UNIVERSITÉ DE GENÈVE

PRESS RELEASE

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Evolution Told by Turtle Scales

A study from UNIGE reveals that turtles use both genetic signals and mechanical forces to develop the scales on their heads, highlighting a shared evolutionary heritage with crocodiles and dinosaurs.

In vertebrates, the formation of feathers, hair, and scales is typically governed by molecular genetic factors. However, crocodile head scales are an exception, as they form through a purely mechanical process of skin folding. A new study from UNIGE shows that turtles employ both of these distinct processes to develop the scales on different parts of their heads. These findings suggest that the mechanical shaping of scales is an ancestral trait, shared with crocodiles and likely dinosaurs, but lost in birds. The study, published in *iScience*, sheds new light on reptile evolution and opens up avenues for innovation in several applied fields.

In most vertebrates, skin appendages such as hair, feathers, or scales originate from placodes — small, specialized skin regions whose spatial organization is controlled by well-conserved genetic signals. Crocodiles are an exception: their head scales do not emerge from placodes but result from simple mechanical folding of the growing skin.

One Head, Two Mechanisms

The laboratory of Michel Milinkovitch, professor in the Department of Genetics and Evolution at UNIGE's Faculty of Science, had previously elucidated this mechanism in crocodiles. This time, the team focused on turtles. The Geneva scientists discovered that turtles combine both strategies — a first among vertebrates. The peripheral scales on the head follow the classic, chemical model, expressing genes typical of placode development. In contrast, the top of the head shows no trace of these genetic signals: here, the skin folds under mechanical stress caused by slower growth of the underlying tissues, especially bone tissue.

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A classic chemical model guides the formation of the peripheral scales, while those at the top are the result of skin folds caused by mechanical stresses linked to bone growth.

High resolution pictures

Patterns Sculpted by Physics

Using 3D light-sheet microscopy and computer modeling, the researchers demonstrated that these mechanical forces are sufficient to produce the irregular polygonal patterns observed in this area. "This mechanical folding explains the asymmetrical shapes of the scales on the top of the head," says Rory Cooper, postdoctoral researcher in Milinkovitch's lab and co-author of the study. "It also accounts for the remarkable variation seen between individuals, and even between the left and right sides of a single individual's head," adds Ebrahim Jahanbakhsh, computer scientist in the Milinkovitch team, and also co-author of the study.

An Inherited Ancestral Reptilian Trait

From an evolutionary perspective, this discovery is significant. Terrestrial and aquatic turtles (collectively known as *Testudinata*) are the closest living relatives of crocodiles and birds. The fact that turtles and crocodiles share a mechanical process for forming head scales suggests it originated in their common ancestor and was later lost in birds.

"This reveals a new facet of reptile evolutionary history: the ability to generate head scale patterns through mechanical forces is an ancient trait —predating the emergence of modern turtles, crocodiles, and birds, and therefore most likely present in dinosaurs," comments Michel Milinkovitch.

Beyond evolutionary biology, these findings are of great interest in the emerging field of biomimetics — the search for innovative solutions inspired by nature — as well as in regenerative medicine. Understanding how complex structures emerge from simple physical rules can inspire advancements in areas such as architecture, tissue regeneration, and the design of innovative materials.

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