**Supplementary Data**

**“A new elasmosaurid from the early Maastrichtian of Angola and the implications of girdle morphology on swimming style in plesiosaurs “**

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***Eosauropterygia pectoral girdle database***

We examined 43 Eosauropterygia specimens with complete pectoral girdles (Supplementary Table1). The areas of their pectoral girdle elements were calculated using ImageJ (Schneider et al., 2012). The humeral and radius ratios derive directly from Ketchum & Benson (2010) from 40 specimens preserving the humerus (Supplementary Table 2) and 32 preserving the radius (Supplementary Table 3).

**Phylogenetics morphometrics methods**

The placodonts *Cyamodus hildegardis*, *Psephochelys polyosteoderma* and *Placodus gigas* SMF R-1035, the pistosaur *Kwangsisaurus orientalis* IVPP V2338 and the nothosaur *Sanchiaosaurus dengi* IVPP V2338 were not included because their morphology is too specialized within Sauropterygia. Basal Eosauropterygia (pachypleurosaurs) are included. All landmarks are Bookstein’s type 2 (Bookstein, 1991). Landmarks were digitized using tpsDig2, after being assembled in tpsUtil (http://life.bio.sunysb.edu/morph/soft-utility.html). In tpsRelW only the alignment was saved, placing all taxa in the same coordinate system and standardizing size (option “Save aligned specimens”). The resulting \*.tps file was parsed to run in TNT v1.1 (Goloboff et al., 2008), resulting in a 40x14-pair matrix in which each element is a pair of x, y coordinates referring to the aligned location of each landmark mapped in a two 2D space. The choice of a 2D landmark character is justified because the Eosauropterygia coracoid is a flat, splayed bone. The script used was landsch.run, available at http://tnt.insectmuseum.org/index.php/Scripts. A total of 14 landmarks were placed for all taxa analyzed following a homology statement and evolutionary scheme proposed in (Araújo and Correia, in press). This homology statement precludes that the posterior border of the coracoid elongated anteroposteriorly in the nothosaur-plesiosaur transition (Araújo and Correia, in press). Also, that the pectoral fenestrum in plesiosaurs is homologous to the “coracoid foramen” in nothosaurs, and the anteromedial coracoid contact was established in plesiosaurs as a result of a medial migration of the medially a coracoid expansion in nothosaurs (Araújo and Correia, in press), equivalent to landmark 6.A crucial advantage of phylogenetic morphometrics is that other alternative homology schemes and evolutionary models can be proposed and tested using a parsimony criterium.

The phylogenetic morphometrics method demands that the specimens are re-aligned during the search for the most parsimonious tree. Data realignment involves superimposing landmark configurations for best fit, and the residual differences can be solved by simple translations and rotations of the landmarks. Rho-theta resistant fit analysis (RFTRA, Rohlf& Slice, 1990) and heuristic minimization of differences (Catalano et al., 2010; Catalano &Goloboff, 2012) are available in TNT. The heuristic minimization of differences is a superimposition technique that minimizes the linear distances in relation to a prescribed configuration (in this case *Neusticosaurus pusillus*). *Neusticosaurus pusillus* was selected as outgroup because it is a basal pachypleurosaurid in several phylogenetic analyses (Rieppel, 2000; Liu et al., 2011). Both of these re-alignment methods were used and ran at all prescribed levels of search thoroughness (level 0 to 4). The levels of search thoroughness are determined by number of replicates (i.e., number repetition of the algorithm for the same matrix), termpoints (i.e., inclusion of the geometric medians between inter-taxic homologous landmarks as possible reconstruction points of the ancestral location), number of cells in the grid (i.e, the higher the number of cells, the greater number of ancestral landmark position reconstructions), nesting level (i.e., the level/number of grids being nested within the original grid), neighbors level (ie., the number of neighboring cells that are included to form a nested grid). High levels of thoroughness require longer run times and more computer processing power, other than these factors the higher the level of thoroughness the more parsimonious the expected results. Selection among the different resulting trees is based upon the provided tree score. The lower the tree scores the more parsimonious the results (Goloboff & Catalano, 2011; Catalano & Goloboff, 2012). See all trees produced below in Supplementary Figures 4-13.

