97), Davis *et al.* (2012, Character 101).

102. Parachordal shape: broad, flat (0); keeled with sloping lateral margins (1).
    Brazeau (2009, Character 98), Davis *et al.* (2012, Character 102), and references therein.

103. Hypotic lamina (and dorsally directed glossopharyngeal canal): absent (0); present (1).
    Davis *et al.* (2012, Character 103), and references therein.

104. Macromeric dermal shoulder girdle: present (0); absent (1).
    Brazeau (2009, Character 99), Friedman & Brazeau (2010, Character 20), Davis *et al.* (2012, Character 104).

105. Dermal shoulder girdle composition: ventral and dorsal (scapular) components (0); ventral components only (1).
    Brazeau (2009, Character 100), Davis *et al.* (2012, Character 105).

106. Dermal shoulder girdle forming a complete ring around the trunk: present (0); absent (1).
    Brazeau (2009, Character 101), Davis *et al.* (2012, Character 106), and references therein.

107. Pectoral fenestra completely encircled by dermal shoulder armour: present (0); absent (1).
    Brazeau (2009, Character 102), Davis *et al.* (2012, Character 107).

Macropetalichthys, *Psarolepis* and *Guiyu* are coded as "1".

108. Median dorsal plate: absent (0); present (1).
Brazeau (2009, Character 103), Davis *et al.* (2012, Character 108).

109. Pronounced internal crista ('keel') on median dorsal surface of shoulder girdle: absent (0); present (1).
Brazeau (2009, Character 104), Davis *et al.* (2012, Character 109).

110. Scapular process of endoskeletal shoulder girdle: absent (0); present (1).
Brazeau (2009, Character 105), Davis *et al.* (2012, Character 110), and references therein.

111. Ventral margin of separate scapular ossification: horizontal (0); deeply angled (1).
Brazeau (2009, Character 107), Davis *et al.* (2012, Character 111), and references therein.

112. Cross-sectional shape of scapular process: flattened or strongly ovate (0); subcircular (1).
Brazeau (2009, Character 108), Davis *et al.* (2012, Character 112), and references therein.

113. Flange on trailing edge of scapulocoracoid: absent (0); present (1).
Brazeau (2009, Character 109), Davis *et al.* (2012, Character 113), and references therein.

114. Scapular process with posterodorsal angle. Absent (0); present (1).
Davis *et al.* (2012, Character 114), and references therein.

115. Endoskeletal postbranchial lamina on scapular process: present (0); absent (1).
Brazeau (2009, Character 110), Davis *et al.* (2012, Character 115).

116. Mineralisation of internal surface of scapular blade: mineralised all around (0); unmineralised on internal face forming a hemicylindrical cross-section.
Brazeau (2009, Character 111), Davis *et al.* (2012, Character 116).

117. Coracoid process: absent (0); present (1).
Brazeau (2009, Character 112), Davis *et al.* (2012, Character 117)

118. Procoracoid mineralisation: absent (0); present (1).
Davis (2002), Hanke & Wilson (2004), Brazeau (2009).

119. Fin base articulation on scapulocoracoid: stenobasal (0); eurybasal (1).
Brazeau (2009, Character 113), Davis *et al.* (2012, Character 119), and references

therein.
Psarolepis and *Achoania* are coded "1" (Zhu & Yu 2009). *Guiyu* (Zhu *et al*. 2009) is changed from "0" to "?".

120. Perforate propterygium: absent (0); present (1).
Brazeau (2009, Character 110), Friedman & Brazeau (2010, Character 41), Davis *et al.* (2012, Character 120), and references therein.

121. Pelvic fins: absent (0); present (1).
Brazeau (2009, Character 117), Davis *et al.* (2012, Character 121).

122. Pelvic claspers: absent (0); present (1).
Brazeau (2009, Character 119), Davis *et al.* (2012, Character 122).

123. Dermal pelvic clasper ossifications: absent (0); present (1).
Brazeau (2009, Character 118), Davis *et al.* (2012, Character 123).
Considering abundant complete specimens of *Cowralepis* lacking any record of dermal pelvic clasper ossifications (Ritchie, 2005), *Cowralepis* is changed from "?" to "0" as in *Coccosteus*.

124. Pectoral fins covered in macromeric dermal armour: absent (0); present (1).
Brazeau (2009, Character 120), Davis *et al.* (2012, Character 124).

125. Pectoral fin base has large, hemispherical dermal component: absent (0); present (1).
Brazeau (2009, Character 121), Davis *et al.* (2012, Character 125).

126. Dorsal fin spines: absent (0); present (1).
Brazeau (2009, Character 123), Davis *et al.* (2012, Character 126), and references therein.
Dialipina is coded "0" based on Schultze & Cumbaa (2001). *Cowalepis* is coded "0" (Ritchie, 2005) as in *Dicksonosteus*, *Buchanosteus* and *Coccosteus*.

127. Anal fin spine: absent (0); present (1).
Brazeau (2009, Character 124), Davis *et al.* (2012, Character 127), and references therein.

128. Paired fin spines: absent (0); present (1).
Brazeau (2009, Character 125), Davis *et al.* (2012, Character 128).
We restrict this character to pectoral fin spines, and treat pelvic fin spines as a separate character (see Character 165). Galeaspids is changed from "0" to "-" (unavailability).

129. Median fin spine insertion: shallow, not greatly deeper than dermal bones/ scales

(0); deep (1).
Brazeau (2009, Character 126), Davis *et al.* (2012, Character 129), and references therein.

130. Intermediate fin spines: absent (0); present (1).
Brazeau (2009, Character 127), Davis *et al.* (2012, Character 130), and references therein.

131. Prepectoral fin spines: absent (0); present (1).
Brazeau (2009, Character 128), Davis *et al.* (2012, Character 131), and references therein.

132. Fin spines with ridges: absent (0); present (1).
Brazeau (2009, Character 129), Davis *et al.* (2012, Character 132), and references therein.

133. Fin spines with nodes: absent (0); present (1).
Brazeau (2009, Character 130), Davis *et al.* (2012, Character 133), and references therein.

134. Fin spines with rows of large retrorse denticles: absent (0); present (1).
Davis *et al.* (2012, Character 134).

135. Synarcual: absent (0); present (1).
Brazeau (2009, Character 132), Davis *et al.* (2012, Character 135).

136. Number of dorsal fins, if present: one (0); two (1).
Brazeau (2009, Character 133), Zhu *et al.* (2009, Character 132), Davis *et al.* (2012, Character 136), and references therein.
The coding of *Guiyu* is changed from “0” to “1” (Zhu *et al.* 2012b).

137. Anal fin: absent (0); present (1).
Brazeau (2009, Character 134), Davis *et al.* (2012, Character 137).

138. Caudal radials extend beyond level of body wall and deep into hypochordal lobe (0); radials restricted to axial lobe (1).
Davis *et al.* (2012, Character 138).

Newly added characters

Skeletal Tissues

139. Resorption and redeposition of odontodes: lacking or partially developed (0); developed (1).
Zhu *et al.* (2009, Character 148), and references therein.

140. Acrodin: absent (0); present (1).
Zhu *et al.* (2009, Character 151), Friedman & Brazeau (2010, Character 46), and references therein.

141. Plicidentine: absent (0); simple or generalized polyplacodont (1).
Zhu *et al.* (2009, Character 152), and references therein.

142. Rostral tubuli: absent (0); present (1).
Zhu *et al.* (2009, Character 150), and references therein.

Dermal Skeleton: scales and fins

143. Peg on rhomboid scale: narrow (0); broad (1).
Zhu *et al.* (2009, Character 139), and references therein.

144. Anterodorsal process on scale: absent (0); present (1).
Zhu *et al.* (2009, Character 140), and references therein.

145. Fringing fulcra: absent (0); present (1).
Zhu *et al.* (2009, Character 143), and references therein. Taxa without lepidotrichia are coded as 'logical impossibility'.

146. Epichordal lepidotrichia in caudal fin: absent (0); present (1).
Zhu *et al.* (2009, Character 142), and references therein.

Dermal Skeleton: skull

147. Dermal intracranial joint: absent (0); present (1).
Zhu *et al.* (2009, Character 21)

148. Large unpaired median skull roofing bone anterior to the level of nasal capsules: absent (0); present (1).
The bone refers to the premedian plate in placoderms (antiarchs, acanthothoracids). We follow Young (1980), and Goujet & Young (1995) in acknowledging the presence of the premedian plate in *Brindabellaspis*.

149. Number of nasals: many (0); one or two (1).
Zhu *et al.* (2009, Character 4), and references therein.

150. Mesial margin of nasal: not notched (0); notched (1).
Zhu *et al.* (2009, Character 3), and references therein.
The condition in placoderms is coded 'unavailability', although the 'postnasal plate' is likely to be equivalent of the nasal in osteichthyans.

151. Dermintermedial process: absent (0); present (1).
Zhu *et al.* (2009, Character 6), and references therein.

152. Posterior nostril: associated with orbit (0); not associated with orbit (1).
Zhu *et al.* (2009, Character 8), and references therein.

153. Position of posterior nostril: external, far from jaw margin (0); external, close to jaw margin (1).
Zhu *et al.* (2009, Character 7), and references therein.

154. Supraorbital (sensu Cloutier & Ahlberg 1996, including posterior tectal of Jarvik): absent (0); present (1).
Zhu *et al.* (2009, Character 10), and references therein.

155. Supraorbital, preorbital and nasal: unfused (0); fused (1).
Zhu *et al.* (2009, Character 11), and references therein.

156. Tectal (sensu Cloutier & Ahlberg 1996, not counting the 'posterior tectal' of Jarvik): absent (0); present (1).
Zhu *et al.* (2009, Character 15), and references therein.

157. Lateral plates: absent (0); present (1).
By lateral plates, we refer to the paired bones lateral to the premedian, the nuchal and the orbital fenestra in antiarch placoderms.

158. Location of pineal foramen/eminence: level with posterior margin of orbits (0); well posterior of orbits (1).
Zhu *et al.* (2009, Character 19), and references therein.

159. Parietals (preorbitals of placoderms) surround pineal foramen/eminence: yes (0); no (1).
Zhu *et al.* (2009, Character 20), and references therein.

160. Complete enclosure of spiracle by skull-roof bones: absent (0); present (1).
Zhu *et al.* (2009, Character 25), and references therein.

161. Number of marginal bones alongside paired median skull roofing bones over the otico-occipital division of braincase: single (0); two or more (1).
Zhu *et al.* (2009, Character 27), and references therein. These marginal bones generally bear main lateral-line canals or grooves.

162. Number of paranuchals: one pair (0), two pairs (1).
As this character is mainly used for placoderms, the codings for osteichthyan taxa are based on the topological equivalents of paranuchals (lateral extrascapular as posterior paranuchal, and tabular as anterior paranuchals, Supplementary Table 1).

163. Large unpaired median bone contributing to posterior margin of skull roof: absent (0); present (1).
In placoderms, this bone is termed the nuchal or centronuchal plate. The large unpaired median bone at the posterior half of skull roof in *Austroptyctodus* and *Campbellodus* is termed 'postpineal' (Denison 1978, 1984) or 'nuchal' (Long, 1995). In these two genera, the posterior edge of this unpaired median bone is far in front of the posterior margin of neighboring flanked bones. Comparison to the skull roof of other placoderms reveals that this unpaired median bone in *Austroptyctodus* and *Campbellodus* is more reasonably termed 'postpineal'. As the 'nuchal plate' in *Rhamphodopsis* (Miles 1967) is not discernible in any specimen photo, we code *Rhamphodopsis* as "?". The codings for osteichthyan taxa are based on the topological equivalents of nuchal (median extrascapular, Supplementary Table 1).

164. Contact of nuchal or centronuchal plate with paired preorbital plates: absent (0), present (1).
This character is inapplicable in antiarchs, *Austroptyctodus*, *Campbellodus* and other taxa without nuchal or centronuchal plate.

165. Posterior process of the paranuchal plate behind the nuchal plate (dorsal face): absent (0), present (1).
This is a character shared by phyllolepids and phlyctaeniids (Dupret 2004, Dupret & Zhu 2008).

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

167. Number of extrascapulars: uneven (0); paired (1).
Zhu *et al.* (2009, Character 29), and references therein.

168. Dermal neck-joint between paired main-lateral-line-bearing bones of skull and shoulder girdle: absent (0); present (1).
Young (2010, Character 15). The dermal neck-joint in placoderms is localized between anterior dorsolateral and paranuchual plates, through which the main lateral line runs.

169. Type of dermal neck-joint: sliding, dermal shoulder girdle plate with flat articluar flange (0); ginglymoid, dermal shoulder girdle plate with articular condyle or fossa (1)

170. Number of sclerotic plates: four or less (0); more than four (1).
Zhu *et al.* (2009, Character 57), and references therein.

171. Foramina (similar to infradentary foramina) on cheek bones: absent (0); present (1).
Zhu *et al.* (2009, Character 56), and references therein.

172. Lacrimal posteriorly enclosing posterior nostril: absent (0); present (1).
Zhu *et al.* (2009, Character 58), and references therein.

173 Most posterior major bone of cheek bearing preopercular canal ("preopercular") extending forward, close to orbit: absent (0); present (1).
Zhu *et al.* (2009, Character 59), and references therein.

174. Number of cheek bones bearing preopercular canal posterior to jugal: one (0); two (1).
Zhu *et al.* (2009, Character 60), and references therein.

175. Bone bearing both quadratojugal pit-line and preopercular canal: absent (0); present (1).
Zhu *et al.* (2009, Character 61), and references therein.

176. Dermohyal: absent (0); present (1).
Zhu *et al.* (2009, Character 62), and references therein.

177. Premaxillae with inturned symphysial processes: absent (0); present (1).
Zhu *et al.* (2009, Character 76), and references therein.

178. Premaxilla forming part of orbit: absent (0); present (1).
Zhu *et al.* (2009, Character 77), and references therein.

179. Preorbital process of premaxilla: absent (0); present (1).
Zhu *et al.* (2009, Character 78), and references therein.

180. Posterior expansion of maxilla (maxilla cleaver-shaped): present (0); absent (1).
Zhu *et al.* (2009, Character 79), and references therein.

181. Ventral margin of maxilla: straight (0), curved (1).
Zhu *et al.* (2009, Character 80), and references therein.

182. Contribution by maxilla to posterior margin of cheek: present (0); absent (1).
Zhu *et al.* (2009, Character 81), and references therein.

183. Course of ethmoid commissure: middle portion through median rostral (0); sutural course (1); through bone center of premaxillary (2).
Zhu *et al.* (2009, Character 105), and references therein.

184. Position of anterior pit-line: on paired median skull roofing bones over the otico-occipital division of braincase (0); on paired median skull roofing bones over the sphenoid division of braincase (1).
Zhu *et al.* (2009, Character 106), and references therein.

185. Middle and posterior pit-lines on postparietal: posteriorly situated (0), mesially situated (1).
Zhu *et al.* (2009, Character 107), and references therein.

186. Position of middle and posterior pit-lines: close to midline (0); near the central portion of each postparietal (1).
Zhu *et al.* (2009, Character 108), and references therein.

187. Course of supraorbital canal: between anterior and posterior nostrils (0); anterior to both nostrils (1).
Zhu *et al.* (2009, Character 109), and references therein.

188. Course of supraorbital canal: straight (0); lyre-shaped (1).
Zhu *et al.* (2009, Character 110), and references therein.

189. Posterior end of supraorbital canal: in postparietal (0); in parietal (1); in intertemporal (2).
Zhu *et al.* (2009, Character 111), and references therein.

190. Contact between otic and supraorbital canals: not in contact (0); in contact (1).
Zhu *et al.* (2009, Character 112), and references therein.

191. Contact of supraorbital and infraorbital canals: in contact rostrally (0); not in contact rostrally (1).
Zhu *et al.* (2009, Character 113), and references therein.

192. Otic canal: not close to margin of skull roof (0); along or close to lateral margin of skull roof (1).
Zhu *et al.* (2009, Character 114), and references therein.

193. Infraorbital canal follows premaxillary suture: no (0); yes (1).
Zhu *et al.* (2009, Character 115), and references therein.

194. Sensory canal or pit-line associated with maxilla: absent (0); present (1).
Zhu *et al.* (2009, Character 116), and references therein.

195. Anterior portion of preopercular canal: present (0); absent (1).
Zhu *et al.* (2009, Character 118), and references therein.

Dermal Skeleton: operculogular series

196. Median gular: present (0); absent (1).
Zhu *et al.* (2009, Character 102), and references therein.

Branchial skeleton

197. Foramen in hyomandibular: absent (0); present (1).
Zhu *et al.* (2009, Character 100), and references therein.

Dentition and mandibular arch

198. Large dermal plates forming outer dental arcade: only with denticles (0), with a monolinear series of large, shedding teeth (1)
Zhu *et al.* (2009, Character 74), and references therein.
Here "large dermal plates forming outer dental arcade" refer to the premaxillary, maxillary, and dentary bones. A monolinear series of large, shedding teeth that lie mesial to smaller denticles is present in the premaxillary, maxillary, and dentary bones of actinopterygians and sarcopterygians (Botella et al. 2007, Friedman & Brazeau 2010).

199. Tooth-bearing median rostral: absent (0); present (1).
Zhu *et al.* (2009, Character 75), and references therein.

200. Teeth of dentary: reaching anterior end of dentary (0); not reaching anterior end (1).
Zhu *et al.* (2009, Character 87), and references therein.

201. Number of coronoids (*sensu lato*, including parasymphysial dental plate but excluding parasymphysial tooth whorl): more than three (0); three (1).
Lu *et al.* (2012, Character 145).

202. Fangs of coronoids (*sensu stricto*): absent (0); present (1).
Zhu *et al.* (2009, Character 94), and references therein.

203. Marginal denticle band on coronoids: broad band, at least posteriorly (0); narrow band with 2-4 denticle rows (1).
Zhu *et al.* (2009, Character 95), and references therein.

204. Infradentary bones: absent (0), present (1).

205. Infradentary foramina: always present (0); variable (1); always absent (2).
Zhu *et al.* (2009, Character 85), and references therein.

206. Large ventromesially directed flange of symphysial region of mandible: absent (0); present (1).
Zhu *et al.* (2009, Character 83), and references therein.

207. Flange-like extension composed of Meckelian ossification and prearticular that reaches below ventral margin of infradentaries: absent (0), present (1).
Zhu *et al.* (2009, Character 84), and references therein.

208. Strong ascending flexion of symphysial region of mandible: absent (0); present (1).
Zhu *et al.* (2009, Character 82), and references therein.

209. Parasymphysial plate: detachable tooth whorl (0); long with posterior corner, sutured to coronoid, denticulated or with tooth row (1); absent (2).
Zhu *et al.* (2009, Character 91), and references therein.

210. Anterior end of prearticular: far from jaw symphysis (0); near jaw symphysis (1).
Zhu *et al.* (2009, Character 96), and references therein.

211. Prearticular-dentary contact: present (0); absent (1).
Zhu *et al.* (2009, Character 98), and references therein.

212. Meckelian bone exposed immediately anterior to first coronoid: yes (0); no (1).
Zhu *et al.* (2009, Character 99), and references therein.

213. Dermal plates on mesial (lingual) surfaces of Meckel's cartilage and palatoquadrate: absent (0); present (1).
We refer the prearticular and entopterygoid in osteichthyans to these plates.

214. Biconcave glenoid on lower jaw: absent (0); present (1).
Friedman & Brazeau (2010, Character 17).

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

216. Metapterygoid with developed mesial ventral protrusion (i.e. commissural lamina *sensu stricto*): absent (0); present (1).
Here we define the commissural lamina *sensu stricto* as a structure of the metapterygoid. The mesial ventral protrusion is known in the metapterygoid in *Buchanosteus* (Young 1979), the protrusion in *Buchanosteus* is less developed than the condition in *Entelognathus* and crown gnathostomes, where the ventral margin of mesial protrusion is about the same level as the ventral margins of the quadrate and the autopalatine.

217. Course of mandibular canal: not passing through most posterior infradentary (0); passing through most posterior infradentary (1).

Zhu *et al.* (2009, Character 119), and references therein.

218. Course of mandibular canal: passing through dentary (0); not passing through dentary (1).
Zhu *et al.* (2009, Character 120), and references therein.

Neurocranium and palate

219. Internasal pits: absent (0); undifferentiated or anterior palatal fossa (1); shallow, paired pits with strong midline ridge (2); deep, pear-shaped pits (3).
Zhu *et al.* (2009, Character 33), and references therein.

220. Fenestra ventrolateralis: absent (0); present (1); common ventral fenestra for anterior and posterior nostrils (2).
Zhu *et al.* (2009, Character 34), and references therein.

221. Ethmoid articulation for palatoquadrate: placed on postnasal wall (0); extends posteriorly to the level of optic nerve (N.II) (1).
Zhu *et al.* (2009, Character 35), and references therein.

222. Eye stalk or unfinished area on neurocranial wall for eye stalk: absent (0); present (1).
Zhu *et al.* (2009, Character 36), and references therein.

223. Developed postorbital cavity: absent (0); present (1).

224. Postorbital pila ascending from basipterygoid process to postorbital process: absent (0); present (1).
Zhu *et al.* (2009, Character 37), and references therein.
The postorbital pila ascending from the basipterygoid process to the postorbital process (i.e., the posterodorsal process in Yu 1998) is found in *Psarolepis* (Yu 1998), *Achoania* (Zhu *et al.* 2001), *Guiyu* (Zhu *et al.* 2009, Qiao & Zhu 2010) and *Styloichthys* (Zhu & Yu 2002). The space between the lateral cranial wall and the medial surface of the pila probably houses the jugular vein (Yu 1998), like that through the lateral commissure in the otico-occipital portion of the crown sarcopterygian neurocranium (Jarvik 1980).

