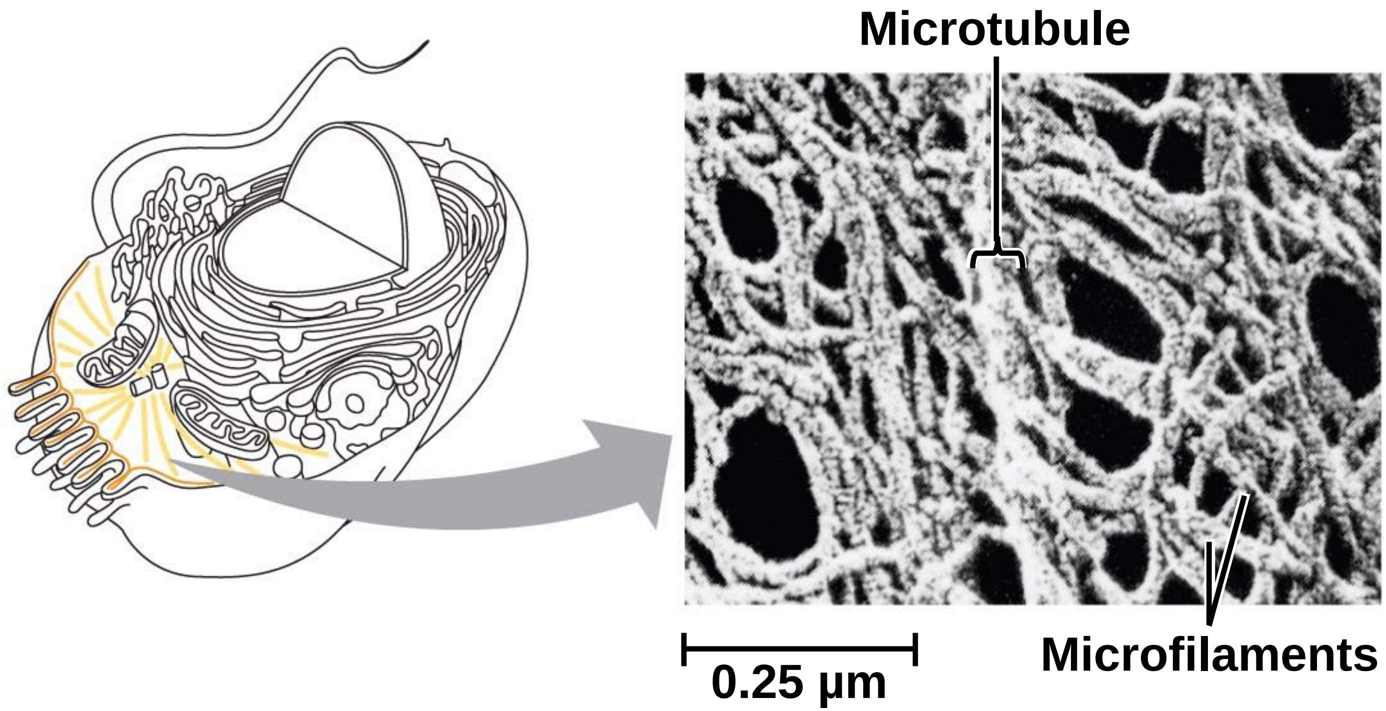
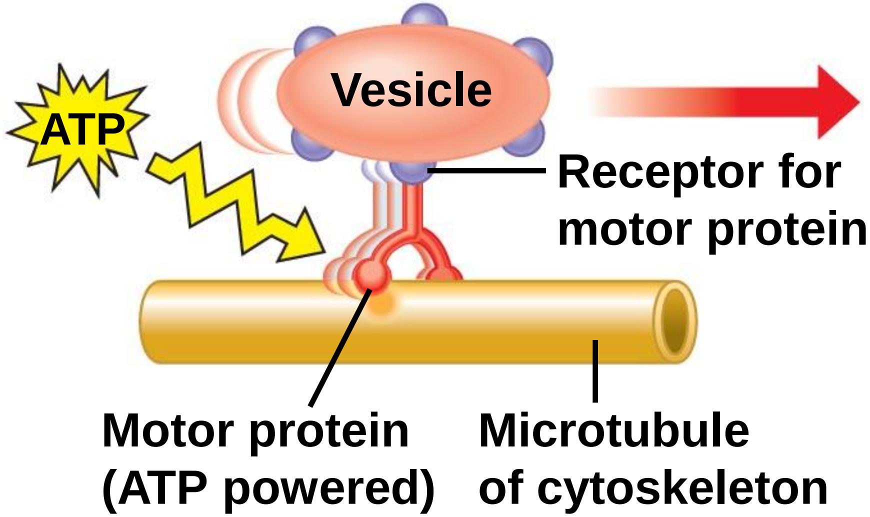
The cytoskeleton is a network of fibers that organizes structures and activities in the cell

- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm
- It organizes the cell’s structures and activities, anchoring many organelles
- It is composed of three types of molecular structures:
  - Microtubules
  - Microfilaments
  - Intermediate filaments

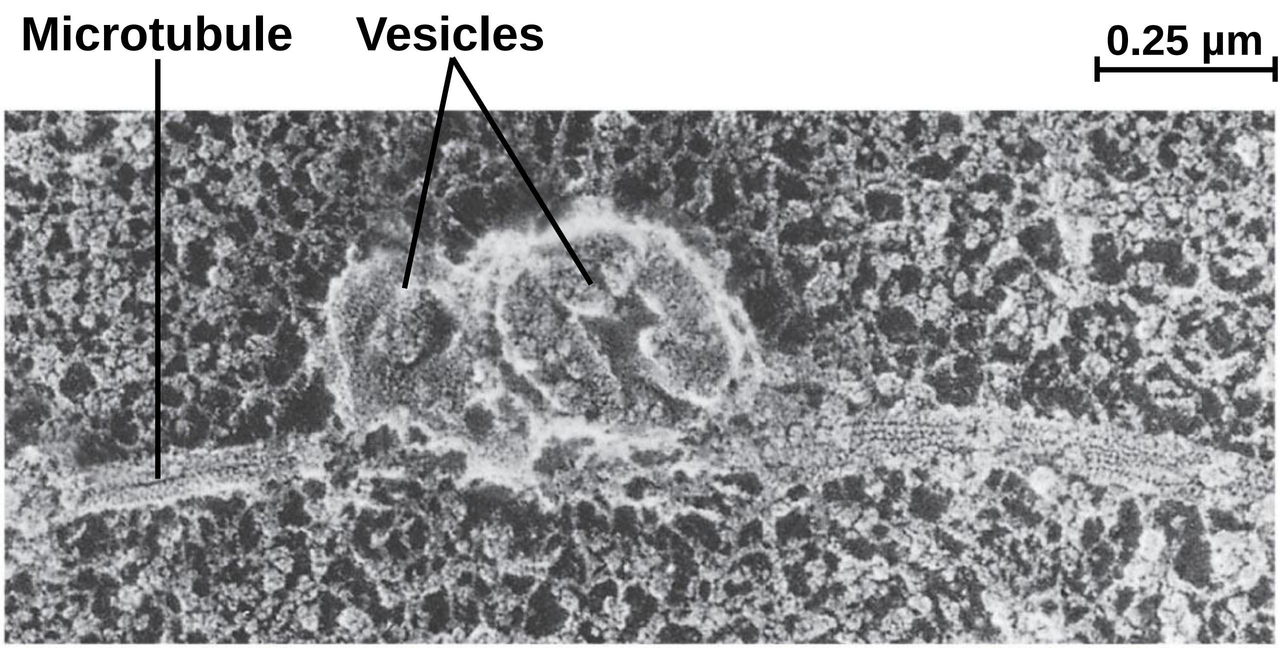

Microtubule
Microfilaments
0.25 µm

Roles of the Cytoskeleton: Support, Motility, and Regulation

- The cytoskeleton helps to support the cell and maintain its shape
- It interacts with **motor proteins** to produce motility
- Inside the cell, vesicles can travel along “monorails” provided by the cytoskeleton
- Recent evidence suggests that the cytoskeleton may help regulate biochemical activities


ATP
Vesicle
Receptor for motor protein
Motor protein (ATP powered)
Microtubule of cytoskeleton

(a)


Microtubule
Vesicles
0.25 µm

(b)

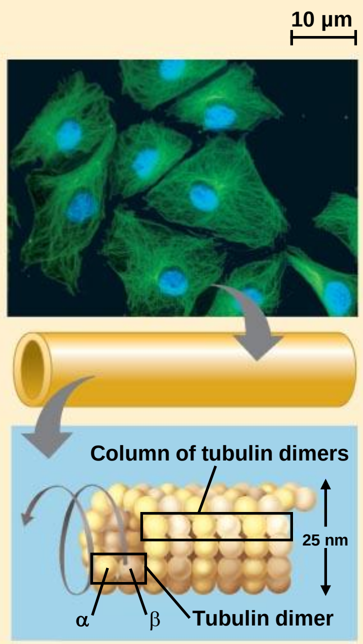
Components of the Cytoskeleton

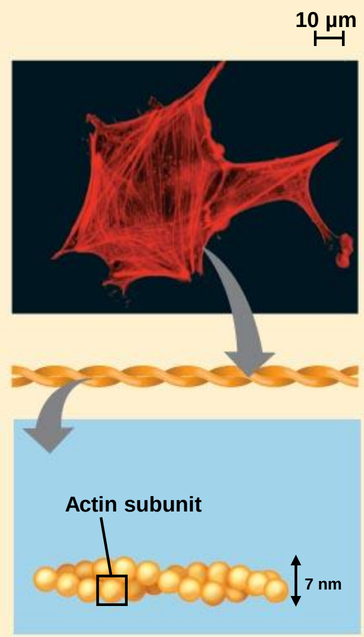
- Three main types of fibers make up the cytoskeleton:
  - *Microtubules* are the thickest of the three components of the cytoskeleton
  - *Microfilaments*, also called actin filaments, are the thinnest components
  - *Intermediate filaments* are fibers with diameters in a middle range

