Condensation of FtsZ Filaments Drives Bacterial Cell Division

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***Short Abstract* — FtsZ is an essential protein for bacterial cell division. It forms a ring (Z-ring) at the division site. This Z-ring contracts and exerts force to divide the cell. Using computational modeling, we show that Z-ring forms through the co-localization of FtsZ and its anchor protein, FtsA, mediated by the favorable alignment of FtsZ filaments. The model predicts that Z-ring undergoes a condensation transition and generates sufficient contractile force to achieve division. *In vivo* fluorescence measurements confirm such predicted FtsZ density increase during bacterial cell division. The mechanism shows that organisms can exploit microphase transitions to generate mechanical forces.**

***Keywords* — force generation, cell division, Z-ring, modeling.**

I. Motivation

Forces are important in biological systems for key cell functions, such as motility, organelle transport, and cell division. Currently, known force generation mechanisms typically involve motor proteins. In bacterial cells, no known motor proteins are involved in cell division. Instead, a ring-like structure (Z-ring) consists of mostly FtsZ, FtsA and ZipA is used to exerting a contractile force and drives bacterial cell division (1-3). Recently, force generation by membrane-bound FtsZ in vesicles was observed (4). Thus, the role of the Z-ring seems to be 2-fold: It recruits cell wall synthesis proteins, facilitating cell wall growth and remodeling (2, 3), and it exerts a weak mechanical force to direct cell wall growth (5). But the question is: what is the mechanism of Z-ring formation and ensuing force generation?

II. Model and Result

Rapid monomer exchange between the ring and the cytoplasm has been observed *in vivo* (6). Earlier *in vitro* studies of FtsZ polymerization showed that FtsZ monomers can form polymer (longitudinal, e_1) bonds and bundling (lateral, e_2) bonds (7-11). Our quantitative analysis indicated that e_1 is -17≈-20 k_BT, and e_2 is -0.2≈-0.5 kBT, depending on the buffer condition (11). Even though e_2 is significantly weaker than e_1, the total lateral interaction scales as the number of lateral contacts in the Z-ring. A smaller e_2 will favor more lateral contacts between filaments, and the density of FtsZ in the ring region will be higher. A bigger e_2 will favor less lateral contacts due to entropic expansion.

We construct a lattice model that considers FtsZ, FtsA and their interactions. FtsZ moving from cytoplasm to membrane is modeled as particle exchanging between the lattice space and an equilibrated reservoir. Metropolis Monte Carlo simulation shows that FtsZ filaments and FtsA localize to the division site and form a Z-ring with un-unified filament alignment. When the size of the ring is allowed to change (by cell wall remodeling), FtsZ filaments get aligned and the Z-ring reduces its radius spontaneously, meaning that free energy decreases and a contractile force (5~20pN, depending on e_2) is generated. This process is accompanied with increase of Z-ring volume density from ~65% to more than 90%, which is consistent with *in vivo* fluorescence experiment.

III. Conclusion

Our model shows that condensation of FtsZ filaments can produce force and drive bacterial cell division, which suggests that microphase transition can be a new kind of mechanism for biological systems to generate force.

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