225. Unconstricted cranial notochord: absent (0); present (1).
Zhu *et al.* (2009, Character 40), and references therein.

226. Descending process of sphenoid (with its posterior extremity lacking periosteal lining): absent (0); present (1).
Zhu *et al.* (2009, Character 41), and references therein.

227. Articulation facet with hyomandibular: single-headed (0), double-headed (1).

Zhu *et al.* (2009, Character 44) and references therein.

228. Hyoid arch articulation: on lateral commissure (0); on otic capsule wall (1).
Brazeau (2009, Character 90), Zhu *et al.* (2009, Character 45), and references therein, Friedman & Brazeau (2010, Character 8).
The lateral commissure in *Ligulalepis* (Supplementery Fig. 9c, d) is much larger than previously assigned (Basden *et al.* 2000), and its posterior portion lies posteroventral to the spiracular groove. The ventral view (Basden *et al.* 2000, fig.1d) shows clearly that the lateral commissure lies anterior to the otic capsule. Consequently, we code "0" for *Ligulalepis* (contra Brazeau 2009) because its hyomandibular facet lies on the lateral commissure, and not on the otic capsule. In placoderms, the lateral commissure is represented by the anterior postorbital process, which bears the hyoid articulation facet and the path for the jugular vein (Goujet 1984) as in *Psarolepis*, *Achoania*, *Guiyu* and crown sarcopterygians.

229. Opercular suspension on braincase: absent (0); present (1).
Brazeau (2009, Character 91).

230. Posterior postorbital process: absent (0); present (1).
Young (1980, figs 24-26).

231. Basicranial fenestra: absent (0); present (1).
Zhu *et al.* (2009, Character 52), and references therein.

232. Otical process (an outgrowth from the lateral wall of the braincase penetrated by the branches of the r. oticus lateralis): absent (0); present (1).
Zhu *et al.* (2009, Character 53), and references therein.

233. Lateral cranial canal: absent (0); present (1).
Zhu *et al.* (2009, Character 55), and references therein. For discussion of the lateral cranial canal, see Zhu *et al.* (2010).

234. Midline canal in basicranium for dorsal aorta: absent (0); present (1).
Friedman & Brazeau (2010, Character 38).

235. Vomerine fangs: absent (0); present (1).
Zhu *et al.* (2009, Character 63), and references therein.

236. Vomeral area with grooves and raised areas: absent (0); present (1).
Zhu *et al.* (2009, Character 64), and references therein.

237. Parasphenoid: protruding forward into ethmoid region of endocranium (0); behind ethmoid region (1).
Zhu *et al.* (2009, Character 65), and references therein.

238. Denticulated field of parasphenoid: without spiracular groove (0); with spiracular groove (1).
Friedman (2007, Character 82), Zhu *et al.* (2009, Character 66), and references therein.

239. Ascending process of parasphenoid: absent (0); present (1).
Zhu *et al.* (2009, Character 67), and references therein.

240. Shape of parasphenoid denticulated field: broad rhomboid or lozenge-shaped (0); broad, splint-shaped (1); slender, splint-shaped (2).
Friedman (2007, Character 168), Zhu *et al.* (2009, Character 68), and references therein.

241. Parasphenoid denticulated field with multifid anterior margin: absent (0); present (1).
Friedman (2007, Character 167), Zhu *et al.* (2009, Character 69), and references therein.

242. Parasphenoid denticle field with anteriorly divergent lateral margins: absent (0); present (1).
Zhu *et al.* (2009, Character 70), and references therein.

243. Parasphenoid denticle field: terminates at or anterior to level of foramina for internal carotid arteries (0); extends posterior to foramina for internal carotid arteries (1).
Zhu *et al.* (2009, Character 71), and references therein.

Paired fins and girdles

244. Presupracleithrum: absent (0); present (1).
Zhu *et al.* (2009, Character 121), and references therein.

245. Anocleithrum: element developed as postcleithrum (0); element developed as anocleithrum *sensu stricto* (1).
Zhu *et al.* (2009, Character 122), and references therein.

246. Dorsal cleithrum (AL of the Placodermi), ventral cleithrum (AVL of the Placodermi) and pectoral spine (SP of the Placodermi): not fused (0); fused (1).
Zhu *et al.* (2009, Character 123), and references therein.

247. Relationship of clavicle to cleithrum: ascending process of clavicle overlapping cleithrum laterally (0); ascending process of clavicle wrapping round anterior edge of cleithrum, overlapping it both laterally and mesially (1).
Zhu *et al.* (2009, Character 126), and references therein.

248. Triradiate scapulocoracoid: absent (0); present (1).
Zhu *et al.* (2009, Character 128), and references therein.

249. Subscapular foramen/fossa: absent (0); present (1).
Zhu *et al.* (2009, Character 129), and references therein.

250. Endoskeletal support in pectoral fin: multiple elements articulating with girdle (0); single element ("humerus") articulating with girdle (1).
Zhu *et al.* (2009, Character 130), and references therein.

251. Pectoral propterygium: absent (0); present (1).
Zhu *et al.* (2009, Character 131), and references therein.

252. Pelvic girdle with substantial dermal component: yes (0); no (1).
Zhu *et al.* (2012b).

Fin spines

253. Pelvic fin spine: absent (0); present (1).

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5) Data matrix with 253 morphological characters for 75 taxa. ? = unavailable character; - = logical impossibility. Data are interleaved to facilitate copying and pasting into NEXUS format. Characters 1-138 are adopted from Davis *et al.* (2012). We made minor revisions on character formulations or codings for 29 of these characters, which appear underlined and boldfaced in the data matrix.

Acanthodes
000120011001011-0110-?-0?00----10-0-1?0----0011101010?01?1??010?0111?011011
1010011001101101001111?001101---0-1010010110010000111100100000100???-------
--?-----?-------?---1----------------????0---0-0------0-?-0?---00-1--?????0?001?00??0----
---------?00111
Achoania
001121?????????1?0-????10??????????????1?1?11??????0?011010?1??00100???1???
??0??????????????????1???????00?1???????????1????????1???????????0?0????1???1
10???01?????????????0????100???????1010???1???1110??10101011011????3011011
1?????????010?0010??????01??
Akmonistion
10012010?0-??21-?1?1---**-**-00----10-0-?01110-0011?000?0101010?01001110101100?
111?11?001??110111010100?0011---0-1-0011011101100010010000000000?0??--------
-?-----?-------?---?----------------?????---?-0------0-?-??---0?-1--020?0????1?00?00------
-------??01?0
Austroptyctodus
0001?0?1?01010?1?0-**?**1-001-0----0110-0010-01100**?**???000?01010?0????101???????
?0????**?**?????????????0???0??000001101-00000100?111001010?000011??????--??00??
???0-00?10100--1-11?------------?-???0???0----?------0---??---0??0--??????????1??????
????????0?0???????
Bothriolepis
0**0**00-0-?--?--?10?0-000010-0----0100-???---?10000??00??**?**0?0???????0?????00?????
???0?????????????0????????000010?????1--00-0--11000-00---000?????----?1???0?0-0
10-0101-0?-11?0-???0------?-???????0----?------0---02---0?00--?0????????????????????
????0?0????0--
Brachyacanthus
000??00??????10??100??-0?11000000-0-????---00??????????1?1???????????????????
??????????????????????????01-10-1010010?0??1?0001110111100011?????--??-----?--
---?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??-
-----?????1
Brindabellaspis
0001**1**0?100010????0-?000?1-?????010???????????????????0?010000000000000-00
000100?00??10000-00010000-0?0000????1-0001010??????0??1??0-?-???????0--??0
1???0?0-00010111100-11??-???????????-???0?000--?????????????????-????--02?100?
???11??00??????????????0?????
Brochoadmones

0101000100?111100110??-0?00----10-0-??1100-00??????????1?1??????????????????
??????????????????????????1---0-??????-?-??1000011111110011?????--??-----?-----?
-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??-----
-??????

Buchanosteus

00?1?0?100010??0?0-001111-0----0110-??1--0?100**1**0??0?001101000001010010-000
00000?00??1000???0011000-0100000011?0?--1?1???????00?1??000-???????0--??00?
????0-00010101011-11??-????------?-???????0----?------0---02---0000--02??10000011
00000010000010?00??????

Campbellodus

000??011?01010?1?0-**?**1-001-**0**----01**0**0-0010-01100**?**0??000?0????????????????????
??????????????????0????????000110???--1-?0??111001010?00-01?01????----?0?????
0-00?10100--1-11?------------?-???0???0----?------0---??---00-0--??????????1?????????
?????0?0?????0?

Cassidiceps

000??00??00101?0?10???-???111?100-0-??0----0???????????1?1??????????????????
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-?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??---
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Cheiracanthus

000120011001010-?111??-**-**?01111100-0-??0----0011001010?01?1?????????????????
???01??????????????????????1---0-1110010?1??10000111100100001?????--??-----?-
----?-------?---1--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
------?????1

Cheirolepis

000120010101012110-01-110-1100101011??10-001111?10000?11?10??????11????1
0????0?0??00???????????1???????00110-?????1???1010000000-00---001?000?--11?
0100101000011010--?10-00010010{01}00002?0?0000100100010000011000200?111
100?0??????0??????10?000101?{01}0101?0110

Chondrenchelys

11012010?00??-1-?1?1---**-**-00----00-0-??1100-0011?00011001110?0?000110??-111??
0?????????????0?00110?0?0011---0-1-00110100-11000000-00---000?????--??-----?--
---?-------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
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Cladodoides

110?????????????-????---?-?????????????111?-0011?00???1010???000001101010000
11111110011011111?0101010001???????????????????????????????????????--??-----?
-----?-------?---?--?--????-------?????---??????---0-?-???--0?-1--02?100???1?0??00---?-?
?--?---??????

Cladoselache

1101201100-???2?-?1?1---**-**-00----10-0-?01110-00110000?0?01?10?0??0111???10???
11?11???????1?1?101010??10?1---0-1-00110101010000100000?000000????--??-----?
-----?-------?---?--?--????----?--?????---?-0???---0-?-???--???1--?????????1??????---?-?
?------????10

Climatius
0001000??000110-?10000-0?11000000-0-??1100-0011?00010?0??1?????????????????
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-----?-------?---1--?--?----------?????---?-??-----0-?-???--00?1--????????????????--------
-?---?????1
Cobelodus
1101?01??0-????-?1?1---**-**-00----10-0-001110-0011?00010101?1??0100011110110101
1111110011011011001010000011---0-1-00110111011000000-00---0000????--??-----?
-----?-------?---?--?--????----?--?????---?-????---0-?-???--???1--02?1?0?0????0?00---?-?
?------??????
Coccosteus
000??01????????0?0-001111-0----0110-??10-0110??????00?11?1??????????????00????
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0-00010101011-11?0-???0------?-01?000?0----?------0---02---000?--?????????????????
????????0?0?????10
Cowralepis
000??0?????????0?0-1?-0**-**1-0????0110-0?10-0110?????00??1??????????????????????
???????????????**0**????????????000110????????01?1?**0**00**0**01-000??1-00????----?0?????
0-00?10101111-10??-????------?-???010?0----?------0---02---00??--??????????????????
???????0?0?????10
Culmacanthus
?00??00??0010101?100??-1?00----00-0-????---?0?????????????1????????????????????
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-0-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??--
----?????1
Debeerius
11012010?0???-1-?1?1---**-**-00----00-0-00101?-0001?000?1001110?0?0?0111??-111??
0?110??????10-0100100?0?00?1---0-1-00110100011?001-01001000100????--??-----?
-----?-------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
------???01?
Diabolepis
001121?????????1?0-?1-1???????????????10-0011?????000011?10?0?100110???101?
1?0?0?1??11??????00111???1001????0?00
11110?00101??????0-??1????000???11011110?11??-?100---11000210?????1101000??
0?0?0?0??010101011??????????
Dialipina
0?**?**??00?011011?0?0-01-101??????0??10??1?-00?1???????????1?1???????????????0???
????????????????????????????00110-???????????1000**0**00-00--??11?0???????1??10??
0{01}?00?110???-??0-?0?????????10????01010?0????1?10????11??0?????????1????????
?????????????????????00?????0
Dicksonosteus
00?110?1?0?????0?0-001111-0----0100-??1??**0**110000????001101000001010010-000
01000?00??10000-0001100000?0000001000?--1-101????000?1-?001-1??????0--??00?
????0-00010101011-1100-???0------?-{01}1?01000----0------0---02---0000--0211100

000110000000010000010?00000???
Diplacanthus
0101?0011001010?0100??-0?00----0??0-??0--0-10?????1??????1??????????????????
??????????????????????????00110-110100000??100001111101000011?????---------?--
---?-------?---1--?--?----------?????---?-??-----0-?-???--0???--????????????????---?-??--?
---?????1
Doliodus
1?0??0?10**0**?????-?1??---0-?0----?0-0-??1110-001**1**??????101010?00?00010???00??1
11?11?00????11??10101000?0????-?????????????????00??1???11?????????---------?--
---?-------?---?--?--?----------?????---?-??-----0-?-???--0?-1--02??0????1?0??00---------?
---????1?
Entelognathus
000??0???0101??0?0-01-111-110010101???1?????101?????00?1010?0000010????00?
01????0???????????011000??10?000010???????????????00??1?????0????????--??00??
??00-00??0111-00?10000???0000?1??????????00??0?0?????110?0??????01??0???1??
0?01100?00?????????0??0??????
Eusthenopteron
00112001001011210 0-01-110-11001010101110-001111100000011110111100110110
101110000?1111111100?0011110101000110-0------000-10-00000-00---0111?010--01
10001--10100001110-?00-10-??0000010????????1?????01???0??11?????????111111
00001010001000100002000011111010
Euthacanthus
00010001?001110-0100??-0?01111100-0-??1100-00?????????0??1??????????????????
???????????????????????????0-110-1110010????100001110111000 11?????--??-----?-
----?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??
------?????1
Galeaspida
0000-0-??**0**0101?0?**1**000?--000-------0-------?----------000000?0-?0000000-000?0----?
0??00?00-?00??000-0000-------?--?0-----0-?--??**-**-?----0???---0---?0----------1-------?---
---------------------?--------------------------?0???-??---?0???-------------------
Gogonasus
001121**0**100101?2100-01-110-1101?010101?10-0011111000000111101110101 10110
001110000??1111?1????0011110101000110-?????????0?????0?????????0?1?101010
0?10001--10100001110-?00-10-??0000010????????1??????1???0??1??????????11111
10000101000100010000 20000?11111?10
Gladiobranchus
000120011001011-?100??-0101000100-0-??0----00?????1??????1?????????????????
???????????????????????????1---0-100100010??10000111111110?11?????--??-----?--
---?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??-
-----?????1
Guiyu
00112001011011 21?0-01-110-1100101010??1**1**-**1**011????000011?10?1???010**0**1??1
0?1??**0**?0????????????????1???????00?**1**10?--?-1???**?**?1??001?1000100?**1**1?000001??
10100101000100111 0-?00-?0110000000000?001000?0?101?11101111001?11011??1?

301?0110???0?????010000001100????01
Hamiltonichthys
11012010?00?120-?110---0-00----10-0-0?1110-0001?0?010101?11?00??0110??-?0??
1???1????????110?0?10001??011---0-1-000101000110001001001010110????---------?
-----?-------?---?--?--?----------?????---?-??-----0-?-???--00?1--0???0????1?0??0?-------
--?---???1?0
Homalacanthus
000??00??001011?0111??--?00--1?00-0-??0----00110010?0?01?1??????011?????1?1??
???01??????????????11??????1?1---0-1110010?1??1000011110010000 10????--??-----?-
----?-------?---1--?--????----?--?????---?-????---0-?-???--???1--?????????1??????---?-??
------??????
Howqualepis
?????00?0110112110-01-110-1100101011?1110101111?1??00?11?10?0110?111???10
1?????0?????????????0?1111???1000110-?-???1??01110000000-00---?011010?011000
1100001000010110-?10-0001001?1100000?00000100100011?00011001200?1?11000
0????0?000?0??1?001111111010??0110
Ischnacanthus
000??00??001010-01000?-0?01101100-0-??110111011100010?0??1?????????????????
????????????????????1?????????1---0-1110011?1??10000111100100011?????--??-----?-
----?-------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
------????11
Kathemacanthus
0101000100?011?-?110??-0?00----00-0-??0----0-?1???000??1?1??????0???????0?????
?????????????????????????1---0-??????-?0??1?0001111111100011??-??---------?-----?-
------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??------?
???11
Kenichthys
001121?101101??100-01-11?-??00101010??10--011?????000011??0?1?100110???10
11????0??11??????????111??????00110-0----1-000-???????0??????????101010??1??
011110100101110-?00-?11001000010111011121001010?10001011100111 0????1111
000?10???0?????000020010?1???????
Ligulalepis
001??0?10??????1?0-?1-1??????????????????????????????0?101010?1?011010010??
1?000010011?1100000111??0???????0????
??0?0??10????-??0-???????????????00?000?0?????1????????????????????????101?00
0?0??1?????????????????????
Lophosteus
???120?101?????0?0-?????????????????????????1????????????????????????????????????
??0???-??????????????
???0???????????0??????????????????????????
??????????????????
Macropetalichthys
00?110?????????1?0-?000**0**1-???????0???????????????????001100?0000000000-000
0?1-1?0???10?00-?0010000-?00?00?**1**????????????????????1???01????????0--??00??

???0-00010111100-????-????------?-???0?0?0---??------0---??---????--???100????1100
00?????????0?0???????

Meemannia

001121?????????1?0-?1-1???????????????1?-0011?????000???????0?????????01?????
????1??11??11??00111??1??????????????????????????????????????0???????0??????
0??0?100???????????????????????0?010???????1??0??10????????????????????????
0??1????????????????????

Mesacanthus

000??00???0?0100?101??--101110000-0-??0----0011??00???01?1???????????????????
??0????????????????????????1---0-111001?0???1000011101010000l1?????--??-----?---
--?-------?---1--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??-
-----??????

Miguashaia

0??1200??010112100-01-111-1????01?10??10-0?111??0??00?11?1???????1?????????
????????????????????????????00110-???????????10???000???--???1??00?--01?000??
010?0?101110-?00-10?0110?0?---??11?021??0?1??1000001111021l?11??10??????1??
????????????????01?0????10

Mimipiscis

001120010110112110-01-110-11001010111110-001111110000011110101100111110l
011110000100111110000011110111000110-0----1-001110000000-00---00110100011
0001100001000010110-?10-0001001011010000100001001001100000110002001111
10000000100000000110001011011010100110

Moythomasia

001120010110112110-01-11?-1100101011?110-001111110000011110101100111110l
011110000100111110000011110111000110-0----1-001110000000-00---00110100011
0001100001000010110-?10-00010010110100001000010010011{01}0000110002001?
?110000000?0000000?110001111111010100110

Obtusacanthus

0101201000?0120-?110??-0?0?0???0??0-??0----00?????????????1??????????????????
???????????????????????????1---0-??????-?-??1?000111?01110011?????--??-----?-----?
-------?---?--?--????----?--?????---??????---0-?-???--????--????????????????---?-??-----
-??????

Onychodus

001120010010012100-01-111-1100?01010?11101011111**0**??**0**0?11**?**10111?001001-?1
0111?**0**?0?1001???????0?1111?????00110-0----1-000?10000000-00---011??00?--0110
000101010?101110-?00-1010110100000011110?1000111010100111001011011?1113
0100010000???0??010010000110001010

Onychoselache

1101?011?0-01-0-?1?1-----00----?0-0-??1110-0001?0?0?0101?1??0????11?????0?????
??0???????????????????1????1---0-1-100101000110001001001010110????---?-----?----
-?-------?---?--?--????----?--?????---??????---0-?-???--???1--????????????????---?-??--
----???11?

Orthacanthus

1101201????????-?1??---0-?0----10-0-001110-00111000101010?1?000001101010000

1111111001101111111010101000011---0-1-0011011??11000100?00??00-10????--??----
-?-----?-------?---?--?--????----?--?????---??0???---0-?-???--???1--?????????1??????---?
-??------??????

Osorioichthys

00?1200?0????1?110-01-11?-1100101011??1???0?1??????????1???????????????????
????????????????????????????00110-???????????????00??0-00---????010?0????01100
00100?1001????10-0001??1?1100?0???0000?00?00?10?00?110?02???????00????????
???????????????????1010??????