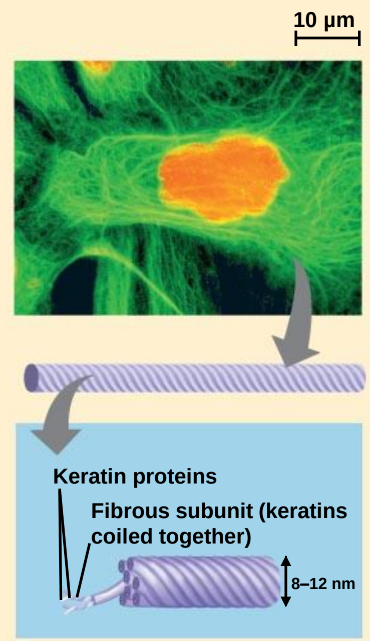
Table 6.1 The Structure and Function of the Cytoskeleton

Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two intertwined strands of actin, each a polymer of actin subunits	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, a dimer consisting of α-tubulin and β-tubulin	Actin	One of several different proteins of the keratin family, depending on cell type
Main functions	Maintenance of cell shape (compression-resisting "girders") Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape (tension-bearing elements) Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape (tension-bearing elements) Anchorage of nucleus and certain other organelles Formation of nuclear lamina

Micrographs of fibroblasts, a favorite cell type for cell biology studies. Each has been experimentally treated to fluorescently tag the structure of interest.







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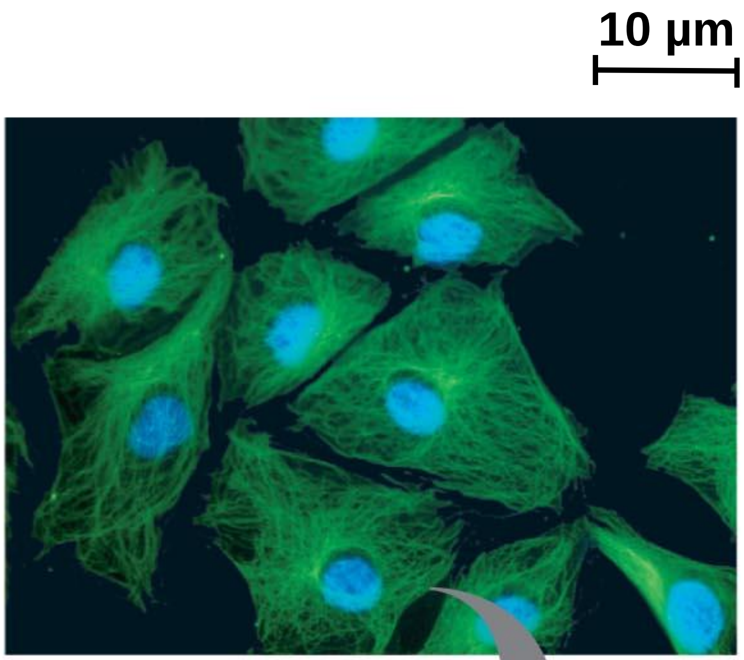
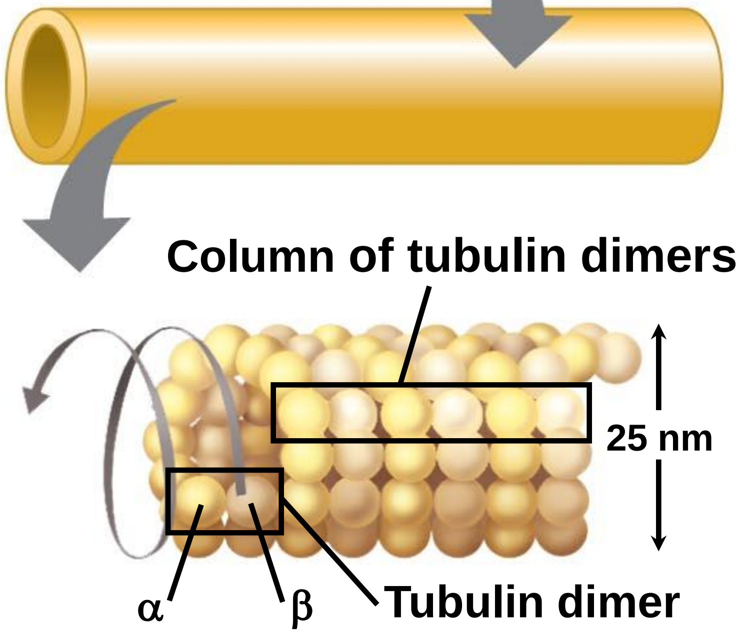
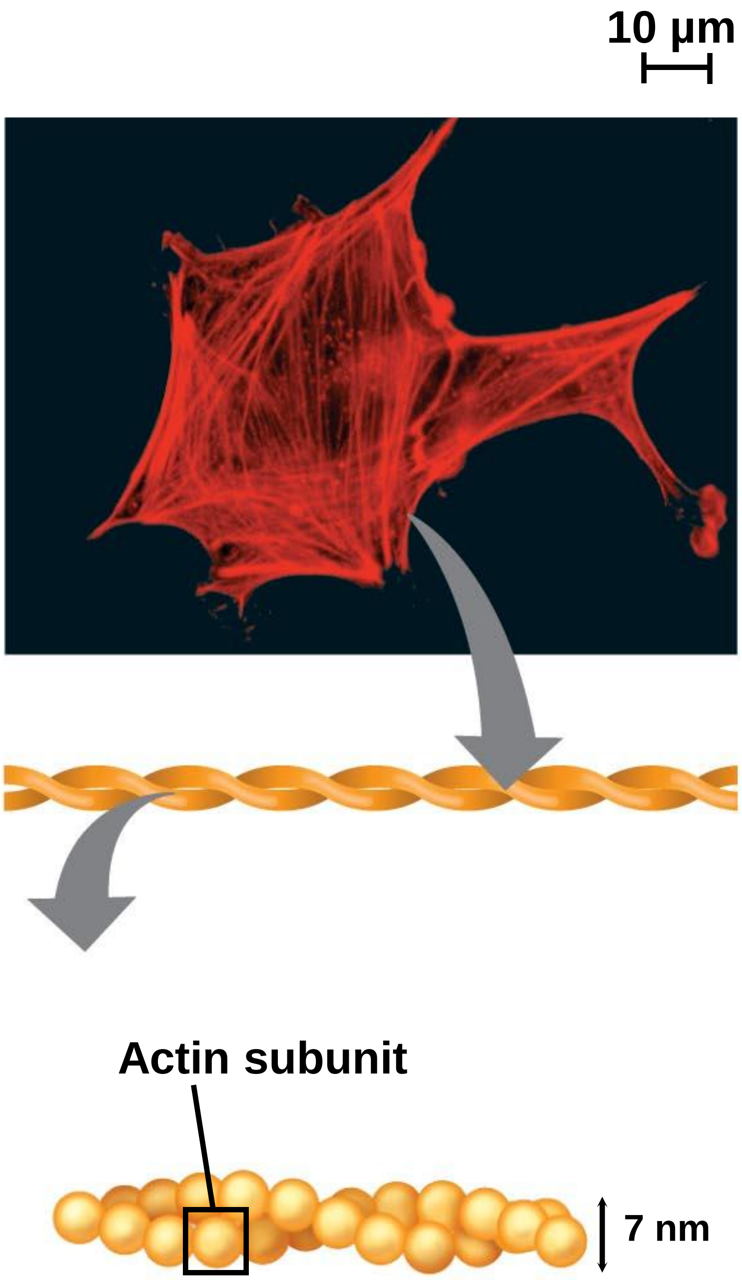
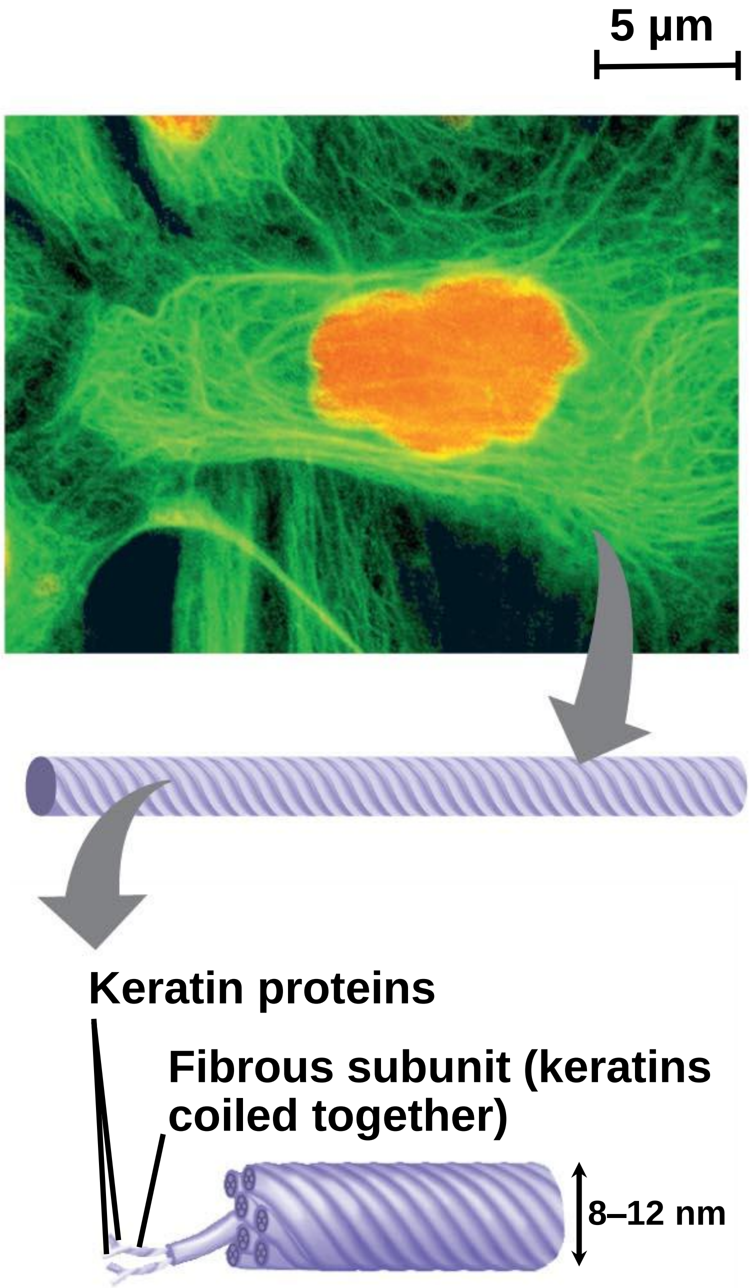




