Multiphase progenetic development shaped the brain of flying archosaurs

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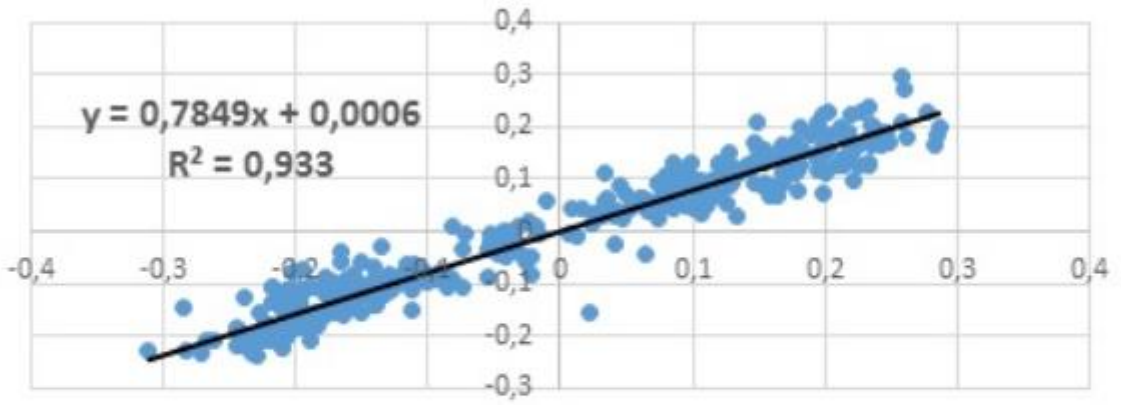
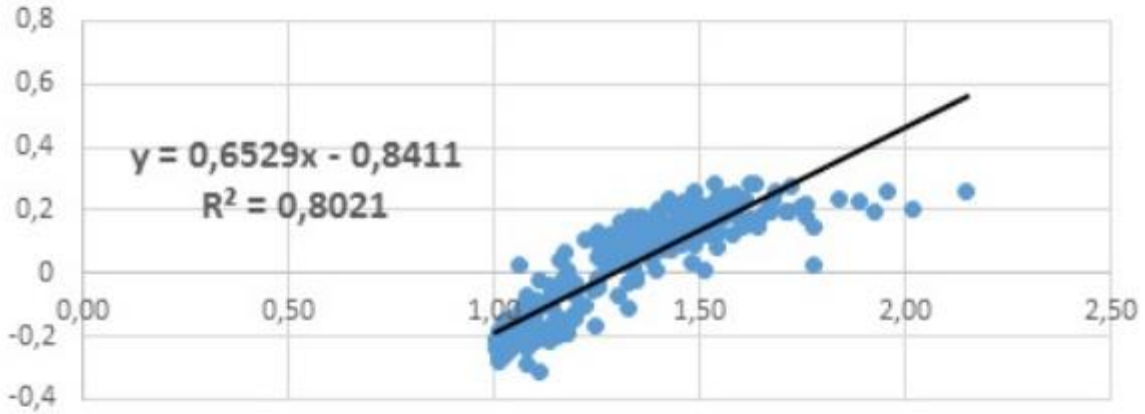
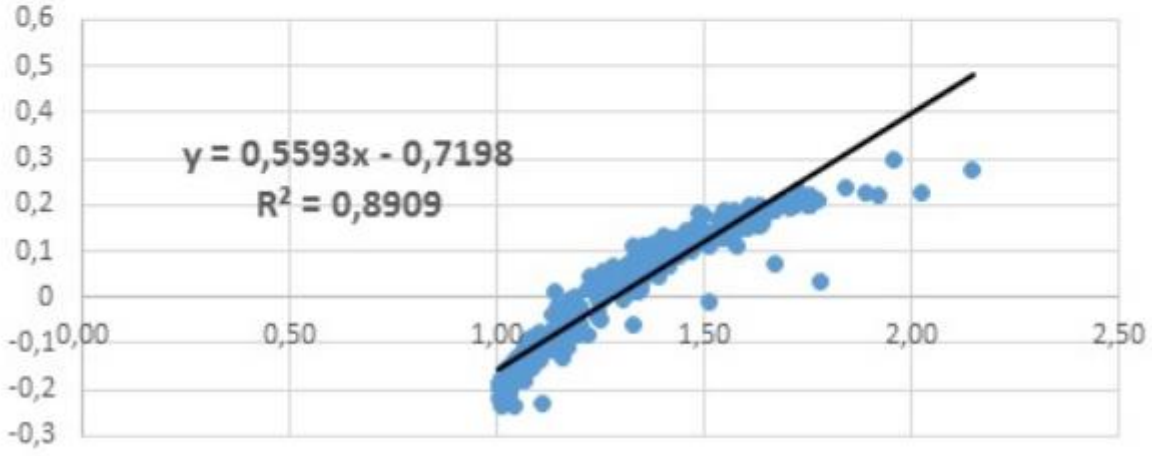
a


