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Supplementary information

An early Cambrian euarthropod with radiodont-like raptorial appendages

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An early Cambrian euarthropod with radiodont-like raptorial appendages

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SUPPLEMENTARY DISCUSSION

CONTENT

DETAILED DESCRIPTION OF *KYLINXIA ZHANGI*

Derivation of name

Our new Cambrian euarthropod *Kylinxia* is named after 'kylin', a well-known mythical creature in China. Kylin is one of the grandsons of the Yellow Dragon and is a chimeric animal that combines body features of different animals including dragon head, deer body, horse hooves, ox tail, fish skin and others. Traditionally, kylin is a symbol of lucky omen and powerful protection. Sculptures of kylin were used as guardians for several tombs of ancient Chinese emperors in the city of Nanjing since 450s AD. A pair of kylin sculptures, originally placed in the ruined imperial Old Summer Palace of the Qing dynasty in Beijing, are now gatekeepers of the State Key Laboratory Building in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences.

Kylinxia zhangi is morphologically distinct from an artiopodan-like euarthropod *Bushizheia yangi* reported recently from the Chengjiang Lagerstätte (O'Flynn *et al*., 2020).

Description and interpretation

General description and preservation. *Kylinxia zhangi* gen. et sp. nov. is known from a total of six specimens preserved in a lateral view (NIGP 171304–171308, YLSNHM 01124), including juveniles and adults ranging 13–67 mm in body length (Fig. 1a, b, Extended Data Figs. 1, 2a, c, e, h). All of the six specimens are almost complete, except for NIGP 171306 (Extended Data Fig. 2c), which lacks the posterior body but has excellent soft-bodied preservation in other body parts. Among the six

specimens, only NIGP 171305 is preserved in the background taphofacies (Extended Data Fig. 2a) and the other five are from the storm event taphofacies of the Chengjiang Lagerstätte (Zhu *et al*., 2001; Hu, 2005). Although the Chengjiang fossils in the background taphofacies had undergone some degree of decay during early fossilization (e.g., Zhao *et al*., 2009), the specimen NIGP 171305 still shows well-preserved soft tissues including the alimentary canal and the ventral nerve cord ('ac', 'vn' in Extended Data Figs. 2a, 6c).

The body of *Kylinxia zhangi* is elongated and arthrodized, and it is divided into head, multi-segmented trunk and pygidium.

Head. Anteriormost of the body are five dorsal stalked compound eyes extending out from the head shield to front. The anterior two eyes are at least twice as large as the posterior three ('ae', 'pe' in Figs. 1c, 2c, g, Extended Data Figs. 1d, e, 2b, d, f, i, 3n, o, 4a–g, 5b). The eyes bear marginal rims ('rm' in Figs. 1c, 2b, c) that may represent possible flattened lens or corneal layers. Eye stalks are short and stout ('es' in Fig. 1c, Extended Data Figs. 2i, 4e). The anteriormost eye region is connected to the more posterior head shield by an arthrodial membrane-like structure ('am' in Fig. 2g, Extended Data Fig. 4a). The head shield is semi-circular and has rounded genal angles ('hs' in Figs. 1c, 2g, Extended Data Figs. 1, 2b, d, f, i, 4a–e), and its lateral margins are rimmed ('hr' in Fig. 2g, Extended Data Figs. 1e, 2f, 4a, c). Posterior to the eye region and stretching out from the ventral side of head shield are a pair of raptorial frontalmost appendages curved in an upward direction ('fa' in Figs. 1c, 2g, Extended Data Figs. 2b, d, f, i, 4a–g). The frontalmost appendages are flexible and are composed of a basal shaft region and a distal articulated region. The shaft is relatively rigid and accounts for up to 20% of the full length of frontal appendage ('sh' in Figs. 1c, 2g, Extended Data Figs. 2b, d, f, i, 4a–g). It has an oblique arthrodial membrane that intersects the inner margin of the shaft with an angle of ~30–45° but has no clear proximal endpoint ('sa' in Figs. 1c, 2g, Extended Data Figs. 2f, i, 3n, 4a, c, e–g, 5b). The distal articulated region comprises 15 podomeres tapering distally in size ('p1–p15' in Figs. 1c, 2g, Extended Data Figs. 2b, d, f, i, 4a–g). These articulated podomeres are flexible in being able to extend forward (Fig. 2g, Extended Data Fig. 4a, f) or curve inward (Fig. 1c, Extended Data Figs. 2d, f, 4b, c, g), making the frontalmost appendage capable of grasping prey. The terminal articulated podomere looks like a claw ('p15' in Fig. 2g, Extended Data Figs. 2f, 4a, c, f). The distal end of shaft and each articulated podomere (terminal podomere excluded) possess a pair of triangular endites ('se', 'ed' in Figs. 1c, 2g–i, Extended Data Figs. 1d, e, 2b, i, 4a, d–g). Sizes of these endites follow a general decreasing trend from proximal to distal, with the longest endite on the first articulated podomere (longer than the shaft endite) and adjacent endites alternating their lengths in a short-long-short pattern ('se', 'ed' in Figs. 1c, 2g, Extended Data Figs. 1d, e, 4a, d–g). The length of each endite is close to but not exceeding the height of its podomere. Up to seven sharp auxiliary spines are attached to both sides of each endite (arrowheads in Fig. 2h, i).

Post-oral appendages. The first four pairs of post-oral appendages, two in the head and one each in the first and second trunk segments, appear to be differentiated uniramous flaps ('da' in Figs. 1c, f, 2g, Extended Data Figs. 2b, f, i, 3n, 4a–e, 5b). Sizes of these four pairs of differentiated appendages increase gradually toward the rear but are significantly smaller than the posterior trunk appendages. The rest of the trunk appendages are homonomous and biramous ('en', 'ex' in Fig. 1a, b, d, e, Extended Data Figs. 1, 2c, e, h). In each of these biramous appendages, endopodite consists of no less than seven podomeres with rounded endites ('en' and arrowheads in Fig. 1d, e, Extended Data Figs. 1e, 2d, 4a, b), exopodite is an oval flap bearing imbricate lamellae along its posterior margin ('ex' in Fig. 1d, g, h, Extended Data Figs. 2f, 6b), and the lengths of endopodite and exopodite are close. The longest

endopodites and exopodites are on the middle trunk segments.

Trunk. Each of the 25 trunk tergites is ribbon-shaped and corresponds to a single pair of appendages (‘t1–t25’ in Fig. 1a, b, Extended Data Figs. 1, 2a, c, e, h). Axial lengths of trunk tergites diminish towards the rear. Pleurae of the trunk tergites have a smooth margin.

Pygidium. The pygidium is subtriangular and covers at least five pairs of appendages (‘py’ in Fig. 1g, h, Extended Data Fig. 6e–h). Three lobes of the tail fan are attached to the pygidium (‘tf’ in Fig. 1g, h, Extended Data Fig. 6e–h). The middle lobe is inserted to the end of the pygidium and bears setae on its posterior margin (‘st’ in Extended Data Fig. 6i), and the two lateral lobes are close in length to the middle lobe and are inserted to the middle to anterior part of the pygidium (‘tf’ in Fig. 1g, h, Extended Data Fig. 6e–h).

Digestive tissue. The alimentary canal runs through the central portion of the body (‘ac’ in Fig. 1a, b, Extended Data Figs. 1, 2a, c, e). The maximum diameter of the alimentary canal is sub-equal to the axial length of the largest trunk tergite (‘ac’ in Fig. 1a, b, Extended Data Figs. 1, 2c, e). The alimentary canal is divided into oesophagus, foregut, midgut and hindgut. A posterior-facing ventral mouth opening is interpreted from the nearly horizontal position of the oesophagus (‘os’ in Fig. 1c, Extended Data Fig. 3n, o). The oesophagus is just above the base of frontalmost appendages in a lateral view and is curved into the dorsal portion of foregut (‘os’, ‘fg’ in Figs. 1c, Extended Data Figs. 2b, 3n, o, 4d, 5b). The midgut is associated with a series of paired digestive glands corresponding to each segment (‘dg’ in Extended Data Figs. 2g, 6a, b). The hindgut is straight and lies in the ventral part of the pygidium, and the anus opening is posteroventral (‘hg’ in Fig. 1g, Extended Data Fig. 6g). A thread of putative gut content eliminated from the hindgut is present in one specimen (‘ec’ in Fig. 1g, Extended Data Fig. 6g).

Nervous tissues in trunk. The nervous system shows structural features from a lateral view (‘vn’, ‘nt’ in Fig. 1a, Extended Data Figs. 1d, 2a, c, 6b–d). The ventral nerve cord lies below the alimentary canal (‘vn’ in Fig. 1a, Extended Data Fig. 3a, c). In each trunk segment, a pair of leg nerves originating from the ventral nerve cord are innervated into the two corresponding appendages separately (arrowheads in Extended Data Fig. 6b–d).

Cephalic soft tissues. Morphological interpretation of soft tissues in head aided by elemental analysis reveals that the alimentary canal is rich in carbon but has little trace of iron, while the neural tissue is preserved as carbon films variably overlapped by iron-rich minerals (Extended Data Fig. 5b–h). The alimentary canal is curved near the very basal parts of the frontalmost appendages, separating the dorsal section of foregut from the ventral oesophagus (‘fg’ and ‘os’ in Figs. 1c, 2c, Extended Data Figs. 2b, 3n, o, 4d, 5b, d). Posteriormost of the head region are leg nerves of the four pairs of differentiated appendages (‘nd’ in Figs. 1c, f, 2g, Extended Data Figs. 2b, 3n, o, 4a, d, 5b, d). Anterior to these is a longer nerve into the shaft of frontalmost appendage (‘nf’ in Figs. 1c, 2c, Extended Data Figs. 2b, 3n, o, 4d, 5b, d). A short section of putative nervous tissue is situated between the oesophageal region and the eyes (‘nb’ in Figs. 1c, 2c, Extended Data Figs. 2b, 3n, o, 4d, 5b, d), and patches in the eye region showing strong overlapping signals of carbon and iron are interpreted as putative protocerebrum (‘pr’ in Extended Data Fig. 5b, d).

Ontogeny

The lengths of four complete specimens of *Kylinxia* are 67 mm (paratype YLSNHM 01124; Fig. 1b, Extended Data Fig. 1c), 50 mm (holotype NIGP 171304; Fig. 1a, Extended Data Fig. 1a), 28 mm (additional material NIGP 171307; Extended Data Fig. 2e), and 13 mm (additional material NIGP

171308; Extended Data Fig. 2h), respectively. They probably represent four different instars. Whether the largest specimen represents an adult remains unknown. The two smaller individuals (NIGP 171307, 171308) are different from the two largest specimens (YLSNHM 01124, NIGP 171304) in bearing a terminal spine on the head shield (Extended Data Fig. 2f, i). Except for the terminal spine, the three larger specimens have similar morphologies. However, the smallest juvenile (NIGP 171308; Extended Data Fig. 2h) exhibits several ontogenetic differences: (1) the number of trunk tergites is 23, instead of 25 in larger individuals (Extended Data Figs. 2h, 6f); (2) the anterior and middle tergites are obviously longer than the posterior ones (Extended Data Fig. 2h); (3) the posteriormost trunk segments bear several pair of limbs that are distinctly shorter than those in larger individuals (Extended Data Fig. 6f); (4) the eyes are larger relative to the size of the head (Extended Data Fig. 2i).

Mode of life

With a pair of functionally flexible radiodont-like frontalmost appendages, *Kylinxia* should be an active predator. The five compound eyes should assist this animal in searching for prey. The long trunk and well-developed exopodite flaps indicate that *Kylinxia* was a good swimmer, and its tail fans could aid in changing directions during locomotion. An almost straight alimentary canal with digestive glands reinforces a predatory identity of *Kylinxia*. Overall, *Kylinxia* would have been a nektobenthic hunter or scavenger in the Cambrian seas (Fig. 3b, Extended Data Fig. 8).

ADDITIONAL REMARKS

Comparisons between *Kylinxia* and radiodont families

As concluded in the main text, the frontalmost appendages of *Kylinxia* are morphologically closest to the frontal appendages of radiodonts among Cambrian euarthropods. Detailed comparisons of frontalmost appendages between *Kylinxia* and the four major radiodont families are given below.

Family Anomalocarididae. *Kylinxia* shares the same architecture of the proximal shaft of frontalmost appendages with *Anomalocaris canadensis* ('sh' in Extended Data Fig. 4f–i). In both taxa, the shaft possesses an oblique arthrodial membrane that has its distal end located next to the proximal side of endites on the shaft but has no clear proximal endpoint ('sa' in Extended Data Fig. 4f–k). A shaft with such an oblique arthrodial membrane and a single pair of endites has only been known from *Kylinxia* and *A. canadensis*. With a close number of distal articulated podomeres (15 in *Kylinxia* and 13 in *A. canadensis*), the frontalmost appendages of *Kylinxia* and *A. canadensis* are also morphologically closest in their functional flexibility of extending and incurving, which is controlled by the expansion and contraction of triangular arthrodial membranes between the distal articulated podomeres (Figs. 1c, 2g, Extended Data Figs. 2d, f, 4a–c, f–i; Daley and Edgecombe, 2014). Both *Kylinxia* and *A. canadensis* also show a clear short-long-short alternating pattern of adjacent endites along the frontalmost appendage, and in both taxa, the lengths of the endites are comparable to the podomere height. The arrangement of auxiliary spines on anterior and posterior margins of each endite is symmetrical in both *Kylinxia* and *A. canadensis*.

