SUPPLEMENTARY INFORMATION

Divergence-time estimates for hominins provide insight into encephalization and body mass trends in human evolution

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Supplementary Table 1. mtDNA partitions and models selected.

Partition	Model	N° sites	mtDNA regions*
1	GTR+I	2975	12SrRNA, 16SrRNA, ND4 pos1
2	HKY+I	1511	tRNAs
3	HKY+I	813	ND3 pos1, CYTB pos1, ND1 pos1
4	HKY+I	2450	ND1 pos2, ND5 pos2, ND4 pos2, ND3 pos2, CYTBpos2, ND2 pos2, ATP6 pos2
5	GTR+G	1942	ND2 pos3, ND4 pos3, ND1 pos3, ND3 pos3, ND4L_pos3, ND5_pos3
6	HKY+I+G	1178	ATP6 pos1, ND5 pos1, ND2 pos1
7	SYM+I	775	COX1 pos1, COX3 pos1
8	GTR	775	COX3 pos2, COX1 pos2
9	GTR+G	1299	COX3 pos3, COX2 pos3, COX1 pos3, ATP6 pos3, ATP8 pos3
10	GTR	327	ND4L pos1, COX2 pos1
11	GTR+I	327	COX2 pos2, ND4L pos2
12	HKY+I	138	ATP8 pos1, ATP8 pos2
13	GTR+I	175	ND6 pos1
14	HKY	175	ND6 pos2
15	GTR	175	ND6 pos3
16	GTR+I	380	CYTB_pos3

*The names indicate standard abbreviations for mtDNA regions and pos1-3 indicate codon sites.

Supplementary Table 2. Radiometric age estimates for the analysed fossil hominins.

Taxon	Age (Ma)	Reference
Sahelanthropus tchadensis	6.4 - 8.08	[1]
Ardipithecus ramidus	4.351 - 4.487	[2]
Australopithecus anamensis	4.05 - 4.2	[3]
Australopithecus afarensis	3.59 - 3.98	[4]
Australopithecus africanus	2.58 - 3.03	[5]
Australopithecus garhi	2.2 - 2.58	[6]
Kenyanthropus platyops	3.53	[7]
Australopithecus sediba	1.975 - 1.979	[8]
Paranthropus aethiopicus	2.6 - 2.8	[9]
Paranthropus boisei	2.15 - 2.25	[9]
Paranthropus robustus	1.8 - 1.9	[10]
Homo habilis	2.26 - 2.4	[11]
African *Homo erectus*	1.45 - 1.65	[12]
Asian *Homo erectus*	1.43 - 1.59	[13]
Georgian *Homo erectus*	1.78 - 1.84	[14]
Homo rudolfensis	2.024 - 2.092	[15]
Homo naledi	0.236 - 0.335	[16]
Homo antecessor	0.936	[17]
Homo heidelbergensis	0.15 - 0.64	[18]
Homo neanderthalensis	0.095 - 0.173	[19]
Homo floresiensis	0.0179 - 0.019	[20]
Homo sapiens	0.04321 - 0.04688	[21]
Denisovan (Denisova 2)	0.1227-0.1944	[22]

Supplementary Table 3. Species used in the present study with their endocranial volume (ECV in cm3), converted ECV into brain mass[23] (in grams), body mass (BM, in grams) PEQ for the different hypotheses, the number of specimens (N) used to obtain ECV and BM for each species and references for ECV, BM and age. Body mass was not available (NA) for two species, *Kenyanthropus platyops* and *Australopithecus garhi*. Abbreviations: d, Dembo et al.[24] hypothesis; s, *Au. sediba* hypothesis; n, *H. naledi* hypothesis; f, *H. floresiensis* hypothesis.

