Physical modelling of ESCRT-III mediated cell division in archaea

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Studying the mechanism of cell division in evolutionary simpler cells can teach us about the mechanistic principles that have been conserved as life evolves into more complex cells. The archaeon Sulfolobus acidocaldarius possesses a cell division cycle similar in structure and logic to that of many eukaryotes. While the archaeal ESCRT-III homologues CdvB and CdvB1/B2 are essential for the final stage of cell division, their exact function in the timely remodelling of the cell membrane is elusive. Based on experimental findings, we suggest a mechanistic model of ESCRT-III mediated division in archaea [1]: As cells prepare to divide, they assemble a non-contractile CdvB ring of a fixed diameter at the cell midzone. The CdvB ring acts as a template for the assembly of a CdvB1/B2 polymer which, like force-generating ESCRT-III polymers in other systems, has a small preferred curvature. As a result, the loss of the CdvB scaffold drives rapid contraction of the CdvB1/B2 ring towards its preferred curvature, constricting the membrane as it does so. In order to test the proposed model, we perform coarse-grained molecular dynamics simulations of a large spherical membrane coupled to an elastic filament that can both change its curvature and disassemble. We map the cell division phase space as a function of the CdvB degradation procedure (i.e. instantaneous, sequential, randomised), as well as the intrinsic curvature and the disassembly rate of the ESCRT-III filament [2]. Our results show that cell division is not achieved by contraction of the ESCRT-III filament alone; disassembly is also required. Furthermore, we analyse the furrow constriction in time and find a good qualitative agreement between simulation and experiment. We thereby determine a molecular mechanism by which the timely degradation of one protein, CdvB, triggers the division of a single archaeal cell into two daughter cells.

[1] G. T. Risa, F. Hurtig, S. Bray, A. E. Hafner, L. Harker-Kirschneck, P. Faull, C. Davis, D. Papatziamou, D. R. Mutavchiev, C. Fan, L. Meneguello, A. A. Pulschen, G. Dey, S. Culley, M. Kilkenny, L. Pellegrini, R. de Bruin, R. Henriques, B. Snjiders, A. Saric, A. Lindås, N. Robinson, and B. Baum,
Proteasome-mediated protein degradation resets the cell division cycle and triggers ESCRT-III-mediated cytokinesis in an archaeon, submitted (2019)

[2] A. E. Hafner, L. Harker-Kirschneck, D. Hrynuik, G. T. Risa, B. Baum, and A. Saric,
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