The main differences between *Kylinxia* and members of Anomalocarididae (including *A. canadensis* and *A. pennsylvanica*) are on the shapes of individual endites and auxiliary spines. The endites of *Kylinxia* are triangular and have a broader base, while those in Anomalocarididae are spike-like and have a narrower base (Daley and Edgecombe, 2014). *Kylinxia* has up to seven very sharp auxiliary spines on either margin of each endite, but *A. canadensis* only has one or two subtriangular

auxiliary spines (absent in *A. pennsylvanica*; Pates and Daley, 2019).

Family Amplectobeluidae. Amplectobeluidae is diagnosed by a shaft region comprising three podomeres (Cong *et al*., 2018; Guo *et al*., 2019), which is not the case in *Kylinxia*. *Ramskoeldia*, assigned to Amplectobeluidae, is similar to *Kylinxia* in its roughly symmetrical arrangement of auxiliary spines (Cong *et al*., 2018). The number of distal articulated podomeres is 13 in *Ramskoeldia*, compared with 15 in *Kylinxia*, although both *Kylinxia* and *Ramskoeldia* have a total of 16 podomeres in their frontalmost appendages. *Amplectobelua*, the type genus of Amplectobeluidae, is distinct from *Kylinxia* in its absence of auxiliary enditic spines on the articulated region, 12 distal articulated podomeres and three-podomerous shaft (Cong *et al*., 2017). *Lyrarapax*, another genus of Amplectobeluidae, is similar to *Kylinxia* in having a serrated row of up to eight auxiliary spines on the anterior margin of its hypertrophied endite (though absent on the posterior margin) (Cong *et al*., 2016), but there are hardly other clear similarities between the two taxa. *Laminacaris* was also phylogenetically resolved within Amplectobeluidae (Lerosey-Aubril and Pates, 2018). It has two shaft podomeres and 13 distal podomeres, slender endites, asymmetrical arrangement of auxiliary spines on each endite (Guo *et al*., 2018), which are different from the character states in *Kylinxia*.

Family Tamisiocarididae. Cetiocaridae, a similar name of Tamisiocarididae Pates and Daley, 2019, may not be valid under the ICZN (Lerosey-Aubril and Pates, 2018). The type genus of Tamisiocarididae is *Tamisiocaris* (Daley and Peel, 2010; Vinther *et al*., 2014). The frontalmost appendage of *Tamisiocaris* has at least 18 distal articulated podomeres, elongated and overlapping endites, adjacent endites of close lengths and tens of auxiliary spines. These features are distinct from those of *Kylinxia*. Another member of Tamisiocarididae, *Anomalocaris briggsi* (e.g., Daley *et al*., 2013b) is closely related to *Tamisiocaris*, but its long and narrow endites are also very different from those in *Kylinxia*.

Family Hurdiidae. Hurdiidae is a morphologically diverse group in Radiodonta (e.g., Daley *et al*., 2009, 2013a; Daley and Budd, 2010), but their key characters of frontalmost appendages are absent in *Kylinxia*. These characters include no more than 10 distal articulated podomeres, absence of triangular arthrodial membranes, a single row of slender endites, multiple longest endites, and no long/short alternation between adjacent endites (e.g., Guo *et al*., 2018).

To sum up, although the frontalmost appendages of *Kylinxia* are not exactly identical to their radiodont counterparts in having no outer spines and being orientated upward, they share most of the key features with Anomalocarididae (general architecture, shaft morphology) or Amplectobeluidae (total number of distal articulated podomeres, morphology of auxiliary spines), with all of these appendages possessing triangular membranes between podomeres and long/short alternation of endites. Thus, *Kylinxia* can serve as an excellent outgroup for investigating the morphological evolution of frontal appendages within Radiodonta. The discovery of such radiodont-like raptorial appendages in *Kylinxia* also suggests caution in assigning isolated appendages to Radiodonta.

Notes on ‘great appendages’

The term ‘great appendage’ has been used for various types of euarthropod appendages with different morphologies or segmental identities (see Lamsdell *et al*., 2013; Aria and Caron, 2015). Apart from the typical short ‘great appendages’ in Megacheira (e.g., Chen *et al*., 2004; Haug *et al*., 2012), other usages of the term include the frontal appendages in Radiodonta (Kühl *et al*., 2009; Chen *et al*., 2004; Haug *et al*., 2012), frontalmost appendages in isoxyids (Vannier *et al*., 2009; Fu *et al*., 2011), post-oral appendages in hymenocarines and Fuxianhuiida (Budd, 2008), and putative raptorial

antennae in artiopodans (Stein, 2010; Shu *et al*., 1996). The term underlies a mixture of perspectives from form and function, with emphasis on either in different contexts. However, 'great appendage' has never been the terminology for any non-raptorial appendages in euarthropods. In this sense, a more functionalist perspective is underlying the term, which should not be favoured in morphological description (Aria and Caron, 2015). The very recent literature tends to employ 'great appendage' *sensu stricto* only for Megacheira. We follow this current trend but also extend the usage of the term to the megacheiran-form frontalmost appendages in *Occacaris* and *Forfexicaris* (Hou, 1999; Vannier *et al*., 2006; Haug *et al*., 2012; Hou *et al*., 2017).

Affinities of frontalmost appendages in Radiodonta and Megacheira

The recent palaeoneurological study of the radiodont brain proposed a protocerebral affinity for the radiodont frontal appendages (Cong *et al*., 2014), while the neuroanatomy of the megacheiran brain suggested a deuterocerebral identity for the megacheiran great appendages (Tanaka *et al*., 2013). However, the different segmental affinities of radiodont and megacheiran frontalmost appendages are inconsistent with the lines of evidence from their external morphologies (Chen *et al*., 2004; Haug *et al*., 2012; Aria *et al*., 2020). The radiodont-like frontalmost appendages attached to a megacheiran-like body in *Kylinxia* provide very strong morphological evidence for the homology between radiodont and megacheiran frontalmost appendages. This homology concept also receives supports from the nearly identical topologies of the frontalmost appendages aligned to other frontal head structures such as eyes and ocular sclerites in Radiodonta and Megacheira (Aria *et al*., 2020). Moreover, the independent origins of the radiodont-like frontalmost appendages in *Kylinxia* are very unlikely because such convergence is not phylogenetically parsimonious given the many shared features of the frontalmost appendages in Radiodonta and *Kylinxia*.

The inconsistencies between the neuroanatomy and other sources of evidence on the affinities of radiodont and megacheiran frontalmost appendages could be explained by alternative hypotheses. On one hand, the protocerebral affinity of radiodont frontalmost appendages has been questioned by the uncertainties in interpreting the neural tissues, which makes rendering a final assessment difficult (Aria *et al*., 2020). However, these controversies surrounding the segmental affinity of radiodont frontalmost appendages can only be resolved by direct investigation on radiodonts, which is out of the scope of this current paper.

On the other hand, even under the current consensus views on the protocerebral and deuterocerebral origins of frontalmost appendages in Radiodonta and Megacheira, respectively (Ortega-Hernández, 2017), a straightforward explanation for this segmental mismatch would be a protocerebral to deuterocerebral positional transformation of the frontalmost appendages during the evolution from Radiodonta to *Kylinxia*/Deuteropoda. This model could explain the origin of deuterocerebral frontalmost appendages, the diagnostic character of Deuteropoda (Ortega-Hernández, 2016). Such a positional shift of appendages has a known mechanical basis from the evolutionary developmental biology, which is the homeotic mutation with the displacement of appendages caused by changed expressions of the *Hox* genes (e.g., Hughes and Kaufman, 2002). This evo-devo mechanism is not restricted to experiments in the lab, because the changes in the expression patterns of *Hox* genes have been demonstrated to be crucial in the origin of key euarthropod groups (e.g., Akam, 1998; Ronshaugen *et al*., 2002). Although in the case of euarthropod frontalmost appendages *Hox* genes may not be the right causes because their typical expression domains do not fall within the protocerebral and deuterocerebral segments (e.g., Jager *et al*., 2006), other head patterning genes (see

examples in Ortega-Hernández *et al*., 2017) might have played the roles in achieving a position shift of frontalmost appendages in stem-group euarthropods.

Given the alternative models discussed above, the segmental identity of radiodont frontalmost appendages has not been settled yet, and this character is coded as uncertain (?) in our phylogenetic data matrix (see below; character 170). Last but not least, it shall be noted that the uncertainties surrounding the segmental affinity of radiodont frontalmost appendages do not influence our current phylogenetic topologies and the phylogenetic position of *Kylinxia*. This has gone through our phylogenetic tests with the state of character 170 in radiodont frontalmost appendages coded as protocerebral (0), where the exactly same tree topologies were recovered under different models and with various settings of character weighting.

Phylogenetic analyses

Selection of taxa. A total of 81 taxa are included in our phylogenetic analysis (Supplementary Data 1). The extant *Priapulus caudatus* from the cycloneuralian phylum Priapulida and the stem-group priapulid *Circocosmia jinningensis* from the Chengjiang biota are regarded as outgroups. The extant Tardigrada and Onychophora are also included. Cambrian panarthropods including lobopodians and major stem-lineage euarthropods such as Radiodonta, Megacheira, bivalved forms, Fuxianhuiida and Artiopoda are covered. Palaeozoic representatives or closely-related fossil taxa of chelicerates and mandibulates are also included. These fossil taxa are recorded with well-preserved soft parts, especially appendages, which limit the bias caused by taphonomy and preservation in our phylogenetic analysis.

Character coding. To compile our data matrix (Supplementary Data 1), we referred to the published major sources of phylogenetic datasets on early euarthropod fossils, notably including Legg *et al*. (2013), Aria and Caron (2017, 2019) and their very recent updated versions. The coding of characters is supported by examining the vast fossil collections of the Chengjiang and the Burgess Shale housed at the Nanjing Institute of Geology and Palaeontology, China and the Smithsonian National Museum of Natural History, USA, respectively. All characters are treated as unordered. Meristic characters are coded into discrete character states based on prior investigations.

Given the great morphological disparity of frontalmost appendages in Cambrian euarthropods, we have coded a series of characters covering the various morphological aspects of these appendages to explore the morphological evolution of frontalmost appendages in early euarthropods (chars. 168–212).

Phylogenetic results. We have used both Bayesian and parsimony approaches in inferring phylogenies from the same morphological character matrix (Supplementary Data 1). For the parsimony approach, parallel analyses were performed with equal and implied character weighting settings. The parsimony analyses recovered 8 most parsimonious trees under equal character weighting (MPTs, lengths = 686, Consistency Index CIs = 0.509, Retention Index RIs = 0.871) and a single MPT under a series of implied character weighting parameters (concavity constant k = 2, 3, 5, 10). These MPTs have lengths of 63.80066 (k = 2), 51.91166 (k = 3), 38.34910 (k = 5) and 23.72382 (k = 10), Consistency Indices CIs of 0.506 (k = 2) and 0.507 (k = 3, 5, 10), and Retention Indices RIs of 0.870 (k = 2) and 0.871 (k = 3, 5, 10). Newick formats of strict consensus trees can be found in Supplementary Data 1.

The results from both Bayesian and parsimony methods and various character weighting settings reveal largely the same topologies between major euarthropod groups (Fig. 3a, Extended Data Fig. 9; Supplementary Data 1). An exception is the grouping between Isoxyida and ‘great-appendage’

bivalved forms, which was recovered as paraphyly in the Bayesian analysis but as monophyly in the parsimony analysis. Another inconsistent part of the tree is the interrelationships between mandibulate-related groups including Hymenocarina, Myriapoda, some 'Orsten' taxa and pancrustacean representatives, the results of which vary among different methods and character weighting settings. Such results did not provide further information on resolving the recently debatable issue on mandibulate origin (Aria and Caron, 2017; Edgecombe, 2017). On a smaller scale, the phylogenetic resolutions and fine-scaled interrelationships of the same euarthropod groups change among results from different methods or weighting parameters, which can be found as different groupings in the lobopodian grade, either monophyletic or paraphyletic non-hurdiid radiodonts, the polytomy in *Fortiforceps* clade of Megacheira or in Fuxianhuiida. Note that most of the topological differences between trees from different methods and parameters are reflected by relatively low nodal supports on other trees. These small-scaled differences, however, do not influence our evolutionary interpretations on broad patterns.