Property	Microfilaments (Actin Filaments)
Structure	Two intertwined strands of actin
Diameter	7 nm
Protein subunits	Actin
Main functions	Maintenance of cell shape Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility Cell division



Property	Intermediate Filaments
Structure	Fibrous proteins supercoiled into thicker cables
Diameter	8–12 nm
Protein subunits	One of several different proteins of the keratin family
Main functions	Maintenance of cell shape Anchorage of nucleus and certain other organelles Formation of nuclear lamina

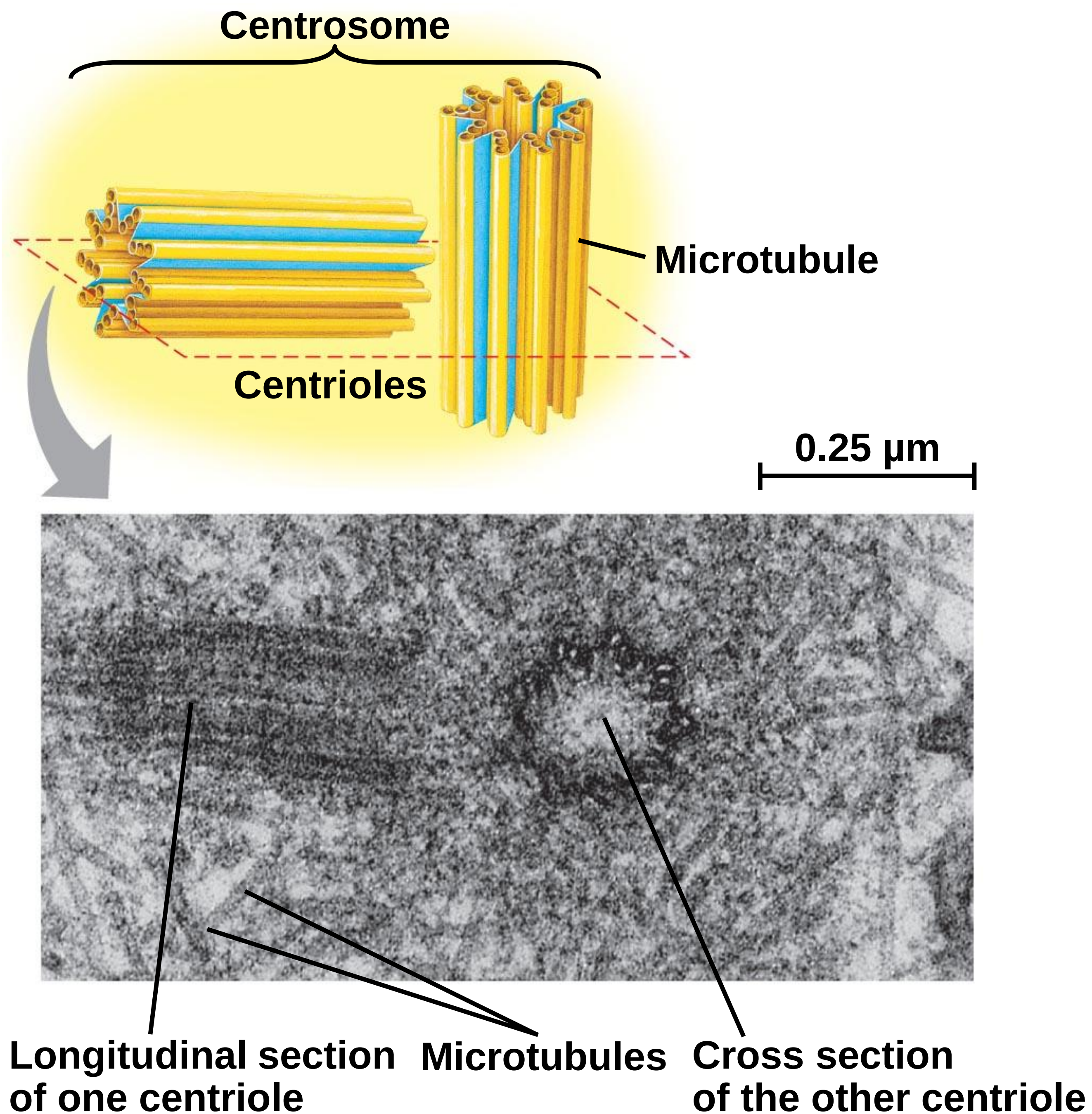


Microtubules

- **Microtubules** are hollow rods about 25 nm in diameter and about 200 nm to 25 microns long
- Functions of microtubules:
  - Shaping the cell
  - Guiding movement of organelles
  - Separating chromosomes during cell division

Centrosomes and Centrioles

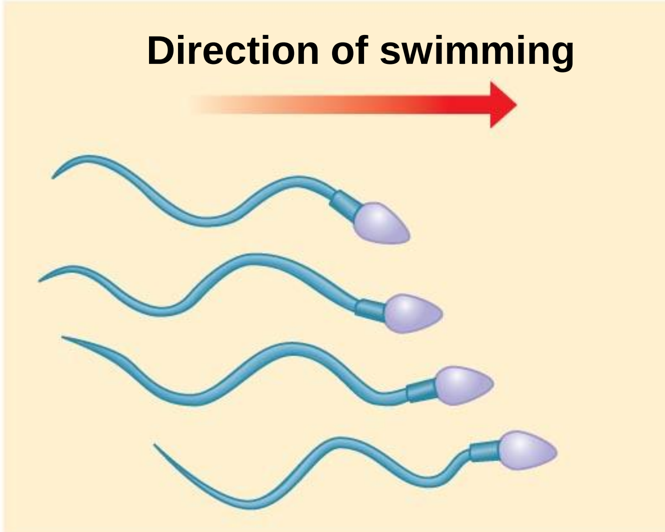
- In many cells, microtubules grow out from a **centrosome** near the nucleus
- The centrosome is a “microtubule-organizing center”
- In animal cells, the centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring



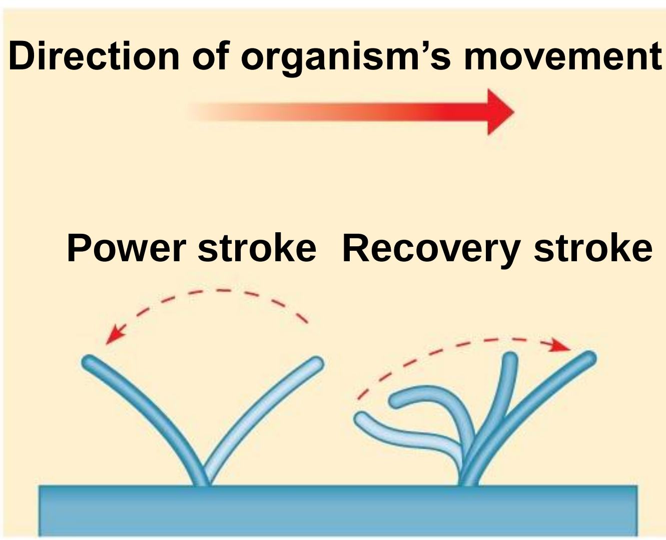
Centrosome
Microtubule
Centrioles
0.25 µm
Longitudinal section of one centriole
Microtubules
Cross section of the other centriole

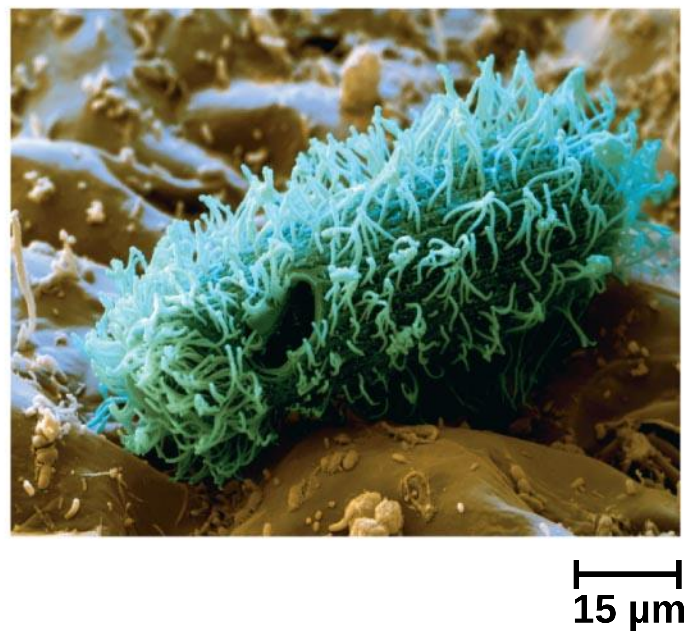
Cilia and Flagella

- Microtubules control the beating of **cilia** and **flagella**, locomotor appendages of some cells
- Cilia and flagella differ in their beating patterns