Osteolepis

00112101011011 2100-01-11?-1100101010??10-001111????0011110?1?10011011?1
01110??0011?1111??0?00111?0101000110-???????????10000000-00---?11110?01001
10001--10100001110-?00-10-??????????????????1?????011??0??11??????????111110
0001010001000100002000011111?10

Osteostraci

0001000100?010?0?10000--000-----0-0-------?----------00000000-?0000000-000?0----?
0??00-00-?00??000-??000000-0??--?0-100-0-000?0?-00---00??---0---?0----------?-----
--?-----------------------?-------------------------?0??0-??---?0???-----------???0--

Parayunnanolepis

0??1?0?1?0?10?10?0-000010-0----0100-????????0??????????0????????????????????
???????????????????????????000010?????????0?10010000?00---?00?????----?1???0?
0?010-0101-0?-11??-???0------?-???????0----?------0---??---????--?0?????????????????
??????0?0????000

Parexus

000??01100???10??100??-0?11000000-0-??1100-00?????????0??1?????????????????
???????????????????????????01-10-1010010?0??10000111111110011?????--??-----?-
----?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??
------?????1

Poracanthodes

00010001000101???10???-0????????0?????110111 0**1**1??00????????????????????????
????????????????????????????1---0-1110011????1?000111?00100011?????---?-----?-
----?-------?---?--?--?----------?????---????-----0-?-???--0?-1--????????????????---?-??-
-?---?????1

Porolepis

00112101011011 2100-01-110-110?101010?11101011111000000011110?11?0011011?1
01110**0**?0??101??1????001111??01?00110-0----1-000?10000000-00---?11?10101001
10???10???0??00110-??0-???0???000?????1?1??10???1011?11101???0?11?11111121?
0001??000???0???1010???1????1010

Powichthys

001121?10110112100-01-11?-1100?0101???11??011?????000011110?111001101??1
01?1?0?0??10????????0011110?01000110-???????????????????0??????????101111??0
0001111010110111????00-??10??00001011101111000 10?0?10111010100 0110????112
1000?1110?011?010110100101111 1101?

Promesacanthus

0001?001101101?0?101??-**-**101110000-0-??0----0011???010??1?1??????????????????

????1???????????????????????1---0-111000001??1?000111011100001?????--??-----?--
---?-------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
------??????
Psarolepis
0011**2**1?10**1**?0??**2**1?0-01-?10-?????????????11?10**1**1?????0**0**0011**0**10?1?10010011?10?
11?**0**?0?1001???100000111??????00?**1**??????-1??0**1**?????01?10?0100????000001??1
0??110???0100??10-??0-?1010??111000010110000?010??11101110101011011??113
011011000?0001??01000000??{01}0000101
Pterichthyodes
0**?**0??0-1?0???010?0-00??10-0?---0100-??0--???0?????????**?**0?0???????0????????????
?????????????????0????????0?0010?????1--00-0--11?00?00--?000?????----?1???0?0-0
10-0101-0?-11??-???0------?-???????0----?------0---??---????--??????????????????????
???0?0???????
Ptomacanthus
?00??0?1?00111???100??-0101?0001??????1100-00110000???01?10??0????0????0??
??0000?????????????????????10?011-0-100001010??10000111011110011?????--------
-?-----?-------?---?--?--?----------?????---????-----0-?-???--0?-1--????????????0??0------
---?---?????1
Pucapampella
110??0?????????-????---?-??????????????????????????????1????000001101?1100?11
01011001?0?101010111?00100???--??-?---?--
---?-???????---?--?--????-------?????---??????---0-?-???--????--?2?10????1?0??00---?-?
?--?---??????
Rhamphodopsis
000??0???????0?1?0-**?**1-001-0----0110-??10-01100????????0??????????????????????
????????????????0????????00011??0?--1-????111001010?0110?10?????--???0?????0
-00?1010??01-11?------------?-???0???0----?------0---??---0???--??????????1?????????
????0?0??????1
Sigaspis
0????0???0???010?0-00111?-0----010??????????0??????????????????????????????????
??????????????????????????000010?????????1?1?0000?1??000-??????????????0?????
0?00?10101000?10?0-???0------?-11?????0--???------0---??---????--?????????????????
????????0?0?????00
Styloichthys
001121?101101?2100-01-11?-????????????11??011?????000011110?1?1001101?010
1110??0?1101?????0?0011100101000110-0----1-000-???????0??????????00?011??1??
?01????00?01110-??0-?1?0010??0101110111200?101??101???100100110????11210
10?1110?01??0?00001011??111110??
Tamiobatis
1101?0?1-0-01??-?11?---0-?????????????1110-0011?000??101??0?000001101010000
111111?001???111110101000001?---??????1???????????1??1??110???0????--??-----?
-----?-------?---?--?--????----?--?????---??????---0-?-???--???1--02???0?0?1??0?00---?
-??------?????1
Tetanopsyrus

000120011001010-?110??-0?00----00-0-??10-0?10010001????1?1?????????????????
????????????????????????????1---0-100001001??1000011100011001 1?????---------?--
---?-------?---?--?--?-------?--?????---?-??-----0-?-???--00?1--????????????????---?-??--?
---?????1

Tristychius

11012011?0-??-?-?1?1-----00----00-0-?01110-0001?0?010101010?000001101?-10001
01?-0?001?????11101000?10011---0-1-001101000110001001001010110????--??-----?
-----?-------?---?--?--????----?--?????---?-????---0-?-???--???1--????????????????---?-??
------???110

Youngolepis

001121?101101?2100-01-11?-?????0101???11??01111???000011110?0110011011010
11100?0011011111?00001111010100011 0-0----1-000-???????0??????????101111??0?
00111???00101110-?00-?1100100001011101111001 1010?100110101100110??11121
000?1110?001001101010{01}1??111110??

Lupopsyrus

000??0100?0??20???1???????1010?00?0???00?0?00??????????????????????????????
????????????????????????????1???0-10??????1??10-0011111111 0011?????--??-----?--
---?-------?---?--?--????----?--?????---?-????---0-?-???--????--????????????????---?-??-
-----?????1

Rhadinacanthus

000??0????????????????????0100?0??????0?????0?????????????????????????????????
?????????????????????????????0-1?11????1??10-0011111111 0011?????--??-----?----
-?-------?---?--?--????----?--?????---??????---0-?-???--????--????????????????---?-??--
----?????1

Vernicomacanthus

000??0???????1?????????????10???1??????11?0?00?????????????????????????????????
?????????????????????????????0-1?00????1??10-0011111111 0011?????--??-----?----
-?-------?---?--?--????----?--?????---??????---0-?-???--????--????????????????---?-??--
----?????1

6) Characters and character states defining major clades shown in Supplementary Figure 3. Asterisks indicate ambiguous character states resolved using DELTRAN and ACCTRAN. Character state is "1", unless marked otherwise.

Delayed-transformation apomorphy lists (DELTRAN):

Node 1 (jawed vertebrates): 18(0); 33*; 115;

Node 2: 5*; 25; 85*; 128*;

Node 3: 56; 148(0);

Node 4: 39*; 58; 66; 69; 77(0); 101; 121*; 164(0); 220(2)*;

Node 5 (crown-group gnathostomes + *Entelognathus* + ptyctodonts): 11; 12(0); 13; 21; 136;

Node 6 (crown-group gnathostomes + *Entelognathus*): 23*; 27; 47*; 76*; 95*; 162*; 216;

Node 7 (crown-group gnathostomes): 5(2)*; 14*; 82*; 86*; 88*; 89*; 96; 97; 106; 107*; 108(0); 132*; 137*; 230(0); 251*; 252*;

Node 8 (total-group chondrichthyans): 11(0); 12; 15(0)*; 18; 33(0); 126*; 127; 170*; 253*;

Node 9: 5(0); 21(0)*; 40; 44(0); 46*; 52*; 130; 131;

Node 10: 29; 67*; 71*; 72*; 81*; 91*; 118; 228*;

Node 11: 30; 111; 112; 133(0);

Node 12: 13(0); 104*; 131(0);

Node 13: 39(0);

Node 14: 9*; 20*; 136(0);

Node 15: 19; 50; 129; 130(0);

Node 16: 15; 27(0); 74*; 102*;

Node 17: 30(0); 31(0); 117(0);

Node 18: 42*; 44; 116; 130(0);

Node 19: 28(0)*; 129;

Node 20: 2; 19*; 27(0); 104*;

Node 21: 12(0);

Node 22: 5(2); 7; 14(2);

Node 23 (Chondrichthyes *sensu stricto* or conventionally-defined chondrichthyans): 1;

77*; 79*; 93*; 94(0)*;

Node 24: 41*; 54*; 78*; 80; 90; 92; 96(0); 101(0); 103; 114*;

Node 25: 20*; 122*; 127(0)*; 128(0); 130(0)*; 131(0)*; 133(0); 253(0);

Node 26: 32;

Node 27: 62; 90(0); 119*; 136(0)*; 137(0);

Node 28: 65;

Node 29: 72(0); 99;

Node 30: 46(0); 77(0); 81(0); 97(0); 118(0);

Node 31: 91(0); 93(0);

Node 32: 8(0)*; 15*; 53; 54(0); 57*; 73; 74*; 137(0);

Node 33: 99; 114(0); 134*;

Node 34: 72(0);

Node 35: 8(0); 39(0)*;

Node 36: 31(0); 105*;

Node 37: 26; 28(0)*;

Node 38: 112;

Node 39: 9; 13(0); 27(0); 51;

Node 40: 129;

Node 41: 39(0)*; 113; 115(0); 130;

Node 42: 131;

Node 43 (total-group osteichthyans): 10; 45*;

Node 44: 35*; 43(0)*; 128(0)*; 161(0)*; 168(0)*; 198; 204*;

Node 45: 3*; 16; 72*; 94(0)*; 100*; 233*;

Node 46: 60*; 63*; 189(0); 224*;

Node 47 (crown-group osteichthyans): 15(2)*; 24*; 25(0)*; 37*; 38*; 46*; 48*; 55*; 62*; 70; 74*; 75*; 87*; 98*; 102*; 110(0)*; 117(0)*; 138*; 213*; 214*; 215*; 220(0)*; 229(0)*;

Node 48: 40; 61; 147; 152*; 154*; 161; 184*; 200*; 209(0)*; 210*; 211*; 218*; 219(3); 225; 245*;

Node 49: 42; 126; 128; 133(0)*; 158; 159(0); 199; 202*; 203; 208; 221*; 243(0)*; 252(0); 253;

Node 50: 6; 119*; 151; 177; 205(0); 206;

Node 51: 149(0); 156; 170*; 172*; 173(0); 175; 186*; 189(2); 195; 224(0); 233(0); 240*; 246*; 250; 251(0);

Node 52: 6; 57*; 67*; 83; 101(0)*; 143*; 171; 180; 182; 183; 188; 193; 194(0); 219(2); 220; 227; 231*; 237(0); 247; 248; 249;

Node 53: 139; 141*; 151; 197*; 202*; 206; 222(0)*; 235*;

Node 54: 201; 238;

Node 55: 142; 147(0); 153*; 189*;

Node 56: 61(0); 192; 200(0); 236;

Node 57: 40(0); 84; 144(0)*; 190*; 219; 240(2);

Node 58: 159(0); 171(0); 243(0);

Node 59: 10(0); 175(0)*;

Node 60: 10(0); 25; 174; 185; 190*;

Node 61: 17; 36; 49; 67*; 119*; 136(0); 145*; 167*; 176; 187(0); 191; 217(0); 234; 237(0); 240*; 242; 246*; 248;

Node 62: 140; 150; 155; 178*; 179; 244*;

Node 63: 68*; 120*; 146(0)*; 159(0); 160*; 238*; 241*;

Node 64: 57*; 77*; 181; 186*; 197; 212*; 222(0)*;

Node 65: 16; 107*; 122; 123; 126*; 135*; 163(0); 166;

Node 66: 34;

Node 67: 22; 23*; 24*; 119; 186*;

Node 68: 55*; 64*; 95*; 135*; 165; 166; 223*;

Node 69: 34; 252*;

Node 70: 109;

Node 71: 24*; 124; 157*;

Node 72: 125

Accelerated-transformation apomorphy lists (ACCTRAN):

Node 1 (jawed vertebrates): 5*; 7*; 18(0); 33*; 57*; 85*; 115; 121*;

Node 2: 25; 39*; 47*; 107*; 128*; 135*; 162*; 220(2); 251*;

Node 3: 56; 76*; 148(0); 152*;

Node 4: 23*; 57(0)*; 58; 66; 69; 77(0); 95*; 101; 162(0)*; 164(0); 223*;

Node 5 (crown-group gnathostomes + *Entelognathus* + ptyctodonts): 5(2)*; 11; 12(0); 13; 15(0)*; 21; 60*; 74*; 82*; 86*; 88*; 89*; 126*; 136; 138*; 209(0)*; 240*; 253*;

Node 6 (crown-group gnathostomes + *Entelognathus*): 7(0)*; 14*; 27; 35*; 37*; 45*; 117(0)*; 132*; 135(0)*; 137*; 162*; 169(0)*; 204*; 216; 252*;

Node 7 (crown-group gnathostomes): 46*; 67*; 72*; 75*; 94(0)*; 96; 97; 106; 108(0); 161(0)*; 168(0)*; 170*; 196*; 215*; 223(0)*; 229(0)*; 230(0); 244*;

Node 8 (total-group chondrichthyans): 11(0); 12; 18; 21(0)*; 28(0)*; 33(0); 35(0)*; 45(0)*; 52*; 54*; 71*; 81*; 91*; 105*; 127; 138(0)*; 204(0)*; 228*;

Node 9: 5(0); 40; 44(0); 117*; 130; 131;

Node 10: 29; 78*; 104*; 118;

Node 11: 28*; 30; 62*; 68*; 94*; 102*; 111; 112; 133(0);

Node 12: 13(0); 42*; 131(0);

Node 13: 5(2)*; 9*; 20*; 39(0);

Node 14: 136(0);

Node 15: 19; 50; 129; 130(0);

Node 16: 15; 27(0);

Node 17: 30(0); 31(0); 117(0);

Node 18: 29(0)*; 44; 48*; 116; 129*; 130(0);

Node 19: 15*; 19*; 32*; 37(0)*; 74(0)*; 75(0)*; 77*; 79*; 93*; 114*; 129;

Node 20: 2; 27(0);

Node 21: 12(0); 32(0)*; 39(0)*; 41*;

Node 22: 5(2); 7; 14(2); 130(0)*;

Node 23 (Chondrichthyes *sensu stricto* or conventionally-defined chondrichthyans): 1; 20*; 39*; 122*; 127(0)*; 131(0)*;

Node 24: 80; 90; 92; 96(0); 101(0); 103;

Node 25: 128(0); 133(0); 253(0);

Node 26: 32; 119*; 132(0)*; 136(0)*;

Node 27: 62; 90(0); 137(0);

Node 28: 65;

Node 29: 48*; 59*; 72(0); 99;

Node 30: 46(0); 77(0); 81(0); 97(0); 100*; 118(0); 134*;

Node 31: 8(0)*; 57*; 74*; 91(0); 93(0);

Node 32: 53; 54(0); 73; 89(0)*; 134(0)*; 137(0); 251(0)*;

Node 33: 15(0)*; 32*; 59*; 99; 114(0);

Node 34: 72(0);

Node 35: 8(0); 15(0)*; 27*; 40(0)*;

Node 36: 31(0); 67(0)*; 72(0)*;

Node 37: 12(0)*; 26;

Node 38: 112;

Node 39: 9; 13(0); 16*; 27(0); 46(0)*; 51;

Node 40: 39(0)*; 129; 133(0)*;

Node 41: 105(0)*; 113; 115(0); 130;

Node 42: 15*; 44(0)*; 104*; 117*; 131; 133*;

Node 43 (total-group osteichthyans): 3*; 10; 15(2)*; 38*; 43(0)*; 48*; 55*; 62*; 63*; 87*; 98*; 100*; 102*; 110(0)*; 119*; 126(0)*; 128(0)*; 133(0)*; 213*; 214*; 220(0)*; 224*; 233*; 253(0)*;

Node 44: 198;

Node 45: 16; 24*; 25(0)*; 246*;

Node 46: 189(0);

Node 47 (crown-group osteichthyans): 57*; 70; 154*; 186*; 222(0)*;

Node 48: 40; 61; 67(0)*; 101(0)*; 147; 161; 172*; 184*; 200*; 202*; 210*; 211*; 218*; 219(3); 221*; 225; 235*; 243(0)*; 245*;

Node 49: 42; 57(0)*; 108*; 126; 128; 158; 159(0); 199; 203; 208; 222*; 240(0)*; 246(0)*; 252(0); 253;

Node 50: 6; 151; 171*; 172(0)*; 177; 205(0); 206;

Node 51: 119(0)*; 143*; 149(0); 156; 173(0); 175; 189(2); 190*; 195; 224(0); 231*; 233(0); 244(0)*; 250; 251(0);

Node 52: 6; 67*; 83; 141*; 153*; 171; 180; 182; 183; 188; 193; 194(0); 196(0)*; 197*; 205(0)*; 219(2); 220; 221(0)*; 226*; 227; 237(0); 243*; 247; 248; 249;

Node 53: 139; 144(0)*; 151; 206;

Node 54: 189*; 201; 232*; 238;

Node 55: 142; 144*; 147(0); 190(0)*;

Node 56: 61(0); 192; 200(0); 231(0)*; 236; 242*;

Node 57: 40(0); 84; 200(0)*; 205*; 209*; 219; 226(0)*; 240(2);

Node 58: 159(0); 171(0); 175(0)*; 243(0);

Node 59: 10(0);

Node 60: 10(0); 25; 174; 177*; 185; 202(0)*;

Node 61: 17; 36; 49; 68*; 77*; 136(0); 145*; 160*; 167*; 170(0)*; 176; 178*; 187(0); 191; 196(0)*; 209(2)*; 212*; 217(0); 234; 237(0); 242; 248;

Node 62: 120*; 140; 146(0)*; 150; 152(0)*; 154(0)*; 155; 179; 238*; 239*; 241*;

Node 63: 159(0);

Node 64: 181; 197;

Node 65: 16; 23(0)*; 68*; 95(0)*; 122; 123; 163(0); 166;

Node 66: 34;

Node 67: 22; 24*; 55*; 64*; 107(0)*; 110(0)*; 119; 186*; 221*;

Node 68: 165; 166; 252*;

Node 69: 34; 76(0)*;

Node 70: 109; 189(0)*;

Node 71: 24*; 124; 157*;

Node 72: 4(0)*; 121(0)*; 125;

Summary of nodal synapomorphies in one of the 1117 MPTs from the full dataset (Supplementary Fig. 3)

The node uniting *Entelognathus* and crown-group gnathostomes (Node 6, Supplementary Fig. 3) is supported by two unambiguous characters (Character 27: presence of bony hyoidean gill-cover series; Character 216: metapterygoid with developed commissural lamina). Under *DELTRAN* optimization, this node is supported by one uniquely shared character (C.I. = 1, Character 216) and six homoplasious characters (C.I. less than 1). Under *ACCTRAN* optimization, the node is supported by one uniquely shared character (C.I. = 1, Character 216) and 14 homoplasious characters (C.I. less than 1), such as presence of gular plates (Character 35), presence of maxillary and dentary bones (Character 45), and presence of infradentary bones (Character 204).

The node uniting *Entelognathus*, ptyctodonts and crown-group gnathostomes (Node 5, Supplementary Fig. 3) is supported by five unambiguous characters. Under *DELTRAN* optimization, this node is supported by five homoplasious characters (C.I. less than 1). Under *ACCTRAN* optimization, the node is supported by 14 homoplasious characters (C.I. less than 1) and four uniquely shared characters (C.I. = 1, Character 60: anterior and dorsal to foramen myodome for superior oblique eye muscles; Character 82: labyrinth cavity not separated from the main neurocranial cavity by a cartilaginous or ossified capsular wall; Character 86: sinus superior; Character 88: trigemino-facial recess).

Crown-group Gnathostomata (Node 7, Supplementary Fig. 3) is supported by five unambiguous characters. Under *DELTRAN* optimization, this node is supported by 11 homoplasious characters (C.I. less than 1) and five uniquely shared characters (C.I. = 1, Character 82: labyrinth cavity not separated from the main neurocranial cavity by a cartilaginous or ossified capsular wall; Character 86: sinus superior; Character 88: trigemino-facial recess; Character 106: dermal shoulder girdle not forming a complete ring around the trunk; Character 230: posterior postorbital process absent). Under *ACCTRAN* optimization, the node is supported by 13 homoplasious characters (C.I. less than 1) and five uniquely shared characters (C.I. = 1, Character 106; Character 168: dermal neck-joint between paired main-lateral-line-bearing bones of skull and shoulder girdle absent; Character 215: metapterygoid and autopalatine contacts separated by gap between commissural lamina of palatoquadrate and cheek bones; Character 229: no opercular suspension on braincase; Character 230).

The conventionally-defined chondrichthyans (Chondrichthyes *sensu stricto*, Node 23, Supplementary Fig. 3) are supported by one unambiguous character (Character 1: tessellate prismatic calcified cartilage). Under *DELTRAN* optimization, this node is supported by four moplasious characters (C.I. less than 1) and one uniquely shared character (C.I. = 1, Character 1). Under *ACCTRAN* optimization, the node is supported by five homoplasious characters (C.I. less than 1) and 1 uniquely shared character (C.I. = 1, Character 1).

Total-group Chondrichthyes (Node 8, Supplementary Fig. 3) is supported by five unambiguous characters. Under *DELTRAN* optimization, this node is supported by nine homoplasious characters (C.I. less than 1). Under *ACCTRAN* optimization, the node is supported by 16 homoplasious characters (C.I. less than 1) and two uniquely shared characters (C.I. = 1, Character 71: glossopharyngeal nerve (N. IX) exit through metotic fissure; Character 228: hyoid arch articulation on otic capsule wall).

Total-group Osteichthyes (Node 43, Supplementary Fig. 3) is supported by one unambiguous character (Character 10: body scales with peg-and-socket articulation). Under *DELTRAN* optimization, this node is supported by two homoplasious characters (C.I. less than 1). Under *ACCTRAN* optimization, the node is supported by 19 homoplasious characters (C.I. less than 1) and five uniquely shared characters (C.I. = 1: Character 38: interhyal; Character 43: teeth ankylosed to dermal bones absent; Character 87: external (horizontal) semicircular canal joins the vestibular region at the level of posterior ampulla; Character 213: dermal plates on mesial surfaces of Meckel's cartilage and palatoquadrate; Character 214: biconcave glenoid on lower jaw).