Experiment with *Kylinxia* omitted. To test the impacts of *Kylinxia* on the phylogenetic relationships of euarthropods, we conducted an experimental analysis on the same morphological character matrix with only *Kylinxia* excluded (Supplementary Data 2). Remarkably, isoxyids were retrieved as the closest euarthropod groups to Radiodonta with both Bayesian and parsimony models, which is more basal than Megacheira and Panchelicerata (Extended Data Fig. 10; Supplementary Data 2). Such a very basal placement of isoxyids was typical of previous phylogenetic studies (e.g., Legg *et al*., 2013; Aria and Caron, 2017, 2019). By comparing to the very basal position of Megacheira + Panchelicerata and the uptree placement of isoxyids got from our original analysis (Extended Data Fig. 9; Supplementary Data 1), the experiment with *Kylinxia* omitted proved that the inclusion of the chimeric *Kylinxia* changed the phylogenetic relationships of euarthropod stem groups by revealing tighter affinities between Radiodonta and great-appendaged euarthropod stem groups including Megacheira and great-appendage bivalved forms. This experiment also explains that the uptree placement of isoxyids in our original analysis is a consequence of including *Kylinxia* (see next section for further discussion).

In the experiment with *Kylinxia* omitted, 'great-appendage' bivalved forms (*Occacaris* and *Forfexicaris*) constituted a clade with Megacheira + Panchelicerata (Bayesian inference and parsimony method with implied weighting) or with isoxyids (parsimony method with equal character weighting), which was analogous to the results found in the original analysis (see previous section for details; Fig. 3a; Extended Data Fig. 9; Supplementary Data 1).

Detailed results of the experiment are listed below. Newick formats of strict consensus trees can be found in Supplementary Data 2. Under equal character weighting, the parsimony analyses recovered 8 most parsimonious trees (MPTs, lengths = 669, Consistency Index CIs = 0.522, Retention Index RIs = 0.876). Under a series of implied character weighting parameters (concavity constant k = 2, 3, 5, 10), the parsimony method found a single MPT described as below: k = 2 (length = 60.76442, Consistency Index CI = 0.516, Retention Index RI = 0.873), k = 3 (length = 49.60546, Consistency Index CI = 0.518, Retention Index RI = 0.874), k = 5 (length = 36.70367, Consistency Index CI = 0.519, Retention Index RI = 0.875) and k = 10 (length = 22.70447, Consistency Index CI = 0.519, Retention Index RI = 0.875).

Notes on the phylogenetic position of Isoxyida. Isoxyida has been retrieved as a close group to Radiodonta in a couple of notable phylogenetic studies (e.g., Legg *et al*., 2012, 2013; Aria and Caron, 2017, 2019), although such a placement remains debatable (e.g., Ortega-Hernández *et al*., 2017; Daley

et al., 2018). Those characters supporting a tight link between Isoxyida and Radiodonta included weakly sclerotized body and trunk appendages, similar tail processes and an overall similarity in their frontalmost appendages (e.g., Legg and Vannier, 2013). For the frontalmost appendages, because both isoxyids and radiodonts, as well as other basal euarthropod groups, exhibited great morphological variations, we consider assessing overall similarities may not be very helpful in resolving the evolutionary patterns of frontalmost appendages in early euarthropods. In our phylogenetic analyses, we have included those reported shared characters of isoxyids and radiodonts and have used a series of characters in coding the morphological variations of frontalmost appendages (chars. 168–181, 188–212). Isoxyida was consistently reconstructed with a position higher than the clade comprising Megacheira and Panchelicerata in Bayesian and parsimony analyses and under various character weighting settings when *Kylinxia* is included (Fig. 3, Extended Data Fig. 9). Although a paraphyletic or monophyletic grouping of Isoxyida and 'great-appendage' bivalved forms was found in Bayesian or parsimony analysis, respectively (Fig. 3, Extended Data Fig. 9).

We believe such an uptree placement of Isoxyida is partly a 'side-effect' of a basal placement of Megacheira on the tree, which gains supports from the tight link between Radiodonta and Megacheira indicated by the chimeric *Kylinxia*. This interpretation was proved by our phylogenetic experiment with *Kylinxia* omitted, where the very basal placement of Isoxyida was recovered (Extended Data Fig. 10; see discussion in previous section). On the other hand, the raptorial frontalmost appendages in isoxyids show more antenniform features. For instance, their articulated podomeres are generally homonomous and are absent in short-long-short alternation of endite lengths, and no auxiliary enditic spines, namely smaller spines on a major enditic spine that are shared by Radiodonta, *Kylinxia* and Megacheira, have been found in isoxyid frontalmost appendages but is a typical feature of the euarthropod antennae. Remarkably, some isoxyids bear multi-podomerous frontalmost appendages with paired needle-shaped enditic spines on each distal podomere (e.g., 'D3' in Fig. 3a; Extended Data Fig. 7l–o; *Isoxys volucris* in Stein *et al*., 2010; *I. auritus* in Fu *et al*., 2014), which are strikingly similar to putative predatory antennae found in some artiopodans (e.g., 'E1' in Fig. 3a; Extended Data Fig. 7p, q; *Kuamaia lata* in Shu and Zhang, 1996; *Kiisortoqia soperi* in Stein, 2010; *Bushizheia yangi* in O'Flynn *et al*., 2020) and hymenocarines (e.g., 'E3' in Fig. 3a; *Clypecaris serrata* in Yang *et al*., 2016). These morphological features of isoxyid frontalmost appendages provide additional support on a higher phylogenetic placement of Isoxyida, which is reflected by our phylogenetic results.

CHARACTER LIST

Each source of characters is indicated by the abbreviations of references (listed below) followed by the index of the character in its original dataset. For each character, sources with the same definition are included in the same bracket. Annotation before sources are denoted as follows: cf. – similar character definition, coding may not be the same; part. – only a smaller set of character states from the source coded; ref. – different character definition, but inspired by the source of character.

Abbreviations of references. AC2019, Aria and Caron (2019); AC2017, Aria and Caron (2017); AR2015, Aria *et al*. (2015); BU2002, Budd (2002); CA2017, Caron and Aria (2017); CB2004, Cotton and Braddy (2004); DA2009, Daley *et al*. (2009); DU2019, Du *et al*. (2018); ER1999, Edgecombe and Ramsköld (1999); HA2010, Haug *et al*. (2010); KU2009, Kühl *et al*. (2009); LU2011, Liu *et al*. (2011); LG2012, Legg *et al*. (2013); LG2013, Legg *et al*. (2013); MA2009, Ma *et al*. (2009); MA2014, Ma *et al*. (2014); MY2019, Mayers *et al*. (2019); PA2010, Paterson *et al*. (2010); RC1998, Ramsköld and

Chen (1998); RS2011, Rota-Stabelli *et al*. (2011); SC2015, Smith and Caron (2015); VA2009, Vannier *et al*. (2009); VI2014, Vinther *et al*. (2014); YA2015, Yang *et al*. (2015); YA2018, Yang *et al*. (2018); ED2011, Edgecombe *et al*. (2011); OH2013, Ortega-Hernández *et al*. (2013); ZH2016, Zhang *et al*. (2016).

Cuticle

1. Annulation of integument on main body: (0) absent; (1) present.
References: cf. [DA2009-26], cf. [RS2011-19; LG2012-2; LG2013-2], cf. [LU2011-28], cf. [MA2014-30], part. [SC2015-37, 38; YA2015-36, 37; ZH2016-47, 48], ref. [CA2017-2; AC2017-2; AC2019-2].
A feature of unsclerotized cuticle.

2. External metameric boundaries on main body: (0) invisible or ambiguous; (1) visible and delimited.
References: cf. [DA2009-25], cf. [RS2011-18; LU2011-1; LG2012-1; LG2013-1], cf. [MA2014-29], ref. [SC2015-34; YA2015-32; ZH2016-44], ref. [CA2017-2, 3].
Visible boundaries on the body wall, including arthrodial membranes.

3. Sclerotization of main body: (0) absent; (1) present.
References: part. [DA2009-1], part. [MA2009-21; MA2014-28], part. [LU2011-27], part. [RS2011-20; LG2012-3; LG2013-3], part. [SC2015-35; YA2015-33; ZH2016-45], ref. [CA2017-3; AC2017-3; AC2019-3].
We distinguish sclerotization, the hardening of cuticle, from arthrodization, the division of cuticle by arthrodial membranes (next character).

4. Arthrodization of main body: (0) absent; (1) present.
References: ref. [BU2002-10], part. [DA2009-1], part. [MA2009-21; MA2014-28], part. [LU2011-27], part. [RS2011-20; LG2012-3; LG2013-3], ref. [CA2017-3; AC2017-3; AC2019-3].
See the previous character.

5. Integumental sclerites or nodes on head: (0) absent; (1) present.
References: ref. [SC2015-2; YA2015-2, ZH2016-2], ref. [CA2017-17, 18].
These are the sclerotized plates, spines or nodes in lobopodians (see characters below).

6. Integumental sclerites or nodes on trunk: (0) absent; (1) present.
References: cf. [RC1998-3], cf. [MA2009-28; MA2014-39; LG2013-583], cf. [LU2011-30], ref. [SC2015-41; YA2015-39; ZH2016-52], ref. [CA2017-37; AC2017-13; AC2019-13].
See the previous character.

7. Integumental sclerites with extended reticulated plate-like base: (0) absent; (1) present.
References: ref. [SC2015-43, 44; YA2015-41, 42; ZH2016-54, 55], part. [CA2017-38].
Typical in *Microdictyon*, *Onychodictyon* and some palaeoscolecids.

8. Integumental sclerites with prominent spine: (0) absent; (1) present.
References: cf. [RC1998-4], cf. [MA2009-29; MA2014-40; LG2013-585], cf. [LU2011-31], ref. [SC2015-43, 44; YA2015-41, 42; ZH2016-54, 55], part. [CA2017-38; AC2017-14; AC2019-14].

Present in *Hallucigenia*, luolishaniids and *Onychodictyon*.

9. Integumental sclerites, relative height to trunk diameter: (0) shorter or comparable; (1) at least 1.5 times longer.
References: cf. [CA2017-39].
Sizes of the lobopodian sclerites.

10. Integumental sclerites, more than two elements per metamere: (0) absent; (1) present.
References: cf. [LU2011-32; LG2013-584], ref. [SC2015-49; YA2015-47; ZH2016-60], ref. [CA2017-40].
A feature in luolishaniids.

11. Integumental sclerites, paired spines per metamere: (0) absent; (1) present.
A synapomorphy in *Hallucigenia*.

12. Integumental sclerites, size change along body axis: (0) close; (1) anteriormost and posteriormost ones smaller, intermediate ones larger.
Obvious in luolishaniids.

13. Papillae or other cuticular derivatives on trunk annuli: (0) absent; (1) present.
References: [RC1998-7], [MA2009-32; MA2014-41; LG2013-586], [SC2015-50; YA2015-51; ZH2016-64], [CA2017-35; AC2017-11; AC2019-11].
Common in many lobopodians and Onychophora.

14. Tergites: (0) absent; (1) present.
References: part. [LG2012-53; LG2013-53].
Dorsal sclerites of the euarthropod exoskeleton.

15. Sternites: (0) absent; (1) present.
References: part. [LG2012-53; LG2013-53], [SC2015-36; YA2015-34; ZH2016-46], [CA2017-42], cf. [AC2017-54, 61; AC2019-66, 78].
Ventral sclerites of the euarthropod exoskeleton.

16. Pleurites: (0) reduced or fused; (1) developed.
References: [AC2017-152; AC2019-203].
Lateral sclerites of the euarthropod exoskeleton.

17. Cuticle biomineralized: (0) absent; (1) present.
References: part. [ER1999-1], [CB2004-30; PA2010-1; ED2011-1; OH2013-40], [LU2011-4], [RS2011-21; LG2012-4; LG2013-4], cf. [AC2017-4; AC2019-4], part. [DU2019-40].
Such as the calcified exoskeleton in trilobites.

Eyes
18. Eyes: (0) absent; (1) present.

References: [DA2009-10], ref. [MA2009-17], [LU2011-13], cf. [SC2015-16; YA2015-29; ZH2016-22], ref. [CA2017-21].
Macroscopic structure with cluster of cellular photoreceptors.

19. Ocelli as primary eyes: (0) absent; (1) present.
References: part. [CA2017-22], cf. [AC2017-18; AC2019-18].
Eye made of a single lens.

20. Compound eyes: (0) absent; (1) present.
References: cf. [DA2009-11], cf. [MA2009-18; MA2014-27], cf. [LU2011-14], cf. [RS2011-94; LG2012-354; LG2013-354; YA2018-20], cf. [SC2015-18; YA2015-31; ZH2016-24], part. [CA2017-22; AC2017-22; AC2019-22].
A single eye comprising multiple ommatidial lenses.