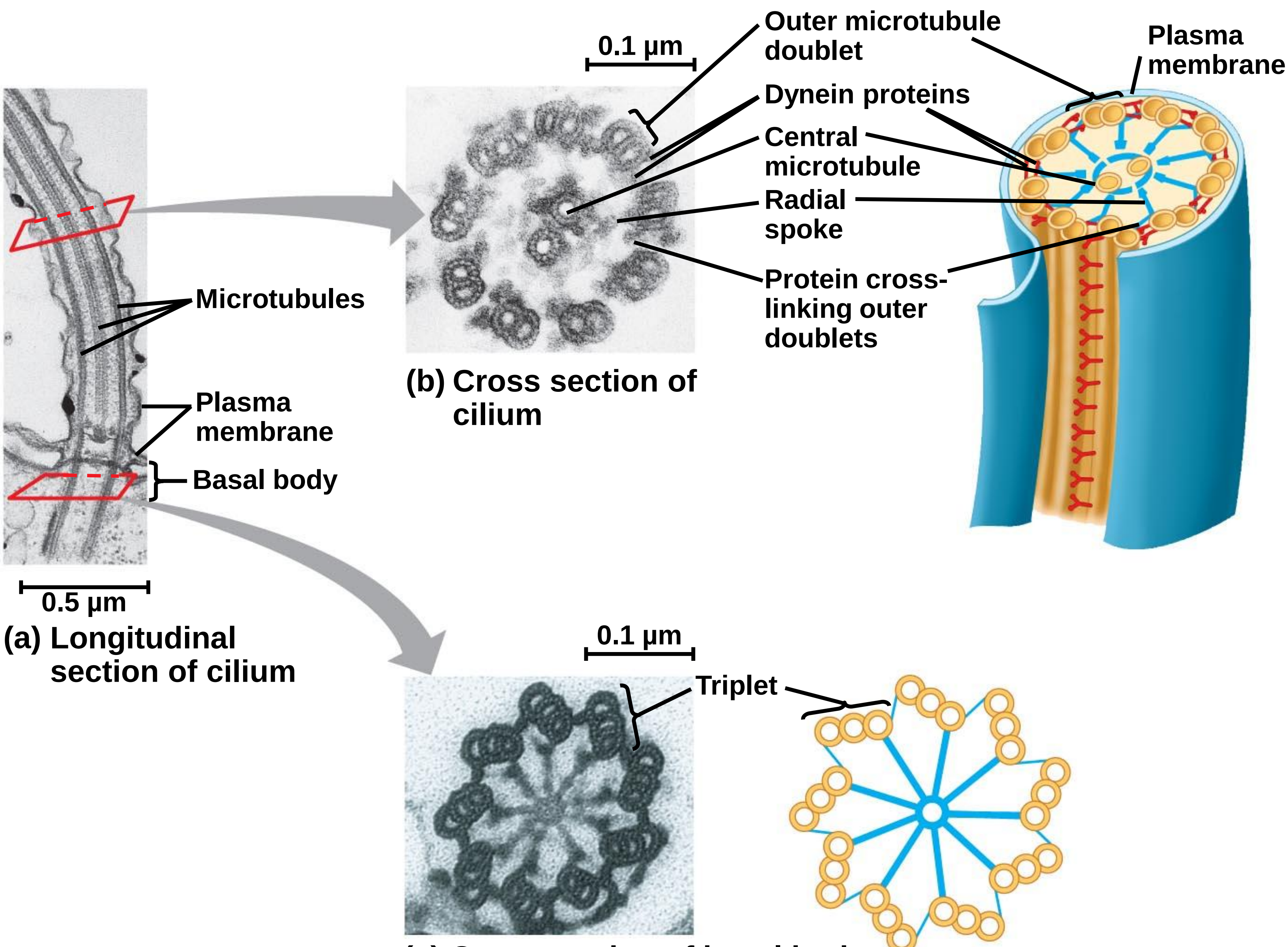
(a) Motion of flagella





(b) Motion of cilia

- Cilia and flagella share a common ultrastructure:
  - A core of microtubules sheathed by the plasma membrane
  - A **basal body** that anchors the cilium or flagellum
  - A motor protein called **dynein**, which drives the bending movements of a cilium or flagellum

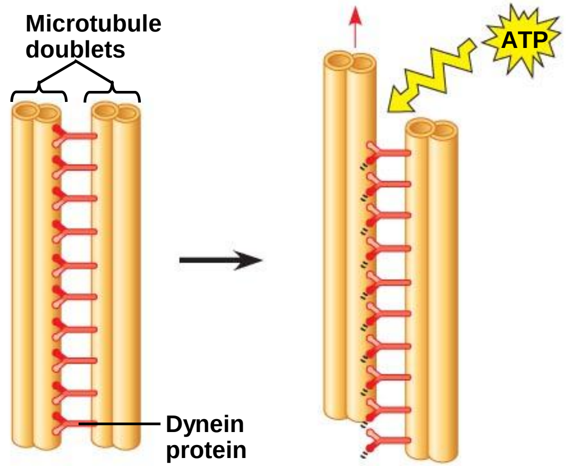


(a) Longitudinal section of cilium

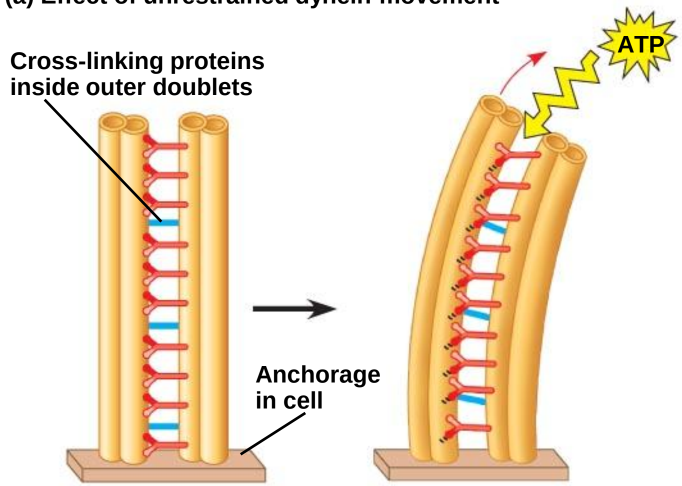
(b) Cross section of cilium

(c) Cross section of basal body

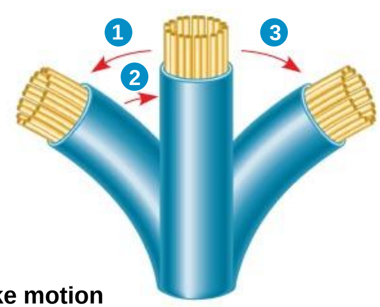
- How dynein “walking” moves flagella and cilia:
  - Dynein arms alternately grab, move, and release the outer microtubules
  - Protein cross-links limit sliding
  - Forces exerted by dynein arms cause doublets to curve, bending the cilium or flagellum



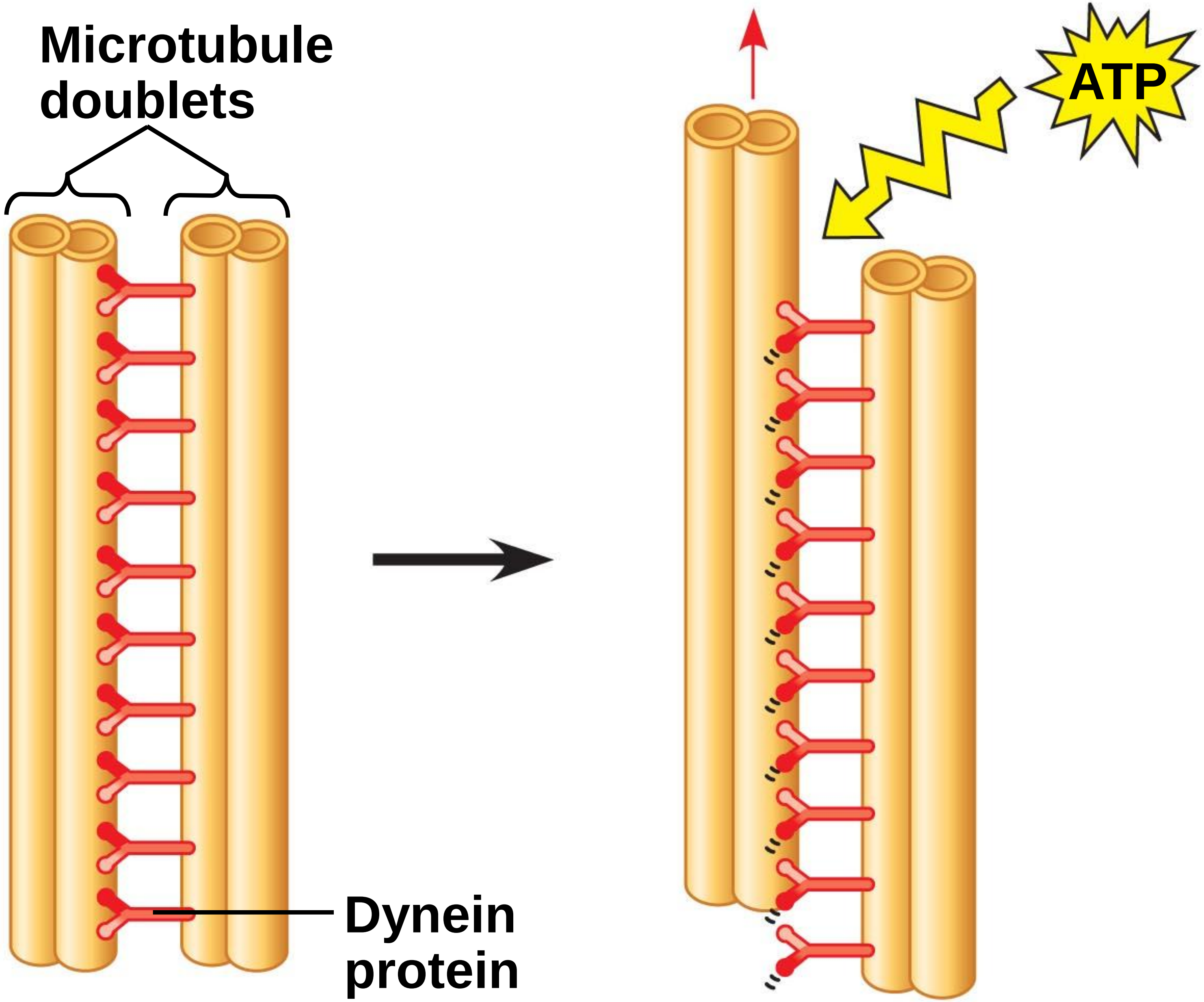
(a) Effect of unrestrained dynein movement