**Comparisons and implications of phylogentic morphometrics**

Phylogenetic morphometrics (Goloboff & Catalano, 2011) allows evaluation of landmark configuration schemes providing a test to models of morphological evolution. Parsimony analysis is used to test an evolutionary hypothesis of the evolution of the coracoid outline. Parsimony analysis, as used in traditional phylogenetic analysis, can be extended to a two- or three-dimensional realm with phylogenetic morphometrics. By only using a single phylogenetic morphometric character, the outline of the coracoid, we were able to provide a testable model of the evolution of this element in Eosauropterygia and clearly discern the two main morphotypes: Elasmosauridae (i.e., short preglnoid projection, and intercoracoid vaciuity) and Polycotylidae (i.e., long preglenoid projection, developed posterior wings of the coracoid, and no large intercoracoid fenestration) (Fig. 5a). Surprisingly, the phylogenetic significance of the coracoid shape is clearly demonstrated by the fact that the most parsimonious cladogram (tree score is 4.2, Fig. 5d) broadly mirrors the current understanding of the relationships among Eosauropterygia derived using traditional methods (see Liu et al., 2011).

**Evolutionary changes in the pectoral girdle**

***Non-Plesiosaur Eosauropterygia—*** The reorganization of the pectoral girdle in the basal neodiapsid-pachypleurosaur is marked by profound morphological transformations (Fig. 6): (1) major reduction of the interclavicle including the posterior process, (2) the reduction of the coracoid buttresses, (3) the reduction of the scapula dorsal blade, (4) the coracoid re-orientation to the horizontal plane, (5) the ventralization of the scapula, (6) the formation of the clavicular-scapular arch. This important morphological gap is unknown in the fossil record although the answer may lie in Early Triassic marine/transitional sedimentary record. Although nothosaur and pachypleurosaur pectoral girdles are somewhat conservative morphologically, they are readily distinct from their basal neodiapsid ancestors (Fig. 6). These osteological, and inferred mycological modifications are adaptations for a marine lifestyle (e.g., re-orientation of the scapula and coracoid), and associated atrophy of terrestriality-related features (e.g., reduction of the coracoid buttresses, see above). Without understanding these basal transformations, it is not possible to correctly interpret the condition in highly derived eosauropterygians, such as plesiosaurs.

The coracoid is a morphologically conservative element in pachypleurosaurs and nothosaurs (Rieppel, 2000, Fig. 6). Across the evolution of Eosauropterygia the major transformations of the coracoid occur during the pistosaur to plesiosaur transition (Fig. 6 and Fig. 5a: note the landmark optimization on the hypothetical ancestor reconstruction at the *Corosaurus*/*Pistosaurus* node). The major transformations are (see Fig. 5b,c): (1) the median migration of the medial coracoscapular contact, with the formation of the anterior projection of the coracoid (landmark 5, accounting for 7.6% of the total tree score); (2) the reorientation of the thickened glenoidal portion (landmark 7, accounting with for 8.1% of the total tree score); (3) posterior expansion of the coracoid (landmarks 10, 11, 12, 13, 14, accounting for 40% of the total tree score.

Landmark 5 depicts an analogous model of morphological transformation to that proposed by Liu et al. (2011) cladistic analysis. Rieppel’s model proposes that the coracoid foramen is much enlarged in plesiosaurs, yet without providing further details on how this transformation occurred. Along these lines, we propose that the median migration of the medial scapula-coracoid contact left a large opening typically designated in plesiosaurs as the pectoral fenestration, and is homologous to the coracoid foramen in non-plesiosaur eosauropterygians (see also Araújo and Correia, in press). Landmark 7 depicts the observation made by Sues (1987) in which the thickened glenoidal portion of *Pistosaurus* is oriented diagonally relative to the anterioposterior axis of the coracoid, but in more derived sauropterygians the thickened glenoidal portion is oriented transversely.