Crown-group Osteichthyes (Node 47, Supplementary Fig. 3) is supported by one unambiguous character (Character 70: hyoid ramus of facial nerve (N. VII) exits through posterior jugular opening). Under *DELTRAN* optimization, this node is supported by 16 homoplasious characters (C.I. less than 1) and seven uniquely shared characters (C.I. = 1: Character 38: interhyal; Character 70; Character 87: external (horizontal) semicircular canal joins the vestibular region at the level of posterior ampulla; Character 213: dermal plates on mesial (lingual) surfaces of Meckel's cartilage and palatoquadrate; Character 214: biconcave glenoid on lower jaw; Character 215: metapterygoid and autopalatine contacts separated by gap between commissural lamina of palatoquadrate and cheek bones; Character 229: no opercular suspension on braincase). Under *ACCTRAN* optimization, the node is supported by four homoplasious characters (C.I. less than 1) and one uniquely shared character (C.I. = 1: Character 70).

Part B. Supplementary Table 1

Scheme illustrating the nomenclature of large dermal plates in sarcopterygians, actinopterygians, non-*Entelognathus* placoderms and *Entelognathus*. The current tentative framework is based on Stensiö (1963), Gardiner (1984a, b), Forey & Gardiner (1986) as well as new data from *Entelognathus*. It is hoped that the framework will be tested and refined by future studies.

Sarcopterygii	Actinopterygii	*Entelognathus*	Placodermi excluding *Entelognathus* (generally accepted terms)	Placodermi excluding *Entelognathus* (terms in Stensiö, 1963)
rostral or mosaic rostral bones	rostral or mosaic rostral bones	premedian	premedian	premedian
		rostral	rostral	rostral
postrostral or mosaic postrostral bones	postrostral or mosaic postrostral bones	pineal	pineal	pineal
nasal series	nasal series	-	postnasal	postnasal
parietal	frontal	-	preorbital	preorbital
postparietal	parietal	central	central	parietal
intertemporal	dermosphenotic	postorbital	postorbital	postorbital
supratemporal	intertemporal	marginal	marginal	marginal
extratemporal	extratemporal	postmarginal	postmarginal	dorsal pre-opercular
tabular	supratemporal	anterior paranuchal	anterior paranuchal	anterior paranuchal
lateral extrascapular	lateral extrascapular	posterior paranuchal	paranuchal or posterior paranuchal	paranuchal or posterior paranuchal
		posterior paranuchal	posterior paranuchal	posterior paranuchal
median extrascapular	median extrascapular	nuchal	nuchal	nuchal
-	-	postnuchal	extrascapular	extrascapular
-	-	median dorsal	median dorsal or anterior median dorsal	median dorsal or anterior median dorsal
posttemporal	posttemporal	anterior dorsolateral	anterior dorsolateral	posttemporal
supracleithrum	supracleithrum	posterior dorsolateral	posterior dorsolateral	supracleithrum
anocleithrum	postcleithrum	posterior lateral	posterior lateral	anocleithrum
cleithrum	cleithrum	anterior lateral	anterior lateral	dorsal cleithrum
		anterior ventrolateral	anterior ventrolateral	ventral cleithrum
		spinal	spinal	spinal
clavicle	clavicle	Interolateral	Interolateral	clavicle
-	-	antero-ventral	antero-ventral	antero-ventral

interclavicle	interclavicle	anterior medio-ventral	anterior medio-ventral	interclavicle
-	-	posterior medio-ventral	medio-ventral or posterior medio-ventral	medio-ventral or posterior medio-ventral
-	-	posterior ventrolateral	posterior ventrolateral	posterior ventrolateral
jugal	jugal	jugal	suborbital	suborbital
lacrimal	lacrimal	lacrimal	-	-
opercular	opercular	opercular	submariginal	middle pre-opercular
premaxillary	premaxillary	premaxillary	-	-
maxillary	maxillary	maxillary	-	-
dentary	dentary	dentary	-	-
infradentary	infradentary	infradentary	-	-
submandibular	submandibular	submandibular		
gular	gular	gular	-	-
coronoid	coronoid	(unknown)	infragnathal	mixicoronoid
vomer	vomer	(unknown)	anterior supragnathal	vomer
dermopalatine	dermopalatine	(unknown)	posterior supragnathal	palatino-pterygoid
ectopterygoid	ectopterygoid			
parasphenoid	parasphenoid	(unknown)	parasphenoid	parasphenoid

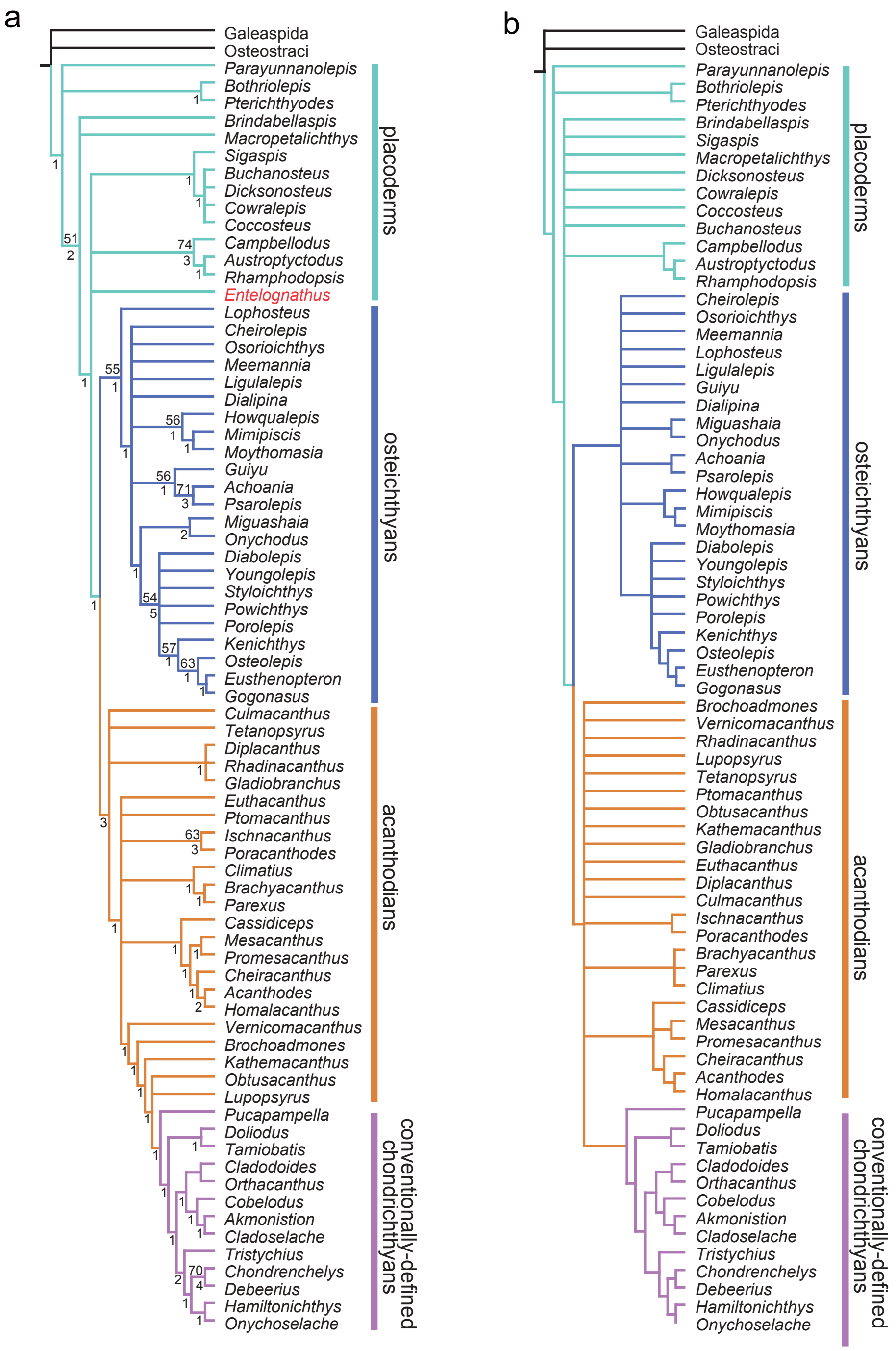
Part C. Supplementary Figures 1-27 with legends

Abbreviations used in supplementary figures

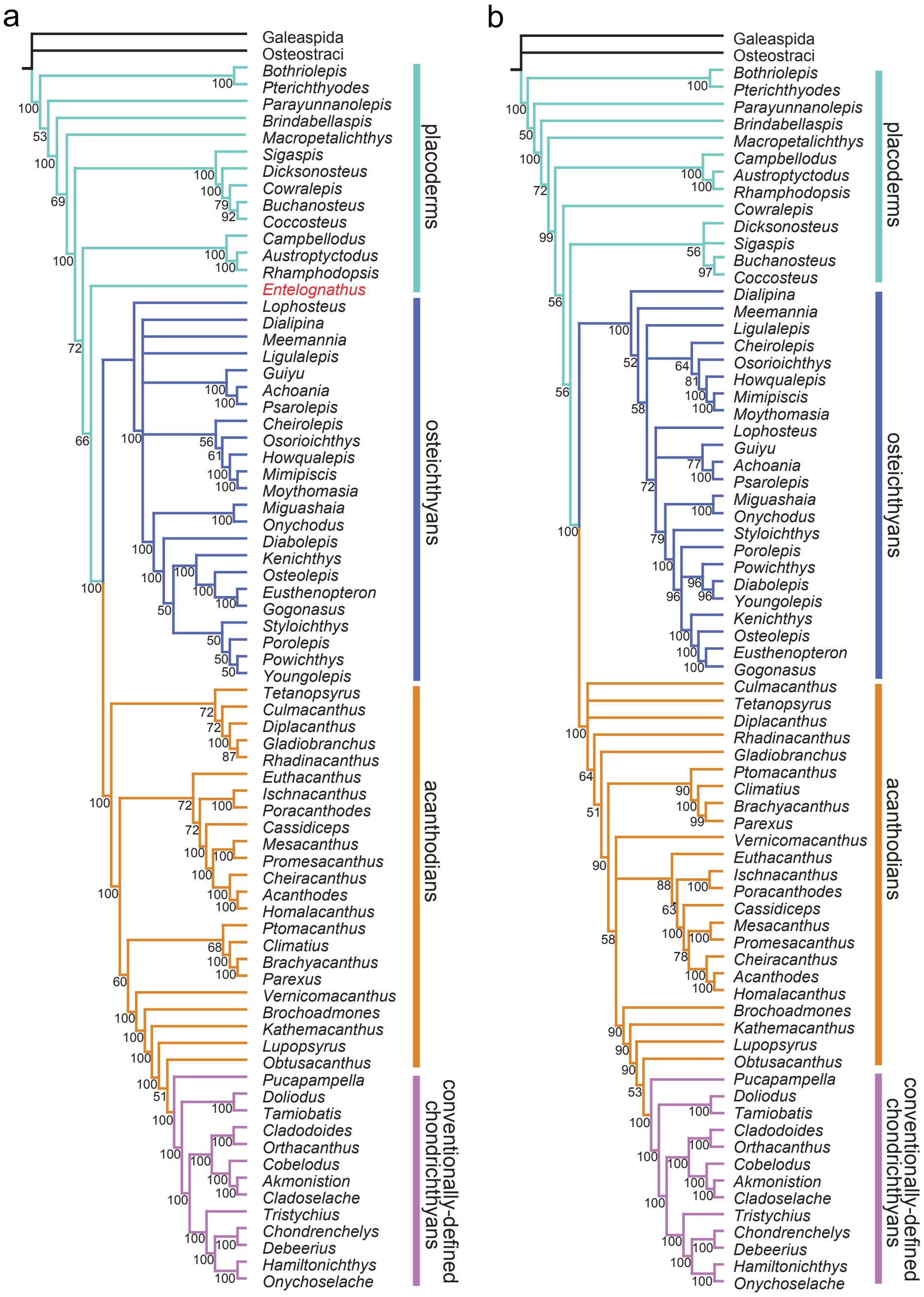
aclm, anocleithrum
adl, anterior dorsolateral plate
ae.add, anterior extension of adductor chamber
al, anterior lateral plate
av, anteroventral plate
avl, anterior ventrolateral plate
ce, central plate
clav, clavicle
clm, cleithrum
co, commissural lamina
c.sp, contact for spinal plate
de, dentary
dp, posterior ventral depression of braincase
f.am, fossa for adductor mandibulae muscle
f.hm, hyomandibular facet
f.sc, flank scales
fo.cu, cucullaris fossa
fo.po, postorbital fossa
gr.ju, groove for jugular vein
gu, principal gular
gu.m, median gular
hp, hypophysial opening
id, infradentary
id1-3, first to third infradentary
ig, infragnathal
il, interolateral plate
ioc.ot, otic branch of infraorbital line groove
ioc.pt, postorbital branch of infraorbital line groove
ju, jugal
l, left side
lac, lacrimal
lc, main lateral line groove
l.lam, lateral lamina of palatoquadrate
l.avl, lateral lamina of anterior ventrolateral plate
l.ext, lateral extrascapular
l.pvl, lateral lamina of posterior ventrolateral plate

m, marginal plate
mand, mandibular line groove
md, median dorsal plate
mvp, median ventral pit
mx, maxilla
mx.f, facial lamina of maxilla
mx.p, palatal lamina of maxilla
m.ext, median extrascapular
nc, notochord
no, nostril
n.scl, notch for sclerotic ossification
nu, nuchal plate
oa.al, overlapped area by anterior lateral plate
oa.av, overlapped area by anteroventral plate
oa.avl, overlapped area by anterior ventrolateral plate
oa.md, overlapped area by median dorsal plate
oa.ptnu, overlapped area by postnuchal plate
oa.pvl, overlapped area by posterior ventrolateral plate
oa.scl, overlapped area by sclerotic plate
oa.sk, covered area by skull roof
occ, occipital cross commissure
op, opercular
orb, orbital fenestra
pbr, postbranchial lamina
pdl, posterior dorsolateral plate
peri.pq, perichondral lining of palatoquadrate
pf, pectoral fenestra
pi, pineal plate
pi.po, postorbital pila
pl, posterior lateral plate
pm, postmarginal plate
pmc, postmarginal line groove
pmx, premaxilla
pmx.f, facial lamina of premaxilla
pmx.p, palatal lamina of premaxilla
pna, anterior paranuchal plate
pnp, posterior paranuchal plate
po, postorbital

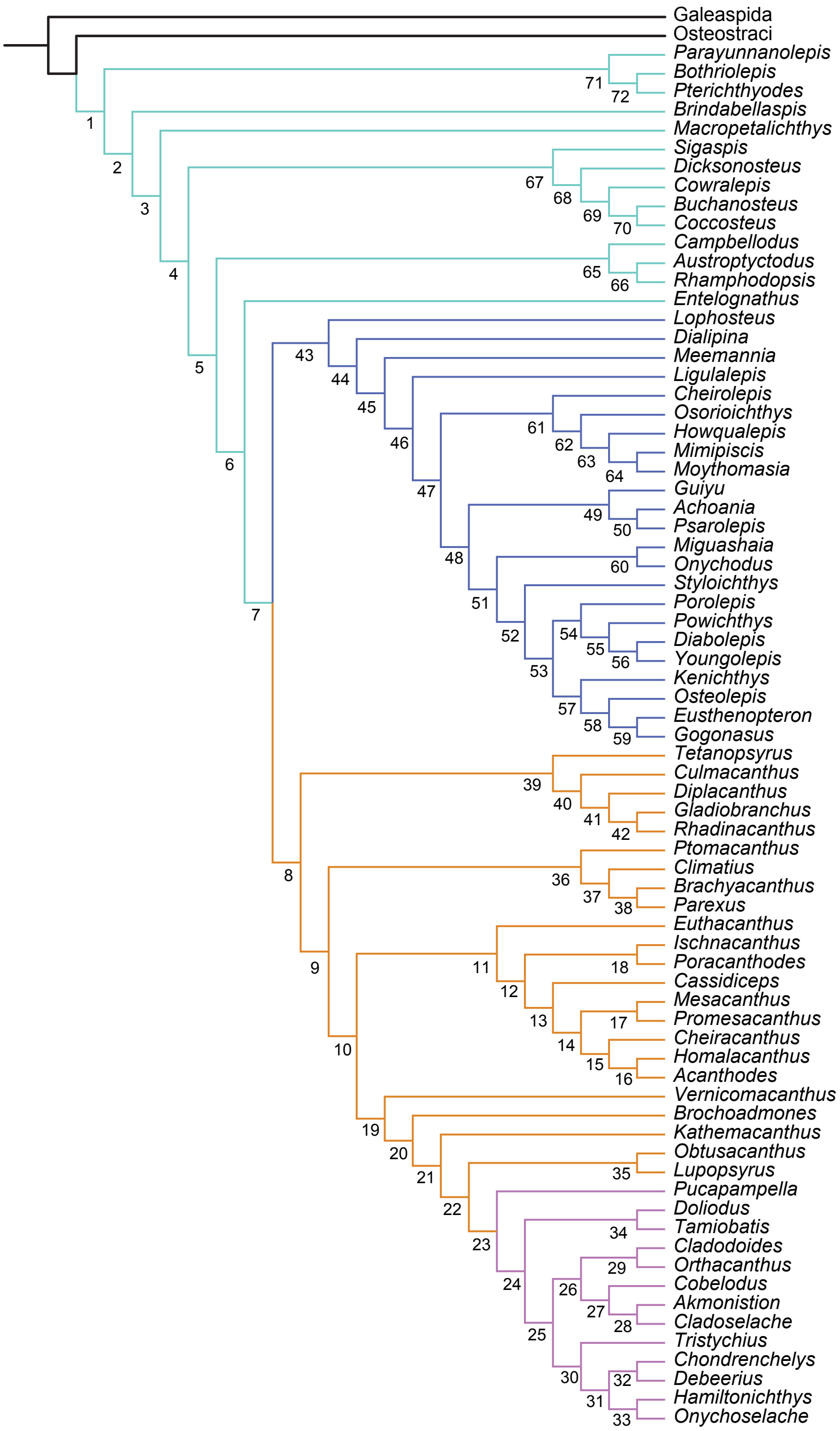
pop, preopercular
ppl, posterior pitline
pq, palatoquadrate
prm, premedian
pr.apo, anterior postorbital process
pr.bp, basipterygoid process
pr.csp, craniospinal process
pr.ect, ectethmoid process
pr.ppo, posterior postorbital process
pr.pre, preglenoid process
pso, postsuborbital plate
pt, post-temporal
ptnu, postnuchal plate
pto, postorbital plate
pvl, posterior ventrolateral plate
p.sc, scale of pectoral fin
qj, quadratojugal
qu.con, quadrate concavity
Rbr, branchiostegal ray series
r, right side
ro, rostral plate
sbm.a, anterior submandibular
sbm.p, posterior submandibular
scap, scapulocoracoid
scl, sclerotic plate
sclm, supracleithrum
sm, submarginal plate
so, suborbital plate
sop, subopecular
sorc, supraoral line groove
sp, spinal plate
spir, spiracular opening
sq, squamosal
vlr, ventrolateral ridge of trunk armour
vl.sc, scales along trunk ventrolateral ridge
v.avl, ventral lamina of anterior ventrolateral plate
v.ju, opening of jugular vein
v.pvl, ventral lamina of posterior ventrolateral plate



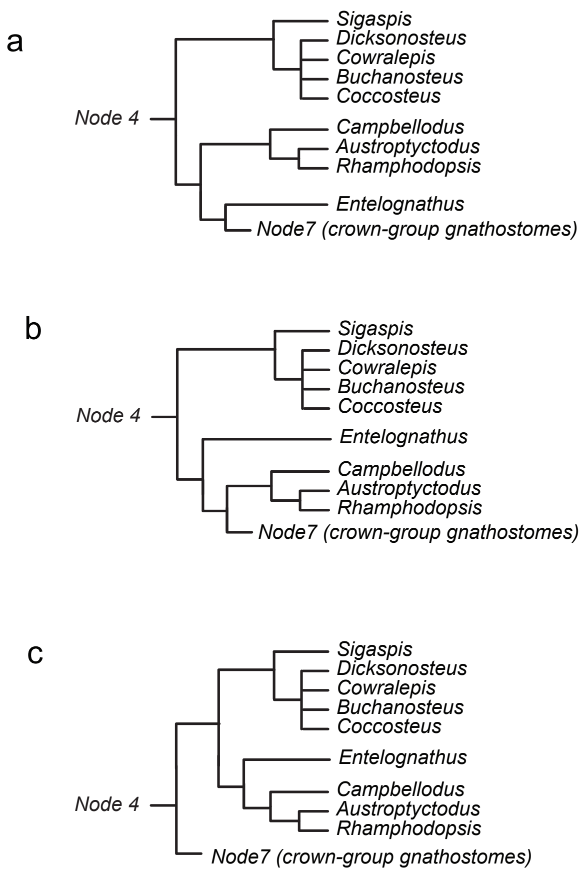
Supplementary Figure 1. a, Strict consensus tree of the 1117 most parsimonious trees using the full dataset, which is a modified dataset with 253 characters and 75 taxa (including *Entelognathus*) (tree length = 598, consistency index = 0.4398). The dataset is based on the original dataset of Davis *et al.* (2012) with revised codings for 29 characters, with 115 additional characters, and with 15 additional taxa. Numbers at nodes represent Bremer decay indices (below) and bootstrap values (where the latter are greater than 50%, above). **b**, Strict consensus tree of the 64133 most parsimonious trees based on the same dataset as in (**a**), but with the exclusion of *Entelognathus* codings (tree length = 588, consistency index = 0.4473).