PC scores Type I landmarks versus semilandmarks
y = 0,7849x + 0,0006
R² = 0,933
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
-0,4
-0,3
0
0,1
0,2
0,3
0,4

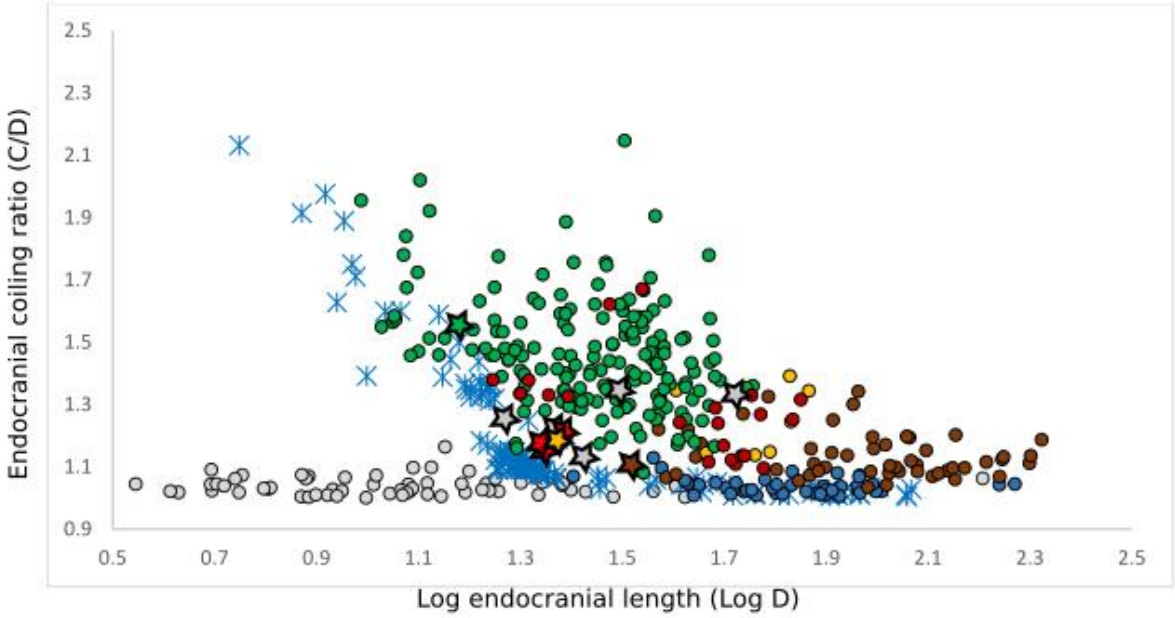
b


C/D versus PC scores Type I landmarks
y = 0,6529x - 0,8411
R² = 0,8021
0,8
0,6
0,4
0,2
0
-0,2
-0,4
0,00
0,50
1,00
1,50
2,00
2,50