21. Eye stalks: (0) absent or very reduced; (1) present.
References: cf. [DA2009-12; RS2011-98; LG2012-358; LG2013-358; YA2018-21], ref. [AC2017-29; AC2019-30].
For compound eyes only. May be incorporated into the head shield.

22. Anteroposterior position of compound eyes in head: (0) anteriormost; (1) anterior; (2) middle; (3) posterior.
References: ref. [OH2013-20; DU2019-20].
Most are anteriormost. Can be accommodated by anterior structures of head shield, covered by the middle part of head shield, or extremely posterior as in hurdiids.

23. Compound eyes accommodated by dorsal bulge on fused head shield: (0) absent, (1) present.
References: ref. [ER1999-6; CB2004-22; PA2010-5; ED2011-10; OH2013-22; LG2012-362; LG2013-362; DU2019-22], part. [AC2017-27; AC2019-28].
A feature in artiopodans.

24. Eye stalks of compound eyes covered by fused head shield: (0) absent; (1) present.
As in artiopodans.

25. Eye stalks of compound eyes incorporated into fused head shield, forming eye ridges: (0) absent; (1) present.
References: ref. [ER1999-4; PA2010-3; ED2011-8], cf. [AC2017-28; AC2019-29].
A synapomorphy of trilobites.

26. Compound eyes with eye slits: (0) absent; (1) present.
References: [ER1999-7; CB2004-23, OH2013-23; LG2012-363; LG2013-363; DU2019-23], ref. [AC2019-57].
Present in certain xandarellids. Distinguished from the trilobite suture (next character).

27. Compound eyes bounded by suture on fused head shield: (0) absent; (1) present.

References: cf. [CB2004-28; OH2013-31; DU2019-31], ref. [AC2019-5, 57].
For trilobite sutures.

28. Lenses calcified: (0) absent; (1) present.
References: cf. [CB2004-21; PA2010-4; LG2012-361; LG2013-361].
As in the eyes of trilobites.

29. Median eyes: (0) absent; (1) present.
References: ref. [DA2009-12], ref. [CB2004-24; PA2010-11; ED2011-11; OH2013-24; LG2012-13; LG2013-13; DU2019-24], ref. [LU2011-13], part. [SC2015-17; YA2015-30; ZH2016-23], cf. [AC2017-19; AC2019-19].
Can be compound eyes or ocelli.

30. Number of median eyes: (0) one; (1) two; (2) three; (3) at least four.
References: cf. [AC2017-20; AC2019-20].
See previous character.

31. Four or five eyes arranged in a sub-transverse band across head shield: (0) absent; (1) present.
References: cf. [ED2011-9; LG2012-360; LG2013-360].
For *Leanchoilia*.

32. Five compound eyes with size differentiation: (0) absent; (1) present.
A feature seen in *Opabinia* and *Kylinxia*.

33. Relative diameter of compound eyes compared with length of bivalved carapace: (0) < 5%; (1) 5–10%; (2) > 10%.
References: cf. [VA2009-4].
Eyes in isoxyids appear large relative to their bivalved carapace.

Oral structures
34. Position of mouth opening: (0) terminal; (1) ventral.
References: cf. [BU2002-2; DA2009-4], cf. [MA2009-14; MA2014-21], cf. [LU2011-12], cf. [RS2011-128; LG2012-401; LG2013-401], cf. [CA2017-23; AC2017-123; AC2019-159], Ortega-Hernández *et al*. (2017).
A terminal mouth is typical for lobopodians. Onychophora and euarthropods have a ventral mouth.

35. Orientation of mouth opening: (0) anterior; (1) ventral; (2) posterior.
References: cf. [DA2009-5], cf. [RS2011-129; LG2012-402; LG2013-402], cf. [MA2014-25], cf. [SC2015-7; YA2015-23; ZH2016-11], ref. [AC2019-160], cf. [YA2018-80], Ortega-Hernández *et al*. (2017).
Anterior in lobopodians. Ventral in Onychophora, *Pambdelurion* and Radiodonta. Posterior in *Opabinia* and deuteropods.

36. Telescoping feeding apparatus: (0) absent; (1) present.

References: ref. [SC2015-12; ZH2016-18].
For scalidophorans and tardigrades.

37. Circumoral structures in a radial arrangement: (0) absent; (1) present.
References: ref. [RC1998-2], cf. [BU2002-1; DA2009-6], cf. [MA2009-15; MA2014-22], ref. [LU2011-2], cf. [RS2011-130; LG2012-404; LG2013-404], cf. [SC2015-9; YA2015-25; ZH2016-14], cf. [CA2017-24], cf. [YA2018-81].
Likely a plesiomorphy for Ecdysozoa. Absent in deuteropods.

38. Differentiation of elements in the outer ring of circumoral structures: (0) absent; (1) present.
References: ref. [DA2009-8; LG2013-712], cf. [SC2015-10; ZH2016-15].
Present in Onychophora and Radiodonta.

39. Number of inner spines on the elements in the outer ring of circumoral structures: (0) absent or single; (1) multiple.
References: cf. [ZH2016-16].
Can be a single one in *Pambdelurion* and or multiple in Radiodonta.

40. Sclerotized circumoral plates in a radial arrangement: (0) absent; (1) present.
References: cf. [DA2009-7], cf. [MA2009-16; MA2014-23], cf. [LU2011-3], cf. [RS2011-131; LG2012-405; LG2013-405], part. [CA2017-25; AC2017-124, 125; AC2019-161, 162], part. [YA2018-82].
Present in *Megadictyon*, *Pambdelurion* and Radiodonta.

41. Sclerotized circumoral plates forming oral cone: (0) absent; (1) present.
References: cf. [LG2013-711].
Typical in *Pambdelurion* and Radiodonta.

42. Symmetrical pattern of sclerotized circumoral plates: (0) ‘triradial’; (1) ‘tetraradial’.
References: Daley and Bergström (2012); Zeng *et al*. (2018).
A triradial oral cone is present in *Anomalocaris canadensis*.

43. External surface of sclerotized circumoral plates: (0) smooth or bearing weak nodes; (1) bearing prominent scale-like nodes.
References: Zeng *et al*. (2018).
Absent or weak nodes in hurdiids.

44. Furrowed folds on sclerotized circumoral plates: (0) absent; (1) present.
References: Zeng *et al*. (2018).
Present in Anomalocarididae and Amplectobeluidae.

45. Labrum: (0) absent; (1) present.
References: ref. [AC2017-58], [AC2019-68].
Labrum is distinguished from hypostome (next character) by Aria and Caron (2017).

46. Hypostome: (0) absent; (1) present.
References: ref. [CB2004-27], [DA2009-13], cf. [RS2011-132; LG2012-406; LG2013-406], cf. [AC2017-56; AC2019-73].
See previous character.

47. Hypostome attachment: (0) wide attachment, with or without suture; (1) natant; (2) narrow overlap with pre-hypostome; (3) narrow attachment at hypostomal suture.
References: [PA2010-12; LG2012-408; LG2013-408], ref. [AC2017-57; AC2019-74].
States 1–3 for the majority of artiopodans.

48. Hypostome accommodating antennae and extensively covering the mouth: (0) absent; (1) present.
References: [AC2017-59; AC2019-75].
An apomorphy of artiopodans.

49. Hypostome butterfly-shaped: (0) absent; (1) present.
References: ref. Yang *et al*. (2018).
A character shared by *Chengjiangocaris* and *Alacaris* of Fuxianhuiida.

Digestive system
50. Gut morphology: (0) simple and straight; (1) bearing a series of digestive diverticula or glands.
References: cf. [DA2009-16], cf. [LU2011-34], cf. [RS2011-235; LG2012-431; LG2013-431], cf. [MA2014-42], [VI2014: 16], cf. [SC2015-53; YA2015-52; ZH2016-65], cf. [CA2017-28; AC2017-132; AC2019-167], cf. [YA2018-83], Vannier *et al*. (2014).
A simple gut without additional structures is plesiomorphic in panarthropods.

51. Gut, triangular lateral extension into trunk appendages: (0) absent; (1) present.
References: part. [AC2017-134; AC2019-169].
Found in a number of euarthropods.

52. Branching digestive diverticula in head: (0) absent; (1) present.
References: ref. [AC2017-139; AC2019-174].
Typical for naraoiids.

53. Anus opening, position: (0) terminal; (1) ventral.
References: ref. [AC2017-203; AC2019-260].
Similar to the states for position of mouth opening.

Body (non-appendicular structures)
54. Metamerism of main body: (0) absent; (1) present.
References: cf. [MA2009-19; LG2013-581].
A series of differentiated or non-differentiated paramorphs such as appendages.

55. Number of body metameres: (0) ≤ 20; (1) 21–24; (2) 25–37; (3) 38–43; (4) ≥ 44.

References: ref. [BU2002-18], cf. [DA2009-2], part. [LU2011-33].
For both lobopodians and euarthropods. Can be somites or segments.

56. Number of dorsal divisions or tergites: (0) ≤ 7; (1) 8–13; (2) 14–19; (3) 20–33; (4) ≥ 34.
For both lobopodians and euarthropods.

57. Size change of main body along body axis: (0) cylindrical; (1) broad anteriorly and tapering posteriorly.
References: ref. [DA2009-40], ref. [MA2009-20], [VI2014-13], ref. [SC2015-70; YA2015-70; ZH2016-85].
Lobopodians have a generally cylindrical body.

Head (non-appendicular structures)
58. Anterior paired projections: (0) absent; (1) present.
References: cf. [RS2011-148; LG2012-167; LG2013-167], ref. Ortega-Hernández and Budd (2016), ref. [AC2017-68; AC2019-70, 86].
Found in a couple of lobopodians and euarthropods.

59. Head sclerotization: (0) absent; (1) present.
References: [YA2018-23].
Distinguished from sclerotization of trunk.

60. Unsclerotized head part possessing non-appendicular proboscis with a clear posterior boundary: (0) absent; (1) present.
References: ref. [LU2011-1], ref. [LG2012-403; LG2013-403], ref. [CA2017-27; AC2017-126; AC2019-163].
Typical in scalidophorans. An anteriormost ‘proboscis’-like structure is also seen in *Onychodictyon* and *Aysheaia*.

61. Unsclerotized head part, anteriormost part adjoined to bases of frontalmost appendages: (0) absent; (1) present.
References: ref. [MA2009-25; LG2012-10; LG2013-10; MA2014-36], ref. [LU2011-10], ref. [LU2011-10], ref. [SC2015-27; YA2015-17; ZH2016-37], ref. [CA2017-7].
For a very anterior position of frontalmost appendages in lobopodians.

62. Unsclerotized head part protruded: (0) absent; (1) present.
References: cf. [RC1998-1], ref. [SC2015-6; ZH2016-8], ref. [CA2017-8].
Seen in a majority of lobopodians.

63. Unsclerotized head part inflated, narrowed at base of protrusion: (0) absent; (1) present.
References: part. [RC1998-1], ref. [MA2009-26; MA2014-37], ref. [SC2015-6; ZH2016-8], ref. [CA2017-9].
A common feature of *Cardiodictyon* and *Hallucigenia*.

64. Unsclerotized head part elongated and tubular: (0) absent; (1) present.
References: part. [RC1998-1], ref. [SC2015-6; ZH2016-8], part. [CA2017-9].
A notable feature in *Paucipodia* and *Microdictyon*.

65. Anteriormost sclerite associated with eyes (ocular sclerites): (0) absent; (1) present.
References: [DA2009-14; LG2012-12; LG2013-12; YA2018-17], ref. [LU2011-12], ref. [OH2013-30; DU2019-30], cf. [SC2015-4; YA2015-4; ZH2016-4], ref. [CA2017-20; AC2017-127; AC2019-35], Ortega-Hernández (2015).
A common feature in Cambrian euarthropods.

66. Anteriormost sclerites forming a sclerite complex: (0) absent; (1) present.
References: Daley *et al*. (2013); Cong *et al*. (2017); Liu *et al*. (2018); Moysiuk and Caron (2019).
Present in Radiodonta.

67. Configuration of anteriormost sclerites: (0) central element oval, lateral elements connected by peduncular structures; (1) central 'H-element' and paired lateral 'P-elements'.
References: ref. [YA2018-19], Daley *et al*. (2013); Cong *et al*. (2017); Liu *et al*. (2018); Moysiuk and Caron (2019).
Distinguishing the sclerite complexes of hurdiids and other radiodonts.

68. Ocular sclerite as a dorsal plate with pronounced marginal rim covering anteriormost head part: (0) absent; (1) present.
References: part. [VR2015-59; YA2015-5; ZH2016-5], ref. [YA2015-6; ZH2016-6], ref. [YA2018-18].
Such a pronounce marginal rim is present in Anomalocarididae, Amplectobeluidae and possibly *Peytoia*.