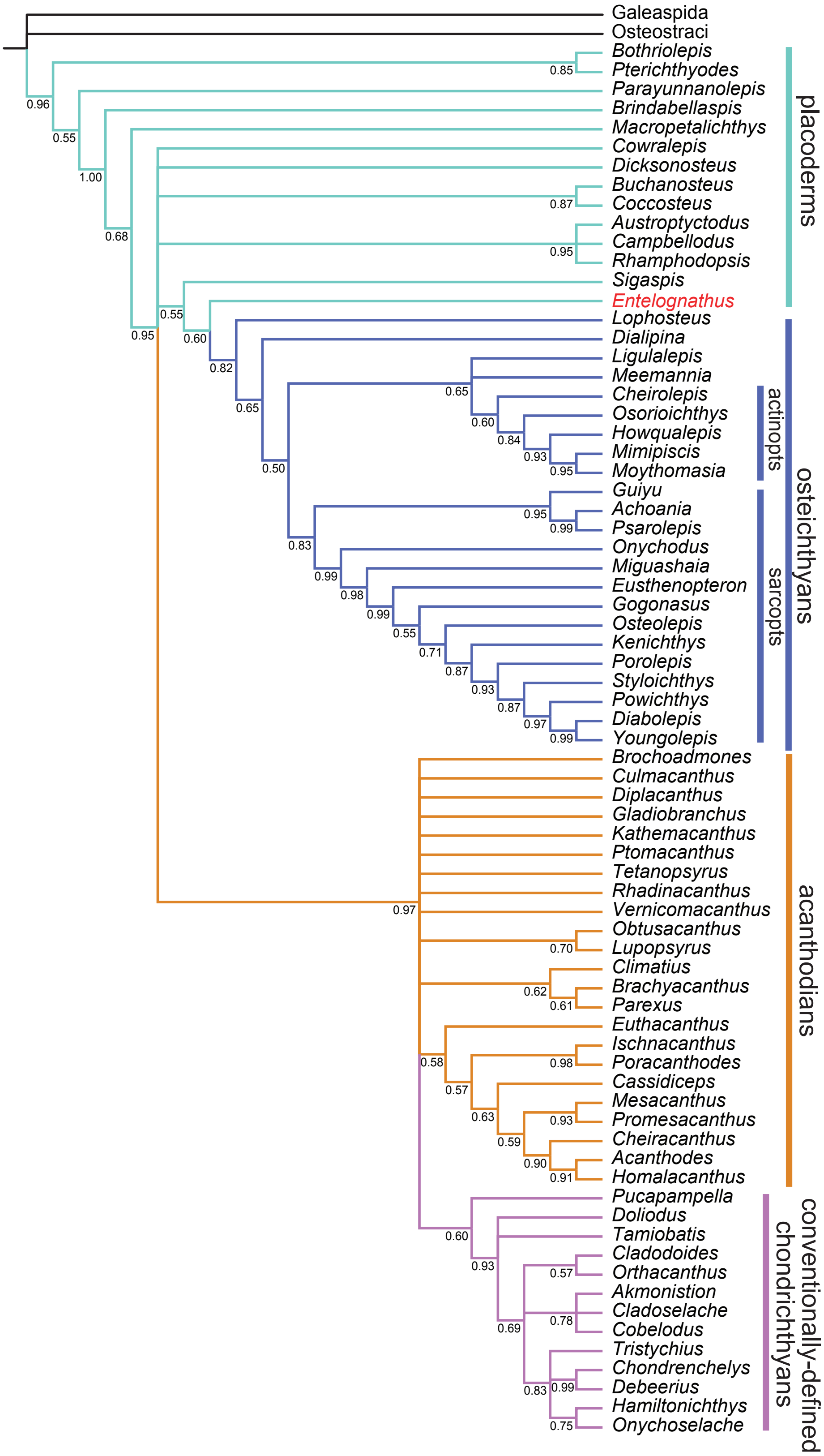
Supplementary Figure 2. a, 50% majority-rule consensus tree of the 1117 most parsimonious trees using the full dataset, which is a modified dataset with 253 characters and 75 taxa (including *Entelognathus*) (tree length = 598, consistency index = 0.4398). The dataset is based on the original dataset of Davis *et al.* (2012) with revised codings for 29 characters, with 115 additional characters, and with 15 additional taxa. Numbers at nodes represent Bremer decay indices (below) and bootstrap values (where the latter are greater than 50%, above). **b**, 50% majority-rule consensus tree of the 64133 most parsimonious trees based on the same dataset as in (**a**), but with the exclusion of *Entelognathus* codings (tree length = 588, consistency index = 0.4473).



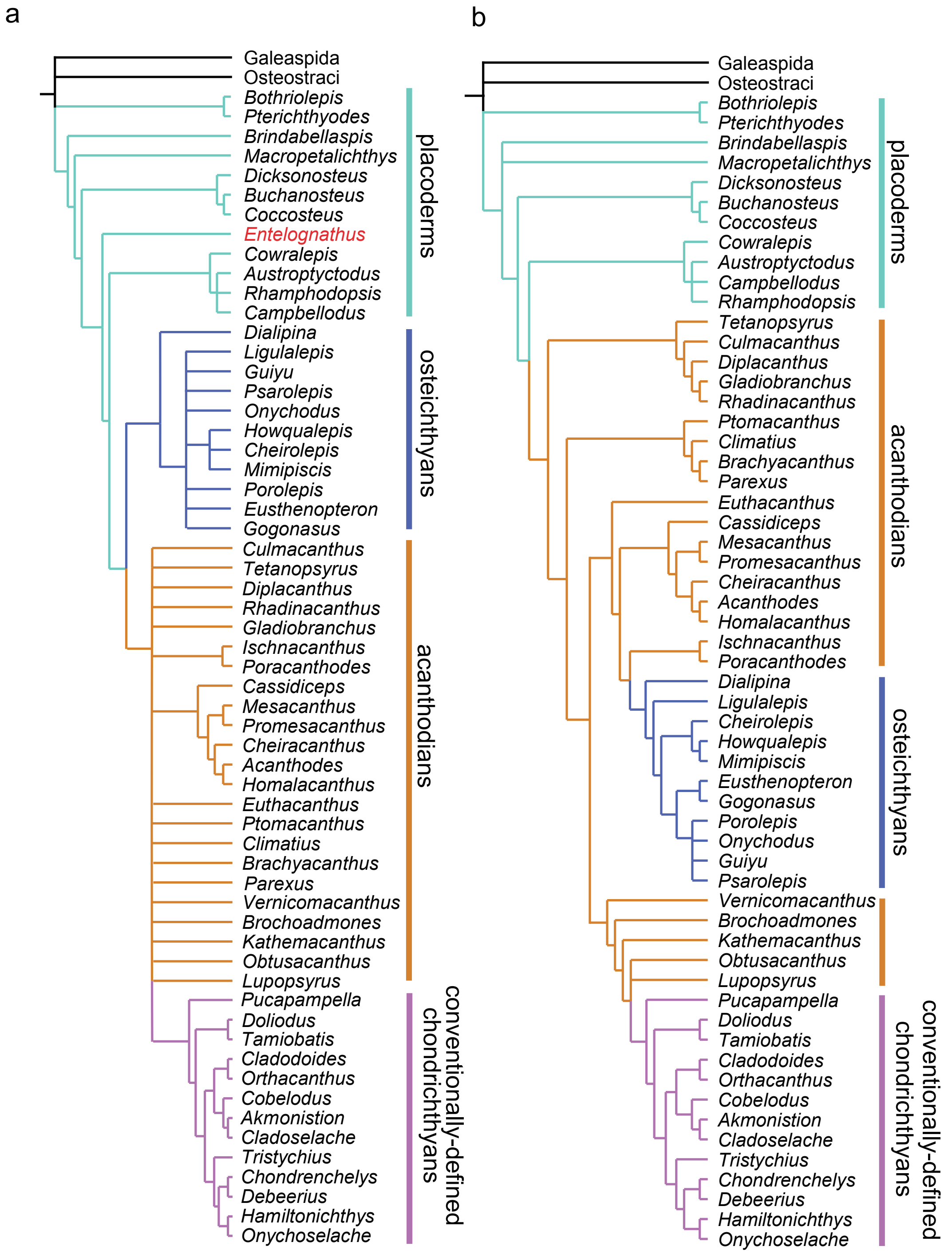
Supplementary Figure 3. One of the 1117 most parsimonious trees from the analysis of the full dataset, with node numbers defining various clades (tree length = 598; consistency index = 0.4398; homoplasy index = 0.5602; retention index = 0.8131; rescaled consistency index = 0.3576).



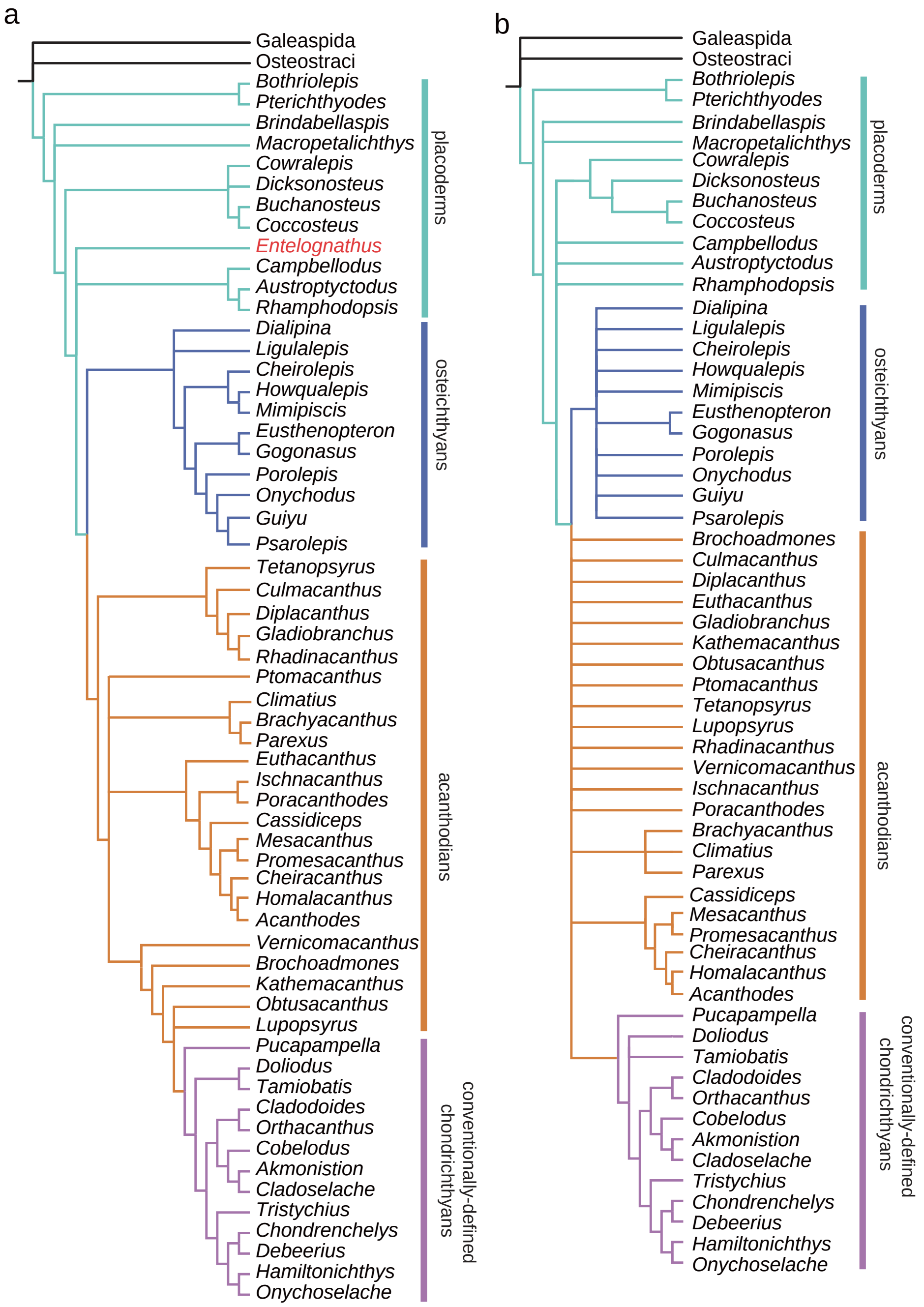
Supplementary Figure 4. Three sets of the 1117 most parsimonious trees (MPTs) from the analysis of the full dataset. **a.** *Entelognathus* as the sister group of crown gnathostomes, 738 MPTs, 66% of the total 1117 MPTs. **b.** ptyctodonts as the sister group of crown gnathostomes, 66 MPTs, 6% of the total 1117 MPTs. **c.** the *Enteolognathus* - ptyctodonts - arthrodire cluster as the sister group of crown gnathostomes, 313 MPTs, 28% of the total 1117 MPTs.



Supplementary Figure 5. Bayesian analyses of the full dataset, which is a modified dataset with 253 characters and 75 taxa including *Entelognathus*. Values associated with nodes indicate the frequency with which those bipartitions occur among sampled trees (posterior probabilities). The standard deviation of split frequencies reaches 0.00658.

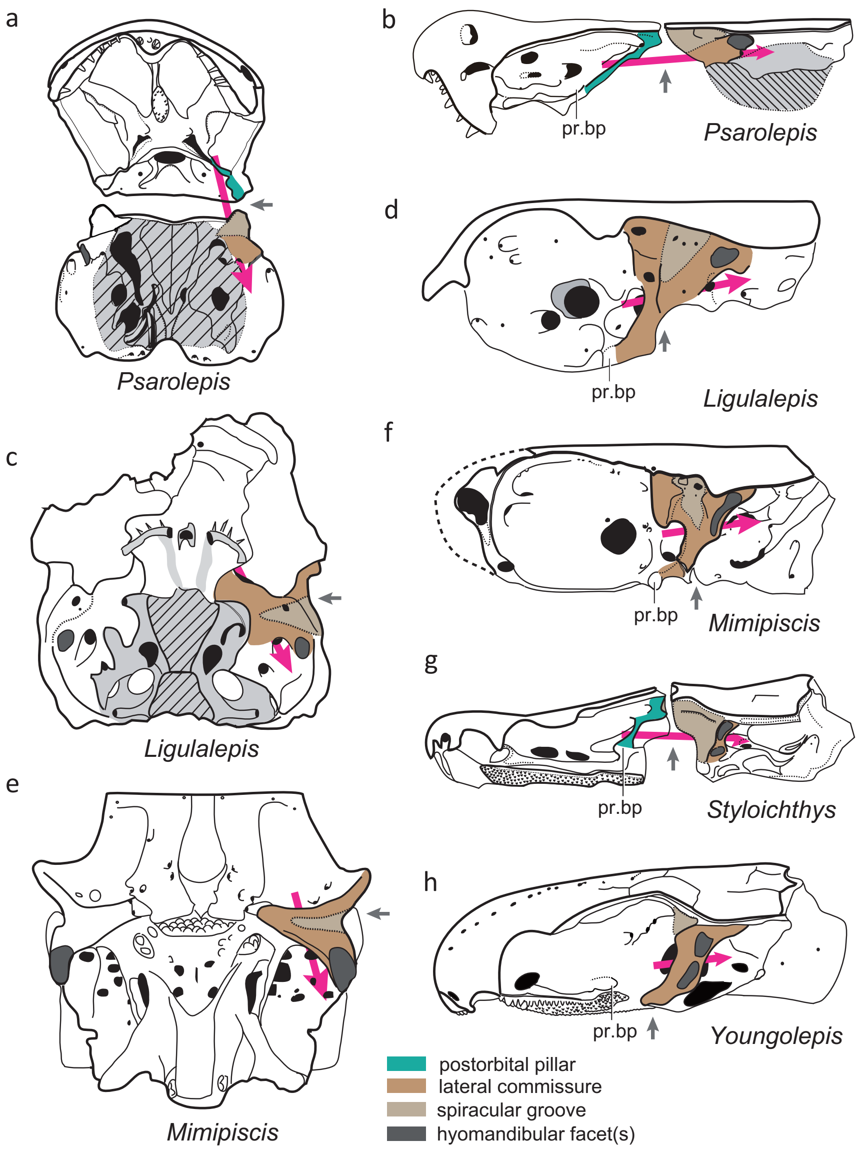


Supplementary Figure 6. a, Strict consensus tree of 503 most parsimonious trees using subset 1, which is the same dataset as Davis *et al*. (2012), but with the addition of *Entelognathus* codings to the original 138 characters and 60 taxa (tree length = 360, consistency index = 0.3917). **b**, Strict consensus tree of 512 most parsimonious trees using subset 1, but with the exclusion of *Entelognathus* codings (tree length = 356, consistency index = 0.3961). The topologies are identical to those in supplementary figure 16 of Davis *et al.* (2012).

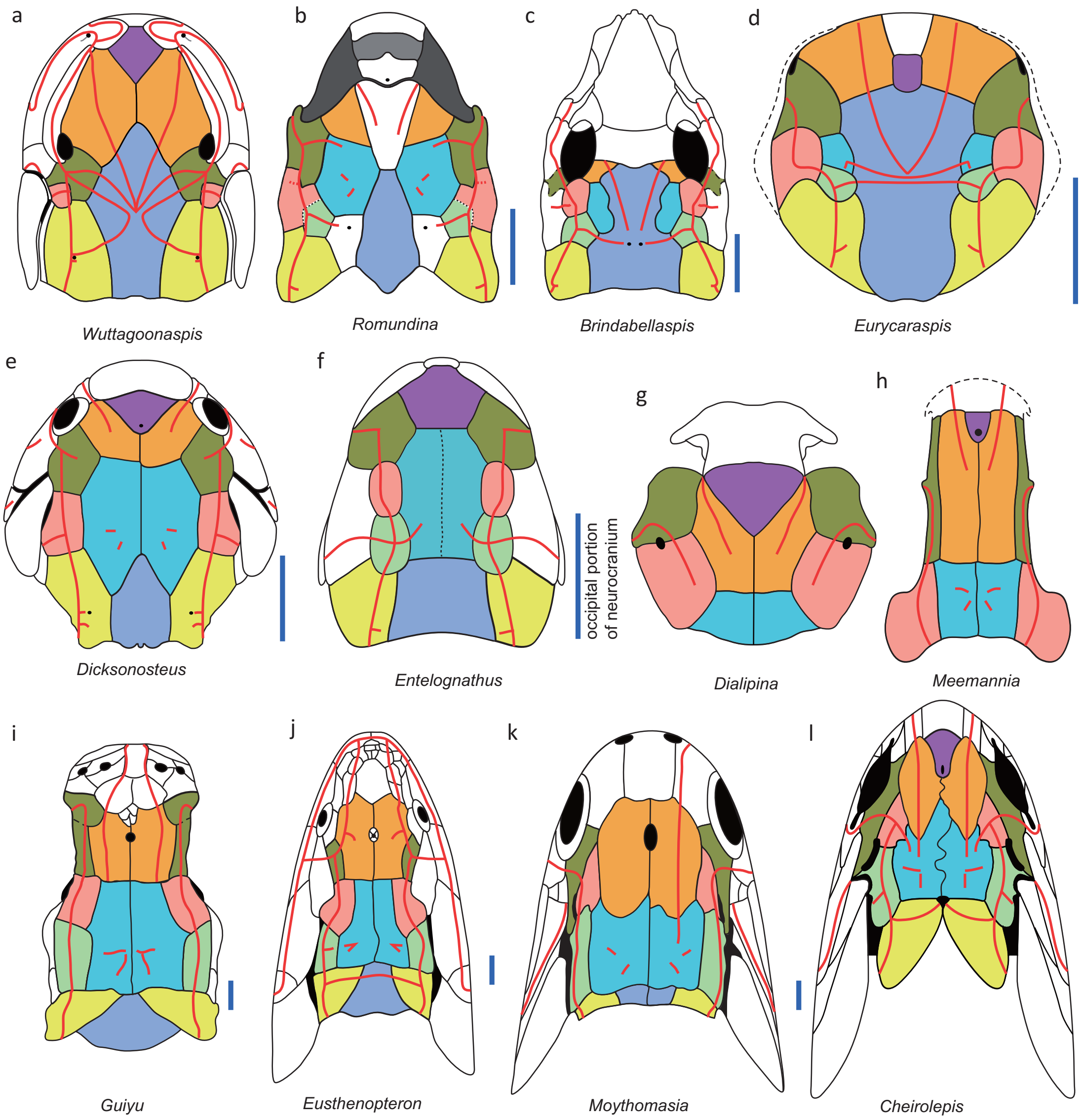


Supplementary Figure 7. a, Strict consensus tree of the 121 most parsimonious trees using subset 2, which is a modified dataset of 138 characters and 61 taxa (including *Entelognathus*) (tree length = 360, consistency index = 0.3917). The dataset is based on the original dataset of Davis *et al.* (2012), but with revised codings for 29 characters, which are underlined and boldfaced in the data matrix. **b**, Strict consensus tree of the 2875 most parsimonious trees based on the same dataset as in (**a**), but with the exclusion of *Entelognathus* codings (tree length = 356, consistency index = 0.3961).