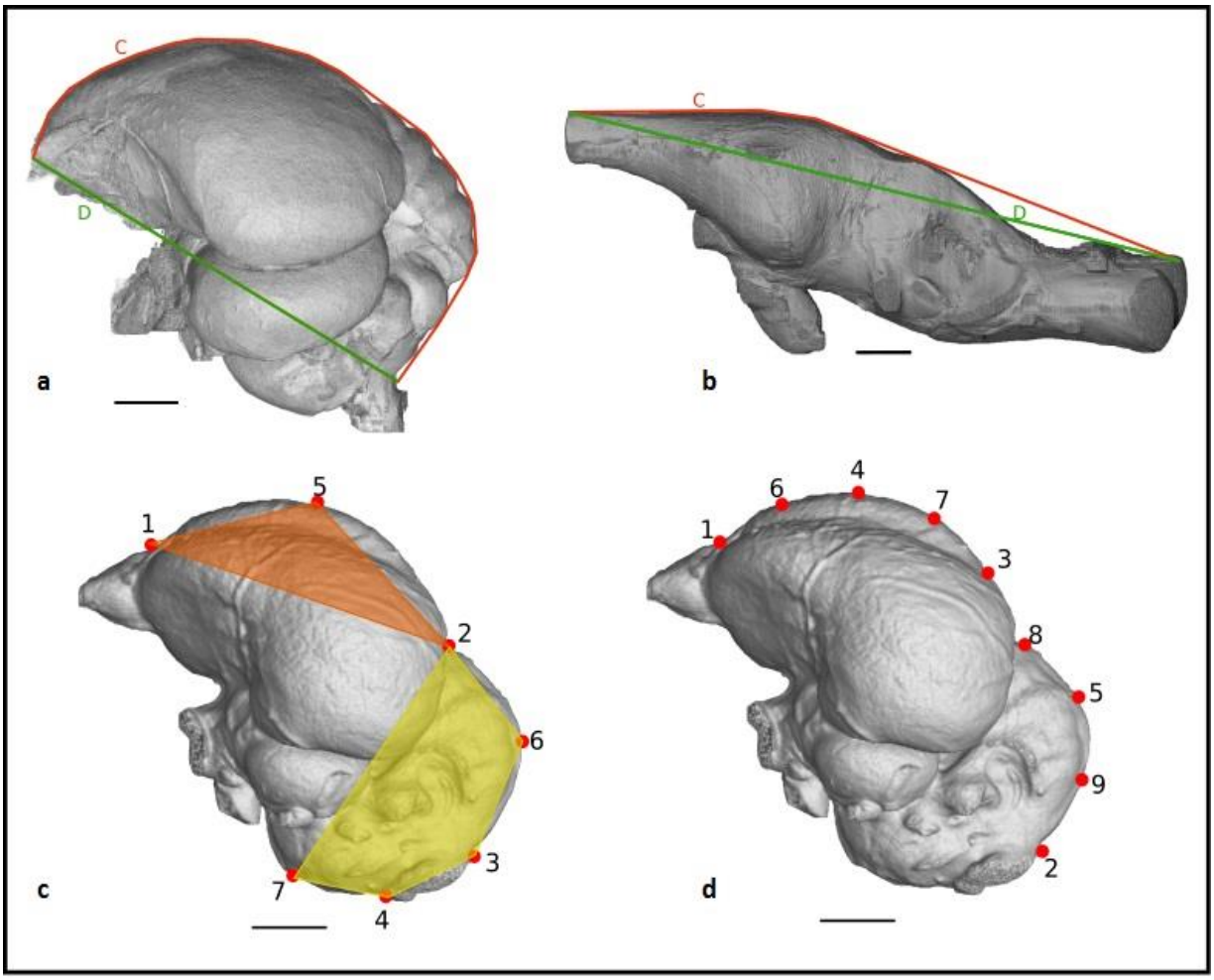
c


C/D versus PC scores semilandmark
y = 0,5593x - 0,7198
R² = 0,8909
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,3
0,00
0,50
1,00
1,50
2,00
2,50