(b) Effect of cross-linking proteins

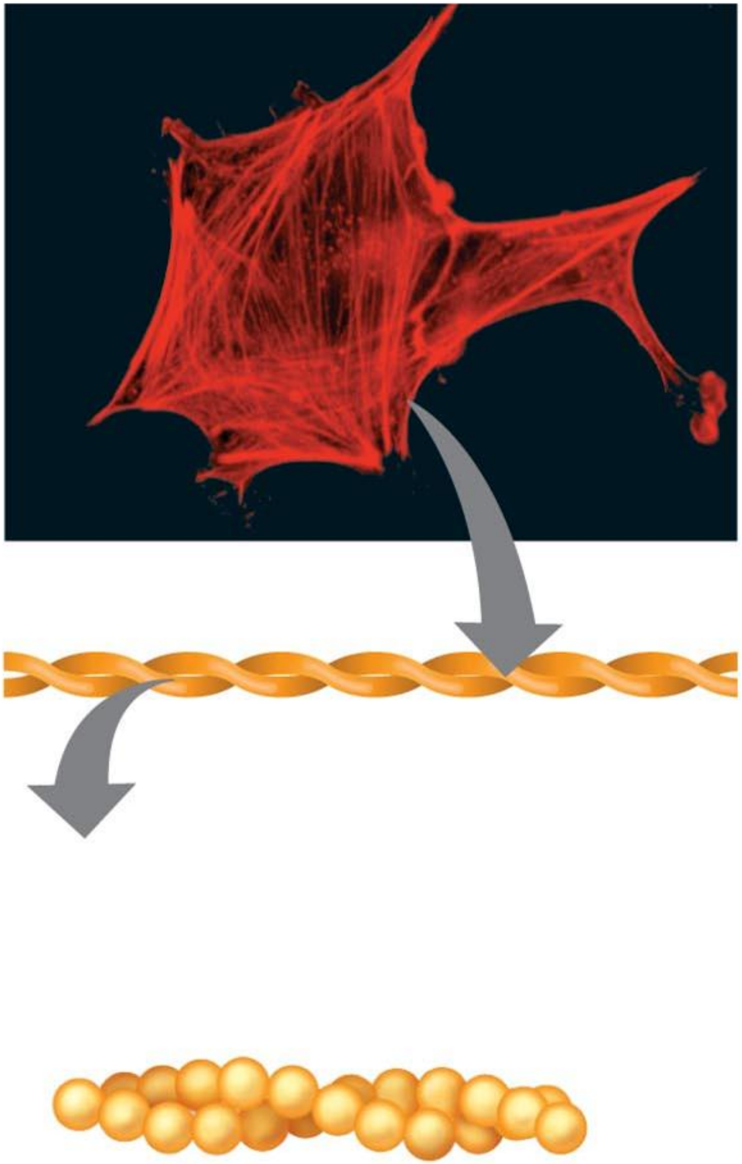


(c) Wavelike motion



(a) Effect of unrestrained dynein movement

Property	Microfilaments (Actin Filaments)
Structure	Two intertwined strands of actin
Diameter	7 nm
Protein subunits	Actin
Main functions	Maintenance of cell shape Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility Cell division



Microfilaments (Actin Filaments)

- **Microfilaments** are solid rods about 7 nm in diameter, built as a twisted double chain of **actin** subunits
- The structural role of microfilaments is to bear tension, resisting pulling forces within the cell
- They form a 3-D network called the **cortex** just inside the plasma membrane to help support the cell's shape
- Bundles of microfilaments make up the core of microvilli of intestinal cells

Actin Filaments

- Thinner, shorter and more flexible than microtubules
- Contains G-actin, and F-actin
- Actin- most abundant intracellular protein in most Eukaryotic cells
- Comprises 10% by weight of total cell protein in muscle cells, 1-5% in non-muscle cells
- Actin polymerization requires K+, Mg 2+, ATP, and Calcium

G-actin and F-actin

- G-actin: exists as a globular monomer
- F-actin: is a helical filamentous polymer of G-actin subunits all oriented in the same direction
- Microfilaments in a cell are constantly shrinking or growing in length
- Bundles and meshworks of microfilaments are forming and dissolving continuously

Dynamics of Actin Assembly

- Nucleation- G-actin clumps into short, unstable oligomers, 3-4 subunits long, and acts as a stable seed or nucleus.
- Elongation phase- The nucleus rapidly increases in length by the addition of actin monomers to both of its ends.

Dynamics of Actin Assembly

- Steady-State
  - The ends of actin filaments are in a steady state with monomeric G-actin.
  - After their incorporation into a filament, subunits slowly hydrolyze ATP and become stable F-actin.

