Nature publication: Mechanical tensions as a driver of evolution

When embryos grow, cells and tissue are constantly bumping into each other. This creates considerable mechanical tensions that could endanger the development of the animal. A research team from the University of Hohenheim in Stuttgart and the Japanese RIKEN Center for Biosystems Dynamics Research in Kobe have now discovered that fly embryos have sophisticated strategies to deal with this pressure. The different fly species have developed two fundamentally different solutions. This ability to control mechanical tension could be a key to why so many different body plans have evolved over the course of Earth's history. The results can now be read in the scientific journal Nature.

"The development of an embryo is a precisely choreographed sequence of processes in which cells collide, tissue grows, shifts, and interlocks. This sometimes creates considerable mechanical tensions that can impair the development of the tiny organism," explains study leader Professor Steffen Lemke from the University of Hohenheim.

"Whether a viable animal develops at all depends crucially on how these tensions are absorbed," the expert continues. "Until now, however, it was unclear whether there are special mechanisms preventing such conflicts between the newly developing tissues."

Crucial development phase – Gastrulation

Together with scientists from the RIKEN Institute in Japan, the researchers from the Department of Zoology at the University of Hohenheim took a closer look at a crucial developmental stage of embryonic development in various fly species: gastrulation.

At this stage, simple cell layers develop into the structures for complex tissues such as muscles, skin, nervous system, and digestive tract. "Almost every cell in the embryo is in motion. At first glance, this process appears chaotic, but in fact it is strictly coordinated. Without precise control, dangerous deformations or malformations can occur," explains Verena Kaul, a scientist from the University of Hohenheim who was involved in the study.

Tissue tectonic collision

"If the tissues of the head and torso were allowed to expand unchecked in the early fly embryo, collisions would inevitably occur," she explains. "Very slowly, but with dramatic consequences: Deep furrows appear." A process that the researchers vividly describe as a "tissue tectonic collision."

"This process is comparable to the collision of tectonic plates in the earth's crust, which creates mountain ranges and deep-sea trenches. Something we know very well as residents of Japan," explains developmental biologist Yu-Chiun Wang from the RIKEN Center for Biosystems Dynamics Research. Such a collision leads to a sudden deformation of the area connecting the head and torso. It can severely disrupt development and often ends in the death of the organism."

Head furrow as a "mechanical catch basin"

The research team found two fundamentally different strategies that fly embryos use to absorb such tensions and thus ensure healthy development. Some species, including the well-known fruit fly (*Drosophila melanogaster*), temporarily form a characteristic indentation in the tissue, the so-called cephalic furrow or head furrow. It is the result of the interplay between genetic control and mechanical self-organization.

"This head furrow is conspicuous because it is only present temporarily and does not contain any characteristic tissue of its own," explains Bipasha Dey, a scientist in the Japanese team. "Its function is crucial: It acts like a mechanical catch basin by taking pressure off the growing tissue and preventing dangerous collisions of the tissue plates from the head and torso region."

If the researchers suppress the formation of the head furrow experimentally, the tissues collide unchecked. A kind of replacement furrow is formed. However, its development is not genetically controlled, but is based on purely mechanical processes. This results in severe malformations of the head and nervous system, which are usually fatal for the embryo.

Other fly species use a different strategy

The embryos of other fly species, such as *Chironomus riparius*, which belongs to the midge family, or the black soldier fly (*Hermetia illucens*), do not have this head furrow.

Instead, they control the pressure by aligning their cell divisions in a particular way: Many cells do not divide – as in the fruit fly – within the tissue layer, but in an oblique or vertical direction. This means they take up less space within the layer. The consequence: The tissue can only expand to a limited extent, less pressure is exerted on the neighboring cells, and the risk of uncontrolled, spontaneous folding is reduced.

The researchers were also able to show that the orientation of cell divisions can be specifically altered. When they experimentally increased the production of a certain protein in fruit fly embryos, the cell divisions changed their orientation. They then resemble those of other fly species, which means that spontaneous indentations in the area between the head and torso are partially or completely absent – the young embryos develop largely normally.

Working group at the MPI-CBG in Dresden confirms results

For a long time, the research team was not sure whether it could really trust its results. "We were extremely relieved when a research group from the Max Planck Institute of Molecular Cell Biology and Genetics (MPI-CBG) in Dresden presented its work at a congress. They arrived at very similar results independently via a different route – a confirmation of our observations," says a pleased Professor Lemke.

In their investigations, study leaders Dr. Pavel Tomancak and Dr. Bruno C. Vellutini are also looking at the mechanisms by which embryos of fruit flies counteract mechanical stress. In addition to genetic analyses, they developed a computer model that simulates the physical processes in the head furrow. Their results are published simultaneously with those of the German-Japanese working group in the scientific journal Nature.

Mechanical instabilities as a motor of evolution

"Our results show that evolution can produce several solutions to the same problem," emphasizes zoologist Lemke. "Whether through the formation of a head furrow or through the realignment of cell divisions – both mechanisms ensure the fragile balance between growing tissues. This diversity of solutions could be a key to the emergence of new forms in evolution."

"In animals living today which branched off from the main lineage of flies 250 to 150 million years ago, the cells divide outside the tissue layer to prevent the head and torso tissue from colliding," he reports. "On the other hand, species which branched off from the main lineage of flies around 150 million years ago and later form a head furrow."

"This allows us to take a new, broader look at evolution: It is probably not exclusively driven by genetic changes. How organisms deal with physical forces also seems to be important. The ability to control mechanical tension could be a key to why so many different body plans have evolved over the course of Earth's history," Professor Lemke says in conclusion.

Nature publication:
Bipasha Dey, Verena Kaul, Girish Kale, Maily Scorcelletti, Michiko Takeda, Yu-Chiun Wang, Steffen Lemke: Divergent evolutionary strategies pre-empt tissue collision in gastrulation, Nature 3. September 2025, DOI: 10.1038/s41586-025-09447-4

Related publication:
Bruno C. Vellutini, Marina B. Cuenca, Abhijeet Krishna, Alicja Szałapak, Carl D. Modes, Pavel Tomancak: Patterned invagination prevents mechanical instability during gastrulation. Nature, 3. September 2025, DOI: 10.1038/s41586-025-09480-3

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