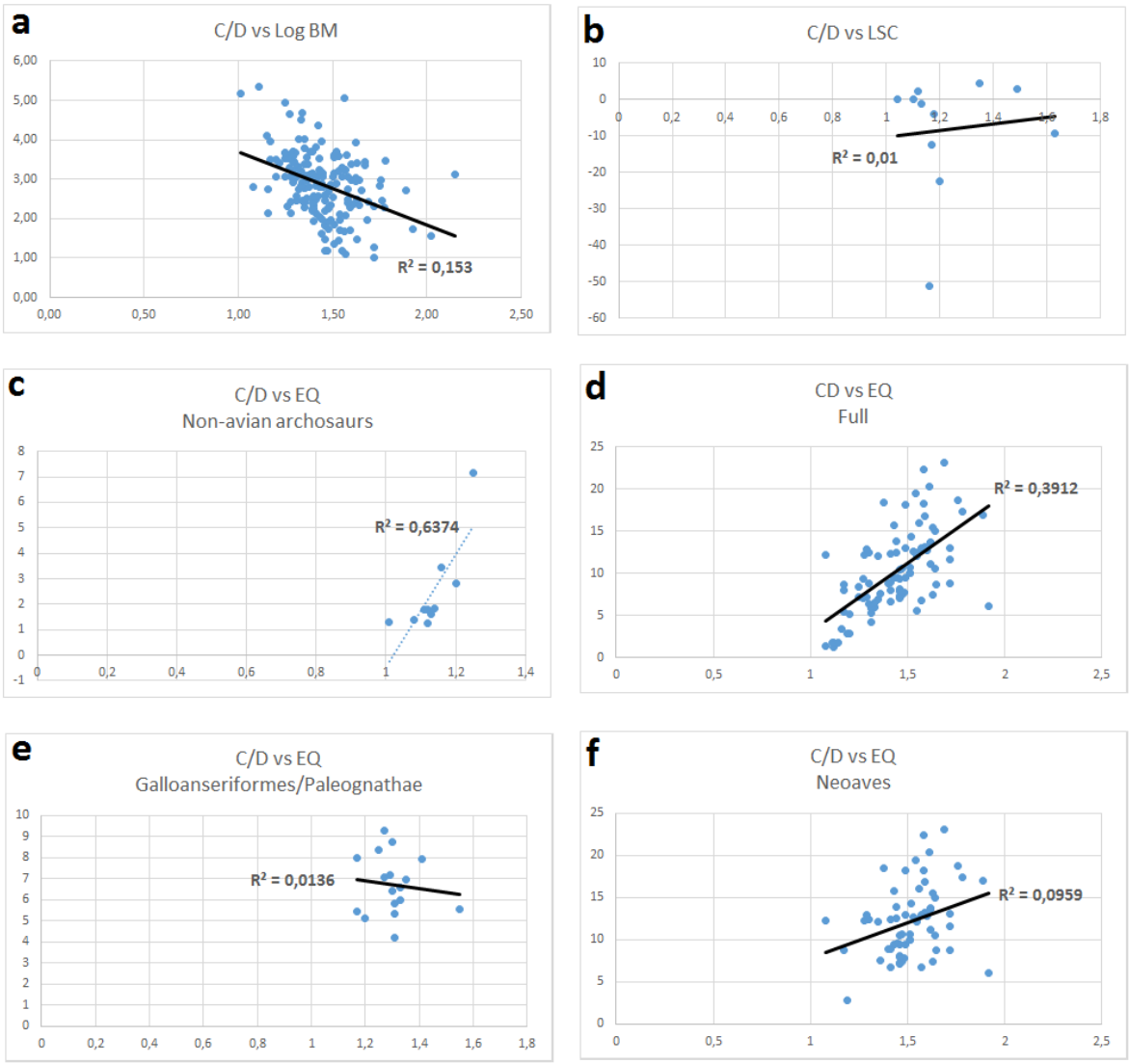
Extended Data Figure 1. Correlation plots between PC scores of Type I landmarks, semi-landmarks and endocranial doming (C/D). Correlation of PC Type I landmarks scores versus PC semi-landmark scores (a), C/D ratio versus PC Type I landmarks scores (b), C/D ratio versus PC semi-landmark scores (c).



