June 2001: Myosin

Molecular Motion
All of the different movements that you are making right now--your fingers on the computer keys, the scanning of your eyes across the screen, the isometric contraction of muscles in your back and abdomen that allow you to sit comfortably--are powered by myosin. Myosin is a molecule-sized muscle that uses chemical energy to perform a deliberate motion. Myosin captures a molecule of ATP, the molecule used to transfer energy in cells, and breaks it, using the energy to perform a "power stroke." For all of your voluntary motions, when you flex your biceps or blink your eyes, and for all of your involuntary motions, each time your heart beats, myosin is providing the power.

Sprinting with Myosin
Myosin requires huge amounts of ATP when muscles are exerted. When you start running, the supply of ATP in your muscles lasts only about a second. Then, the muscle cells shift to phosphocreatine, a backup source of energy, which can be converted quickly into about 10 seconds worth of ATP. Then, if you are still running full tilt, your muscles start using glycogen, a molecule that stores glucose. This lasts for a minute or two, building up toxic acids as the sugar is used up. Then, the sprint is over and you have pushed your muscles to the limit. If, however, you slow down and pace yourself, your muscles can perform much longer. The blood vessels will dilate and your heart rate will increase, bringing twenty times as much blood through the muscles. Your muscle cells can then use this extra oxygen to produce far more ATP from the sugar in glycogen. Instead of collapsing after a short sprint, you now have the resources for a mountain hike or a marathon.
Anatomy of a Molecular Muscle

Myosin is composed of several protein chains: two large "heavy" chains and four small "light" chains. The structures available in the PDB, such as the one shown above, contain only part of the myosin molecule. In the illustration above, from PDB entry 1b7t, atoms in the heavy chain are colored red on the left-hand side, and atoms in the light chains are colored orange and yellow. The whole molecule is much larger with a long tail that has been clipped off to allow the molecule to be studied. Fortunately, the crystal structures include most of the "motor" domain, the part of the molecule that performs the power stroke, so we can look at this process in detail.
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Power in Numbers
Each myosin performs only a tiny molecular motion. It takes about 2 trillion myosin molecules to provide the force to hold up a baseball. Our biceps have a million times this many, so only a fraction of the myosin molecules need to be exerting themselves at any given time. By working together, the tiny individual power stroke of each myosin is summed to provide macroscopic power in our familiar world. The painting shows how myosin is arranged inside muscle cells. About 300 myosin molecules bind together, with all of the long tails bound tightly together into a large "thick filament." A short segment of a thick filament is shown in red, next to a scale drawing of a single myosin molecule. The many myosin heads extending from the thick filament then reach over to actin filaments, shown in blue and green, and together climb their way up.
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The Power Stroke
ATP contains a key phosphate–phosphate bond that is difficult to create and is used to power many processes inside cells. You might be surprised to find, however, that breakage of this phosphate–phosphate bond is not directly responsible for the power stroke in myosin. Instead, it is release of the phosphate left over after ATP is cleaved that powers the stroke. Think of myosin like an arm that can flex towards you or push away. The cleavage of ATP is used in a priming step. When ATP is cleaved, myosin adopts a bent, flexed form, like in the structure on the left (PDB entry 1br1). This prepares myosin for the power stroke. The flexed myosin then grabs the actin filament and release of phosphate snaps it into the straight "rigor" form, as shown on the right (PDB entry 2mys). This power stroke pushes the myosin molecule along the actin filament. When finished, the remaining ADP is replaced by a new ATP, the myosin lets go of the actin filament. Then, it is ready for the next stroke.

Note that these illustrations only show the proteins—-the ATP, ADP and phosphate molecules are bound inside the proteins and are not visible from this view.
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Exploring the Structure
This myosin motor domain, from entry 1b7t, is nearly straight, close to the rigor form. You can explore several interesting features. At the tip of the molecule is a cleft that binds to the actin filament. Notice that the ADP molecule (in green) is bound at the base of this deep cleft. It is thought that changes in the nucleotide, as it cycles from ATP, to ADP and phosphate, to ADP alone, are transmitted along this cleft to change the way that myosin interacts with actin. In the middle of the molecule is the "converter" domain that changes shape when phosphate is released. On the left side of the molecule is a long alpha helix with the two light chains (orange and yellow) bound around it. This is the "lever arm" that amplifies the converter shape change into a large power stroke.