Unexpected role of noise in spine formation

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The development of periodic structures in embryos giving rise to the formation of, e.g., spine segments, is controlled not by genes but by simple physical and chemical phenomena. Researchers from the Institute of Physical Chemistry of the Polish Academy of Sciences, the Centre National de la Recherche Scientifique and the University Pierre et Marie Curie have proposed a straightforward theoretical model to describe the process, and studied how the segmentation is affected by internal, thermodynamic noise of the system. The results turned out to be counterintuitive.

In an early stage of embryogenesis in vertebrates, periodic segments called somites are formed in their dorsal mesoderm. With time, they transform into, i.a., vertebrae, spine elements. A Polish-French team from the Institute of Physical Chemistry of the Polish Academy of Sciences (IPC PAS) in Warsaw and the Centre National de la Recherche Scientifique (CNRS) and the University Pierre et Marie Curie (UPMC) in Paris has presented a straightforward theoretical model describing the formation of similar patterns. An analysis of the model properties has revealed that the formation of such patterns is surprisingly affected by the internal noise that is present in any physical system.

"We are convinced that the laws of physics and chemistry can explain biological phenomena and the evolution of living organisms", says Dr Bogdan Nowakowski from IPC PAS. "That's why we attempted to model theoretically one of the elements of vertebrate embryogenesis: the formation of periodic structures in somitogenesis. We did it by considering the minimal scheme of chemical reactions involving only a few components".

The chemistry of far-from-equilibrium phenomena knows spectacular Belousov-Zhabotinsky oscillating reactions (you can watch them in many movies on Youtube). The reactions occur in aqueous solutions of appropriate reagents with various concentrations. If addition of a component results in deviation of the system from the state of thermodynamic equilibrium, then chemical wavefronts start to propagate in the liquid. Their existence results in periodic colour changes of the solution. If the reaction takes place in a thin solution layer, e.g., in a Petri dish, one can observe permanently forming and propagating colour rings.

The model proposed by the scientists from the IPC PAS, CNRS and UPMC is exceptionally straightforward. It involves three chemical reactions and four substances including two ones forcing a non-equilibrium state in the system under study. The parameters of the model are adjusted so as to induce reactions leading to clear spatial oscillations of concentrations of the solution components. The result are periodic patterns, stable in time, so called Turing structures.

In nature, periodic structures in embryos are probably formed in a more complicated way, involving perhaps several dozens of reactions or even more. "Our model is a purely theoretical concept, a signal indicating that a part of the phenomena occurring during somitogenesis are controlled by truly simple mechanisms", stresses Nowakowski.

Having in hand a theoretical model describing the dynamics of a phenomenon observed in embryogenesis, the Polish-French team was able to verify the effect of internal noise on the described process. In nature, the noise is a consequence of the discrete, molecular structure of matter, an unavoidable, stochastic effect occurring in every physical system. In a theoretical model, noise can be introduced or suppressed at will. This also means that the theoreticians can do what the experimentalists cannot: to compare a naturally non-existing noiseless system with a noisy system – and to assess the effect of thermodynamic fluctuations on the segmentation process.

"Usually, one assumes that an accidental noise disturbs the existing order. Our simulations gave an opposite result. After the noise has been introduced into the model, periodic patterns started to appear significantly faster, just after the chemical wavefront has passed", describes Nowakowski. The thermodynamic fluctuations turned out to accelerate the formation of the periodic spatial pattern and to stabilize it in time. Moreover, the system formed easier the patterns, in a clearly broader range of parameter values.

More information: The research has been carried out under the Polish-French Polonium Program, and the results are published in the *Europhysics Letters* journal.

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