Supplementary Figure 8. a, Strict consensus tree of the 772 most parsimonious trees using subset 3, which is an expanded modified dataset of 253 characters and 61 taxa (including *Entelognathus*) (tree length = 525, consistency index = 0.4743).The dataset is based on the original dataset of Davis *et al.* (2012), with revised codings for 29 characters and with 115 additional characters. **b**, Strict consensus tree of the 769 most parsimonious trees based on the same dataset as in (**a**), but with the exclusion of *Entelognathus* codings (tree length = 513, consistency index = 0.4834).



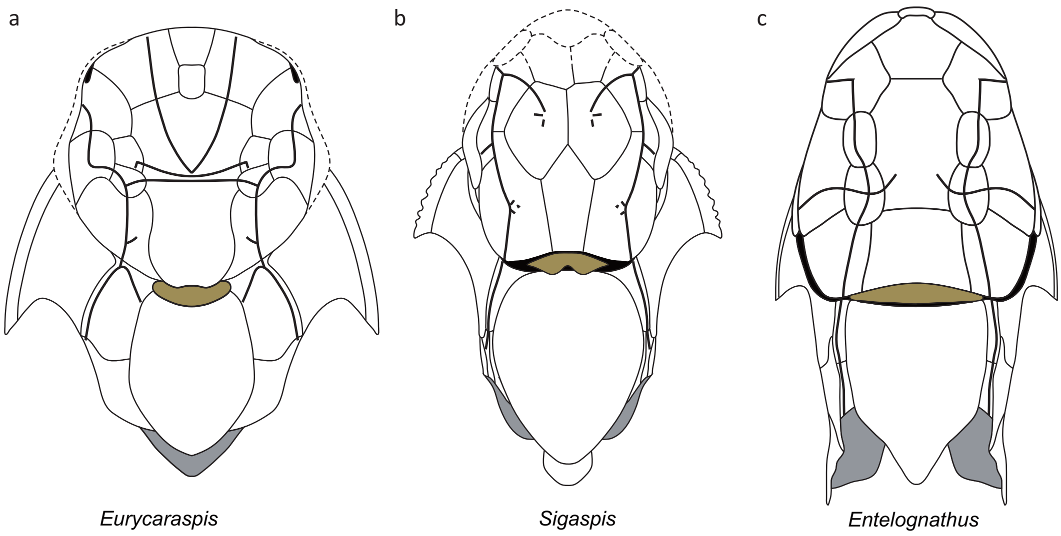
Supplementary Figure 9. Position of hyomandibular facet(s) in relation to the lateral commissure in selected osteichthyans. **a**, **b**, *Psarolepis*. **c**, **d**, *Ligulalepis*. **e**, **f**, *Mimipiscis*. **g**, *Styloichthys*. **h**, *Youngolepis*. Small grey arrows indicate the position of basicranial fissure or the approximate division between ethmosphenoid and otico-occipital portions (as in *Youngolepis* and other forms where the basicranial fissure is absent). Red arrows indicate the passage of jugular vein. Illustrations are modified from Basden *et al.* (2001), Gardiner (1984), Yu (1998), Chang (1982), Zhu & Yu (2002). Not in scale.



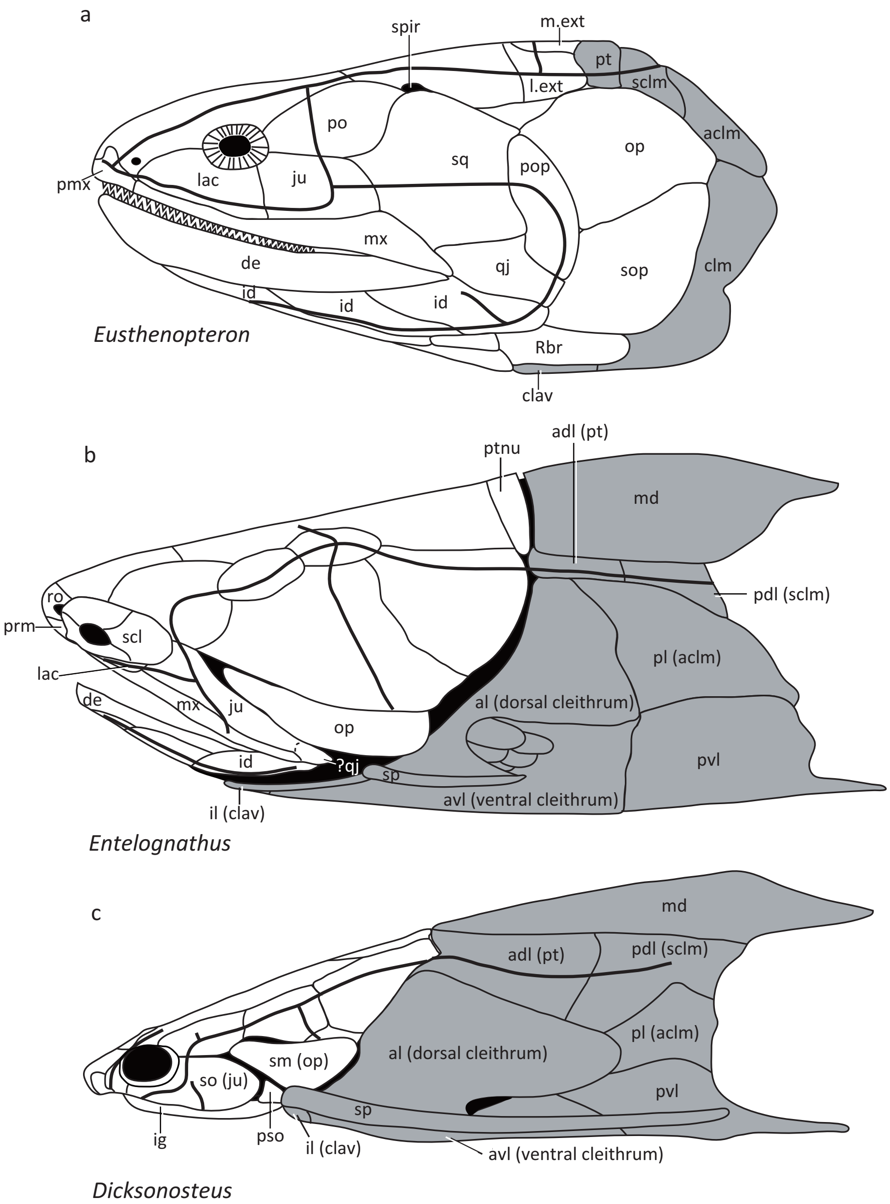
	placoderms	sarcopts	actinopts
	pineal		pineal
	preorbital	parietal	frontal
	central	postparietal	parietal
	postorbital	intertemporal	dermosphenotic

	placoderms	sarcopts	actinopts
	marginal	supratemporal	intertemporal
	anterior paranuchal	tabular	supratemporal
	paranuchal or posterior paranuchal	lateral extrascapular	
	nuchal	median extrascapular	

Supplementary Figure 10. Comparison of skull-roof dermal bone pattern in osteichthyans and placoderms including *Entelognathus*. **a**, Arthrodire (*Wuttagoonaspis*, after Ritchie 1973). **b**, Acanthothoracid (*Romundina*, after Goujet & Young 2004). **c**, Acanthothoracid (*Brindabellaspis*, after Young 2010). **d**, Petalichthyid (*Eurycaraspis*, after Liu 1991). **e**, Arthrodire (*Dicksonosteus*, after Goujet 1984). **f,** *Entelognathus*. **g**, Stem-group Osteichthyes (*Dialipina*, after Schultze & Cumbaa 2001). **h**, Stem-group Osteichthyes (*Meemannia*, after Zhu *et al.* 2006). **i**, Sarcopterygii (*Guiyu*, after Qiao & Zhu 2010). **j**, Sarcopterygii (*Eusthenopteron*, after Jarvik 1980). **k**, Actinopterygii (*Moythomasia*, after Jessen 1968). **l**. Actinopterygii (*Cheirolepis*, after Pearson & Westoll 1979). Vertical bar represents the proportional length of the occipital portion of braincase.



Supplementary Figure 11. Comparison of the postnuchal in placoderms. **a**, Petalichthyid *Eurycaraspis*, after Liu 1991). **b**, Arthrodire (*Sigaspis*, after Goujet 1973). **c**, *Entelognathus*. The postnuchal (in yellowish grey) is equivalent to the "extrascapular" of placoderms. We propose that the extrascapular series of osteichthyans are equivalent to the nuchal and posterior paranuchal of placoderms (Supplementary Table 1).



Supplementary Figure 12. Comparison of dermal bone pattern of the cheek, shoulder girdle and jaws in osteichthyans and placoderms including *Entelognathus*. **a**. Osteichthyes (*Eustenopteron*, after Jarvik 1980). **b**. *Entelognathus*. **c**. Arthrodira (*Dicksonosteus*, after Goujet 1984).

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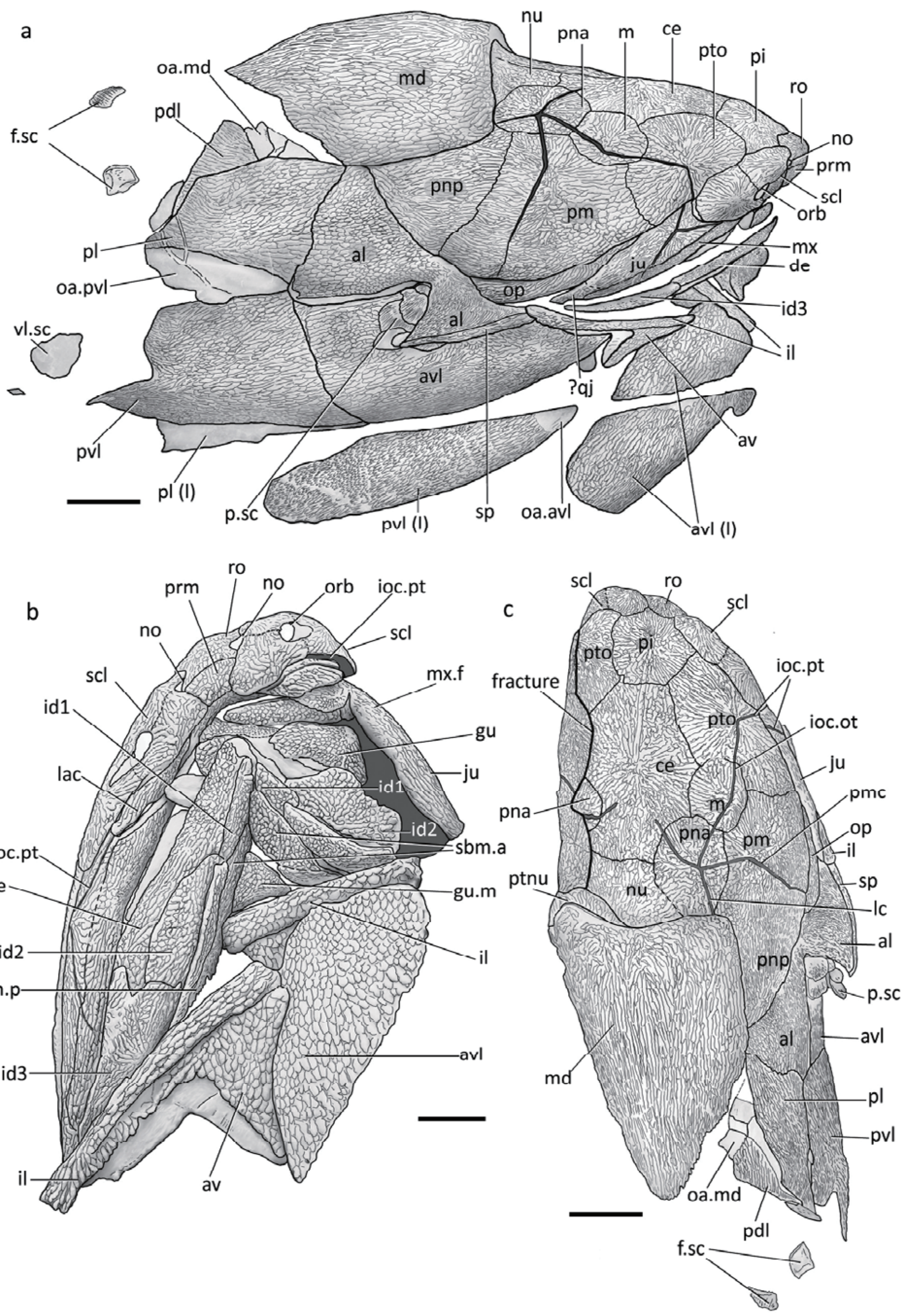

Supplementary Figure 13. Illustrative drawings of the holotype (IVPP V18620) in lateral (**a**), anteroventral (**b**) and dorsal (**c**) views. For photos, see Figs 2b-d, Supplementary Figs 14a, 16, 17. Scale bar, 1 cm.

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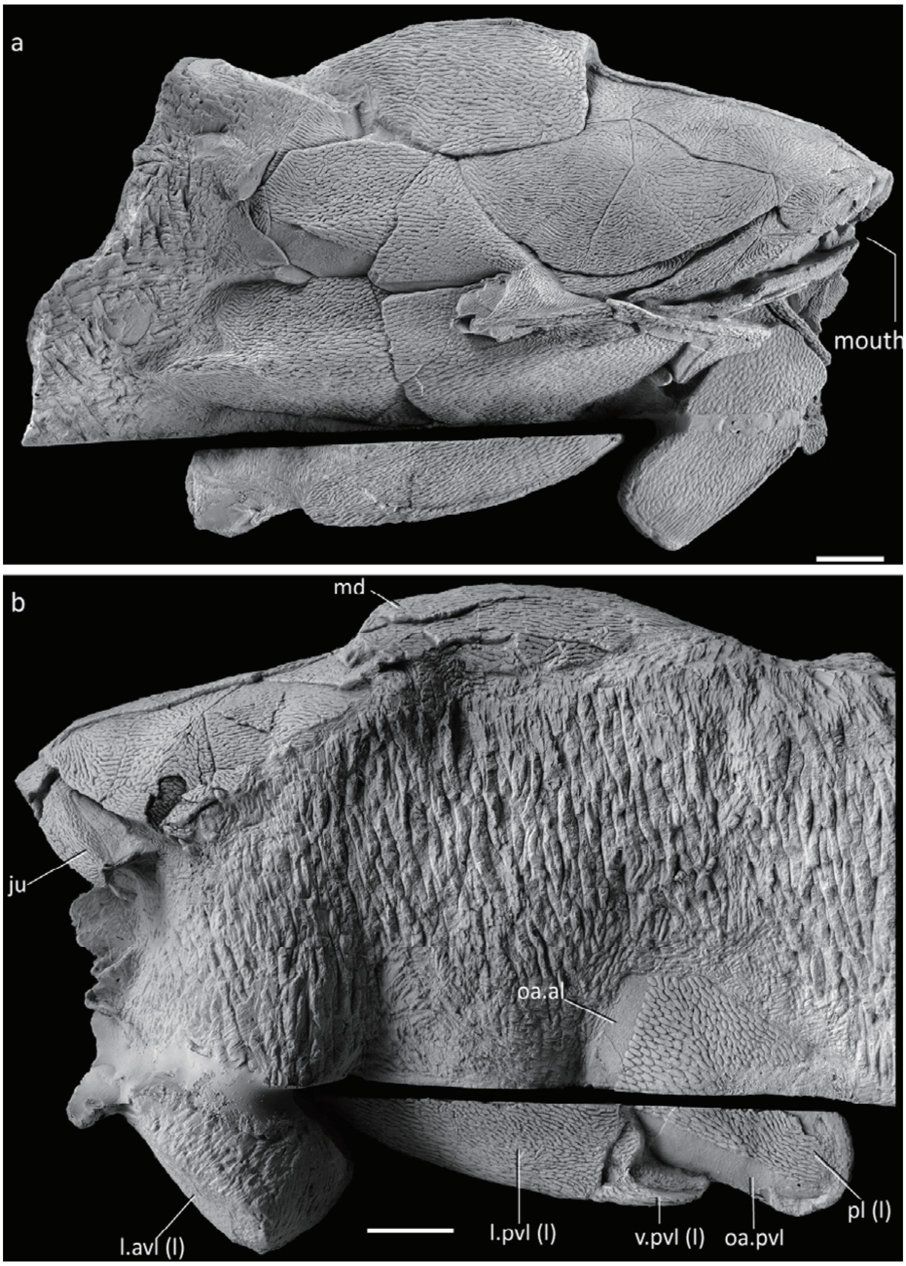
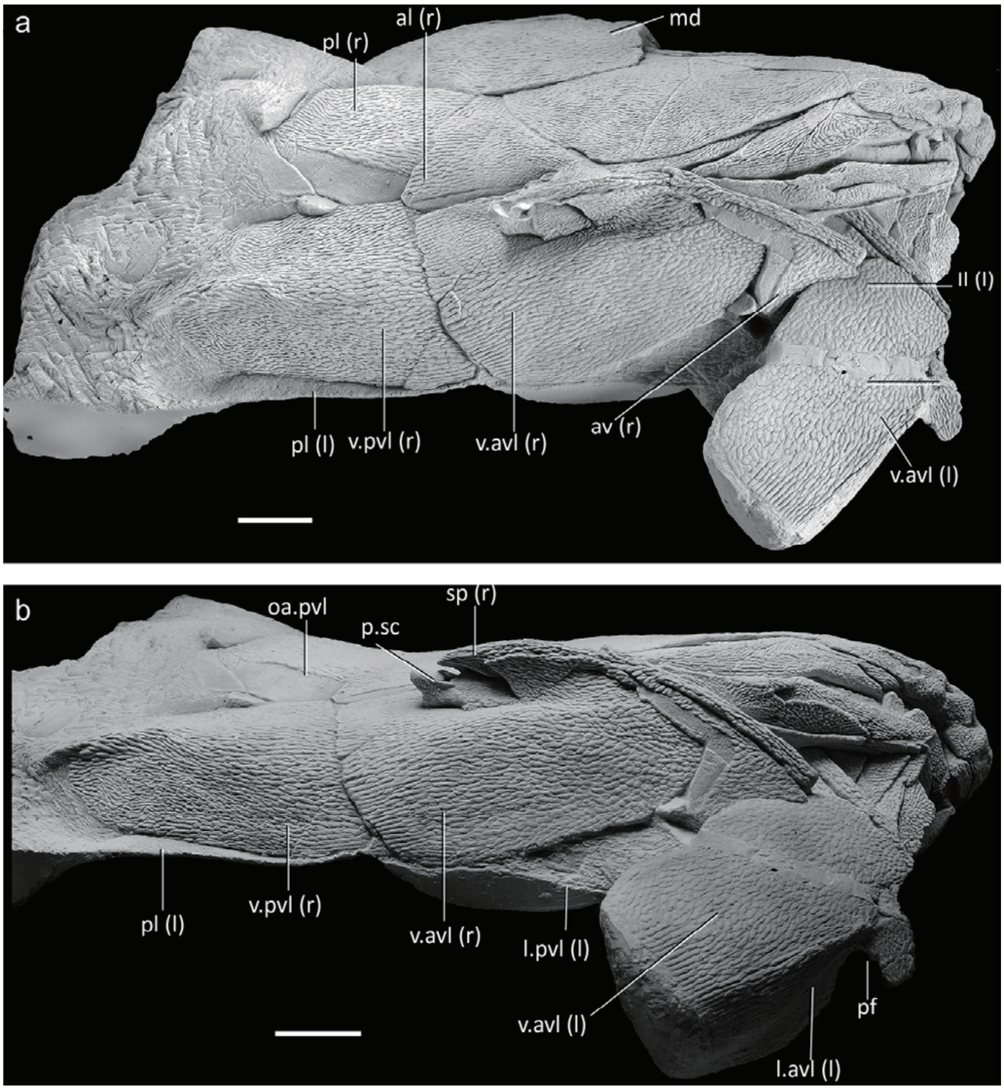
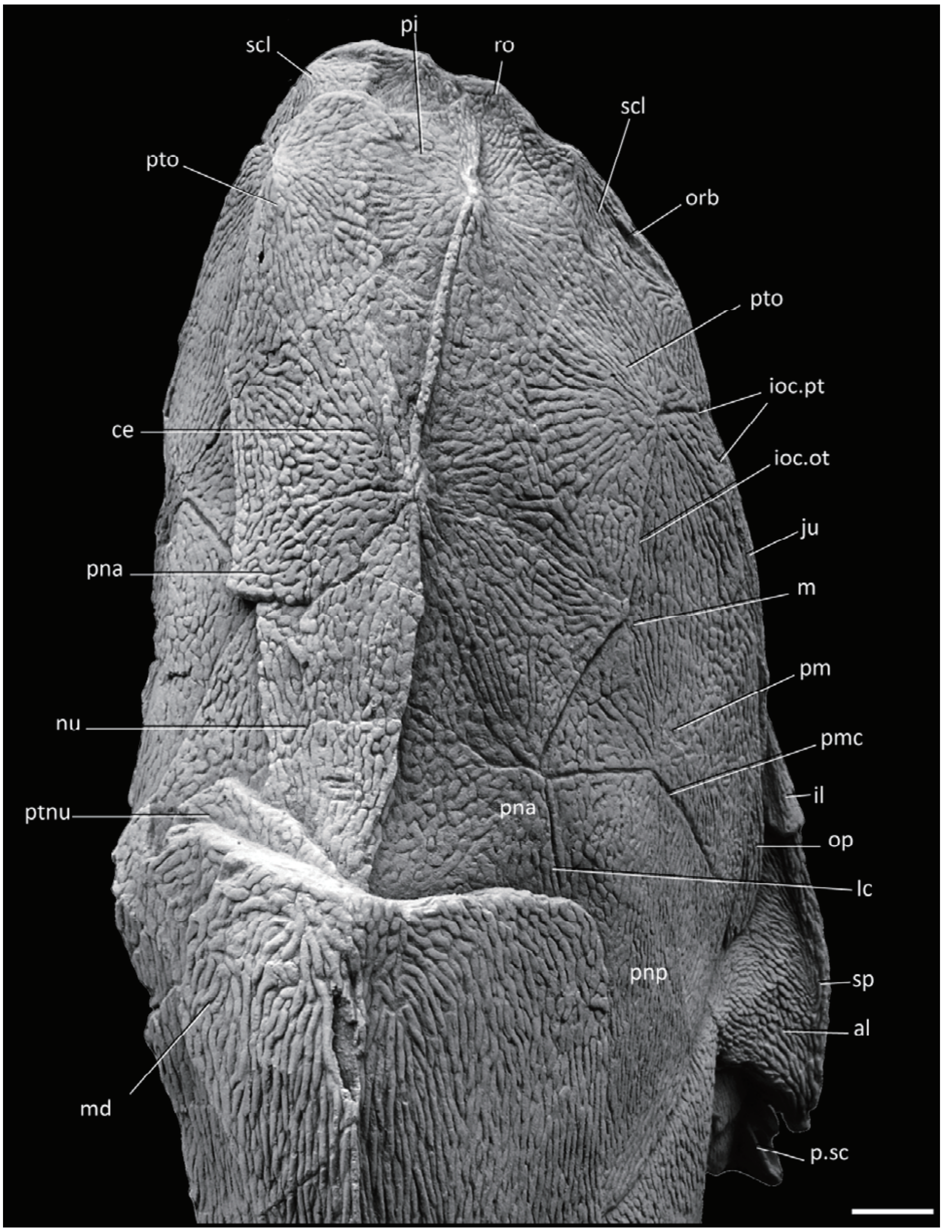


