April 2005: Kinesin

Kinesin
Because cells are so tiny, many cellular processes use simple random diffusion to get materials from one place to another. For instance, when a molecule of glucose is broken down in glycolysis, the ten enzymes and all the intermediate pieces are thrown together in the cytoplasm, and by randomly bumping around, everything manages to find its proper place. For small molecules and proteins, random diffusion is fast enough to get the job done, but for some larger tasks, cells have to take a more active approach. This is where molecular motors come in. Cells make a variety of motors that drag large cellular objects to their proper destinations.

Molecular Motors
Cells built three types of ATP-powered motors that move along protein filaments. Myosins, such as the impressive myosins used to power our muscles, use the energy of ATP to move along actin filaments. Kinesins and dyneins, on the other hand, walk along microtubules, dragging their cargo along with them. All of these motors are typically composed of a motor domain, which splits ATP and converts the energy into motion, and a cargo-binding domain, which connects to the object being moved. The kinesin shown here (PDB entry 3kin) is composed of two chains. The two motor domains are at the top, with ADP in red. A long, flexible stalk connects the motor domains to the cargo-binding domains at the bottom. The lower part of the molecule is shown schematically here because only the motor domains and a small neck at the top of the stalk were seen in the crystal structure.

Riding the Rails
Kinesins are used for many tasks in cells. Typical cells contain an array of microtubules, all pointed from the center of the cell outwards to the surface. Kinesins are used to drag large objects, like lysosomes or endoplasmic reticulum, outwards away from the nucleus and towards the surface. Dyneins are used for the opposite function, to pull things inwards. Kinesins drag materials down the enormous length of nerve axons--this function is how kinesins were discovered. Kinesins are also used to slide microtubules next to one another, for instance, during the process of creating two separate systems of microtubules to separate chromosomes when the cell divides.

Step-by-Step
Kinesins and myosins perform their functions differently. Myosin reaches over to an actin filament, performs its power stroke, and then quickly releases the filament. So, in order to move a large distance, many myosin molecules must be working together, each doing their part. Kinesin, however, can work by all by itself. Kinesin crawls hand-over-hand along a microtubule. At each step, one motor domain holds on tightly while the other one releases its hold, flips up to the next step on the microtubule, and grabs on there. In this way, the two motor domains work together along the microtubule, taking several hundred 8 nanometer steps before they stop. For a movie of kinesin in action, take a look at http://www.scripps.edu/cb/milligan/projects.html.
This Way or That?

Our cells build about 40 different types of kinesin for different functions. They all have a similar motor domain that uses ATP to perform its power stroke. But this motor is attached to many different types of adapters that attach the motor to the object that needs to be moved. Two kinesins are shown here--conventional kinesin at the top (PDB entry 2kin) and ncd at the bottom (PDB entry 2ncd). Notice that the two motor domains are connected differently to the stalk. The result of this difference is that these two kinesins move in opposite directions on the microtubule.
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Exploring the Structure
Now that the structures of several molecular motors have been determined, we can see that the mechanism of powered motion is very similar in different kinesins, and remarkably, in myosin as well. The trick used by molecular motors is to link the small change of breaking the ATP phosphate-phosphate bond into a large structural change in the motor.

Two kinesin structures are shown here: the one on the left shows kinesin before the power stroke (PDB entry 1bg2), and the one on the right is after the power stroke (PDB entry 2kin). In each case, only one motor domain is shown and ADP is shown in red. The ATP-binding portion, colored blue here, changes slightly as the ATP is cleaved and the phosphate dissociates. The small change pushes on the relay helix, shown here in green, causing it to change slightly in shape. This forms a perfect pocket for the neck linker, shown in yellow. Before the power stroke, the pocket is too small and the linker is flexible and disordered. After the power stroke, the pocket is the right size for the linker to zipper into the protein, dragging along the neck and any cargo attached to it.