Self-Assembly of a Bacterial Nanomachine: Flagella Grow Through an Injection-Diffusion Mechanism

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The external filament of the bacterial flagellum is several times longer than a bacterial cell body and is made out of up to 20,000 flagellin subunits.

A type III export apparatus (T3SS) located at the base of the flagellum utilizes the proton motive force as the primary energy source to translocate axial components of the flagellum across the inner membrane. Exported substrates travel through a narrow 2 nm channel within the structure and self-assemble at the tip of the growing flagellum. The T3SS-dependent export of flagellar building blocks is a remarkable fast process and more than 1,700 amino acids per second are transported during filament growth.

A fundamental problem concerns the molecular mechanism of how the long, external filament grows at a rapid rate outside the cell in the absence of any cellular energy sources. I will present evidence to support a model of flagellum growth where the filament growth rate is driven by both diffusion and proton motive force-dependent injection of subunits.

We monitored the dynamic assembly of individual flagella using *in situ* labelling and real-time immunostaining of elongating flagellar filaments and found that the rate of flagellum growth decreases with length. Inhibition of the proton motive force-dependent export apparatus prevented filament elongation. Finally, competitive export of flagellin mutant proteins deficient in head-to-tail chain linkage did not impair the flagellum growth rate, suggesting that the previously proposed chain mechanism does not contribute to the filament elongation dynamics.

In summary, we propose that a simple, injection-diffusion mechanism controls the growth of the flagellar filament outside the cell.