Species	ECV (cm3)	Brain mass (g)	Body mass (g)	PEQ-d	PEQ-s	PEQ-n	PEQ-f	N (brain)	N (body)	Data source
Gorilla gorilla	490.4	508.1	120950	0.65	0.68	0.69	0.63	56	13	ECV and BM from[25]
Pan troglodytes	366.2	379.4	44967	1.06	1.02	1.03	1.14	65	60	ECV and BM from[26]
Sahelanthropus tchadensis	365	378.1	58000	0.87	0.85	0.86	0.90	-	-	ECV from [27]; BM from [28]
Ardipithecus ramidus	300	310.8	50000	0.80	0.77	0.78	0.85	-	-	ECV and BM from [29]
Australopithecus anamensis	367.5	380.7	46300	1.04	1.00	1.01	1.11	-	1	ECV from [30]; BM from [31]
Australopithecus afarensis	446	462.1	39100	1.44	1.36	1.38	1.57	5	12	ECV from [32]; BM from [33]
Australopithecus africanus	460	476.6	30500	1.80	1.67	1.69	2.01	9	5	ECV from [32]; BM from [33]
Paranthropus robustus	476	493.1	36050	1.64	1.54	1.55	1.80	-	-	ECV from [34]; BM from [35]
Paranthropus boisei (Omo, L339y-6)	427	442.4	41300	1.32	1.26	1.27	1.43	-	-	ECV from [34]; BM from [35]
Paranthropus aethiopicus (KNM-WT17000)	410	424.8	38000	1.35	1.28	1.29	1.48	-	-	ECV from [34] ; BM from [35]
Australopithecus sediba	420	435.1	25800	1.88	1.71	1.73	2.13	1	2	ECV from [36]; BM from [33]
Homo habilis	624.3	646.8	32600	2.32	2.16	2.18	2.58	6	2	ECV from [37,38]; BM from [33]
Homo rudolfensis	752	779.1	55200	1.85	1.81	1.83	1.95	1	3	ECV from [39,40]; BM from [41]
African *Homo erectus*	871	902.4	48900	2.36	2.28	2.30	2.51	5	5	ECV from [41] (sensu lato, includes the juvenile); BM from [31]
Asian *Homo erectus*	991	1026.7	51400	2.58	2.50	2.53	2.73	36	9	ECV from [42]; BM from [33]
Homo heidelbergensis	1242	1286.7	70600	2.53	2.52	2.54	2.58	21	12	ECV from [42]; BM from [43]
Homo neanderthalensis	1404	1454.5	72109	2.81	2.80	2.83	2.87	27	23	ECV from [42]; BM from [43]
Homo floresiensis	425.7	441	27500	1.81	1.66	1.68	2.04	1	1	ECV from [44]; BM from [33]
Homo sapiens	1349	1397.6	57849.1	3.21	3.14	3.17	3.35	122	51	ECV and BM from [26]
Homo antecessor (Spain)	1257.5	1302.8	69700	2.58	2.57	2.60	2.65	2	20	ECV from[45]; BM from [46]
Georgian *Homo erectus*	546	565.7	40700	1.71	1.62	1.64	1.85	5	1	ECV [47]; BM from [31]
Homo naledi	512.5	531	44000	1.51	1.44	1.46	1.62	2	8	ECV[48]; BM from [31]
Kenyanthropus platyops (KNM-WT 40000)	425	440.3	NA	NA	NA	NA	NA	-	-	ECV from [49]
Australopithecus garhi (BOU-VP-12/130)	450	466.2	NA	NA	NA	NA	NA	-	-	ECV from [40,50]