69. Expanded head sclerite with posterior notches accommodating eyes, covering a large head region: (0) absent; (1) present.
References: cf. [ER1999-10; CB2004-26; OH2013-28; LG2012-11; LG2013-11; DU2019-28], ref. [DA2009-15], part. [VR2015-59; YA2015-5; ZH2016-5], ref. [YA2015-6, 7; ZH2016-6, 7].
A synapomorphy of hurdiids.

70. Ocular sclerite accommodated by fused head shield: (0) absent; (1) present.
References: ref. [YA2015-6; ZH2016-6].
For megacheirans.

71. Ocular sclerite accommodated by bivalved head carapace: (0) absent; (1) present.
References: ref. [YA2015-6; ZH2016-6].
For 'bivalved' euarthropods.

72. Ocular sclerite accommodated by semi-circular head carapace: (0) absent; (1) present.
References: ref. [YA2015-6; ZH2016-6].
For fuxianhuiids.

73. Ocular sclerite accommodated by notched fused head shield: (0) absent; (1) present.
References: ref. [YA2015-6; ZH2016-6].
For concilitergan artiopodans.

74. Ocular sclerite covered by true head shield: (0) absent; (1) present.
References: ref. [YA2015-6; ZH2016-6].
For non-concilitergan artiopodans.

75. Post-ocular tergal sclerotization in head: (0) absent; (1) present.
References: cf. [AC2017-33; AC2019-38].
Typical in deuteropods.

76. Carapace connected to the head region at its anterior part, posterior part free: (0) absent; (1) present.
References: cf. [BU2002-3], ref. [LU2011-22], ref. [OH2013-25; LG2012-22, 43; LG2013-22, 43], part. [CA2017-19; AC2017-34; AC2019-39].
For 'bivalved' euarthropods and fuxianhuiids.

77. Simple head carapace covering only a few anterior trunk tergites: (0) absent; (1) present.
References: cf. [LG2012-24; LG2012-24; LG2013-24], ref. [LG2012-43; LG2013-43], part. [AC2017-35; AC2019-40].
For the free head carapace of fuxianhuiids.

78. Simple head carapace, morphology: (0) semi-circular; (1) heart-shaped.
References: ref. Yang *et al*. (2018).
A heart-shaped carapace is characteristic of *Chengjiangocaris* and *Alacaris*.

79. Bivalved carapace: (0) absent; (1) present.
References: cf. [BU2002-4; LG2012-23; LG2013-23], cf. [LU2011-23], ref. [LG2012-43; LG2013-43], cf. [OH2013-26; DU2019-26], part. [AC2017-35; AC2019-40].
For 'bivalved euarthropods' including isoxyids and hymenocarines.

80. Body length covered by bivalved carapace, length of anterior appendages excluded: (0) > 70%; (1) 45–70%; (2) < 45%.
References: ref. [AC2017-37; A2019-45].
The isoxyid body is largely covered by bivalve carapace. The abdomen in various hymenocarines can be long or short relative to the carapace.

81. Head carapace or shield, straight medial hinge: (0) absent; (1) present.
References: cf. [BU2002-6], cf. [YA2018-32].
Present in bivalved euarthropods and *Fuxianhuia*.

82. Valve shape of bivalved carapace: (0) symmetrical respective to sagittal axis, ventral margins tight ('*Isoxys* type'); (1) asymmetrical respective to sagittal axis, anteroventral margin tight, posteroventral margin ample ('*Canadaspis* type'); (2) symmetrical respective to sagittal axis, ventral margins ample

('*Branchiocaris* type'); (3) symmetry variable, ventral margins ample (as in *Jugatacaris* and *Odaraia*).
References: ref. [AC2019-42].
Different morphotypes of bivalved carapaces.

83. Bivalved carapace, relative length of anterior spine compared to valve length: (0) absent or tiny spines; (1) short spine; (2) long spine.
References: part. [BU2002-5], cf. [LG2013-590], ref. [YA2018-3, 4].
Long spines are typical in *Isoxys*. The anterior spine is distinguished from the posterior one (next character).

84. Bivalved carapace, relative length of posterior spine compared to valve length: (0) absent or tiny spines; (1) short spine; (2) long spine.
References: part. [BU2002-5], cf. [LG2013-590], ref. [YA2018-3, 4].
See previous character.

85. Bivalved carapace, average length of valves in adults, anterior and posterior spines excluded: (0) shorter, < 3.5 cm; (1) longer, > 4 cm.
Trying to distinguish between so-called 'smaller' and 'larger' bivalved euarthropods.

86. Bivalved carapace covering cephalothorax only: (0) absent; (1) present.
References: ref. [AC2017-37; A2019-45].
A feature shared by hymenocarines.

87. Bivalved carapace, posterior margin notched from dorsal view: (0) absent; (1) present.
For distinguishing the bivalved carapaces in isoxyids and hymenocarines.

88. Isoxyid-type bivalved carapace, curvature of anterior dorsal margin of valve: (0) almost straight; (1) curved.
References: Stein *et al*. (2010); Fu *et al*. (2011, 2014); Legg and Vannier (2013); Aria and Caron (2015).
Used to distinguish between different isoxyid species.

89. Isoxyid-type bivalved carapace, relative lengths of anterior and posterior spines: (0) posterior spine longer; (1) anterior spine longer.
References: Stein *et al*. (2010); Fu *et al*. (2011, 2014); Legg and Vannier (2013); Aria and Caron (2015).
Used to distinguish between different isoxyid species.

90. Soft-tissue bundle into the anterodorsal end of bivalved carapace: (0) absent; (1) present.
References: Fu *et al*. (2011); Aria and Caron (2015).
A soft-tissue feature only seen in isoxyids.

91. Fused head shield: (0) absent; (1) present.
Reference: ref. [RS2011-83; LG2012-14; LG2013-14], ref. [LU2011-14], ref. [SC2015-3; YA2015-3; ZH2016-3], part. [CA2017-19; AC2017-34; AC2019-39].
Absent for those with free head carapaces.

92. Head shield articulated with reduced anterior trunk tergites: (0) absent; (1) present.
References: cf. [ER1999-9; CB2004-38; OH2013-48; LG2012-44; LG2013-44; DU2019-48].
For xandarellids.

93. Transverse ridges or notches as segmental impression on head shield: (0) absent; (1) present.
References: ref. [AC2017-42; AC2019-50].
Present in several megacheirans.

94. Glabellar furrows or lobes: (0) absent; (1) present.
References: cf. [OH2013-35; LG2012-33; LG2013-33].
For trilobite glabella only.

95. Anterior margin of head shield or carapace: (0) convex; (1) almost straight; (2) subtriangular, rostral; (3) concave.
References: cf. [A2015-I.2].
Convex in most euarthropods. States 1–3 coded for various megacheirans.

96. Additional anterior marginal structures of head shield: (0) absent; (1) pointed medially; (2) notched on single tergite.
References: ref. [ED2011-2], part. [OH2013-28; LG2012-11; LG2013-11; DU2019-28], part. [LU2011-11].
Pointed in *Leanchoilia*. Notched in conciliterган artiopodans.

97. Genal angles of head shield: (0) rounded genal angles; (1) acute genal angles; (2) genal spines; (3) spine-like extension.
References: ref. [RS2011-93; LG2012-39; LG2013-39], cf. [OH2013-36; DU2019-36], ref. [AC2019-55].
Showing great variations among euarthropods.

98. Medial notch on posterior margin of head shield: (0) absent; (1) present.
References: ref. Chen *et al*. (2019).
For xandarellids.

99. Doublure of head shield: (0) absent or weak; (1) strong.
References: cf. [LU2011-25], cf. [OH2013-27; LG2012-25; LG2013-25; DU2019-27], cf. [AC2017-45; AC2019-53].
Strong doublure is common in head shield of artiopodans. Distinguished from doublure in free head carapace.

100. Doublure of head carapace: (0) absent or weak; (1) strong.
References: cf. [LU2011-25], cf. [OH2013-27; LG2012-25; LG2013-25; DU2019-27], cf. [AC2017-45; AC2019-53].
See previous character.

101. Structure of protocerebrum: (0) cycloneuralian brain or non-dorsally restricted ganglionic protocerebrum; (1) dorsal restriction of protocerebrum.
References: Smith *et al*. (2017).

102. Suboesophageal ganglion completely fused to thoracic plus abdominal ganglia: (0) absent; (1) present.
References: [TA2013-19].
A feature shared by Megacheira and Chelicerata (Tanaka *et al*., 2013).

103. Stomodeum extends to rostral margin of protocerebrum: (0) absent; (1) present.
References: [TA2013-141].
A feature shared by Megacheira and Chelicerata (Tanaka *et al*., 2013).

104. Number of segments in head region or covered by head shield or carapace: (0) 1–2; (1) 3-4; (2) four and one-half; (3) 5; (4) ≥ 6.
References: ref. [ER1999-2; PA2010-2; ED2011-3], cf. [BU2002-30; DA2009-3], cf. [PA2010-2], cf. [RS2011-84; LG2012-27; LG2013-27], cf. [LU2011-27], ref. [OH2013-5, 8, 47; LG2012-281; LG2013-281; DU2019-5, 8, 47], ref. [AC2017-31; AC2019-34, 56].
The ‘four and one-half’ state is typical for a number of artiopodans (Edgecombe and Ramsköld, 1999; Scholtz and Edgecombe, 2005).

Trunk or thorax (non-appendicular structures)
105. Metameres longest in middle trunk, shortening towards anterior and posterior: (0) absent; (1) present.
Reference: ref. [RC1998-8; LG2013-588], ref. [YA2015-50; ZH2016-63], ref. [CA2017-53, 54].
Typical for luolishaniids. Inapplicable for euarthropods.

106. Number and form of annuli between legs per metamere on trunk: (0) > 7, narrow; (1) < 6, wide.
References: cf. [RC1998-6; LG2013-587], cf. [CA2017-43].
A smaller number of wide annuli is typical in *Onychodictyon* and *Aysheaia*.

107. Dorsal/tergal boundary between head and thorax/trunk: (0) absent; (1) present.
Visible boundary between these tagmata, such as arthrodial membranes (also see characters below).

108. Articulation between head and thorax/trunk non-functional; (0) absent; (1) present.
References: [CB2004-36; OH2013-46; LG2012-42; LG2013-42].
As in tegopeltids.

109. Occipital lobe: (0) absent; (1) present.
References: [AC2017-41; AC2019-49].
Typical for trilobites.

110. Trunk narrowed anteriorly relative to head shield: (0) absent; (1) present.
References: [OH2013-49; LG2012-52; LG2013-52].
A feature in naraoiids.

111. Dorsal/tergal boundary between thorax/trunk and pygidium/tail: (0) absent; (1) present.
References: ref. [LG2013-616].
Visible boundary between these tagmata, including arthrodial membranes (also see characters above and below).

112. Dorsal/tergal boundaries in thorax/trunk: (0) absent; (1) present.
References: ref. [MY2019-2; AC2019-187].
Visible boundaries between thoracic or trunk metameres, including arthrodial membranes (also see characters above).

113. Articulations of trunk tergites: (0) tergites non-overlapping; (1) extensive overlap of tergites; (2) edge-to-edge pleural articulations.
References: cf. [DA2009-24], [OH2013-44; LG2012-59; LG2013-59; DU2019-44], ref. [AC2017-156, 157; AC2019-207, 208].
State 1 for a majority of deuteropods. Different among artiopodans.

114. Trunk tergites weakly sclerotized: (0) absent; (1) present.
References: Legg and Vannier (2013); Aria and Caron (2015).
Isoxyids appear to have a weakly sclerotized trunk, as in Radiodonta.

115. Articulating half rings on trunk segments: (0) absent; (1) present.
References: [OH2013-80; LG2012-72; LG2013-72].
For conciliterga artiopodans.

116. Thickened inter-segmental rims on both trunk segments and head shield: (0) absent; (1) present.
References: Aria *et al*. (2020).
As in *Jianfengia* and *Sklerolibyon*.

117. Straight cuticular ridge along with articulation between adjacent trunk segments: (0) absent; (1) present.
References: Aria *et al*. (2020).
As in *Jianfengia* and *Sklerolibyon*.

118. Tergal boundaries in trunk effaced: (0) absent; (1) present.
References: ref. [ER1999-15; CB2004-35, 36; OH2013-45, 46; LG2012-65; LG2013-65; DU2019-45, 46], ref. [MY2019-5; AC2019-189].
As in tegopeltids.

119. Posterior tergal articulations functional, anterior ones variably fused: (0) absent; (1) present.
References: [OH2013-51; LG2012-66; LG2013-66; DU2019-51], ref. [MY2019-3; AC2019-188].

Absent in naraoiids and tegopeltids.

120. Decoupling of multiple tergites and sternites/appendages in trunk: (0) absent; (1) present.
References: cf. [ER1999-13; CB2004-33; PA2010-14; OH2013-43; LG2012-58; LG2013-58; DU2019-43], cf. [AC2017-150; AC2019-201].
Present in fuxianhuiids, myriapods and some xandarellids.

