Wing-beat mechanism revealed by ultrafast X-ray movies

Japan Synchrotron Radiation Research Institute (JASRI) has succeeded in deciphering the mechanism of high-frequency wing-beat of insect, by irradiating the chests of beating insects and recording ultrafast X-ray movies at a rate of 5,000 frames/s.

Smaller insects beat their wings at higher frequencies, and in the case of mosquitoes, they beat their wings 500 times a second. They can beat at such high frequencies because their flight muscles undergo self-sustained oscillations while they remain constantly activated. These self-sustained oscillations are caused by the process of stretch activation (SA, a process in which a muscle generates a large force when externally stretched). The molecular mechanism of SA has been unknown in spite of researches for decades. It has been shown recently that insects express many flight muscle-specific proteins, and a prevailing hypothesis is that these proteins are responsible for SA.

In this study, the researchers have succeeded in recording diffraction patterns from beating bumblebees at an unprecedented rate of 5,000 frames/s, by irradiating their thoraces with intense X-rays from the high-flux BL40XU beamline of SPring-8. The bumblebees beat their wings 120 times a second (8 ms per wing-beat cycle), so that 40 frames were taken for each wing-beat cycle. This allowed detailed analyses of the movement of proteins in the flight muscles. In addition, it was possible to estimate the changes of length and force of muscles from the analyses of diffraction patterns.

An important outcome of the study is the detection of a signal that precedes each SA event, in the right timing for triggering SA. This signal is inferred to come from a deformation of myosin, the contractile protein responsible for force generation. The deformation-induced generation of large force by myosin has long been reported for vertebrate skeletal muscle. Thus, insect flight muscle relies on a general property of muscle also found in vertebrates, rather than their specific proteins, in creating SA.

Because of the common mechanism shared by insect flight muscle and vertebrate muscles, insect flight muscle is expected to serve as a model material to better understand the functions of skeletal and cardiac muscles of vertebrates. This is particularly important for studying cardiac muscle, because of the suggested role of SA in heartbeat.

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Reference: "The Molecular Trigger for High-Speed Wing Beats in a Bee"
H. Iwamoto and N. Yagi.
Science, **341** 1243-1246 (2013)

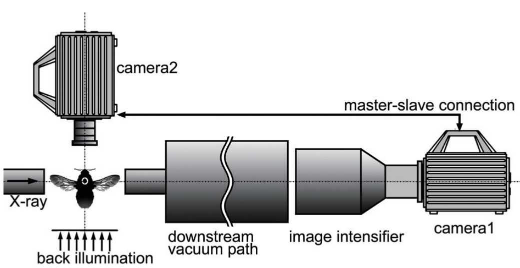

Fig. 1. Experimental setup.
Two fast CMOS video cameras are connected in a master-slave fashion, and they synchronously record diffraction patterns and wing-beats.

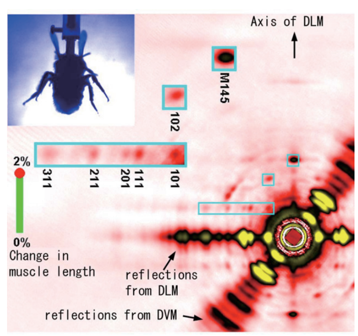

Fig. 2. One of the frames of X-ray movies.
Data from all the bees used in the experiment have been summed after rotating the patterns so that the axis of Dorsal longitudinal muscle fibers is vertical. The regions of interest are magnified in blue boxes (all of the reflections in the boxes come from DLM).

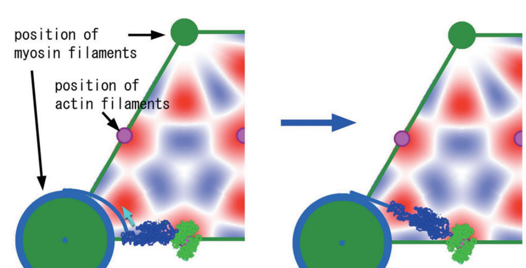

Fig. 3. Model that explains the observed intensity change of reflection (the 111 spot in Fig. 2).
This is a magnified view of the cross section of muscle. The blue irregular-shaped object is the myosin molecule, and the green one is the actin molecule. The intensity change of the 111 spot that precedes an SA event is explained if the myosin molecule undergoes a twisted motion as shown (from left to right).