A computational model of nuclear self-organization in syncytial embryos.

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Electronic Supplementary Material

Effect of linear spring interaction potentials during interphase

In investigating the role of temporal changes in the cytoskeleton on nuclear ordering we have taken the force between the nuclei during interphase as constant in spatial distance (though not in time). The form of the internuclear force is specified by Eq. (4). Here we briefly consider the implications of instead choosing a linear spring-based model in which the forces between neighboring nuclei are still described by Eq. (4), but with $\hat{F}_{\max}$ now dependent on the distance between the nuclei, specifically with

$$\hat{F}_{\max} = \begin{cases} k\left(1 - \frac{1}{c_1}\left|\mathbf{x}_i - \mathbf{x}_j\right|\right) & \left|\mathbf{x}_i - \mathbf{x}_j\right| < c_1, \\ \frac{kq}{c_2 - c_1}\left(\left|\mathbf{x}_i - \mathbf{x}_j\right| - c_1\right) & c_1 \leq \left|\mathbf{x}_i - \mathbf{x}_j\right| < c_2, \\ \frac{kq}{c_3 - c_2}\left(c_3 - \left|\mathbf{x}_i - \mathbf{x}_j\right|\right) & c_2 \leq \left|\mathbf{x}_i - \mathbf{x}_j\right| < c_3, \\ 0 & c_3 \leq \left|\mathbf{x}_i - \mathbf{x}_j\right|. \end{cases} \tag{ESM.1}$$

The parameters c_1, c_2, c_3, k, q are constants, and the model implements a cutoff for the interaction potential with a linear decrease of attraction to zero. All distances are non-dimensional. This force law introduces additional fit parameters into the model. We look in figure S1a at the effect of varying just one of these additional parameters, the spring rest length c_1. Starting with 600 nuclei the average ordered internuclear spacing post division is 0.112, so that for example if $c_1 > 0.112$ then post division the springs will be predominantly compressed. We find that the nuclear array is unable to order when the spring rest length is such that the array is primarily in tension, with the experimentally observed ordering dynamics recaptured as we tend towards larger rest lengths for which the internuclear forces are primarily repulsive. In these repulsive regimes we cannot distinguish between the models of constant force between nuclei and linear spring-like forces. Additionally, we observe that it is necessary to take care when using linear spring-based force laws to choose parameter regimes such that the array does not rip apart and generate unphysical voids. An example of this phenomenon is shown in figure S1b.

Proto-peak dependence on initial nuclear separation

A striking feature of the agreement between the plots in figure 4 of the main text is the existence of the first smaller peak in disorder before the main process of disordering occurs as a result of spindle elongation. This proto-peak in the ordering curves occurs as a result of chromosome segregation and the instantaneous introduction of small finite distances in the system. To show this we investigated how the height of this peak in σ/μ depends on the initial distance at division d. We find that the as the separation of the two daughter cells increases so the height of the proto-peak decreases, see figure S2.

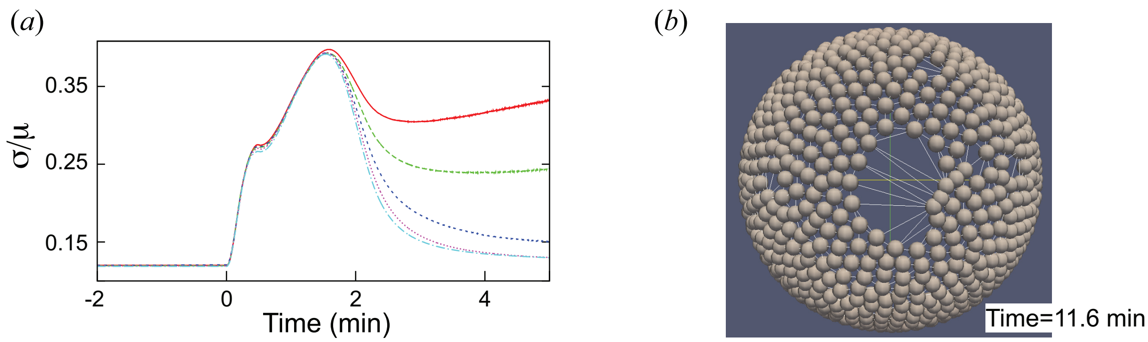

Figure S1. Linear spring-like reordering forces. (a) The effect of varying spring rest length on the simulation reordering dynamics as quantified by σ/μ with $c_1 = 0.100, 0.105, 0.110, 0.115, 0.125$ from top to bottom, respectively. (b) Generation of voids within the simulation with spring-based force laws ($c_1 = 0.11$). Simulation parameters for (a), (b): $c_2 = 1.4c_1$, $c_3 = 1.8c_1$, $k = 10$ and $q = -0.6$, $N = 600$ and all other parameters as for figure 4.

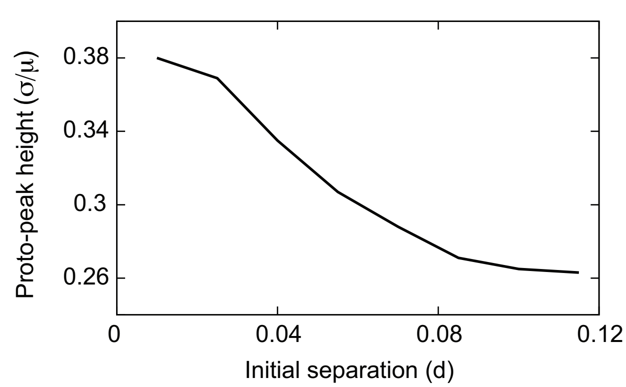

Figure S2. Plot of the maximum height of the first proto-peak in σ/μ (as seen in figure 4) against the initial separation d of daughter nuclei at mitosis. Increasing the separation d decreases the proto-peak height.

Movies

Video S1. Experimental movie of a *Drosophila melanogaster* embryo going through the 13th division of its syncytial development. The fluorescence images are obtained from embryos whose nuclei express Histone H2Av-GFP. (Scale bar 10μm).

Video S2. Simulation of a syncytial embryo undergoing mitosis, nuclear rearrangement and spatial reordering.