Nucleation, Elongation, and the Steady-State

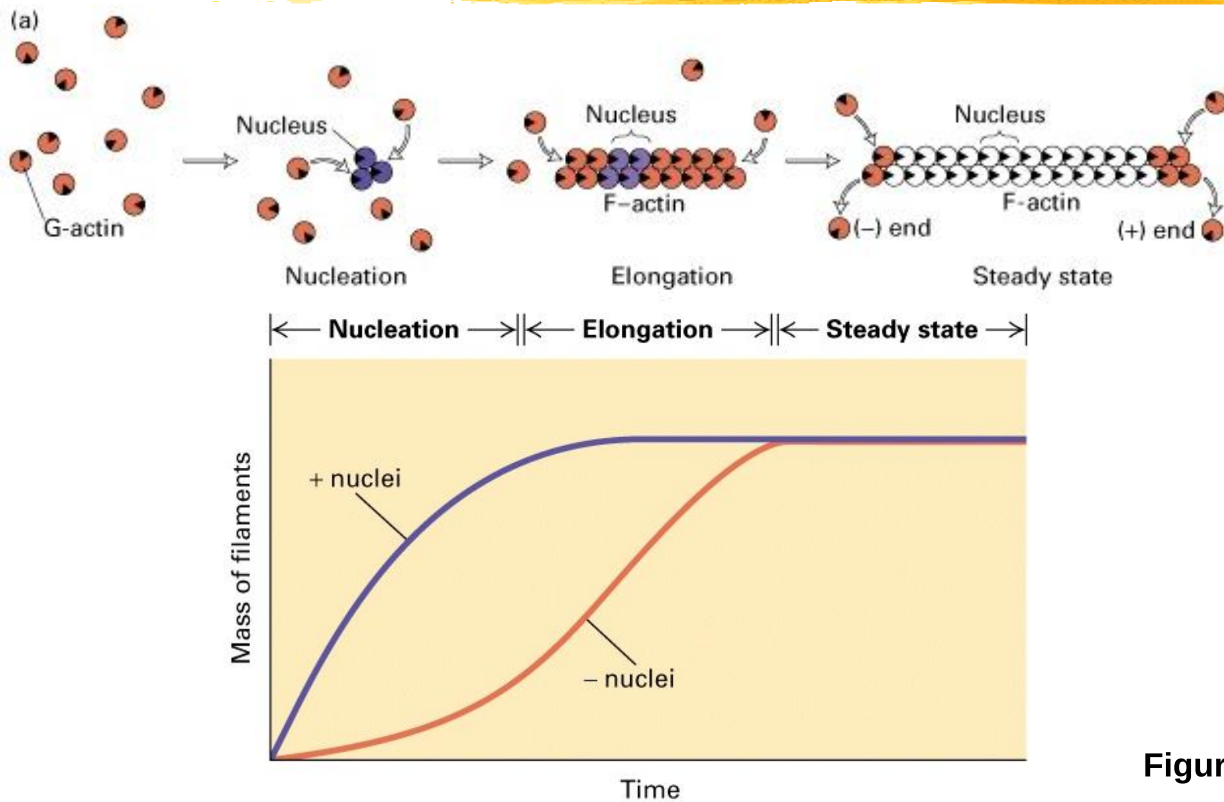
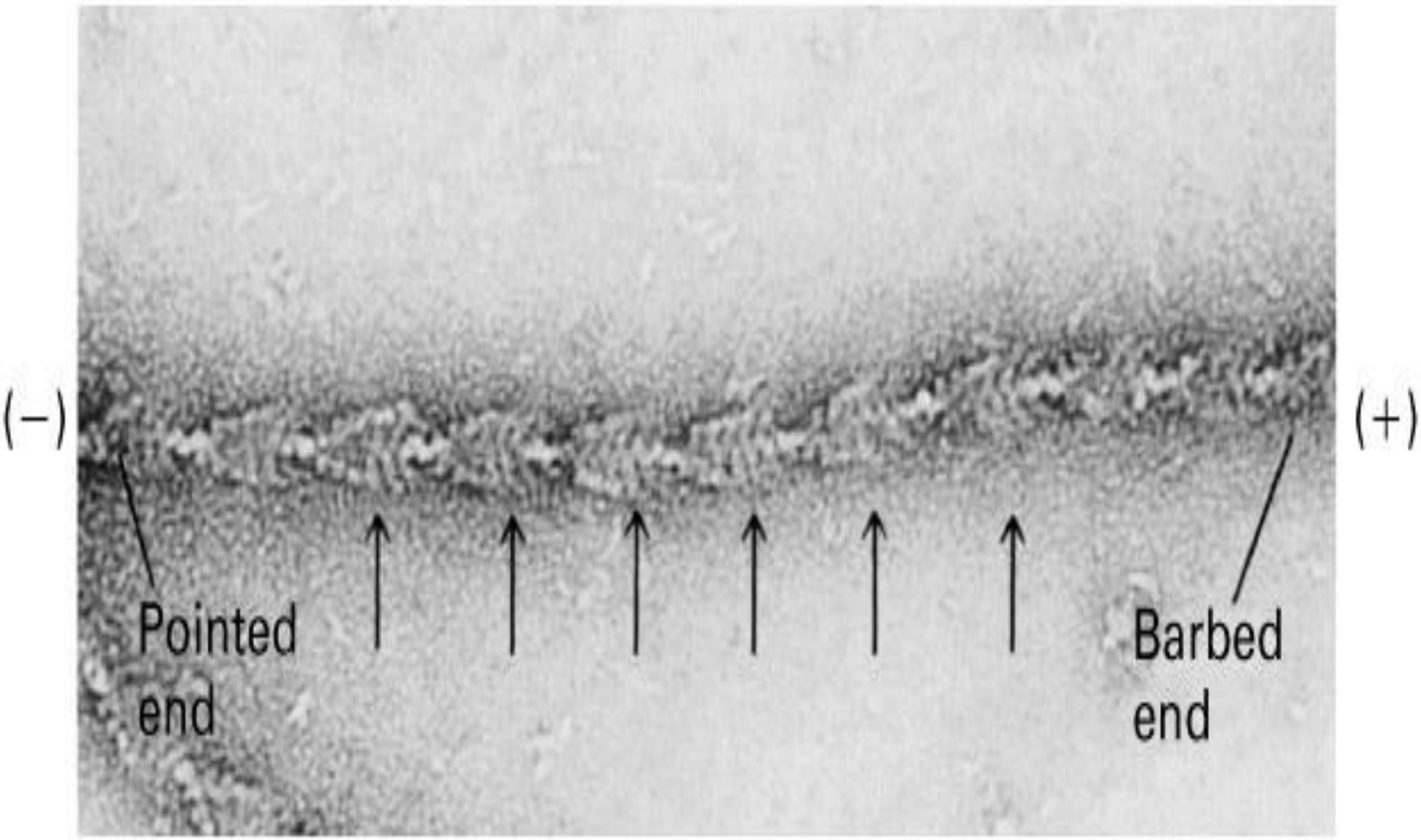


Figure 18-11

Dynamics of Actin Assembly

- All subunits in an actin filament point toward the same direction of the filament
  - Exhibits polarity-actin subunit exposed to the surrounding solution is the (-) end
  - The cleft that has contact with the neighboring actin subunit that is not exposed is the (+) end
  - Actin filaments grow faster at the (+) end than the (-) end

F-actin has structural and functional polarity



Actin Filaments participate in a variety of cell functions:

- Anchorage and movement of membrane proteins-
  - filaments are distributed in 3-dimensional networks throughout the cell
  - used as anchors with in specialized cell junctions

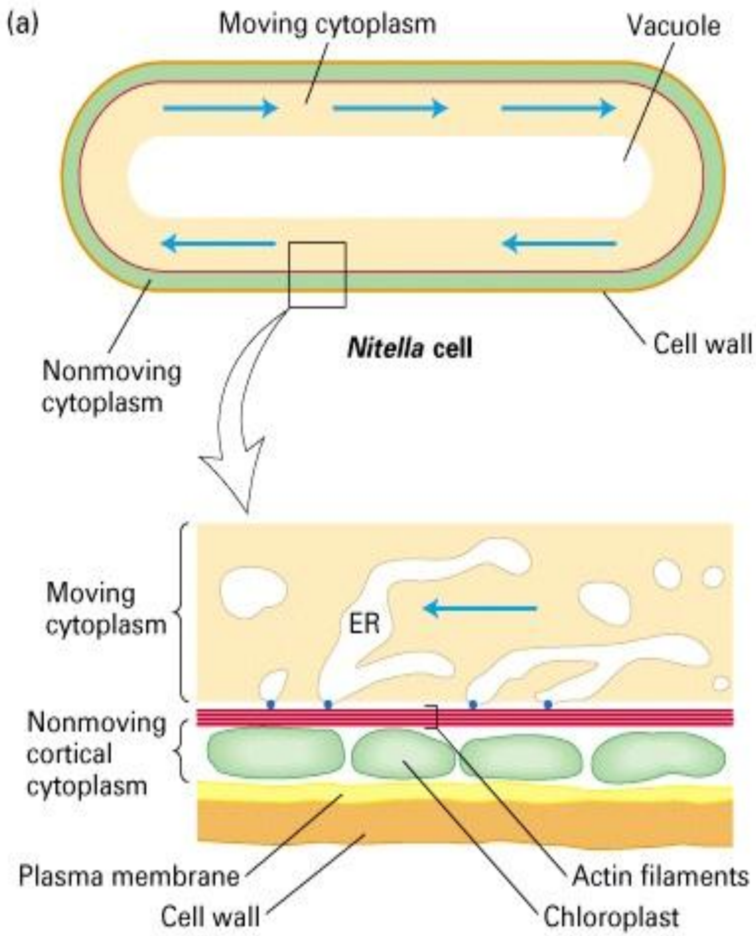
Actin Filaments participate in a variety of cell functions:

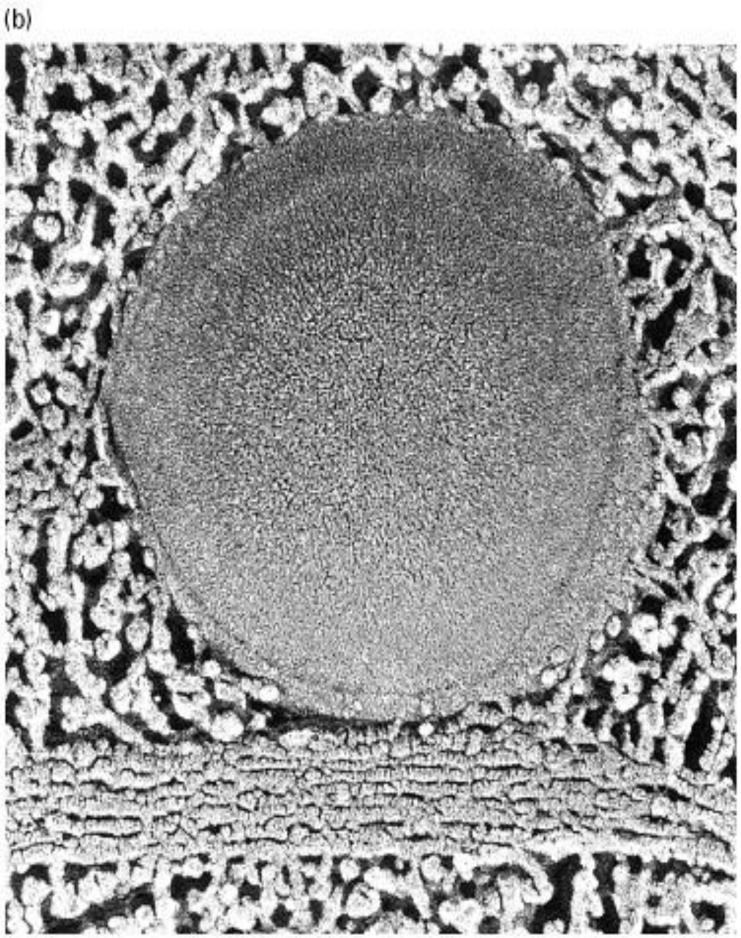
- Formation of the structural core of microvilli
  - On epithelial cells, help maintain shape of the cell surface

Actin Filaments participate in a variety of cell functions:

