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STRUCTURAL BIOLOGY

Flagella propeller unveiled

Flagella, which many bacteria use to swim, couple a powerful biological motor to rotation of a helical propeller — the flagellar filament. Now, Yonekura and colleagues report a remarkable achievement. High resolution electron cryomicroscopy combined with image analysis has been used to solve the structure of the bacterial flagellar filament.

The bacterial flagellum consists of a motor embedded in the cell membrane linked to an external filament. Flagellin subunits assemble into so-called protofilaments in two different conformations, L-type and R-type. Supercoiled bundles of 11 protofilaments can form left-handed or right-handed helices. The motor can rotate clockwise or counter-clockwise. Rotation of the helical bundles mimics a propeller and moves the bacterial cell. When the motor rotates counter-clockwise, protofilaments form a left-handed propeller that rotates and drives the cell forwards. When the motor rotates clockwise, some of the protofilaments switch to form a right-handed propeller.The bundled filaments fall apart and the cell stops and re-orientates in a random manner. Reversing motor rotation allows bacteria to change direction.

In 2001, Samatey *et al.* solved the crystal structure of the R-type protofilament, which showed how flagellin subunits were arranged — but crystallisation proved difficult because flagellin tended to polymerise, so they used a truncated flagellin subunit. This study didn't reveal interactions between protofilaments.

Now, a complete model of the R-type filament has been built by Yonekura *et al.* using electron cryomicroscopy and image analysis. Not only is this fascinating for microbiologists, it's the first example of an atomic resolution model of any protein using this method. The stunning resolution obtained — 4 Å — enabled direct comparison to the R-type crystal structure. This showed that flagellin subunits are held together by hydrophobic interactions, and that the central channel of the flagellum is lined with polar residues. This could be relevant to export of unfolded proteins through the flagellum—like flagellin, which is exported then added to the growing filament tip — and for type III virulence protein secretion through a needle complex that is similar to the flagellum.

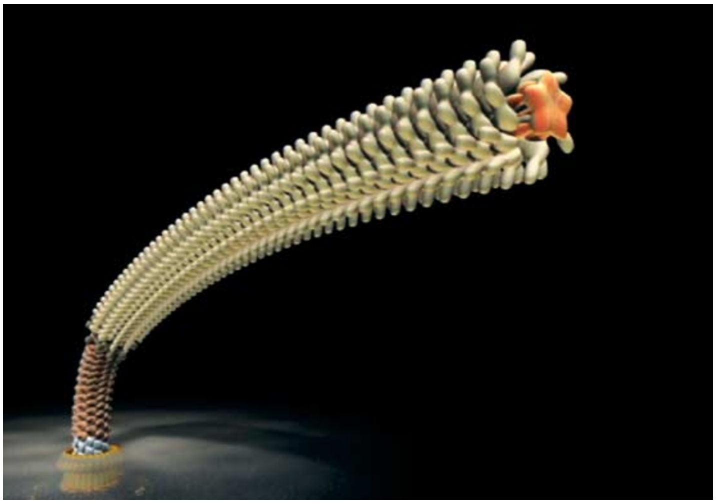
When the structure of the L-type filament is solved, the puzzle of how this molecular machine works may finally be solved. Since flagellin self-assembles into filaments — and self-assembly is a fundamental requirement for mass production of nanomachines — uncovering how the bacterial flagella works will take us one step closer to designer nanomachines.

Susan Jones

References and links

ORIGINAL RESEARCH PAPER Yonekura, K. *et al*. Complete atomic model of the bacterial flagellar filament by electron cryomicroscopy. *Nature* **424**, 643–650 (2003).

FURTHER READING Samatey, F. A. *et al*. Structure of the bacterial protofilament and implications for a switch for supercoiling. *Nature* **410**, 331–337 (2001).



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