Landmarks 10 through 14 depict the expansion of the coracoid’s lateral border posteriorly, previously noted by Watson (1924), which is thought to be a result of an muscle attachment area increase for the coracobrachialis and brachialis in derived pistosaurs and plesiosaurs (Fig. 5a). These muscles together with the supracoracoideus form a developmentally cohesive muscle group in reptiles called the ventral mass musculature (Sewertzoff, 1904).

***Plesiosaurs—*** The morphological disparity among the pectoral girdle elements in Plesiosauria has been acknowledged as having phylogenetic significance by White (1940) and Welles (1962), but has only recently been codified and used in phylogenetic analysis (O’Keefe, 2001;Drukenmiller& Russell, 2008; Ketchum & Benson, 2010; Benson et al., 2012; Evans, 2012, Benson &Druckenmiller, 2014). Microcleididae (sensu Benson et al., 2012), possesses the plesiomorphic conditions of a broad preglenoid projection, and reduced ventral portion of the scapula, reduced coracoid foramen, as well as retention of large clavicles and interclavicle (e.g., *Westphaliosaurus*, *Seeleyosaurus*). Leptocleididae share affinities with the Polycotylidae pectoral girdle in having a coracoid median perforations and a narrow but anteriorly expanded preglenoid projection (Fig. 6). On the other hand, Cryptocledidae (sensu Evans, 2012) shares affinities with Elasmosauridae (Fig. 4), but does not possess posterior lateral coracoid wings and no intercoracoid vacuity (Fig. 5).

The pectoral girdle experienced major transformations across Eosauropterygia, for example with the formation of the longitudinal pectoral bar. In non-plesiosaur eosauropterygians, the scapulae do not meet medially. Instead, they are separated by a large pectoral fenestra (Rieppel, 2000). Medially, the coracoids abut weakly and, the clavicles strongly interlock. In plesiosaurs, the median migration of the medial coracoscapular contact and the reduction of the preglenoid projection allow a scapula-scapula contact (Fig. 6), although in basal plesiosaur forms the scapula-scapula contact is weak or inexistent (see Smith, 2007 following phylogeny of Benson et al., 2012). An extensive longitudinal bar is only present in some elasmosaurids such as *Cardiocorax* and YPM1644 (potentially also in *Libonectes* and *Elasmosaurus*), which increases muscle attachment area and reinforces the pectoral girdle as a single structural unit. In these taxa and other Late Cretaceous elasmosaurids, the ventral area of the scapula is subequal to the area of the coracoid (Fig. 7b). However, in polycotylids, plesiosaurids, Lower Creteceouselasmosaurs and basal cryptocleidids the ventral area of the scapula remains small (<0.4) relative to the coracoid area (Fig. 7b). The most extreme case is in plesiosaurids in which the ventral area of the scapula is only about 15% of the area of the coracoid (Fig. 7b). On the other hand, in *Cardiocorax* the coracoid has nearly 50% more the area of the scapula-clavicle complex together (Fig. 7). Such discrepancies among plesiosaurs seem to suggest that not only the locomotory muscles play different roles from clade to clade but also the enlargement of the coracoid is decoupled from the ventral expansion of the scapula (see also Fig. 7b).

The clavicle and its relationship with the scapula is subject of a remarkable transformation in Eosauropterygia as well. In non-plesiosaur eosauropterygians the clavicles are tightly sutured together medially and oriented transversely (e.g., *Nothosaurus*) or obliquely anteriorly (e.g., *Ceresiosaurus*). Also the scapula and clavicle form a rigid structural unit by means of a posterior process of the clavicle that tightly articulates with the medial side of the scapula (Rieppel, 2000). However, in all plesiosaurs the clavicle-interclavicle complex becomes greatly reduced including basalmost taxa such as *Macroplata* (Ketchum & Smith, 2010) or *Attenborosaurus* (Sollas, 1881), or even in Late Cretaceous polycotylids (e.g., *Dolichorhynchops*see Williston, 1903). The scapuloclavicular articulation is in most cases weak (e.g., *Attenborosaurusconnybeari*, *Rhomaleosauruscramptoni, Peloneustesphilarcus, Hauffiosauruszanoni, Westphaliasaurussimonensii, Tricleidusseeleyi, Leptocleidussuperestes, Dolichorhynchopsosborni*) but it can be extensively developed anteriorly in Late Cretaceous Elasmosauridae (e.g., TMM2245-1*, Cardiocoraxmukulu,* and possibly YPM1644). In these late Cretaceous elasmosaurs the clavicle can account for nearly the half area as the scapula (e.g., *Cardiocorax*, Fig. 3).