Extended Data Figure 2. Bivariate plot of log-transformed endocast length (Log D) versus endocranial doming (C/D) in all tested sauropsids. Small colour-coded circles represent phylogenetic groups: Lepidosauria (grey), crocodilians (blue), non-maniraptoriform dinosaurs (brown), Maniraptoriformes (yellow), Paleognathae (red), and Neognathae (green). Colour-coded stars represent key fossil endocasts of Pterosauria (grey), *Cerebavis cenomanica* (green), *Archaeopteryx lithographica* (red), *Halszkaraptor escuillei* (yellow), and *Heterodontosaurus tucki* (brown).



Extended Data Figure 3. Exemplified measurements of endocranial doming. Illustrated measurements for a) *Ficedula albicollis*, and b) *Crocodylus niloticus*. Green line captures endocast length between the anteriormost tip of the telencephalon and the opisthion ("D"). Red line depicts the length between the same points measured as a convex hull along the dorsal surface of the endocast ("C"). Positioning of Type I (c) and semilandmarks (d). Type I landmarks envelope telencephalic shape (orange area) and rhomboncephalic shape (yellow area). Scale bar length: a) 1.5 mm, b) 10 mm, c) and d) 5mm.



Extended Data Figure 4. Correlation plots between endocranial doming and biological indices. Correlation of C/D ratio versus log-transformed body mass (a), C/D ratio versus alert cranial angle[56] (b), C/D ratio versus encephalisation quotient for non-avian archosaurs (c), full archosaurian dataset (d), Galloanseriformes and Paleognathae (e) and Neoaves (f).

Extended Data Table 1

Abbreviations:

CT: Characterised using conventional X-ray Computed Tomography; ESRF: Characterised using synchrotron radiation based computed tomography; ESRF collection: Curated at the European Synchrotron Radiation Facility; LFAC: La Ferme aux Crocodiles, Pierrelattes, France; TL: Thierry Loeb, Echirolles, France; ENS: Ecole Normale Supérieure, Lyon, France; MHN Grenoble: Curated at Museum d'Histoire Naturelle, Grenoble, France; MNHN: Curated at Museum National d'Histoire Naturelle, Paris, France; CCEC: Centre de Conservation et d'Etude des Collections, Lyon, France; Peaugres: Safari de Peaugres, Peaugres, France.

Extended Data Table 2. Statistics of F-Test for Equality of Two Variances and t-test for Two Samples Assuming Unequal Variances comparing the ontogenetic trajectories of *Crocodylus niloticus* and *Gallus gallus*.

F-Test for Equality of Two Variances

	Variable 1	*Variable 2*
Mean	1,55557807	1,32548981
Variance	0,10694632	0,07108515
Observations	13	46
df	12	45
F	1,50448181	
P(F<=f) one-tail	0,15808312	
F Critical one-tail	1,97449795	

t-test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	1,55557807	1,32548981
Variance	0,10694632	0,07108515
Observations	13	46
Pooled Variance	0,07863487	
Hypothesised Mean Difference	0	
df	57	
t Stat	2,61223033	
P(T<=t) one-tail	0,00573997	
t Critical one-tail	1,67202889	
P(T<=t) two-tail	0,01147995	
t Critical two-tail	2,00246546	

Extended Data Table 3

Abbreviations:

BM: Body Mass for adult specimens[42,53,54] and crocodilian ontogenetic series[55]; LSC: Lateral Semicircular Canal orientation used for assessing head posture[56]; EQ: Encephalisation Quotient[57];

Extended Data Table 4. Statistics for correlation between biological indices and C/D ratio.

	p-value	
Shapiro test for CD	0.0005713	
Shapiro test for body mass	0.07662	Kendall tau
Correlation for CD vs body mass	5.757e-08	-0.2787634

	p-value	
Shapiro test for CD	0.02488	
Shapiro test for LSC angle	0.001813	Kendall tau
Correlation for CD vs LSC angle	0.8793	-0.05454545

Extended Data Table 5. Statistics for correlation between encephalisation quotient and C/D ratio.

	p-value
Bartlett Test	0.001815

Groups	p-value	Kendall tau
Non-avian archosaurs	0.007058	0.6741999
Full dataset	2.968e-11	0.4825782
Paleognathae/Galloanserae	0.534	-0.1132471
Neoaves	0.005265	0.2430949

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