Supplementary References

1. Lebatard, A. E. *et al.* Cosmogenic nuclide dating of *Sahelanthropus tchadensis* and Australopithecus bahrelghazali: Mio-Pliocene hominids from Chad. *Proc. Natl. Acad. Sci. U. S. A.* **105**, 3226–3231 (2008).
2. Woldegabriel, G. *et al.* The geological, Isotopic, botanical, invertebrate, and lower vertebrate surroundings of ardipithecus ramidus. *Science* **326**, 65-65e5 (2009).
3. Leakey, M. G., Feibel, C. S., McDougall, I., Ward, C. & Walker, A. New specimens and confirmation of an early age for *Australopithecus anamensis*. *Nature* **393**, 62–66 (1998).
4. Leakey, M. D., Hay, R. L., Curtis, G. H., Drake, R. E. & Jackes, M. K. Fossil hominids from the Laetolil Beds. *Nature* **262**, 460–466 (1978).
5. Herries, A. I. R. *et al.* A multi-Disciplinary perspective on the age of *Australopithecus* in southern Africa. in *Paleobiology of Australopithecus. Vertebrate Palaeobiology and Paleoanthropology Series* (eds. Reed, K. E., Fleagle, J. G. & Leakey, R. E.) 21–40 (Springer, Dordrecht, 2013). doi:10.1007/978-94-007-5919-0_3.
6. Brown, F. H., McDougall, I. & Gathogo, P. N. Age ranges of <I>Australopithecus</i> species, Kenya, Ethiopia, and Tanzania. in *Paleobiology of Australopithecus. Vertebrate Palaeobiology and Paleoanthropology Series* (eds. Reed, K. E., Fleagle, J. G. & Leakey, R. E.) 7–20 (Springer, Dordrecht, 2013). doi:10.1007/978-94-007-5919-0_2.
7. Leakey, M. G. *et al.* New hominin genus from eastern Africa shows diverse middle Pliocene lineages. *Nature* **410**, 433–440 (2001).
8. Pickering, R. *et al. Australopithecus sediba* at 1.977 Ma and implications for the origins of the genus *Homo*. *Science* **333**, 1421–1423 (2011).
9. Feibel, C. S., Brown, F. H. & McDougall, I. Stratigraphic context of fossil hominids from the Omo group deposits: Northern Turkana Basin, Kenya and Ethiopia. *Am. J. Phys. Anthropol.* **78**, 595–622 (1989).
10. Pickering, R., Kramers, J. D., Hancox, P. J., de Ruiter, D. J. & Woodhead, J. D. Contemporary flowstone development links early hominin bearing cave deposits in South Africa. *Earth Planet. Sci. Lett.* **306**, 23–32 (2011).
11. Kimbel, W. H., Johanson, D. C. & Rak, Y. Systematic assessment of a maxilla of *Homo* from Hadar, Ethiopia. *Am. J. Phys. Anthropol.* **103**, 235–262 (1997).
12. Gathogo, P. N. & Brown, F. H. Revised stratigraphy of Area 123, Koobi Fora, Kenya, and new age estimates of its fossil mammals, including hominins. *J. Hum. Evol.* **51**, 471–479 (2006).
13. Larick, R. *et al.* Early pleistocene 40Ar/39Ar ages for bapang formation hominins, central jawa, indonesia. *Proc. Natl. Acad. Sci. U. S. A.* **98**, 4866–4871 (2001).
14. Garcia, T. *et al.* Earliest human remains in Eurasia: New 40Ar/39Ar dating of the Dmanisi hominid-bearing levels, Georgia. *Quat. Geochronol.* **5**, 443–451 (2010).
15. Joordens, J. C. A. *et al.* Improved age control on early *Homo* fossils from the upper Burgi Member at Koobi Fora, Kenya. *J. Hum. Evol.* **65**, 731–745 (2013).
16. Dirks, P. H. *et al.* The age of *Homo naledi* and associated sediments in the Rising Star Cave, South Africa. *Elife* **6**, e24231 (2017).
17. Parés, J. M. *et al.* Reassessing the age of Atapuerca-TD6 (Spain): New paleomagnetic results. *J. Archaeol. Sci.* **40**, 4586–4595 (2013).
18. Meyer, M. *et al.* A mitochondrial genome sequence of a hominin from Sima de los Huesos. *Nature* **505**, 403–406 (2014).
19. Peyrégne, S. *et al.* Nuclear DNA from two early Neandertals reveals 80,000 years of genetic continuity in Europe. *Sci. Adv.* **5**, eaaw5873 (2019).
20. Morwood, M. J. & Jungers, W. L. Conclusions: implications of the Liang Bua excavations for hominin evolution and biogeography. *J. Hum. Evol.* **57**, 640–648 (2009).

