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Operation mechanism of rotary molecular motor F_1 probed by single-molecule techniques

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F_1 is a rotary motor protein. Three catalytic β-subunits in the stator $\alpha_3\beta_3$ ring are torque generators, and rotate the rotor γ-subunit by sequential and cooperative conformational changes coupled with adenosine triphosphate (ATP) hydrolysis reaction. F_1 shows remarkable performances such as rotation rate faster than 10,000 rpm, high reversibility and efficiency in chemo-mechanical energy conversion. I will introduce basic characteristics of F_1 revealed by single-molecule imaging and manipulation techniques based on optical microscopy and high-speed atomic force microscopy. I will also discuss the possible operation mechanism behind the F_1, along with structurally-related hexameric ATPases, also mentioning the possibility of generating hybrid molecular motors.