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Turning on the 'radiator': numerical modeling analyses to test an old and elusive theory

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It is well known among biologists that brains are expensive organs that require large amounts of energy for their development, maintenance and function (Mink et al., 1981). Moreover, as a large proportion of the cerebral energy budget is lost as heat, metabolic heat production is also a basic energetic feature characterizing nervous systems (Bertolizio et al., 2011). Considering that slight brain temperature variations may compromise cerebral structure and function, the ability of an organism to efficiently remove the excess of heat produced by its neural tissue seems to have played an important role in the evolutionary history of any species. In this context, heat removal from the brain is mainly performed by the vascular system, although other factors may also be relevant in this regard. In this context, it has been hypothesized that brain size evolution in the genus Homo was possible in part due to the coevolution of a more complex and efficient vascular network. The so called 'Radiator theory' (Falk, 1990) proposes a brain cooling mechanism which is based on the collateral circulation of blood flow between the outside of the skull and the endocranial cavity through perfusion of the emissary, diploic and meningeal vessels, as well as the venous sinuses. It is worth noting that the meningeal and diploic vascular systems are significantly more developed and ramified in modern humans than in other fossil hominids or great apes (Bruner et al., 2005; Hershkovitz et al., 1999). These autapomorphic traits are independent of size variation, suggesting that some physiological adjustments may be also related to non-allometric changes in brain shape. However, in vivo quantitative studies on brain temperature and its regulation are rather scarce and, when available, they provide contradictory and inconclusive results to test these hypotheses. In the present study we used a numerical modeling approach (Bruner et al., 2011; 2012) in order to investigate how cerebral geometric changes (ie. size and shape) may influence the endocranial heat dissipation patterns in modern humans and fossil hominids. Quantitative comparisons between taxa were performed using traditional multivariate techniques and functional data analyses (FDA; Ramsay and Silverman, 2005), while mapping of the thermal loads allowed us to localize these differences directly on the endocranial surface. We quantified and compared thermal loads in different hominids beyond estimations based on size alone, and considering the whole form to evidence the effect of brain size variation. While heat dissipation patterns in fossil species seem to share a common allometric trajectory, we found that, at similar cranial capacities, modern humans display higher thermal loads. After visual inspection of the thermic maps, these non-allometric differences were localized at the level of the cranial base as well as on the parietal lobe surface, regions that have been repeatedly associated with endocranial globularity in modern humans. Implications of these findings and its relation to the radiator theory are discussed accordingly.
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