21. Fu, Q. *et al.* DNA analysis of an early modern human from Tianyuan Cave, China. *Proc. Natl. Acad. Sci. U. S. A.* **110**, 2223–2227 (2013).
22. Douka, K. *et al.* Age estimates for hominin fossils and the onset of the Upper Palaeolithic at Denisova Cave. *Nature* **565**, 640–644 (2019).
23. Stephan, H., Frahm, H. D. & Baron, G. New and revised data on volumes of brain structures in insectivores and primates. *Folia Primatol.* **35**, 1–29 (1981).
24. Dembo, M. *et al.* The evolutionary relationships and age of *Homo naledi*: An assessment using dated Bayesian phylogenetic methods. *J. Hum. Evol.* **97**, 17–26 (2016).
25. Isler, K. *et al.* Endocranial volumes of primate species: scaling analyses using a comprehensive and reliable data set. *J. Hum. Evol.* **55**, 967–978 (2008).
26. Grabowski, M. Bigger brains led to bigger bodies?: The correlated evolution of human brain and body size. *Curr. Anthropol.* **57**, 174–196 (2016).
27. Guy, F. *et al.* Morphological affinities of the *Sahelanthropus tchadensis* (Late Miocene hominid from Chad) cranium. *Proc. Natl. Acad. Sci. U. S. A.* **102**, 18836–18841 (2005).
28. Hemmer, H. Estimation of basic life history data of fossil hominoids. in *Handbook of Paleoanthropology* (eds. Henke, W. & Tattersall, I.) 587–619 (Springer, Berlin, Heidelberg, 2007). doi:10.1007/978-3-642-39979-4_22.
29. White, T. D. *et al. Ardipithecus ramidus* and the paleobiology of early hominids. *Science* **326**, 75–86 (2009).
30. Haile-Selassie, Y., Melillo, S. M., Vazzana, A., Benazzi, S. & Ryan, T. M. A 3.8-million-year-old hominin cranium from Woranso-Mille, Ethiopia. *Nature* **573**, 214–219 (2019).
31. Jungers, W. L., Grabowski, M., Hatala, K. G. & Richmond, B. G. The evolution of body size and shape in the human career. *Philos. Trans. R. Soc. B Biol. Sci.* **371**, (2016).
32. Holloway, R. L., Clarke, R. J. & Tobias, P. V. Posterior lunate sulcus in *Australopithecus africanus*: Was Dart right? *Comptes Rendus - Palevol* **3**, 287–293 (2004).
33. Grabowski, M., Hatala, K. G., Jungers, W. L. & Richmond, B. G. Body mass estimates of hominin fossils and the evolution of human body size. *J. Hum. Evol.* **85**, 75–93 (2015).
34. Falk, D. Evolution of the primate brain. in *Handbook of paleoanthropology* (eds. Henke, W. & Tattersall, I.) 1133–1162 (Springer, Berlin, Heidelberg, 2007).
35. Fleagle, J. G. *Primate adaptation and evolution*. (Academic press, 1999).
36. Berger, L. R. *et al. Australopithecus sediba*: A New Species of Homo-Like Australopith from South Africa. *Science* **328**, 195–204 (2010).
37. Holloway, R. L., Broadfield, D. C. & Yuan, M. S. Hominid Endocasts: Some General Notes. in *The Human Fossil Record: Brain Endocasts—The Paleoneurological Evidence, Volume 3* (eds. Schwartz, J. H. & Tattersall, I.) 283–294 (John Wiley & Sons, Inc., 2005). doi:10.1002/0471663573.ch6.
38. Spoor, F. *et al.* Reconstructed *Homo habilis* type OH 7 suggests deep-rooted species diversity in early *Homo*. *Nature* **519**, 83–86 (2015).
39. McHenry, H. M. Behavioral ecological implications of early hominid body size. *J. Hum. Evol.* **27**, 77–87 (1994).
40. McHenry, H. M. & Coffing, K. *Australopithecus* to *Homo*: Transformations in Body and Mind. *Annu. Rev. Anthropol.* **29**, 125–146 (2000).
41. McHenry, H. M. Body size and proportions in early hominids. *Am. J. Phys. Anthropol.* **87**, 407–431 (1992).
42. De Sousa, A. & Cunha, E. Hominins and the emergence of the modern human brain. in *Progress in Brain Research: Evolution of the Primate Brain* (eds. Hofman, M. A. & Falk, D.) vol. 195 293–322 (Elsevier B.V., 2012).
43. Skinner, M. M. & Wood, B. A. The evolution of modern human life history - A paleontological perspective. in *The Evolution of Modern Human Life History* (eds.

Hawkes, K. & Paine, R.) 331–400 (School of American Research Press, 2006).
44. Kubo, D., Kono, R. T. & Kaifu, Y. Brain size of *Homo floresiensis* and its evolutionary implications. *Proc. R. Soc. B Biol. Sci.* **280**, (2013).
45. Arsuaga, J. L., Martínez, I., Gracia, A., Carretero, J. M. & Carbonell, E. Three new human skulls from the Sima de los Huesos Middle Pleistocene site in Sierra de Atapuerca, Spain. *Nature* **362**, 534–537 (1993).
46. Pablos, A. The Foot in the Homo Fossil Record. *Mitteilungen der Gesellschaft für Urgeschichte* **24**, 11–28 (2015).
47. Lordkipanidze, D. *et al.* A complete skull from Dmanisi, Georgia, and the evolutionary biology of early *Homo*. *Science* **342**, 326–331 (2013).
48. Garvin, H. M. *et al.* Body size, brain size, and sexual dimorphism in *Homo naledi* from the Dinaledi Chamber. *J. Hum. Evol.* **111**, 119–138 (2017).
49. Schoenemann, P. T. Hominid Brain Evolution. in *A Companion to Paleoanthropology* (ed. Begun, D. R.) 136–164 (Blackwell Publishing Ltd., 2013).
50. Asfaw, B. *et al. Australopithecus garhi*: A New Species of Early Hominid from Ethiopia. *Science* **284**, 629–635 (1999).