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GROWTH AND DEVELOPMENT OF THE HUMAN BRAIN

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The development of the human brain remains one of the few unsolved mysteries of science. Impressive advancements in developmental biology, neuroscience, behavior science, and medical imaging have brought us closer than ever to understanding the mechanisms that underpin brain development in health and disease. However, the precise role of mechanics throughout this process remains underappreciated and poorly understood [1]. Here we show that mechanical stretch and strain play a crucial role in cortical folding. Using the nonlinear field theories of continuum mechanics supplemented by the theory of finite growth [2], we model the human brain as a bi-material with the cerebral cortex, a morpho-genetically growing outer layer of gray matter, and the subcortex, a strain-driven growing inner core of white matter. This approach seamlessly integrates the two popular but competing hypotheses that cortical folding is either driven by differential growth or by axon elongation. Through systematic sensitivity analyses, we identify the critical process parameters of cortical folding and quantify their impact brain morphology. We calibrate our model parameters using a sequence of magnetic resonance images during healthy human brain development in preterm infants [3]. We test the hypothesis that malformations in the human brain originate from a misbalance of cortical and subcortical growth. Our results demonstrate that deviations from baseline parameters, in particular from the initial cortical thickness and cortical growth rate, create malformations in folding patterns [4]. Using the gyrification index, the ratio between the total and exposed surface area, we show that these malformations agree qualitatively and quantitatively with the classical pathologies of lissencephaly and polymicrogyria. Understanding the mechanisms of cortical folding during brain development might have direct implications in the diagnostics and treatment of neurological disorders, including severe retardation, epilepsy, schizophrenia, and autism.

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