Uncovering how bacteria move

Nagoya University, Graduate School of Science
Professor Michio Homma

[About my research]

By what mechanism do bacteria move?

In my laboratory, we are studying the energy conversion mechanism of the flagellum, a locomotor organ, in bacteria (some are called harmful bugs), which can be easily analyzed by the molecular level. We also investigate how bacteria sense and process extracellular information, and then understand comprehensively how the flagellar motor is controlled in the system.

Bacterial motor energy conversion

The bacterial flagellum is structurally and functionally quite different from the flagellum of spermatozoa (conventionally written in Chinese characters to distinguish it from the bacterial flagellum), which is the locomotor organ possessed by animals. Animal flagella use ATP as the energy source for their whipping motion. In contrast, bacterial flagella have motor at the base which is buried in cytoplasmic membrane and is rotated by the flow of ions from the outside to the inside of the membrane. Think of it as the difference between a gasoline engine and an electric motor engine. The influx of ions (hydrogen and sodium ions) directly generates the rotational motion (Fig. 1). The motor is connected to the flagellar fiber or filament, which is several times longer than the length of the bacterial cell, as a screw and generates propulsive force by passively rotating filament. This is equivalent to a 160-cm tall person turning a 4-meter string at 1700 revolutions per second, the speed comparable to the engine of an F1 car. The flagellar motor is a supramolecular complex made of many proteins (the supramolecule means a molecule with special abilities) and contains sub-structures such as a motor-protein complex converting ionic energy into mechanical energy, a switch complex controlling the direction of motor rotation, and others.

Electric motors convert the flow of electric current into magnetic force and the attraction and repulsion made from magnetic force cause the motor to rotate. On the other hand, what happens to rotate the biological motor by ion flow? To answer this very question, we are analyzing the overall structure of that motor or energy converter of the main parts in the flagella (Fig. 2). Although we have not yet reached a sufficient resolution enough to investigate the principles of the energy transduction, we are beginning to understand the molecular details of the motor.

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The Mystery of the One Hair on the Head

Bacteria do not move haphazardly when they are swimming. For example, they swim to use their flagella toward where they want to go to find amino acids, such as serine, that serve as a source of nutrients. Many proteins are localized in the cell; each performs its function in the correct number and at the right place. For example, chemotaxis receptors, one of the sensory organs of bacteria, are localized in large clusters at the poles of the cell and serve as sensors to receive information from the outside world. Based on the information from these chemotaxis receptors, bacteria can move to a better environment using flagella, pili, and other motile organs. These locomotory organs are not randomly produced everywhere. Their number and position are appropriately regulated by the genes *flhF* and *flhG* which are shown to control the single polar flagellum of *Vibrio*. It is known that the proteins produced by these two genes are enzymes with the activity to degrade essential molecules in the living body, such as guanosine triphosphate (GTP) and adenosine triphosphate (ATP). However, it is unclear how that activity is used to determine the location. The mechanism by which a single hair grows on the head of the bacterial cell is also unclear.

By our research as described above, we believe that it may lead to the elucidation of new principles in microscopic energy conversion, which may help solve the world's energy problems. However, even if they are not immediately applicable, our current greatest motivation why we are doing research is that, in front of us, there is something that we can not understand.

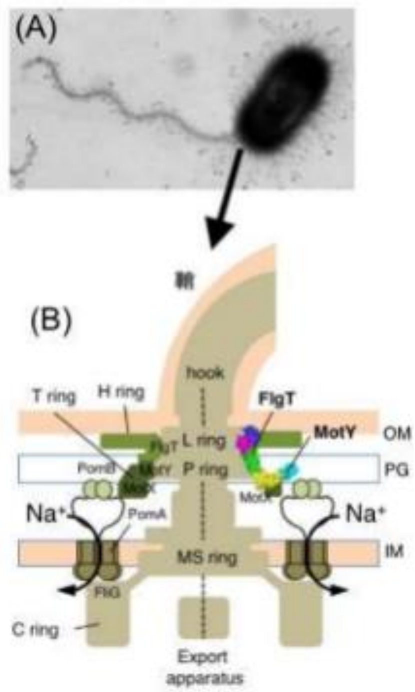

Figure 1: *Vibrio* flagellar motor. (A) Electron micrograph of *Vibrio* cell. The *Vibrio* cell has a single flagellum at the edge or pole of the cell, which rotates like a screw to swim. (B) Schematic model of the motor part. The engine (flagellar motor), that generates the rotational force and is embedded in the membrane (outer and inner membrane), resides at the base of the flagellum. The rotary motor is made of a stator and a rotor. It also consists of a bearing that supports the rotation of the rotor, a hook that acts as a free joint for screw, and a filament that functions like a screw. Several stators are placed around the rotor, and when sodium ions (Na^+) flow through the stators, they interact with the rotor to produce the rotational force.

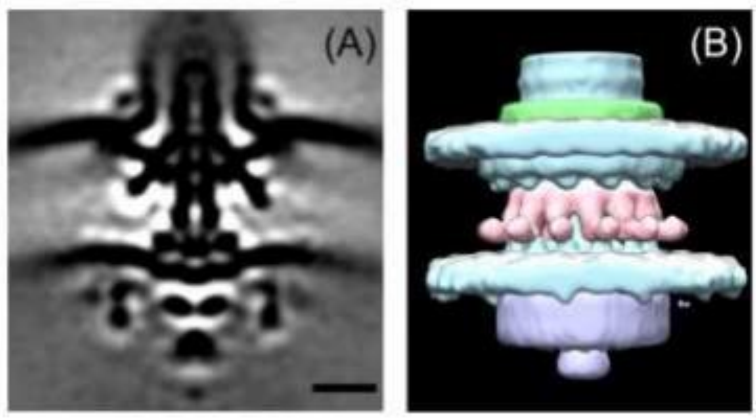

Figure 2: (A) Cross-section of a *Vibrio* flagellar basal body which was quickly frozen. The images of the flagellar basal body part taken by electron microscopy were superimposed to construct a three-dimensional image, and its cross-section is shown. (B) The surface rendered image of three-dimensionally reconstructed *Vibrio* flagellar motor created from cryo-electron tomographic images.