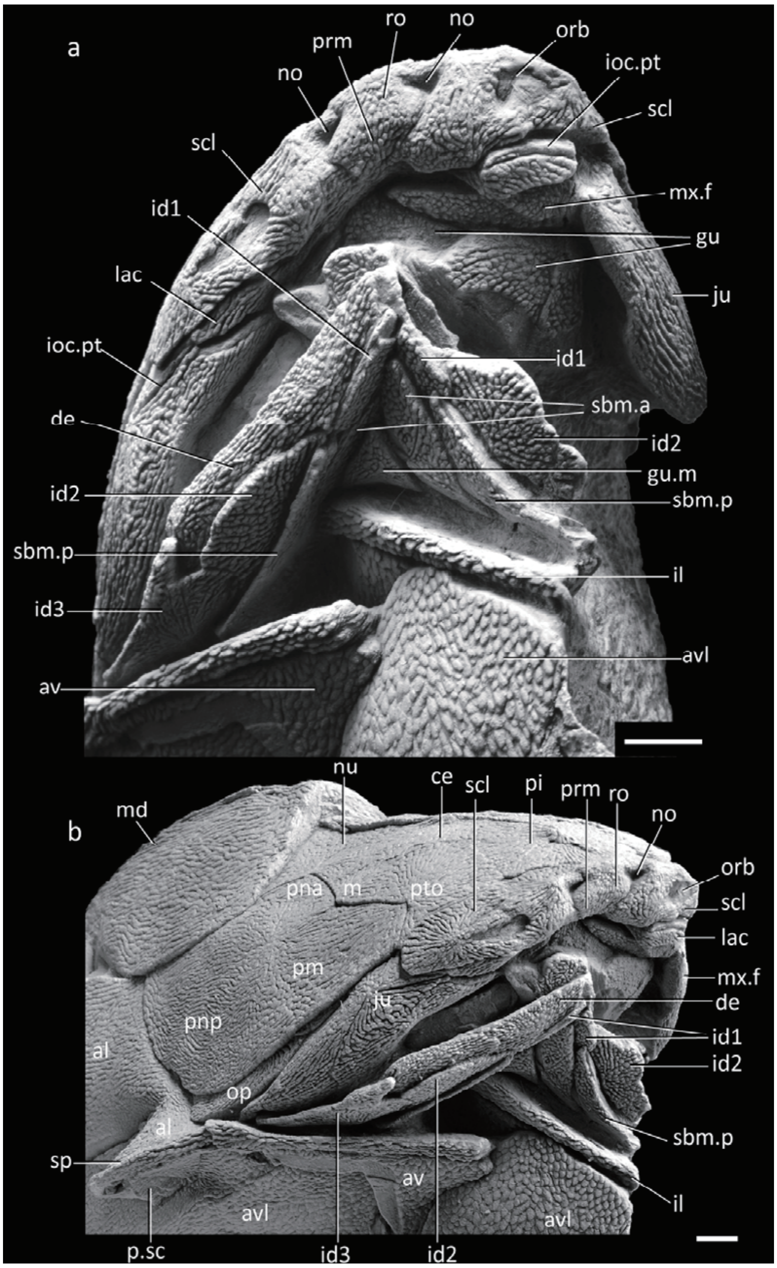
Supplementary Figure 14. Holotype (IVPP V18620) of *Entelognathus primordialis* in right lateral (**a**) and left lateral (**c**) views. A small displaced part of the trunk amour from the left side was accidentally sawed off as extraneous material and repositioned here. Specimen coated with ammonium chloride sublimate. Scale bar, 1 cm.



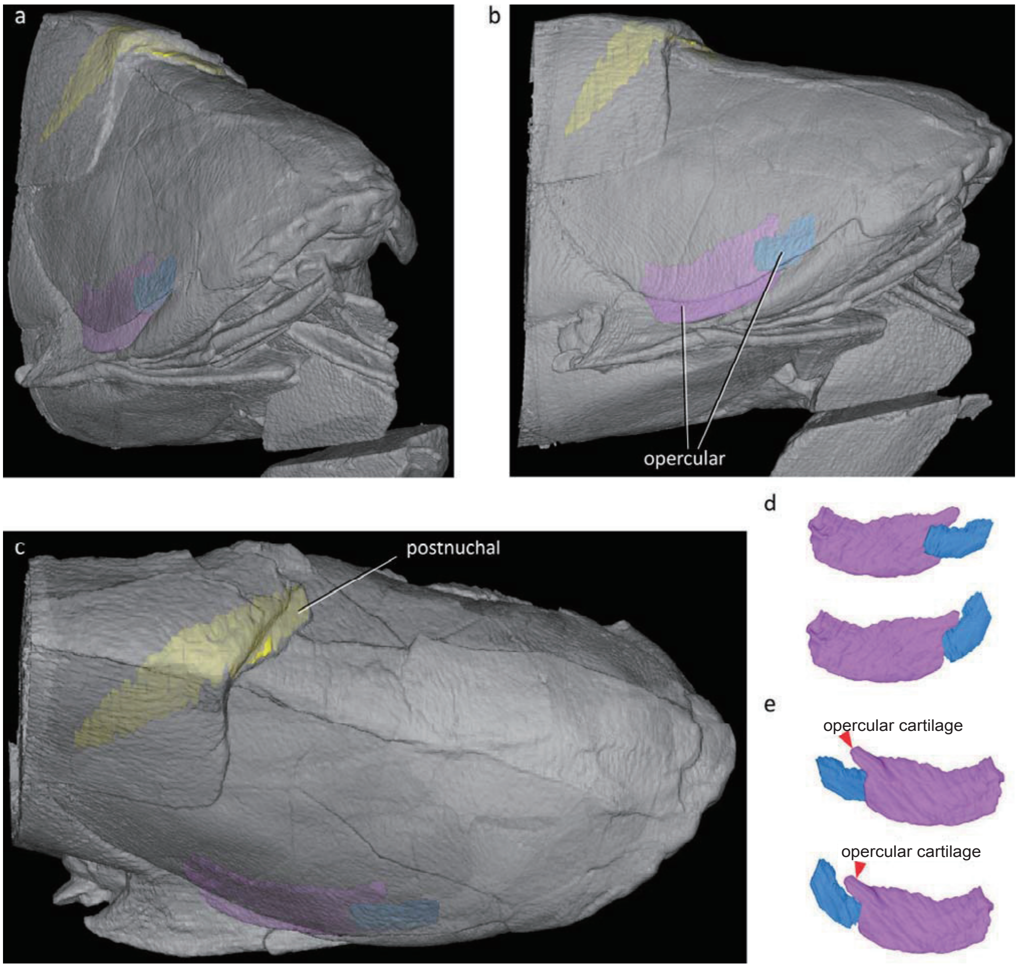
Supplementary Figure 15. Holotype (IVPP V18620) of *Entelognathus primordialis* in lateroventral and ventral (**b**) views. Specimen coated with ammonium chloride sublimate. Scale bar, 1 cm.



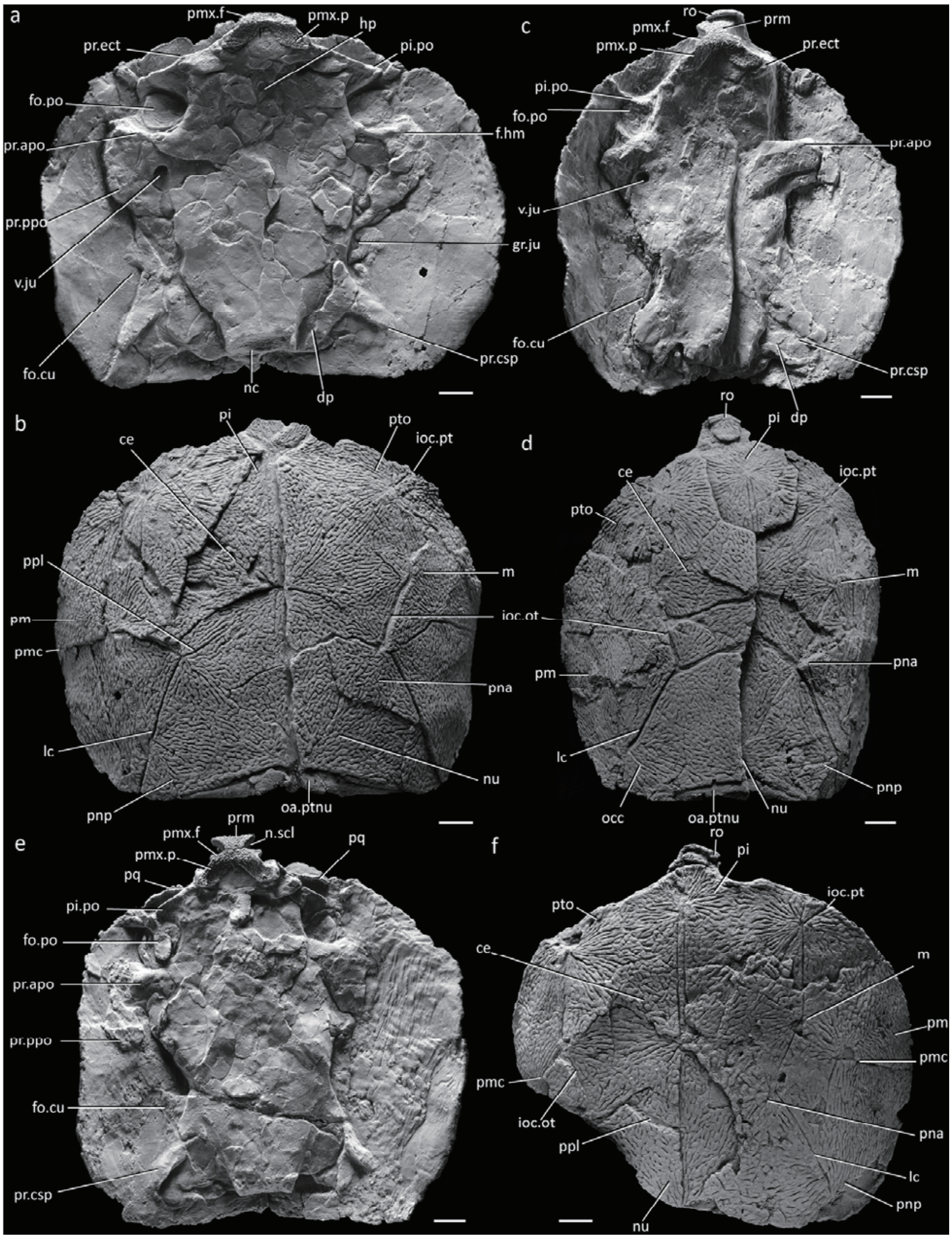
Supplementary Figure 16. Holotype (IVPP V18620) of *Entelognathus primordialis* in dorsal view. Specimen coated with ammonium chloride sublimate. Scale bar, 5 mm.



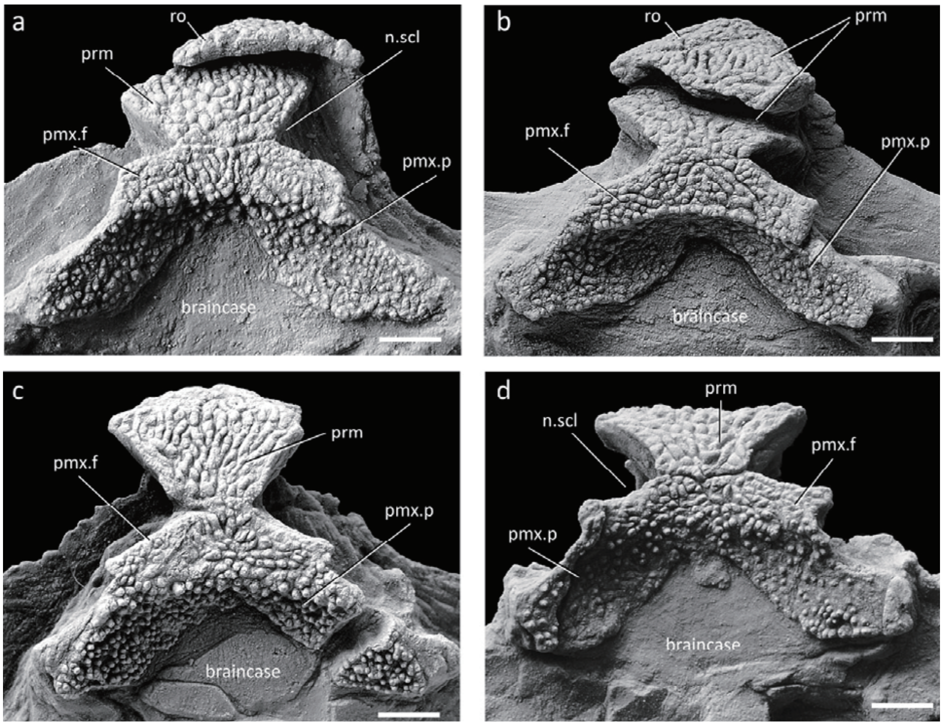
Supplementary Figure 17. Holotype (IVPP V18620) of *Entelognathus primordialis* in anteroventral (**a**) and anterolateral (**b**) views. Specimen coated with ammonium chloride sublimate. See Supplementary Fig. 21a, b for corresponding restorations based on X-ray tomography, Scale bar, 1 cm.



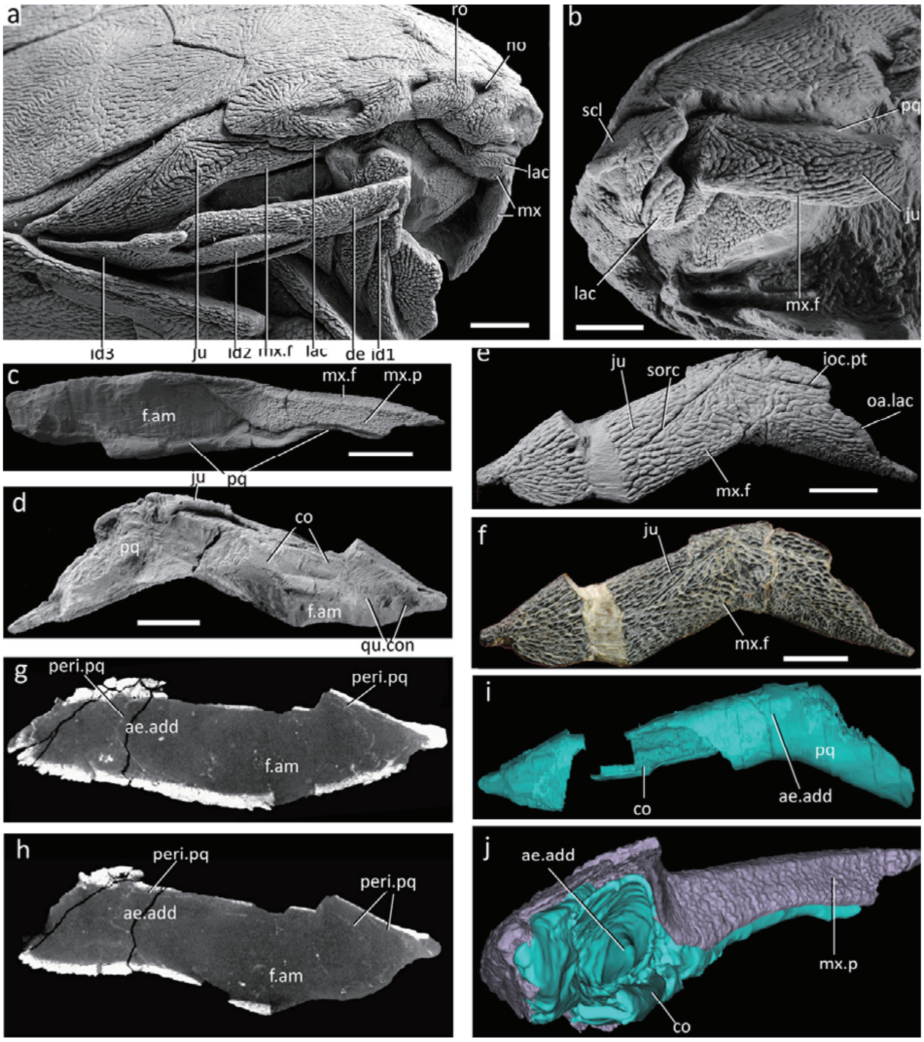
Supplementary Figure 18. Digital restorations based on X-ray tomography showing the unexposed opercular and postnuchal plates in the holotype (IVPP V18620). **a-c**, Anterior part of the specimen in anterolateral (**a**), lateral (**b**) and dorsal (**c**) views. **d**, Opercular in external view, with slightly displaced part shown in preserved position (upper) and restored position (lower). **e**, Opercular and opercular cartilage in mesial view, with slightly displaced part shown in preserved position (upper) and in restored position (lower).



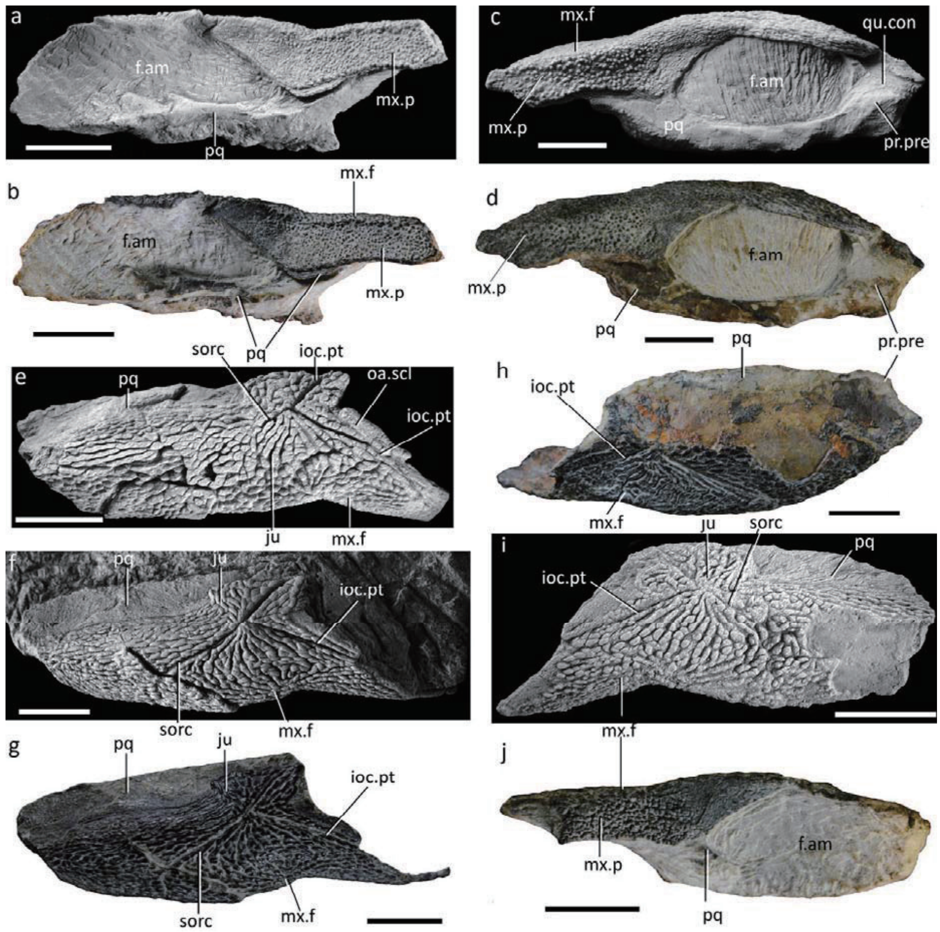
Supplementary Figure 19. Skull roof and braincase of *Entelognathus primordialis*. **a-b**, Skull in ventral (**a**) and dorsal (**b**) views, IVPP V18621.3. **c-d**, Skull in ventral (**c**) and dorsal (**d**) views, IVPP V18621.4. **e**. Skull in ventral view, IVPP V18621.2. **f**, Skull in dorsal view, IVPP V18621.5. Specimens coated with ammonium chloride sublimate. Scale bar, 5 mm.



