Energetic costs, precision, and transport efficiency of molecular motors

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Molecular motors are a key player in tempo-spatial organization of cells. An ideal motor would transport cargo at high speed with minimal error in transport distance (or time), while consuming minimal amount of energy. The travel distance and its variance of motor are, however, constrained by energetic cost. The physical principle that underlies the trade-off relationship between the energetic cost and precision has recently been formulated into the thermodynamic uncertainty relation. In this talk, I will first give a brief overview of thermodynamic uncertainty relation and its physical significance, next address how to calculate the heat dissipated from time traces of a motor protein, and finally discuss which molecular motor has the highest transport efficiency. The energetic cost for kinesin-1 varies non-monotonically with ATP concentration and load (f), and is locally minimized at [ATP] ~ 200 uM and f ~ 4 pN. Remarkably, this local minimum vanishes for a mutant kinesin-1 that has a longer neck-linker, and the cost is much greater for the mutant than the wild type. Calculations show that the energetic cost and precision of motility vary depending on the motor type. For the biological motors that we study, the energetic cost of generating regular time trace or the regularity of motor dynamics for a given cost is effectively optimized under cellular condition ([ATP] ~ 1 mM, f=0-1 pN). We find that among the motors, kinesin-1 at a single molecule level is the most efficient in cargo transport.