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Biological diversity is not just the result of genes

A UNIGE study reveals how mechanics, linked to tissue growth, help generate the diversity of biological structures.

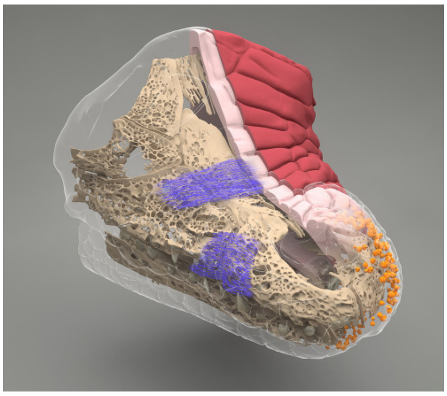
How can we explain the morphological diversity of living organisms? Although genetics is the answer that typically springs to mind, it is not the only explanation. By combining observations of embryonic development, advanced microscopy, and cutting-edge computer modelling, a multi-disciplinary team from the University of Geneva (UNIGE) demonstrate that the crocodile head scales emerge from the mechanics of growing tissues, rather than molecular genetics. The diversity of these head scales observed in different crocodilian species therefore arises from the evolution of mechanical parameters, such as the growth rate and stiffness of the skin. These results, published in the journal *Nature*, shed new light on the physical forces involved in the development and evolution of living forms.

The origin of the morphological diversity and complexity of living organisms remains one of science's greatest mysteries. To solve this puzzle, scientists study a wide range of different species. The laboratory of Michel Milinkovitch, professor in the Department of Genetics and Evolution at the UNIGE Faculty of Science, investigates the development and evolution of vertebrate skin appendages, such as feathers, hair, and scales, to understand the fundamental mechanisms responsible for this diversity. The embryonic development of these appendages is generally thought to be dictated by chemical processes involving interactions between numerous molecules resulting from gene expression.

Like a propagating crack

Previously, the team showed that the embryonic development of crocodile head scales, unlike scales of the body, originates from a process reminiscent of the propagation of cracks within a material under mechanical stress. However, the true nature of this physical process remained unknown.

These scientists have now solved this mystery thanks to their new and highly multidisciplinary work. First, they tracked the appearance of head scales during the development of the Nile crocodile embryo, which lasts around 90 days in total. While the skin covering the jaws remains smooth until day 48, skin folds appear at around day 51. These folds then spread and interconnect to form irregular polygonal scales, including large and elongated scales on the top of the snout, and smaller units on the sides of the jaws.



The precise geometry of tissue layers was acquired with light-sheet fluorescence microscopy (LSFM).

High resolution pictures

Video

If the skin of an animal grows more quickly than the underlying tissue to which it is attached, you can expect the skin to buckle and fold, as its growth is constrained. The team sought to explore whether such a process can explain the appearance of skin folds, and hence scales, in the embryonic crocodile. Therefore, they developed a technique for injecting crocodile eggs with a hormone that activates epidermal growth and stiffening - EGF (Epidermal Growth Factor). The scientists discovered that the activation of growth and increased rigidity of the skin's surface led to a spectacular change in the organisation of skin folds.

"We saw that the embryo's skin folds abnormally and forms a labyrinthine network resembling the folds of the human brain. Amazingly, when these EGF-treated crocodiles hatch, this brain-like folding has relaxed into a pattern of much smaller scales, comparable to those of another crocodilian species - the caiman," explain Gabriel Santos-Durán and Rory Cooper, post-doctoral fellows in Michel Milinkovitch's laboratory and co-authors of the study. Therefore, variations in the rate of growth and stiffening of the skin provide a simple evolutionary mechanism capable of generating a wide diversity of scale forms among different crocodilian species.

A 3D model of jaw development

The scientists then used an advanced imaging technique, known as "light sheet microscopy", to quantify the growth rate and geometries of the various tissues (epidermis, dermis, and bone) that comprise the embryo's head, as well as the organisation of collagen fibres in the dermis. The team used these data to build a three-dimensional (3D) computer model to simulate the constrained growth of the skin. This model also allowed the researchers to explore the effects of changing the specific growth rates and stiffnesses of the tissue layers.

"By exploring these different parameters, we can generate the different head scale shapes corresponding to Nile crocodiles both with or without EGF treatment, as well as the spectacled caiman or the American alligator. These computer simulations demonstrate that tissue mechanics can easily explain the diversity of shapes of certain anatomical structures in different species, without having to involve intricate molecular genetic factors," concludes Ebrahim Jahanbakhsh, a computer engineer in Michel Milinkovitch's laboratory and co-author of the study.

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