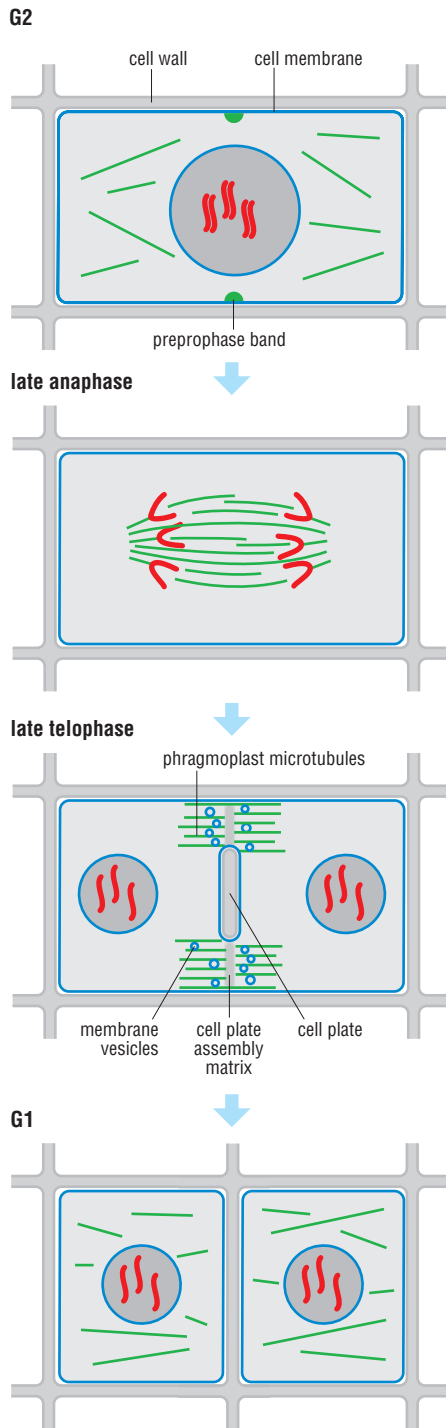


## 8-3 Membrane and Cell Wall Deposition at the Division Site

### Membrane deposition is required during cytokinesis



Cytokinesis in yeast and animal cells depends on extensive remodeling of the cell membrane at the cleavage furrow. The inward movement of the furrow generally results in an increase in the surface area of the cell membrane, and the additional membrane seems to be provided by the insertion of new membrane at the cleavage site. In yeast, new cell wall materials are also deposited at this site, resulting in the process of septation—the formation of a new cell wall, or **septum**, between the daughter cells.

Addition of new membrane occurs by the fusion of membrane vesicles with the plasma membrane near the inner edge of the cleavage furrow. These small vesicles originate in the Golgi apparatus and are targeted to the plasma membrane at the cleavage site by components of the secretory apparatus, including members of the syntaxin family of vesicle-targeting proteins.

In most cell types, microtubules provide the tracks along which membrane vesicles are transported to the site of cleavage. The importance of microtubules for membrane delivery is particularly apparent in the cells of higher plants, in which cytokinesis is entirely a process of membrane and wall deposition—without any need for a contractile ring. Cytokinesis in these cells is directed by an organelle called the **phragmoplast**, an array of microtubules, derived from the anaphase spindle, whose plus ends are embedded in a protein matrix along the cell midline (Figure 8-8). Membrane vesicles carrying the raw materials for cell wall synthesis travel along these microtubules to the center of the phragmoplast, where they promote the deposition of a new membrane and cell wall to form the cell plate. Unlike the case in yeast and animal cells, where all new membrane is added to the preexisting cell membrane, new membrane formation in plants starts in the center of the cell and spreads outward until it meets the plasma membrane.