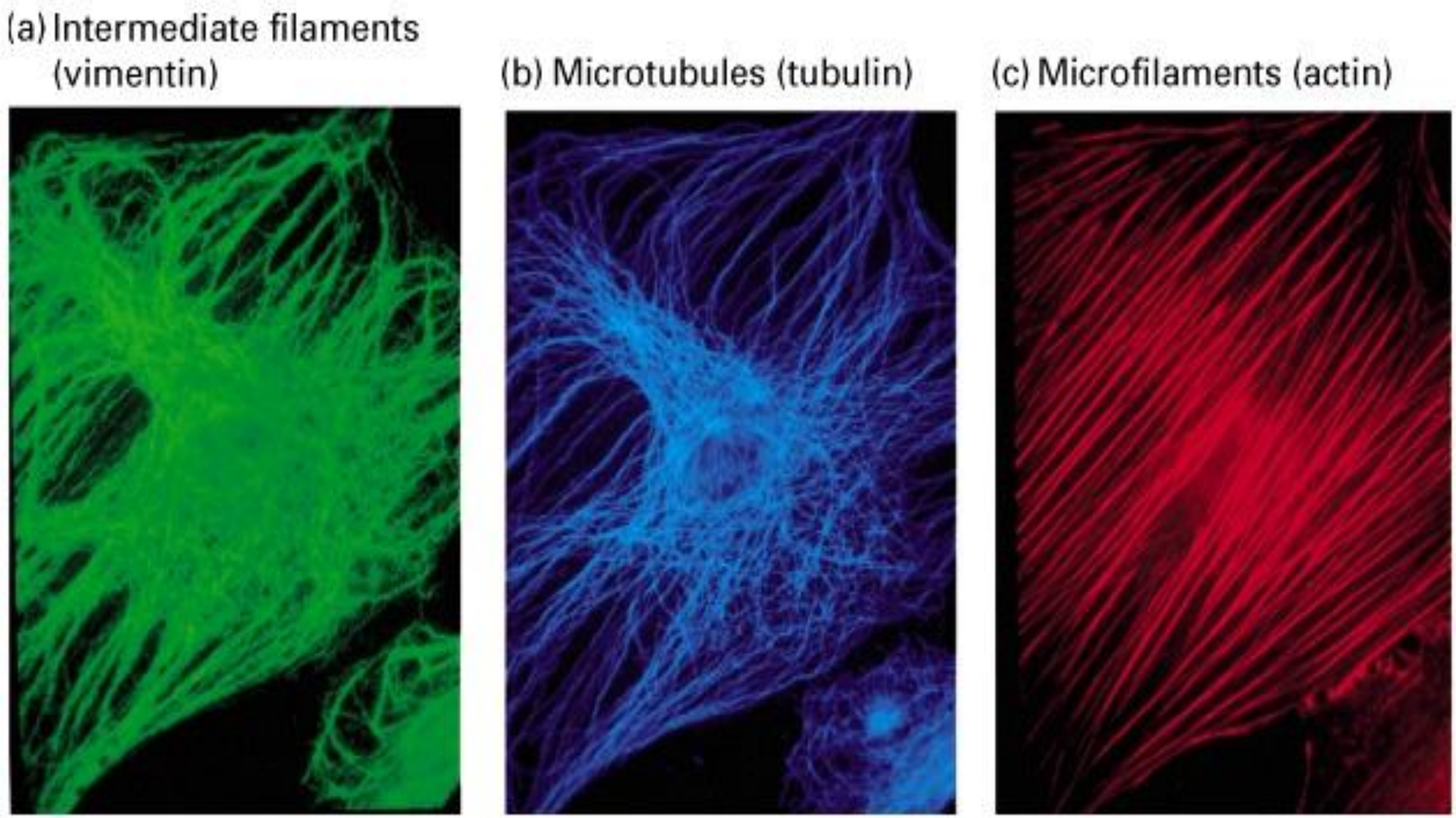
- Locomotion of the cells
  - Achieved by the force exerted by actin filaments by polymerization at their growing ends
  - Used in many migrating cells, particularly on transformed cells of invasive tumors
  - Cells extend processes from their surface by pushing the plasma membrane ahead of the growing actin filaments

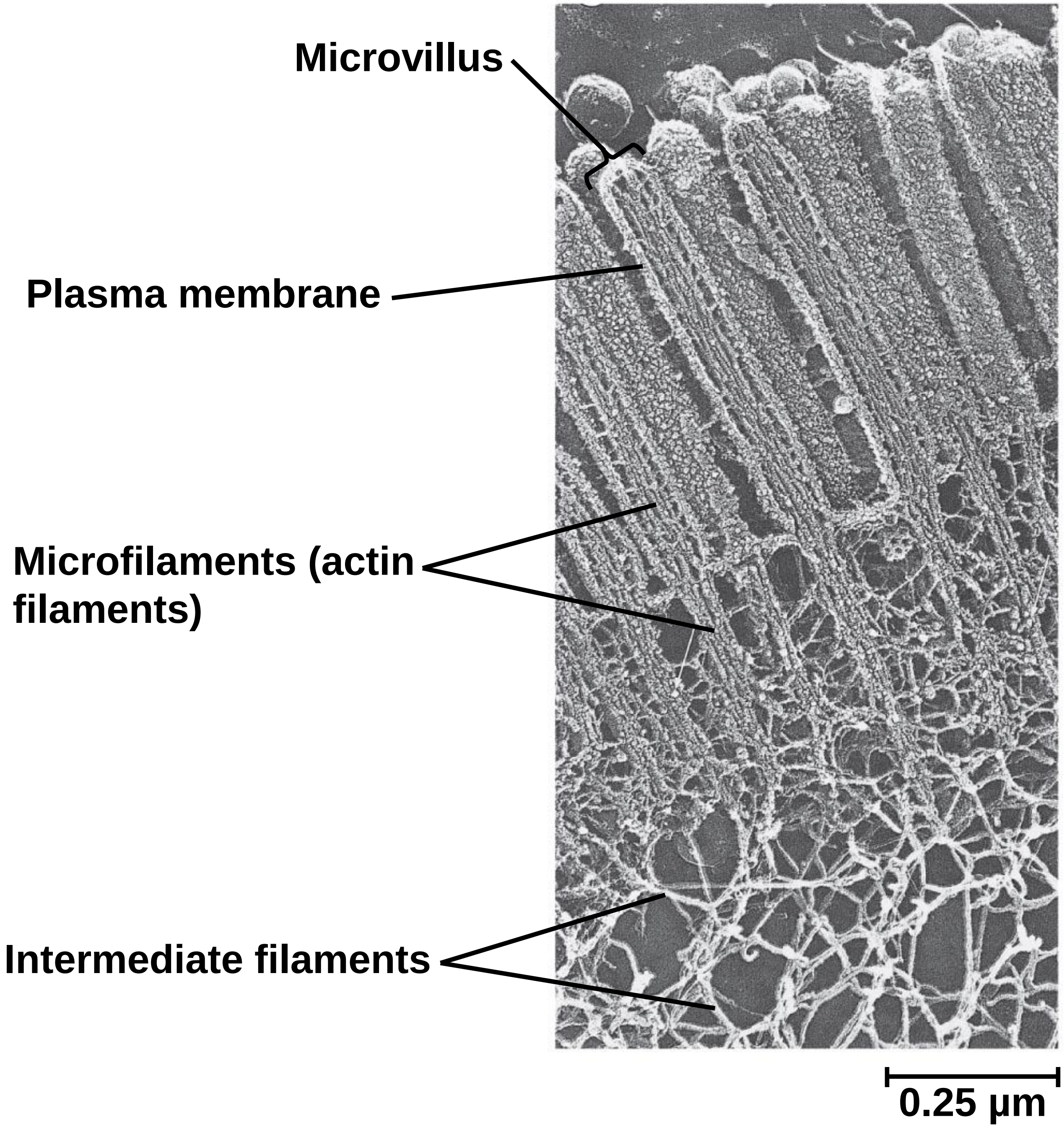
Essential in cytoplasmic streaming



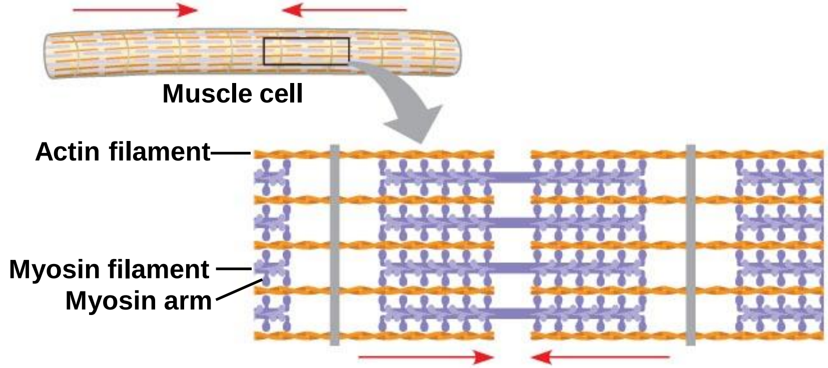


Functions and structure of intermediate filaments distinguish them from other cytoskeletal fibers

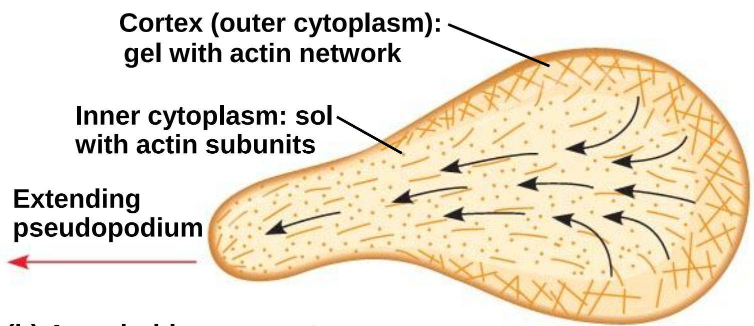



Microvillus
Plasma membrane
Microfilaments (actin filaments)
Intermediate filaments
0.25 µm