121. Anterior tergal boundaries in trunk or thorax reflexed anterolaterally: (0) absent, boundaries traverse or reflexed posterolaterally; (1) present.
References: cf. [ER1999-19; CB2004-40; PA2010-21; ED2011-16; OH2013-50; LG2012-55; LG2013-55; DU2019-50].
A feature of concilitergan artiopodans.

122. Posterior tergites strongly curved compared to anterior tergites: (0) absent; (1) present.
References: cf. [CB2004-45; OH2013-61; LG2012-108; LG2013-108; DU2019-61].
For leanchoilids and *Haikoucaris* of megacheirans, as well as some xandarellids.

123. Orientation of pleurae: (0) horizontal; (1) around body.
References: [AC2017-154; AC2019-205].
Pleurae around body are present in a majority of megacheirans and other euarthropods.

124. Constricted trunk pleural region: (0) absent; (1) present.
Pleurae appear narrowed in several megacheirans.

125. Size of pleurae: (0) short, equal or inferior to body diameter; (1) long, exceeding body diameter.
References: [AC2017-155; AC2019-206], ref. [YA2018-39].
Typical in leanchoilids.

126. Trunk tergite, shape: (0) rounded; (1) pleural tips; (2) extended, forming spines.
Showing great variations among euarthropods.

127. Width change of trunk or thoracic tergites along the length: (0) tapering or narrowing dramatically; (1) narrowing gradually, subequal widths.
Subequal widths of trunk tergites in myriapods and many artiopodans.

128. Tergo-pleural rings in trunk: (0) absent; (1) present.
References: cf. [AC2017-153; AC2019-204].
Present in hymenocarines, some ‘Orsten’ taxa and pancrustaceans.

129. Posterior trunk tergo-pleural rings strongly compacted, disc-like: (0) absent (1) present.
Several hymenocarines possess compacted tergo-pleural rings in their abdomen, differing from those in other hymenocarines.

130. Raised axial region: (0) absent; (1) present.

References: [LG2012-73; LG2013-73; YA2018-41].
Present in fuxianhuiids and many artiopodans.

131. Axial furrows: (0) absent; (1) present.
References: [OH2013-81; LG2012-74; LG2013-74].
Typical for trilobites.

132. Axial spine on non-terminal trunk tergite: (0) absent; (1) present.
References: ref. [ER1999-23; CB2004-42; OH2013-52; LG2012-67; LG2013-67; DU2019-52].
As in some artiopodans.

133. Number of trunk divisions or tergites: (0) 0–1; (1) 2–4; (2) 5–11; (3) 12–19; (4) 20–41; (5) ≥ 42.
References: ref. [AC2017-147, 149; AC2019-195, 196].
For both lobopodians and euarthropods.

134. Number of prothoracic segments: (0) 3; (1) 5 or 6.
References: [YA2018-7].
For fuxianhuiids.

Posterior body
135. Posterior trunk extension: (0) absent; (1) present.
References: cf. [RC1998-9], cf. [MA2009-23; LG2012-23; LG2013-23; MA2014-34], [LU2011-35], cf. [SC2015-73; YA2015-75; ZH2016-91], cf. [CA2017-52].
For lobopodians only.

136. Abdomen as posterior differentiated segments: (0) absent; (1) present.
References: cf. [OH2013-60; LG2012-98; LG2013-98], cf. [AC2017-146; AC2019-193].
For a series of limbless segments in euarthropods.

137. Abdominal tergites narrowed in widths, distinguishing from thoracic tergites: (0) absent; (1) present.
For fuxianhuiids.

138. Number of limbless posterior tergites: (0) 0–2; (1) 3–5; (2) ≥ 6.
References: ref. [BU2002-7], ref. [CB2004-43; ED2011-19; RS2011-252; OH2013-59; LG2012-97; LG2013-97].
Varying among euarthropods.

139. Telson: (0) absent; (1) present.
References: cf. [ED2011-22; OH2013-67; LG2012-131; LG2013-131; YA2018-47; DU2019-67], cf. [AC2017-201; AC2019-257].
Absent in many artiopodans.

140. Telson fringed with setae: (0) absent; (1) present.

References: [ED2011-24; LG2012-138; LG2013-138].
Typical for megacheirans.

141. Posterior tagmata with elongate lateral processes: (0) absent; (1) present.
References: cf. [LG2012-114; LG2013-114; YA2018-75].
Present in a number of euarthropod groups.

142. Posterior tagmata composed of three paired tail flaps: (0) absent; (1) present.
References: [LG2012-115; LG2013-115].
A feature shown in *Anomalocaris*, *Opabinia* and *Isoxys*.

143. Posteriormost lateral processes, morphology: (0) absent; (1) present, isolated; (2) present, fused with middle projection.
References: ref. [BU2002-25, 31], ref. [CB2004-53; ED2011-23; OH2013-68; DU2019-68], ref. [LG2012-123; LG2013-123].
Variable among euarthropods.

144. Posteriormost lateral processes fused: (0) absent; (1) present.
References: [LG2012-116; LG2013-116].
For certain hymenocarines.

145. Posteriormost lateral processes recurved: (0) absent; (1) present.
References: [LG2012-121; LG2013-121].
For a couple of hymenocarines.

146. Posteriormost lateral processes with lanceolate tips: (0) absent; (1) present.
References: [LG2012-122; LG2013-122].
For Radiodonta, *Isoxys* and certain hymenocarines.

147. Medial telson process: (0) absent; (1) present.
References: [LG2012-118; LG2013-118].
For a couple of hymenocarines.

148. Telson shape: (0) paddle-shaped or lanceolate; (1) rod-like; (2) flap-shaped, medial and paired lateral processes fused; (3) paired lateral processes unfused or incompletely fused.
References: ref. [BU2002-25, 31], ref. [CB2004-53; ED2011-23; OH2013-68; LG2012-123, 133; LG2013-123, 133; DU2019-68].
Showing variations among euarthropods.

149. Posteriormost ovoid median plate attached to telson: (0) absent: (1) present.
Present in *Fortiforceps* and *Shankouia* (Chen, 2004).

150. Posteriormost tagma modified into a fluke: (0) absent; (1) present.
References: [LG2012-117; LG2013-117].

For *Isoxys* and certain hymenocarines.

151. Multiple posterior segments fused, forming a pygidium: (0) absent; (1) present.
References: cf. [CB2004-47; PA2010-22; ED2011-21; OH2013-62; LG2012-109; LG2013-109; DU2019-62], cf. [AC2017-209; MY2019-7; AC2019-190].
Typical for artiopodans and a few taxa in other euarthropod groups.

152. Pygidium, general shape: (0) narrowed, bearing median spines; (1) ovoid to semi-circular; (2) widened, subrectangular, with lateral spines.
Showing variations among artiopodans.

153. Relative size of pygidium to cephalon: (0) pygidium absent or micropygous; (1) subisopygous to isopygous.
References: cf. [PA2010-23; LG2012-113; LG2013-113].
Variable among artiopodans, notably in trilobites.

154. Median broad-based spine on pygidium: (0) absent; (1) present.
References: cf. [CB2004-50; OH2013-65; LG2012-111; LG2013-111; DU2019-65].
Present in some artiopodans.

155. Lateral spines on pygidium: (0) absent; (1) present.
References: cf. [ER1999-22; CB2004-51; OH2013-66; LG2012-112; LG2013-112; DU2019-66], cf. [AC2017-212; AC2019-267].
Present in some artiopodans.

156. Caudal cerci: (0) absent; (1) present.
Posteriormost antenniform appendages in certain artiopodans.

157. Tail flaps: (0) absent; (1) present.
For *Opabinia* and radiodonts only.

158. Number of tail flap pairs: (0) single; (1) multiple.
References: cf. [DA2009-42], cf. [MA2009-24; MA2014-35], cf. [LU2011-37], cf. [SC2015-74; YA2015-76; ZH2016-92], ref. [CA2017-56].
Multiple pairs of tail flaps are present in *Opabinia* and non-hurdiid radiodonts.

159. Furcae: (0) absent; (1) present.
References: ref. [LU2011-36], ref. [AC2017-206; AC2019-264].
Present in a couple of radiodonts.

Appendages (general)
160. Paired appendages: (0) absent; (1) present.
References: [DA2009-17], [MA2009-1; MA2014-1], [LG2012-141; LG2013-141], [VI2014: 17], ref. [LU2011-16], [SC2015-1; YA2015-1; ZH2016-1], [CA2017-1; AC2017-1; AC2019-1].

For both lobopods and arthrodized limbs.

161. Lobopodous appendages: (0) absent; (1) present.
References: ref. [CA2017-31; AC2017-8; AC2019-8].
We distinguish lobopodous (unsclerotized) appendages from sclerotized or arthropodized ones (see next character).

162. Sclerotized appendages: (0) absent; (1) present.
References: ref. [RS2011-277; LG2012-148; LG2013-148].
Similar to our treatment on the body, we distinguish sclerotized appendages (with hardened cuticle) from arthropodized ones (with podomeres separated by arthrodial membranes; see next character).

163. Arthropodized appendages: (0) absent; (1) present.
References: ref. [BU2002-11], cf. [DA2009-18], ref. [LU2011-17], ref. [RS2011-277; LG2012-148; LG2013-148], part. [MA2014-2], cf. [CA2017-15].
See previous character.

164. Sclerotized head appendages: (0) absent; (1) present.
References: ref. [LG2012-149; LG2013-149].
The sclerotization or arthropodization of appendages might have not happened simultaneously in head and trunk during the early evolution of euarthropods. See characters below.

165. Arthropodized head appendages: (0) absent; (1) present.
References: ref. [LG2012-149; LG2013-149].
See previous character.

166. Sclerotized trunk appendages: (0) absent; (1) present.
References: ref. [LG2012-150; LG2013-150].
See previous character.

167. Arthropodized trunk appendages: (0) absent; (1) present.
References: ref. [LG2012-150; LG2013-150], part. [MA2014-3], ref. [SC2015-19; YA2015-8; ZH2016-8], cf. [CA2017-34; AC2017-181; AC2019-210].
See previous character.

Frontalmost appendages
168. Frontalmost appendages, position on head: (0) lateral; (1) dorsolateral; (2) ventral.
References: cf. [DA2009-21], cf. [LU2011-6], ref. [LG2012-143; LG2013-143], cf. [MA2014-14], ref. [SC2015-26; YA2015-16; ZH2016-36].
A ventral position of frontalmost appendages is typical for many euarthropods.

169. Frontalmost appendages, orientation: (0) non-specific or lateral; (1) downward; (2) upward.
References: ref. [VA2009-8], ref. [LG2013-644], ref. [AC2017-73; AC2019-106].
Most raptorial forms can be either downward or upward orientated.

170. Frontalmost appendages, segmental identity: (0) protocerebral; (1) deuterocerebral.
References: ref. [BU2002-21], ref. [CA2017-11], Cong *et al*. (2014).
Deuterocerebral frontalmost appendages is a defining character for Deuteropoda.

171. Frontalmost appendages, arthropodization: (0) absent; (1) present.
References: part. [BU2002-11], part. [DA2009-18], cf. [LU2011-7], ref. [MA2014-2, 3], ref. [SC2015-21, 22; YA2015-9, 10; ZH2016-27, 28], part. [CA2017-15, 31], cf. [AC2017-66; AC2019-87].
A synapomorphy for Radiodonta and Deuteropoda.

172. Frontalmost appendages, annulation: (0) absent; (1) present.
For lobopodous forms.

173. Frontalmost appendages, composition of distal annuli or articulated podomeres, appendage terminal excluded: (0) homonomous; (1) heteronomous.
Heteronomous podomeres are present in many raptorial frontalmost appendages.

174. Frontalmost appendages, absolute number of distal articulated podomeres or annuli: (0) smooth or ≥ 16; (1) 8–15; (2) 5–7; (3) 4; (4) 3; (5) ≤ 2.
References: ref. [DA2009-20], ref. [LG2013-642], ref. [SC2015-72; YA2015-74; ZH2016-90], ref. [AC2017-74; AC2019-88].
Showing great variations among euarthropods.

175. Frontalmost appendages, proximal shaft region differentiated from distal articulated podomeres: (0) absent; (1) present.
References: Cong *et al*. (2017, 2018); Pates and Daley (2019).
Coded for the shaft in radiodont frontalmost appendages and the basis in megacheiran great appendages.

176. Relative number of podomeres or annuli in frontalmost appendages compared to that in trunk endopods or legs: (0) close; (1) significantly more; (2) significantly less; (3) reduced.
Varying among different euarthropod groups.

177. Frontalmost appendages specialised, with a unique morphology compared to all other appendages: (0) absent; (1) present.
References: cf. [LG2013-640], ref. [SC2015-20, 24; YA2015-14; ZH2016-26, 30], ref. [CA2017-4; AC2017-7; AC2019-7].
Individualized frontalmost appendages are present in some lobopodians and common in euarthropods.