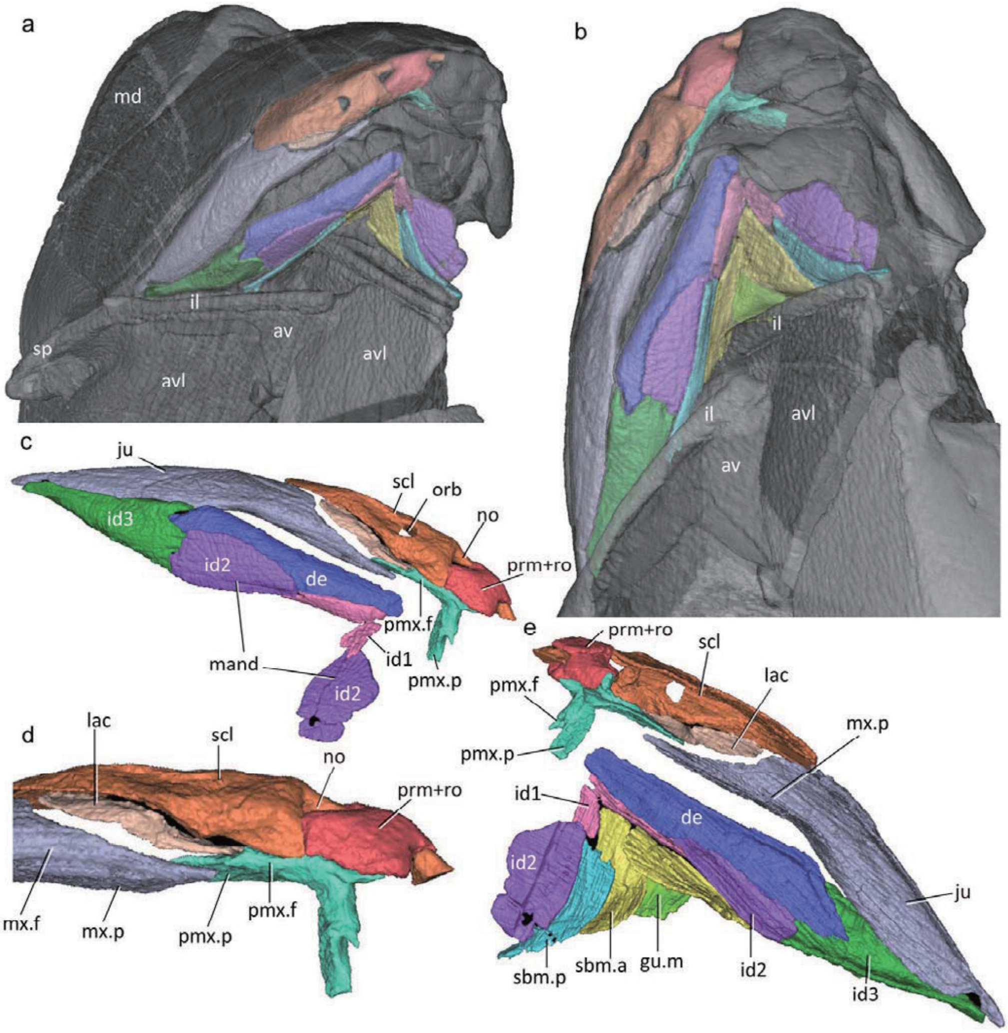
Supplementary Figure 20. Close-up of the skull in ventral view, showing the rostral, premedian and premaxillae. **a**, IVPP V18621.4. **b**, IVPP V18621.5. **c**, IVPP V18621.1. **d**, IVPP V18621.2. Specimens coated with ammonium chloride sublimate. Scale bar, 2 mm.



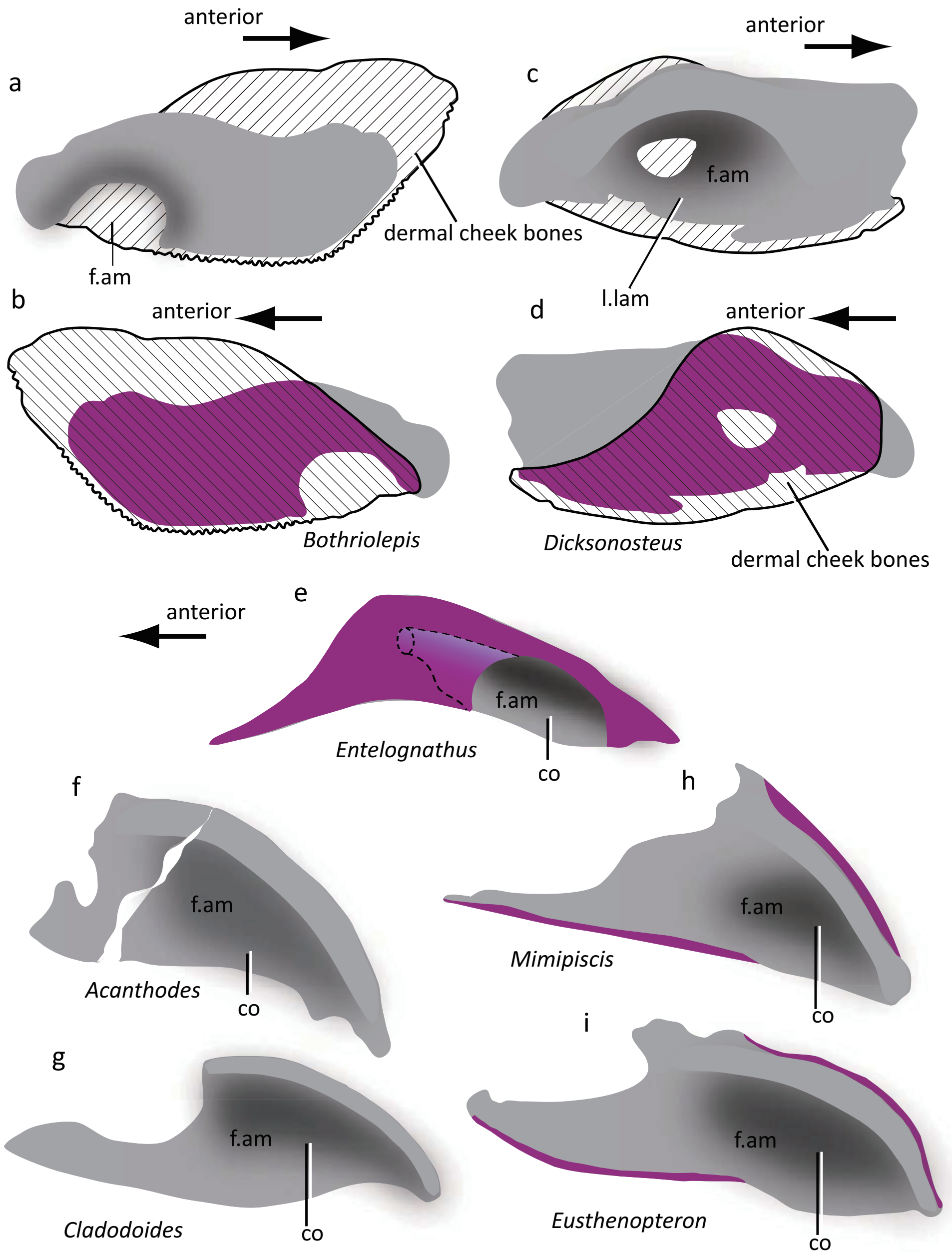
Supplementary Figure 21. Dermal marginal jaw bones and palatoquadrate of *Entelognathus primordialis*. **a**, **b,** Close-up of the holotype (IVPP V18620) in right (**a**) and left (**b**) lateral views. **c-f,** Right cheek and jaw complex in ventral (**c**), medioventral (**d**), and lateral (**e-f**) views, IVPP V18622.3. **g-j**, Digital restorations of IVPP V18622.3. **g-h**, Selected CT scan slices through anterior extension of the adductor chamber. **i.** Palatoquadrate in lateral view, semi-transparent to show the anterior extension of the adductor chamber. **j**, Anterior extension of the adductor chamber viewed from the posterior. Specimens coated with ammonium chloride sublimate in **a-e.** Scale bar, 5 mm.



Supplementary Figure 22. Dermal marginal jaw bones and palatoquadrate of *Entelognathus primordialis*. **a, b**, Right cheek and jaw complex in ventral view, IVPP V18622.5. **c**, **d**, Left cheek and jaw complex in ventral view, IVPP V18622.4. **e**, Right cheek and jaw complex in lateral view, IVPP V18622.5. **f, g**, Right cheek and jaw complex in lateral view, IVPP V18622.7. **h**, Left cheek and jaw complex in lateral view, IVPP V18622.4. **i**, **j**, Left cheek and jaw complex in lateral (**i**) and ventral (**j**) views, IVPP V18622.6. Specimens coated with ammonium chloride sublimate in **a,** **c**, **e**, **f, i**. Scale bar, 5 mm.



Supplementary Figure 23. Digital restorations based on X-ray tomography showing the cheek complex, sclerotic ring, mandible, submandibular and gular series in the holotype (IVPP V18620). **a,** Head and trunk armour in anteroventral view. **b,** Head and trunk armour in ventral view. **c**, Cheek complex, scleroitic ring and mandible, in anterolateral view. **d**, Close-up of **c,** in more palatal view to show the palatal laminae of premaxilla and maxilla. **e**, Cheek complex, sclerotic ring, mandible, submandibular and gular series in internal view.



Supplementary Figure 24. Comparison of palatoquadrate in antiarchs, arthrodires, *Entelognathus* and crown gnathostomes. Note that the palatoquadrate in antiarch and arthrodire placoderms is shown with associated dermal cheek bones (in hatched lines) in mesial (**a, c**) and lateral (**b**, **d**) views, while the palatoquadrate in the remaining taxa (**e-i**) is in lateral view to show the fossa for mandibular adductor muscle. The areas in red (**b, d, e, h, i**) represent the contact faces with large dermal bones. **a,b**, Antiarch (*Bothriolepis*, after Young 1984). **c,d**, Arthrodire (*Dicksonosteus*, after Goujet 1975); note the lateral lamina (lateral to the fossa for mandibular adductor muscle) attaching onto dermal cheek bone. **e**, *Entelognathus*. **f**, Acanthodian (*Acanthodes*, after Jarvik 1977). **g**, Crown chondrichthyan (*Cladodoides*, after Jarvik 1980). **h**, Actinopterygian (*Mimipiscis*, after Gardiner 1984). **i**, Sarcopterygian (*Eusthenopteron*, after Jarvik 1980).

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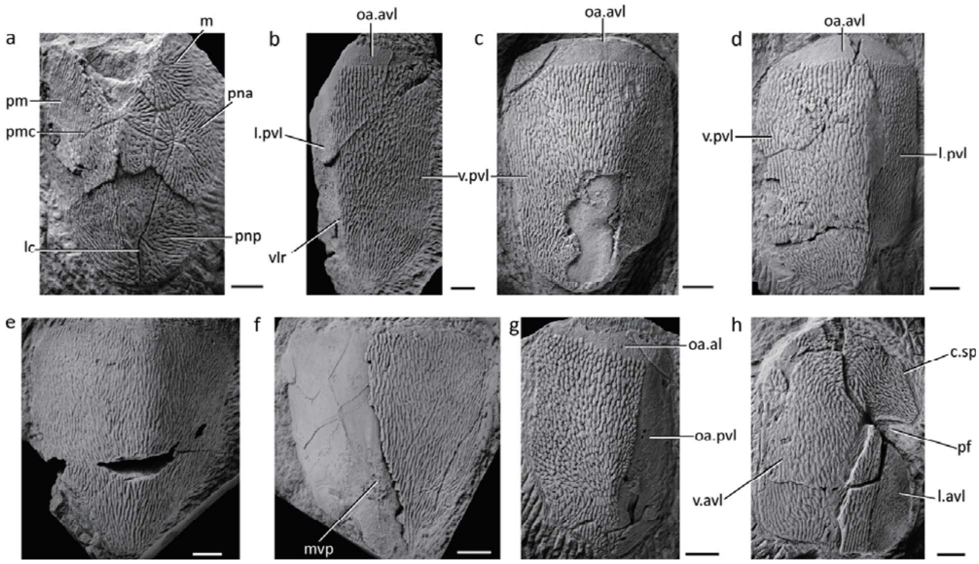
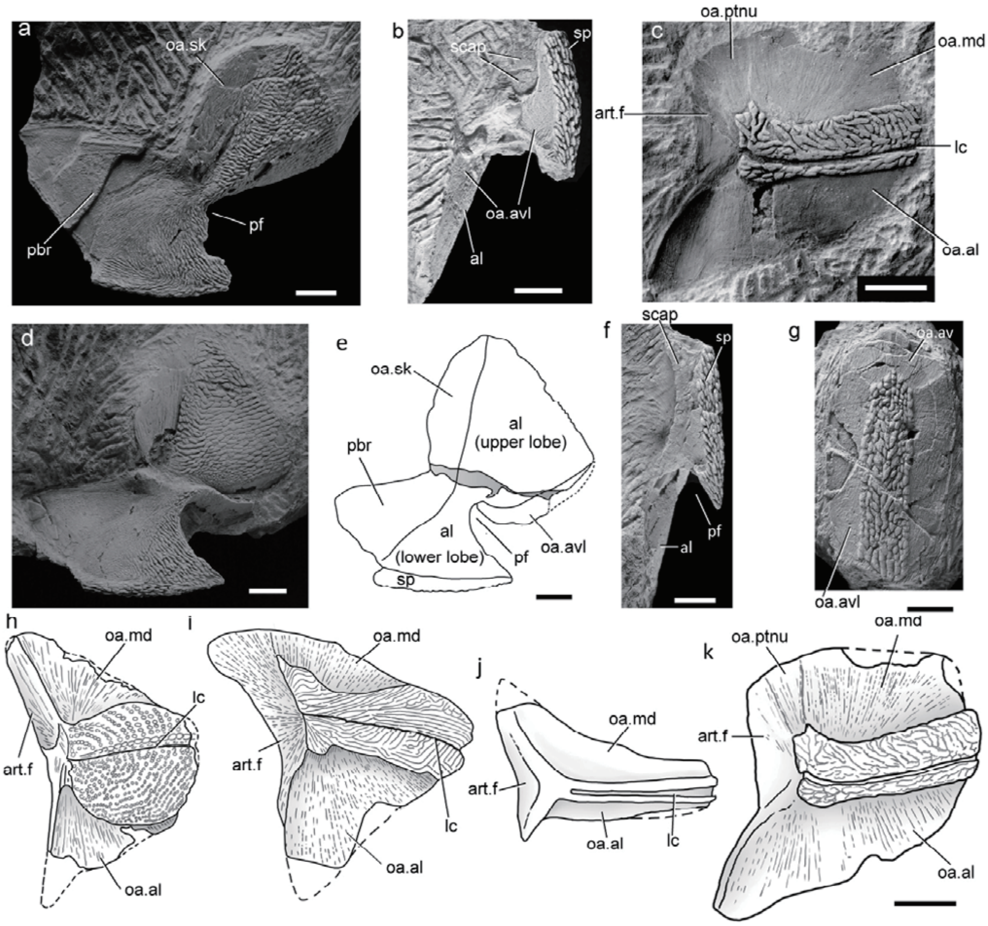
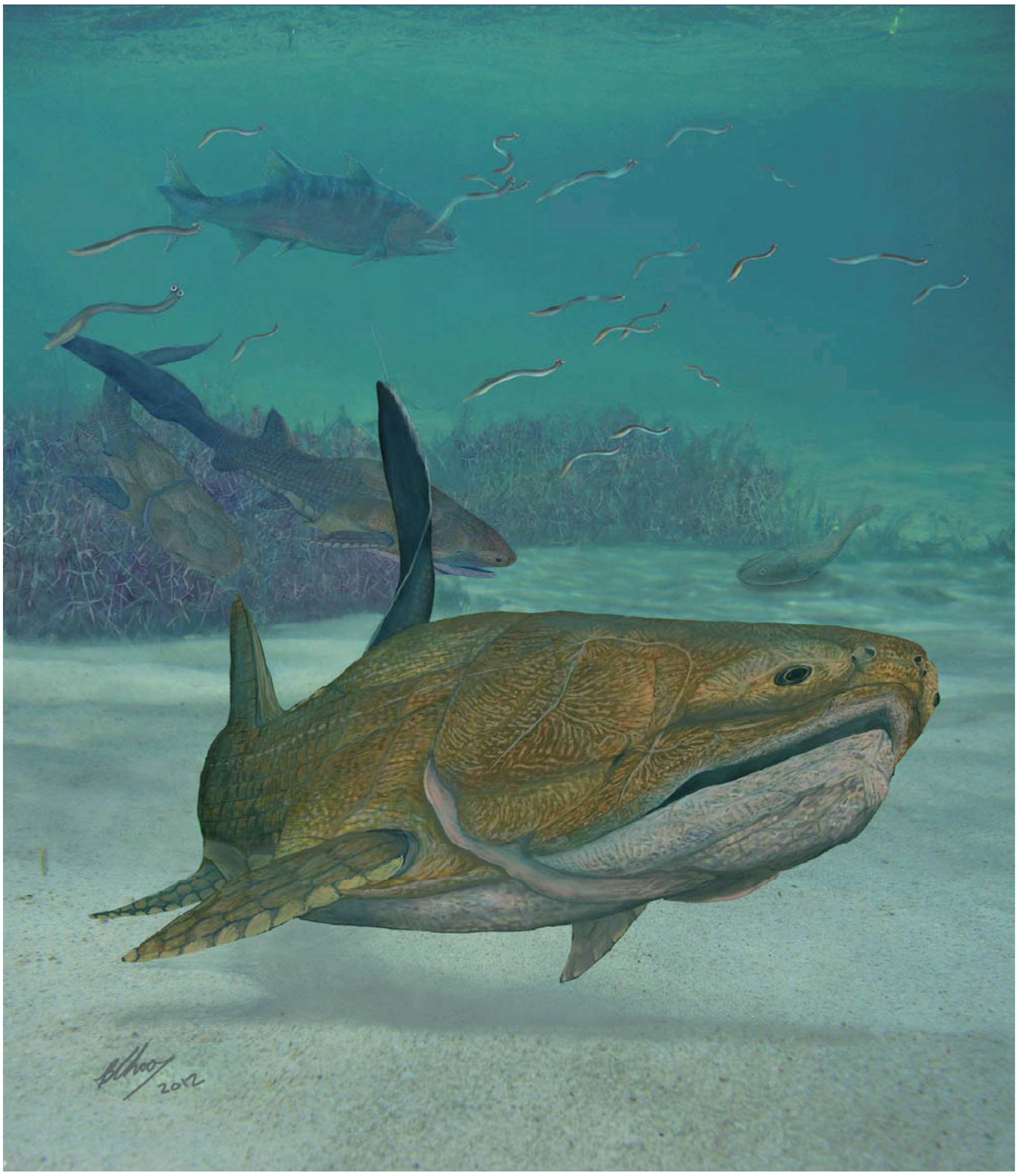


Supplementary Figure 25. *Entelognathus primordialis.* **a**, Part of skull roof in dorsal view, IVPP V18621.6. **b**, Right posterior ventrolateral plate, IVPP V18622.28. **c**, Left posterior ventrolateral plate, IVPP V18622.32. **d**, Left posterior ventrolateral plate, IVPP V18622.33. **e**, Median dorsal plate, IVPP V18622.11.**f**, Median dorsal plate, IVPP V18622.12.**g**, Right posterior lateral plate, IVPP V18622.26.**h**, Left anterior ventrolateral plate, IVPP V18622.22. Specimens coated with ammonium chloride sublimate. Scale bar, 5 mm.



Supplementary Figure 26. a-g, Disarticulated trunk armour plates of *Entelognathus primordialis*. **a**, **b**, Anterior lateral and spinal plates in lateral (**a**) and ventral (**b**) views, IVPP V18622.18. **c**, Left anterior dorsolateral plate, IVPP V18622.17. **d-f**, Anterior lateral and spinal plates in lateral (**d-e**) and ventral (**f**) views, IVPP V18622.19. **g**, Anterior medioventral plate, IVPP V18622.25. Specimens coated with ammonium chloride sublimate. **h-k**, Comparison of anterior dorsolateral plate in *Actinolepis magna* (**h,** after Mark-Kurik 1973, fig. 10E), *Wuttagoonaspis fletcheri* (**i,** after Ritchie 1973, fig. 2a), an indeterminate phyllolepid (**j**, after Young & Long 2005, fig. 10a) and *Entelognathus primordialis* (**k**). h-j, not in scale. Scale bar, 5 mm.



Supplementary Figure 27. Life restoration of *Entelognathus primordialis* from the Kuanti Formation (late Ludlow, Silurian), Qujing, Yunnan, China.

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