Accepted Manuscript

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PII: S0022-5096(17)30435-0
DOI: 10.1016/j.jmps.2017.10.018
Reference: MPS 3212

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 24 May 2017
Revised date: 8 October 2017
Accepted date: 26 October 2017

Please cite this article as: Brian N. Cox , Chad M. Landis , Solitary waves in morphogenesis: determination fronts as strain-cued strain transformations among automatous cells, *Journal of the Mechanics and Physics of Solids* (2017), doi: 10.1016/j.jmps.2017.10.018

Solitary waves in morphogenesis: determination fronts as strain-cued strain transformations among automatous cells

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submitted to *JMPS*
May, 2017
accepted October, 2017

Keywords: determination front, strain cue, strain transformation, solitary wave, automaton

Abstract

We present a simple theory of a strain pulse propagating as a solitary wave through a continuous two-dimensional population of cells. A critical strain is assumed to trigger a strain transformation, while, simultaneously, cells move as automata to tend to restore a preferred cell density. We consider systems in which the strain transformation is a shape change, a burst of proliferation, or the commencement of growth (which changes the shape of the population sheet), and demonstrate isomorphism among these cases. Numerical and analytical solutions describe a strain pulse whose height does not depend on how the strain disturbance was first launched, or the rate at which the strain transformation is achieved, or the rate constant in the rule for the restorative cell motion. The strain pulse is therefore very stable, surviving the imposition of strong perturbations: it would serve well as a timing signal in development. The automatous wave formulation is simple, with few model parameters. A strong case exists for the presence of a strain pulse during amelogenesis. Quantitative analysis reveals a simple relationship between the velocity of the leading edge of the pulse in amelogenesis and the known speed of migration of ameloblast cells. This result and energy arguments support the depiction of wave motion as an automatous cell response to strain, rather than as a response to an elastic energy gradient. The theory may also contribute to understanding the determination front in somitogenesis, moving fronts of convergent-extension transformation, and mitotic wavefronts in the syncytial drosophila embryo.