178. Frontalmost appendages, antenniform: (0) absent; (1) present.
References: part. [BU2002-8], part. [DA2009-19], ref. [MA2009-12, 13; MA2014-19, 20], ref. [ED2011-4], cf. [LU2011: 15], ref. [RS2011-149; LG2012-168; LG2013-168], ref. [SC2015-25; YA2015-12; ZH2016-31], ref. [CA2017-16], ref. [OH2013-1; DU2019-1].
Differentiated from raptorial forms and walking legs.

179. Frontalmost appendages, endites well-developed, raptorial: (0) absent; (1) present.
References: part. [BU2002-8], part. [DA2009-19], ref. [MA2009-5, 6], ref. [ED2011-4], ref. [LU2011-5], ref. [SC2015-25; YA2015-12; ZH2016-31], ref. [CA2017-14], ref. [OH2013-1; DU2019-1].
Frontalmost appendages bearing well-developed endites have been interpreted as raptorial.

180. Frontalmost appendages, terminal structures: (0) similar to other podomeres; (1) claw; (2) cuticular spines.
References: ref. [LU2011-20].
Varying between euarthropod groups.

181. Frontalmost appendages, terminal claw bearing multiple cusps: (0) absent; (1) present.
Present in 'gilled' lobopodians.

182. Frontalmost appendages (unarthropodized), located at the protruded 'neck': (0) absent; (1) present.
In certain lobopodians, the 'head' is protruded forming a neck, where the frontalmost appendages are located.

183. Frontalmost appendages (unarthropodized), antenniform: (0) absent; (1) present.
References: ref. [R1999-16], ref. [SC2015-25; YA2015-12; ZH2016-32].
As in some lobopodians.

184. Frontalmost appendages (unarthropodized), tentacle-like: (0) absent; (1) present.
References: ref. [R1999-15], ref. [LU2011-4], cf. [CA2017-10], ref. [SC2015-25, 71; YA2015-12; ZH2016-32, 89].
As in *Cardiodictyon* and *Hallucigenia*.

185. Frontalmost appendages (unarthropodized), unspecialised lobopod: (0) absent; (1) present.
References: part. [DA2009-23, LG2013-642; MA2014-15], ref. [SC2015-25; YA2015-12; ZH2016-32].
As in *Paucipodia* and *Microdictyon*.

186. Frontalmost appendages (unarthropodized), specialised raptorial lobopod: (0) absent; (1) present.
References: ref. [MA2009-4, LG2013-641; MA2014-13], ref. [SC2015-25; YA2015-12; ZH2016-32].
As in *Megadictyon* and 'gilled' lobopodians.

187. Frontalmost appendages (unarthropodized), non-terminal spinous outgrowths: (0) absent or invisible; (1) present.
References: cf. [SC2015-30; YA2015-19; ZH2016-40], ref. [CA2017-12, 13].
For those in lobopodian forms.

188. Frontalmost appendages (arthropodized), number of podomeres bearing well-expanded endites, terminal podomere excluded: (0) 0 or 1; (1) 2 or 3; (2) 4–7; (3) ≥ 8.
References: cf. [DA2009-22], ref. [ED2011-5; LG2012-180; LG2013-180], cf. [LU2011-8], ref.

[OH2013-2; DU2019-2], ref. [AC2019-94].
Differing among groups.

189. Frontalmost appendages (arthropodized), shaft endite: (0) absent; (1) present.
Known from Radiodonta and *Kylinxia*.

190. Frontalmost appendages (arthropodized), differentiated main spines or main protrusions of endites: (0) absent; (1) present.
References: ref. [RS2011-146; LG2012-145; LG2013-145].
Common in raptorial forms.

191. Frontalmost appendages (arthropodized), relative length of endite to podomere height: (0) absent or shorter; (1) comparable; (2) much longer.
References: ref. [AC2017-69; AC2019-90].
Long endites are typical for hurdiid of frontalmost appendages and 'great appendages'.

192. Frontalmost appendages (arthropodized), relative width of base of endite to podomere length: (0) endite absent or narrowed; (1) comparable, along the entire podomere.
References: ref. [AC2017-77; AC2019-108].
Wide endites are present in hurdiid frontalmost appendages, 'great appendages' and some isoxyids.

193. Frontalmost appendages (arthropodized), morphology of enditic spines: (0) absent; (1) spiky; (2) elongated, blade-like; (3) elongated, finger-like; (4) needle-like.
References: ref. [AC2017-77; AC2019-108].
Showing great variations among euarthropods.

194. Frontalmost appendages (arthropodized), enditic spines originated from distal portion of podomere, tapering distally: (0) absent; (1) present.
Typical in 'great appendages' and chelicerae.

195. Frontalmost appendages (arthropodized), endites broadened laterally, overlapping with adjacent ones: (0) absent; (1) present.
Present in hurdiids.

196. Frontalmost appendages (arthropodized), endites, change of lengths along the appendage: (0) decreasing gradually towards tip; (1) alternating (short-long-short etc.).
As in Anomalocarididae, Amplectobeluidae and *Kylinxia*.

197. Frontalmost appendages (arthropodized), endite pincer-like: (0) absent; (1) present.
References: ref. [LG2013-645].
Typical in Amplectobeluidae.

198. Frontalmost appendages (arthropodized), endites bearing well-developed auxiliary spines: (0) absent; (1) present.

References: cf. [AC2017-78; AC2019-109].
Present in Radiodonta, *Kylinxia* and Megacheira.

199. Frontalmost appendages (arthropodized), endites, auxiliary spines distribution: (0) both anterior and posterior; (1) anterior only.
Auxiliary spines are present only on anterior enditic margin in a number of hurdiids.

200. Frontalmost appendages (arthropodized), chelate or sub-chelate endites on distal podomeres: (0) absent; (1) present.
References: part. [BU2002-8], ref. [LG2013-643; YA2018-64], ref. [AC2019-92].
For Megacheira and Panchelicerata.

201. Frontalmost appendages (arthropodized), length of basal podomere(s): (0) short; (1) elongated.
References: ref. [AC2019-95].
For shaft in radiodont frontalmost appendages or basis in 'great appendages'.

202. Frontalmost appendages (arthropodized), oblique arthrodial membrane in shaft region: (0) absent; (1) present.
Present in *Anomalocaris*, *Amplectobelua* and *Kylinxia*.

203. Frontalmost appendages (arthropodized), proximal podomeres differentiated and peduncle-like: (0) absent; (1) present.
References: ref. [LG2013-647].
A characteristic of 'great appendages'.

204. Frontalmost appendages (arthropodized), peduncle podomere morphology: (0) short; (1) elongated.
References: ref. [AC2019-95].
Elongated peduncle is present in certain megacheirans.

205. Frontalmost appendages (arthropodized) geniculate at the middle pivot, forming an elbowed articulation: (0) absent; (1) present.
References: ref. [LG2013-646; YA2018-63], [AC2019-100].
As in Megacheira and Panchelicerata.

206. Frontalmost appendages (arthropodized), elongate terminal podomere: (0) absent; (1) present.
Present in Megacheira and Panchelicerata.

207. Frontalmost appendages (arthropodized), flagella: (0) absent; (1) present.
References: cf. [BU2002-23], ref. [CB2004-6, 8], cf. [ED2011-6; LG2012-181; LG2013-181], cf. [OH2013-3; DU2019-3], cf. [AC2017-71; AC2019-99].
For leanchoilids.

208. Frontalmost appendages (arthropodized), length of flagella: (0) midlength of trunk; (1) end of

body.
References: cf. [ED2011-7; LG2012-182; LG2013-182].
Length of flagella reaches end of body in *Leanchoilia*.

209. Frontalmost appendages (arthropodized), dorsal spines: (0) absent; (1) present.
References: cf. [AC2017-79; AC2019-110].
A feature of radiodont frontalmost appendages.

210. Frontalmost appendages (arthropodized), length of multi-podomerous antenniform types compared with length of bivalved head carapace: (0) short; (1) long.
References: ref. [AC2017-75; AC2019-107].
For hymenocarines.

211. Frontalmost appendages (arthropodized), raptorial device made of three to four podomeres with elongate endites: (0) absent; (1) present.
References: [AC2019-92].
A potential synapomorphy of Megacheira.

212. Frontalmost appendages (arthropodized), chelate endites only on terminal podomeres, chelicera-like or chelicerae: (0) absent; (1) present.
References: ref. [RS2011-149; LG2012-168; LG2013-168], [AC2017-72; AC2019-101].
For panchelicerates.

Post-oral appendages
213. Anteriormost appendages differentiated from posterior ones: (0) absent; (1) present.
References: [LG2012-144; LG2013-144].
Common in many lobopodians and euarthropods.

214. Differentiated multiple pairs of anterior homonomous unarthropodized appendages: (0) absent; (1) present.
References: ref. [MA2009-3, MA2014-12], ref. [LU2011-11], ref. [SC2015-54; YA2015-72; ZH2016-66], ref. [CA2017-5].
For the tentacles in *Cardiodictyon* and *Hallucigenia* and the setiferous limbs in luolishaniids.

215. Differentiated multiple pairs of anterior homonomous unarthropodized appendages, number of pairs: (0) two to three; (1) five to six.
References: ref. [MA2009-27; MA2014-38; LG2013-582], ref. [YA2015-73; ZH2016-88], ref. [CA2017-5].
Applicable only with the previous character.

216. Differentiated multiple pairs of anterior homonomous unarthropodized appendages, bearing spine-like long claws: (0) absent; (1) present.
References: Caron and Aria (2017).
For claws on anterior appendages in luolishaniids.

217. Multiple post-oral homonomous appendages (legs, flaps) accommodated to head region, differentiated from the frontalmost and other post-oral appendages: (0) absent; (1) present.
Common in euarthropods.

218. Anterior homonomous appendages in head smaller, differentiated in size from posterior ones: (0) absent; (1) present.
References: ref. [AC2017-43; AC2019-126].
As in some radiodonts and basal euarthropods.

219. Anterior reduction of segments and/or appendages: (0) absent; (1) present.
References: [AC2017-43; AC2019-51]. Present in a couple of euarthropod groups.

220. Second antennae on third head segment: (0) absent; (1) present.
A feature of 'crustaceans'.

221. Specialised post-antennal appendages (SPAs): (0) absent; (1) present.
References: ref. [RS2011-163; LG2012-188; LG2013-188], ref. [YA2015-15; ZH2016-35], ref. [AC2017-94; AC2019-144], ref. [YA2018-61, 62].

222. Morphology of appendages on third head segment: (0) homonomous to posterior appendages; (1) heteronomous to posterior appendages, or reduced, forming intercalary segment.
As in mandibulates and related taxa.

223. Mandibles or paired mandible-like appendages: (0) absent; (1) present.
References: part. [RS2011-168; LG2012-224; LG2013-224], ref. [AC2017-107; AC2019-142].
Defining feature of Mandibulata.

224. Mandible morphology: (0) basipodite with elaboration of proximal endite; (1) coxal endite embedded between the labrum and hypopharynx to form a chewing chamber.
References: part. [RS2011-168; LG2012-224; LG2013-224].
Proximal endite is present in a number of 'Orsten' taxa.

225. Mandibular palp: (0) absent; (1) present.
References: [RS2011-176; LG2012-232; LG2013-232].
A plesiomorphy for mandible.

226. Specialised raptorial post-tritocerebral appendages: (0) absent; (1) present.
References: Aria and Caron (2017).
As in *Tokummia* and *Branchiocaris*.

227. Number of unique morphological types of anteriormost appendage pairs: (0) 0; (1) 1; (2) 2; (3) ≥ 3.
Variable across lobopodians and euarthropods.

228. Differentiation of trunk appendages in sets, each consisting of multiple appendages in similar morphology: (0) absent; (1) present.
References: ref. [AC2017-88; AC2019-127].
A pattern seen in panchelicerates and hymenocarines.

229. External metameric boundaries on unarthropodized trunk appendages: (0) absent; (1) present.
Present in a couple of lobopodians.

230. Well-developed papillae or cuticular outgrowth on unsclerotized appendages: (0) absent; (1) present.
As in some lobopodians.

231. Post-oral appendages, length: (0) subequal along length of body; (1) anterior appendages about twice as long as posterior appendages.
References: [VI2014-49; VR2015-50].
State 1 in some lobopodians and many euarthropods.

232. Post-oral telescopic legs or lobopods: (0) absent; (1) present.
For tardigrades and lobopodians.

233. Post-oral telescopic legs or lobopods, multiple rows of cuticular spines in feather-like arrangement: (0) absent; (1) present.
References: cf. [DA2009-29], part. [LU2011-18; LG2013-681], ref. [LU2011-19], cf. [MA2014-9], ref. [SC2015-59; YA2015-59; ZH2016-73], cf. [CA2017-46].
For luolishaniids, as well as *Onychodictyon* and *Aysheaia*.