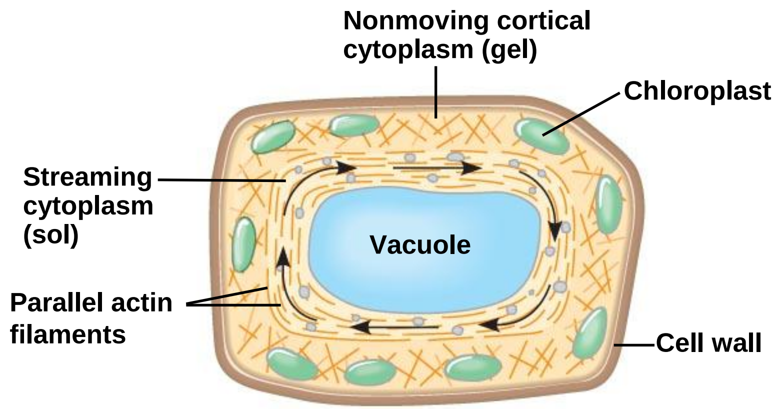
- Microfilaments that function in cellular motility contain the protein **myosin** in addition to actin
- In muscle cells, thousands of actin filaments are arranged parallel to one another
- Thicker filaments composed of myosin interdigitate with the thinner actin fibers



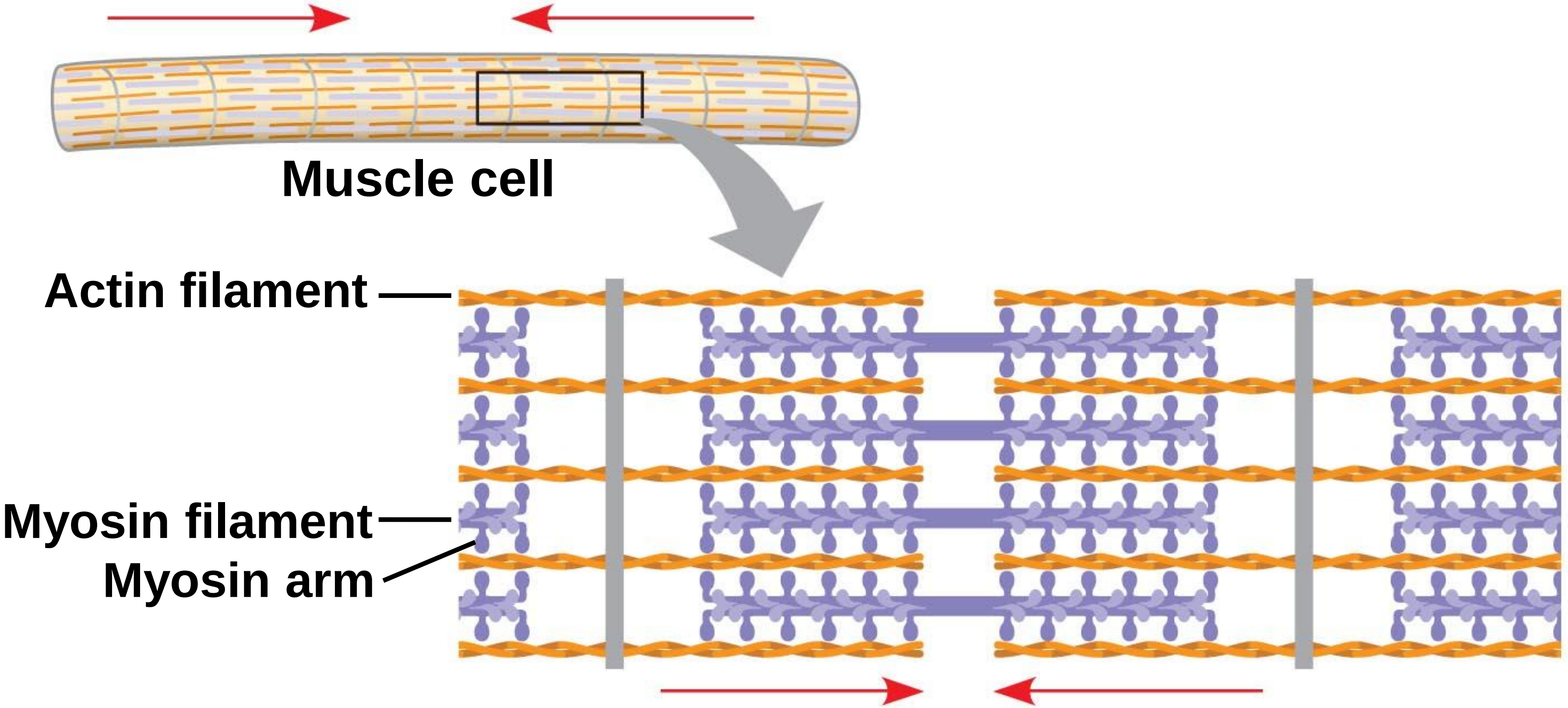
(a) Myosin motors in muscle cell contraction



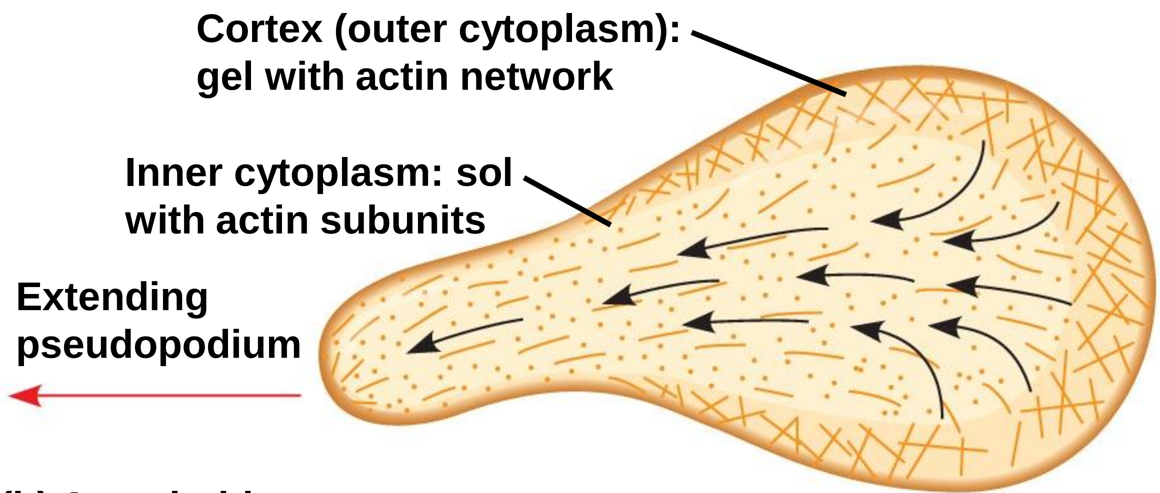
(b) Amoeboid movement



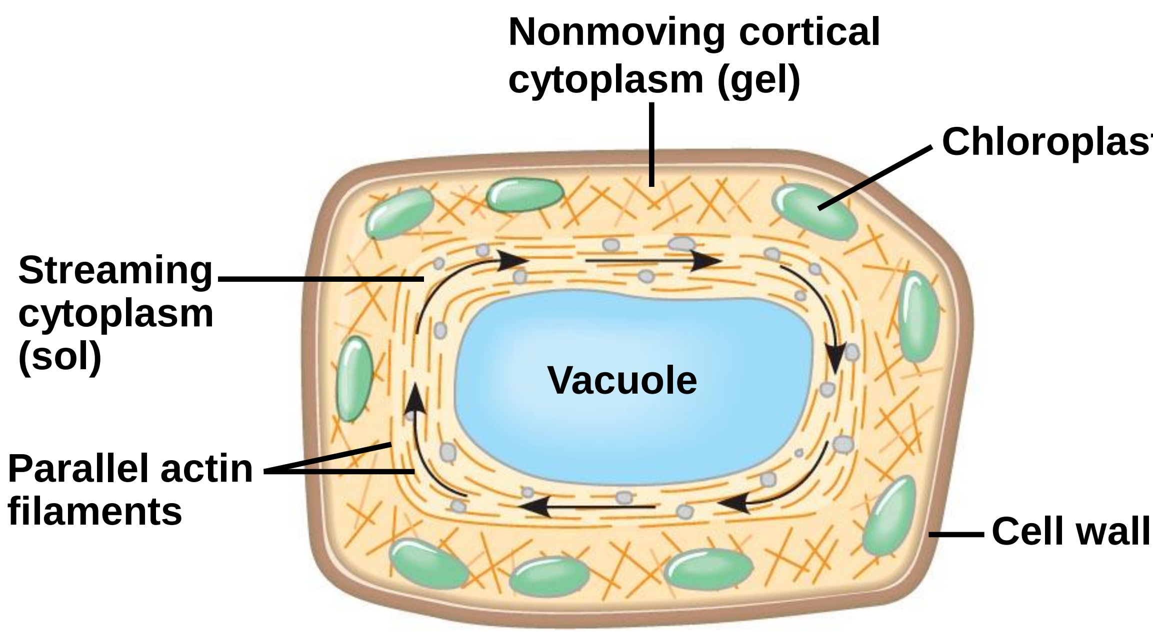
(c) Cytoplasmic streaming in plant cells



(a) Myosin motors in muscle cell contraction



(b) Amoeboid movement



(c) Cytoplasmic streaming in plant cells

- Localized contraction brought about by actin and myosin also drives amoeboid movement
- **Pseudopodia** (cellular extensions) extend and contract through the reversible assembly and contraction of actin subunits into microfilaments

- **Cytoplasmic streaming** is a circular flow of cytoplasm within cells
- This streaming speeds distribution of materials within the cell
- In plant cells, actin-myosin interactions and sol-gel transformations drive cytoplasmic streaming