The pistosaur-plesiosaur median migration of the medial of the coracoscapular contact is not well documented in the fossil record (Fig. 5a), leaving an important morphological gap (Fig. 6). Nevertheless, these modifications had to occur concomitantly with (1) a counterclockwise rotation of the scapuloclavicular contact, which led to a posterior translation of the clavicle-interclavicle complex, (2) a medial elongation of the scapula, and (3) the anterior projection of the preglenoid projection of the coracoid. However, the presence of a medial coracoscapular contact is highly homoplastic even within the same taxa (e.g., Microcleididae: *M. tournemirensis* versus *Westphaliasaurus*, Rhomaleosauridae: *Rhomaleosaurus cramptoni* versus *Meyerasaurus victor*, Elasmosauridae: *Callawayasaurus* versus *Cardiocorax*). Nevertheless, if the medial coracoscapular contact is maintained it only abuts on the lateral side of the preglenoid projection (e.g., *Macroplata, Meyerasaurus, Thalassiodracon, Plesiosaurus, Dolichorhynchops herschelensis*). In Elasmosauridae and basal cryptocleidids the condition is slightly different because the preglenoid projection is narrowed, thus the medial coracoscapular contact adjoins anteriorly. Another feature poorly documented in the fossil record is the expansion of the coracoid (Fig. 6), possibly due to the scarce Late Triassic eosauropterygian record. Regardless, the scarce pistosaur record shows high morphological disparity in the coracoid (Fig. 5a, 6, 7a). The results demonstrate a convergence between basal cryptoclidids (*Muraenosaurus*, *Tricleidus* and *Cryptocleidus*) and polycotylids due to the narrow preglenoid projection and the absence of intercoracoid vacuity (landmarks 4, 5, 9 and 10).

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Supplementary Table Captions

Supplementary Table 1 – Dataset for figure 7C; Ratio between the dorsal blade of the scapula (cm2) and ventral area of the scapula.

Supplementary Table 2– Dataset for figure 7D; Humeral Ratios.

Supplementary Table 3– Dataset for figure 7E; Radius Ratios

Figure Captions

Supplementary Figure 1 – Phylogenetic tree resulting from Ketchum & Benson (2010) datamatrix (refer to methods for details; pruned version of this tree illustrated in Figure 4.)

Supplementary Figure 2 – Phylogenetic tree using matrix and settings of Vincent et al. (2011).

Supplementary Figure 3 – Landmark configurations used for phylogenetics morphometrics analysis; see Figure 5 for preferred tree. All trees illustrated in Supplementary Figures 4-13.

Supplementary Figure 4 – Best tree using search level of thoroughness 3 with Heuristic re-alignment.

Supplementary Figure 5 – Best tree using search level of thoroughness 4 with Heuristic re-alignment.

Supplementary Figure 6 – Tree using search level of thoroughness 0 with Heuristic re-alignment.

Supplementary Figure 7 – Tree using search level of thoroughness1 with Heuristic re-alignment.

Supplementary Figure 8 – Tree using search level of thoroughness 2 with Heuristic re-alignment.

Supplementary Figure 9 – Tree using search level of thoroughness 0 with RFTRA re-alignment.

Supplementary Figure 10– Tree using search level of thoroughness 1 with RFTRA re-alignment.

Supplementary Figure 11 – Tree using search level of thoroughness 2 with RFTRA re-alignment.

Supplementary Figure 12 – Tree using search level of thoroughness 3 with RFTRA re-alignment.

Supplementary Figure 13 – Tree using search level of thoroughness 4 with RFTRA re-alignment.