234. Post-oral telescopic legs or lobopods bearing long setiform spines: (0) absent; (1) present.
References: ref. [SC2015-60; YA2015-60, 61; ZH2016-74, 75], ref. [CA2017-48].
A synapomorphy of luolishaniids.

235. Post-oral telescopic legs or lobopods, relative widths: (0) very narrowed; (1) narrower than trunk diameter; (2) comparable to trunk diameter.
For lobopodians.

236. Post-oral telescopic legs or lobopods, relative length: (0) shorter or close to trunk diameter; (1) at least 1.5 times longer than trunk diameter; (2) state 0 or state 1.
References: ref. [RC1998-12], cf. [CA2017-32; AC2017-9; AC2019-9].
For lobopodians.

237. Number of leg pairs on trunk terminal: (0) one; (1) two.
References: cf. [RC1998-17], cf. [MA2009-30; LG2013-680], ref. [CA2017-55].
For lobopodians.

238. Papillae or spines on legs: (0) absent or tiny; (1) prominent.
References: ref. [RC1998-18], cf. [MA2009-9; LG2013-677], cf. [MA2014-10], ref. [SC2015-61; YA2015-62; ZH2016-76].
Prominent in Onychophora and certain lobopodians.

239. Number of claw elements on leg or frontalmost appendage: (0) none; (1) single; (2) double; (3) multiple.
References: cf. [RC1998-19], ref. [MA2009-10, 11; LG2013-678, 679; MA2014-17, 18], ref. [LU2011-20, 21], ref. [SC2015-63–65; YA2015-64–66; ZH2016-79–81], ref. [CA2017-51; AC2017-15; AC2019-15].
Varying among lobopodians and euarthropods.

240. Stacked structure of claws or sclerites: (0) absent; (1) present.
References: cf. [SC2015-48; YA2015-46; ZH2016-59], cf. [CA2017-41].
A feature common in lobopodians. Also reported in radiodonts (Cong *et al*., 2017).

241. Large distal claw elements with a wide base on appendages: (0) absent; (1) present.
Present in 'gilled' lobopodians and various euarthropods.

242. Number of claws on posteriormost lobopods: (0) multiple; (1) single.
References: cf. [CA2017-58; AC2017-16; AC2019-16].
Differing between lobopodians.

243. Posteriormost claws or legs orientated to the anterior: (0) absent; (1) present.
References: cf. [SC2015-78; YA2015-80; ZH2016-96], cf. [CA2017-59; AC2017-17; AC2019-17].
Present in a number of lobopodians.

244. Post-oral appendages, protopodite or gnathobase-like structures: (0) absent; (1) present.
References: ref. [BU2002-20], cf. [DA2009-35], cf. [RS2011-280; LG2012-152; LG2013-152], cf. [MA2014-8], cf. [SC2015-58; YA2015-58; ZH2016-72], ref. [OH2013-17; D2013-17], ref. [AC2017-165, 174; AC2019-218, 227].
Protopodite, endopodite and exopodite are coded separately (see characters below). The radiodont gnathobase-like structures (e.g., Cong *et al*., 2017, 2018) are treated as a form of protopodites here.

245. Protopodite or gnathobase, fusion of multiple podomeres: (0) superficial repetitive structures invisible; (1) repetitive homonomous enditic structures visible; (2) multiple segmented podomeres and boundaries visible.
References: part. [BU2002-32], ref. [AC2017-166–169; AC2019-219–222].
Protopodite comprising multiple podomeres are typical in hymenocarines and crustacean-related taxa.

246. Protopodite, proximal endite: (0) absent; (1) present.
References: cf. [HA2010-26; LG2013-661].
The proximal endite and coxa are characteristic in crustacean-related taxa. See next character.

247. Protopodite, coxa: (0) absent; (1) present.
Reference: Haug *et al*. (2010)
See previous character.

248. Biramous appendages with endopodites and exopodites: (0) absent; (1) present.
References: ref. [BU2002-13], ref. [DA2009-34], cf. [LU2011-25], cf. [RS2011-278; LG2012-151; LG2013-151; YA2018-68], cf. [MA2014-7], cf. [VR2015-57], ref. [SC2015-57; YA2015-57; ZH2016-69], ref. [AC2017-176; AC2019-229], cf. [AC2017-95; AC2019-133].
Biramy of appendages is found in radiodonts and many euarthropods.

249. Post-oral appendages, jointed legs or endopodites: (0) absent; (1) present.
References: cf. [DA2009-28], cf. [LU2011-26], ref. [OH2013-9; LG2012-282; LG2013-282; YA2018-71; DU2019-9], cf. [MA2014-4].
A feature of deuteropods.

250. Post-oral appendages, endopodite or leg, proximal-distal differentiation of podomeres or annuli towards tip: (0) more or less homonomous, tapering continuously; (1) differentiated, discontinuous change in length-width ratio of podomeres.
References: ref. [AC2017-159; AC2019-211].
Certain euarthropod groups hardly exhibit differentiation of podomeres.

251. Post-oral appendages, endopodite, endites: (0) absent or well-reduced; (1) distal spines only; (2) serrated rows of spines; (3) well-extended endite with a cluster of multiple spines.
References: ref. [RS2012-13; LG2012-301; LG2013-301; YA2018-72], cf. [AR2015-V.7], ref. [AC2017-96, 194–197; AC2019-134, 247–250].
Different in various groups.

252. Post-oral appendages, endopodite, number of podomeres with distal claw included: (0) ≥ 12; (1) 8–11; (2) 7; (3) ≤ 6.
References: ref. [BU2002-12], cf. [DA2009-30], ref. [RS2011-282; LG2012-280; LG2013-280; YA2018-15], ref. [AC2017-160; AC2019-212].
Number of podomeres varies among euarthropod groups.

253. Post-oral appendages, endopodite, chelate terminal podomere: (0) absent; (1) present.
Typical for some chelicerates.

254. Post-oral appendages, endopodite and protopodite as a whole, maximum number of podomeres: (0) ≥ 13; (1) 9–12; (2) 8; (3) ≤ 7.
Number of podomeres varies among euarthropod groups.

255. Protopodite and endopodite podomeres close in lengths: (0) absent; (1) present.
As in hymenocarines and some crustacean-related taxa.

256. Lateral flaps or exopodites: (0) absent; (1) present.

References: ref. [DA2009-31], [VI2014-20], ref. [SC2015-55; YA2015-53; ZH2016-67], cf. [CA2017-50].
Absent in typical lobopodians.

257. Lateral flaps or exopodites, attachment: (0) body flap; (1) protopodite only.
References: ref. [DA2009-36; LG2012-55; LG2013-55], part. [MA2009-7, 8], cf. [LU2011-22], cf. [CA2017-33; AC2017-10; AC2019-10].
A protopodite attachment of exopodite is typical for deuteropods.

258. Exopodite morphology, lateral flaps: (0) absent; (1) present.
As in radiodonts.

259. Exopodite morphology, lobe shape: (0) lobe absent; (1) undivided lobe; (2) shorter proximal lobe and longer distal lobe; (3) proximal lobe no shorter than distal lobe.
References: ref. [BU2002-14], ref. [DA2009-32], ref. [MA2014-6], ref. [SC2015-51, 56, 58; YA2015-54, ZH2016-68], ref. [OH2013-10, 11; DU2019-10, 11].
State 1 is present in various euarthropod groups. State 2 is typical for megacheirans, as well as in *Habelia* (Aria and Caron, 2017). State 3 is typical of a majority of artiopodans.

260. Exopodite morphology, segmented podomeres: (0) absent; (1) present.
References: ref. [BU2002-14], ref. [DA2009-32], ref. [MA2014-6], ref. [SC2015-51, 56, 58; YA2015-54, ZH2016-68], ref. [OH2013-10, 11; DU2019-10, 11].
Typical in panchelicerates.

261. Exopodite morphology, numerous annuli: (0) absent; (1) present.
References: ref. [BU2002-14], ref. [DA2009-32], ref. [MA2014-6], ref. [SC2015-51, 56, 58; YA2015-54, ZH2016-68], ref. [OH2013-10, 11; DU2019-10, 11].
As in some crustacean-related taxa.

262. Multiple exopodite lobes or book gills: (0) absent; (1) present.
References: [AC2019-234].
For panchelicerates.

263. Exopodite differentiated into proximal lobe bearing imbricated lamellar setae and distal lobe fringed by non-lamellar setae: (0) absent; (1) present.
References: ref. [RS2011-285; LG2012-157; LG2013-157].
As in many artiopodans.

264. Proximal lobe of exopodite: (0) flattened lobe; (1) narrowed lobe or shaft.
References: cf. [CB2004-14; PA2010-33; OH2013-11; LG2012-158; LG2013-158; DU2019-11].
Different in artiopodans.

265. Distal lobe of exopodite: (0) large; (1) small to moderate size.
References: cf. [CB2004-15; OH2013-12; LG2012-159; LG2013-159; DU2019-12].

For artiopodans.

266. Exopodites, anterior and posterior parts differentiation: (0) absent; (1) present.
As in radiodonts.

267. Exopodites, rays in a parallel row: (0) absent; (1) present.
References: cf. [DA2009-37; LG-2013-37; SC2015-69; YA2015-69; ZH2016-84].
Present in radiodonts.

268. Exopodites, septa or narrowed proximal part: (0) absent; (1) present.
References: ref. [BU2002-14], ref. [DA2009-33], ref. [OH2013-13; LG2012-160; LG2013-160; DU2019-13], ref. [AC2019-237].
Present in megacheirans, a majority of artiopodans and crustacean-related taxa.

269. Differentiation of setae along exopodite: (0) absent; (1) present.
References: cf. [ED2011-30; LG2012-164; LG2013-164].
Differentiation typical in artiopodans.

270. Trunk exopodite, setae: (0) absent or short fine setae; (1) present.
Types of these setae are coded separately below because they might be present in the same taxon.

271. Trunk exopodite, slightly separated oblanceolate setae: (0) absent; (1) present. References: part. [RS2011-242; ED2011-29; LG2012-313; LG2013-313], ref. [AC2019-231].
Typical for megacheirans, present in some basal panchelicerates as well.

272. Trunk exopodite, lamellar setae: (0) absent; (1) present.
References: part. [RS2011-242; ED2011-29; LG2012-313; LG2013-313].
Common in artiopodans and some hymenocarines. Also coded as present for radiodonts.

273. Trunk exopodite, widely spaced filamentous setae: (0) absent; (1) present.
References: part. [RS2011-242; ED2011-29; LG2012-313; LG2013-313].
Present in a number of euarthropod groups.

274. Non-lamellar marginal setae on exopodite: (0) absent; (1) present.
References: ref. [RS2011-284; LG2012-156; LG2013-156], ref. [OH2013-16; DU2019-16].
Common in euarthropod groups except for megacheirans and panchelicerates.

275. Setal structures: (0) absent; (1) present.
References: ref. [BU2002-15], ref. [DA2009-31, 38], cf. [LG2012-474; LG2013-474], ref. [SC2015-55, YA2015-53, ZH2016-67], ref. [MA2014-5, 32], ref. [AC2017-178; AC2019-232].
Present in ‘gilled’ lobopodians and other euarthropods.

276. Setal structures, distribution: (0) confined laterally, associated with lateral flaps or exopodites; (1) present dorsally.

References: ref. [DA2009-41; RS2011-261; LG2012-475; LG2013-475], ref. [MA2009-31; MA2014-33], cf. [VR2015-51], cf. [YA2015-56; ZH2016-71].
Present dorsally in radiodonts.

277. Setal structures, fusion: (0) unfused; (1) fused across the back.
References: [VR2015-52].
Fused across the back in hurdiids.

278. Imbrication of setal structures: (0) absent; (1) present.
References: cf. [OH2013-14; LG2012-161; LG2013-161; DU2019-14].
Present in a variety of euarthropods.

279. Epipodite: (0) absent; (1) present.
A characteristic of crown-group 'crustaceans'.

280. A series of long internal soft structures deep into trunk appendages: (0) absent; (1) present.
References: Fu *et al*. (2011); Aria and Caron (2015).
Typical in isoxyids. Coded as present also in *Opabinia*.

281. Lengths of appendages subequal along middle trunk, shortening towards anterior and posterior: (0) absent; (1) present.
References: cf. [RC1998-11], ref. [MA2009-2], ref. [MA2014-11], ref. [CA2017-49].
A feature shared by euarthropods and a number of lobopodians.

282. Appendages behind the third pair of appendages, morphology: (0) homonomous, undifferentiated; (1) heteronomous, differentiated into various types.
References: ref. [AC2017-92; AC2019-130].
Differentiated in luolishaniids, panchelicerates, hymenocarines and crustacean-related taxa.

283. Number of appendage pairs: (0) ≤ 8; (1) 9–10; (2) 11–14; (3) 15 or 16; (4) ≥ 17.
References: ref. [RC1998-10].
Can be any appendages, whether arthropodized or not.

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