The importance of microtubules in membrane addition is also illustrated by studies of *Xenopus* embryonic cells. These cells contain a specialized microtubule array, called the furrow microtubule array, that forms at the inner edge of the cleavage furrow (Figure 8-9). It is required for membrane addition at the furrow and provides the tracks along which membrane vesicles are carried to the site of membrane fusion. The furrow microtubule array may be a specialized structure for enhancing membrane addition in the large and rapidly dividing cells of animal embryos, in which the spindle is often quite distant from the cell membrane. In smaller and more slowly dividing somatic cells, astral microtubules and microtubules of the central spindle are thought to provide a similar function.

Deposition of new membrane in cytokinesis is less extensive in yeast, in which the amount of new membrane needed represents a small fraction of total membrane surface area. In budding yeast, for example, most new membrane addition occurs throughout the cell cycle in the

**Figure 8-8 Cytokinesis in a higher plant cell** Just before mitosis, a band of microtubules and actin, called the preprophase band, forms around the cell at its midline. The preprophase band disappears as the cell reaches metaphase, but its position at the cortex remains marked and will determine the future site of division. After anaphase, the microtubules of the spindle form the phragmoplast. These microtubules serve as tracks on which membrane vesicles are carried to the middle of the cell from the Golgi apparatus. These vesicles contain the various glycoproteins and other components that will form the new cell wall. Vesicle fusion results in the formation of a disc-shaped membrane compartment called the cell plate, which expands outward until it eventually contacts and fuses with the cell membrane, thereby separating the daughter cells. A new cell wall is then completed between the daughter cell membranes.

#### Definitions

**midbody:** large protein complex, derived from the spindle midzone, that is involved in the final stages of cell separation in dividing animal cells.

**phragmoplast:** organelle in a dividing plant cell upon which the new cell membranes and cell walls between the two daughter cells are constructed. It corresponds to the central spindle of animal cells.

**septum:** the extracellular wall that forms between two daughter cells in fungi during cell division.

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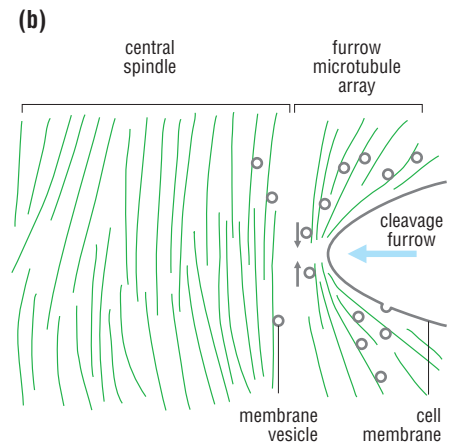
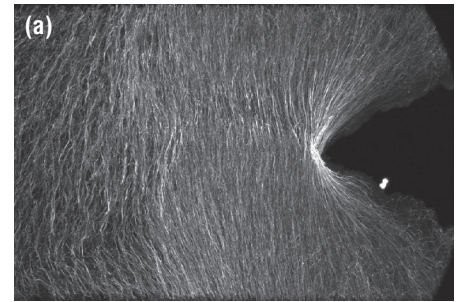
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**Figure 8-9 Microtubule behavior in the cleaving *Xenopus* embryo** (a) Microtubule structure was analyzed near the beginning of the first division of a *Xenopus* zygote. A dense array of microtubules—the furrow microtubule array (FMA)—can be seen at the leading edge of the cleavage furrow (on the right of the photograph). The overlapping microtubules of the spindle midzone lie beneath the FMA. (b) This schematic shows how the FMA is thought to direct the transport of membrane vesicles for fusion to the cell membrane at the cleavage furrow. For simplicity, the contractile ring that lies at the cleavage furrow is not shown. Photograph kindly provided by Michael Danilchik and Kay Larkin. From Danilchik, M.V. *et al.*: *Dev. Biol.* 1998, **194**:47–60.



growing bud, and only a small amount is required at the bud neck in the final stages of division (Figure 8-10). In these cells, as in those of metazoans, new membrane is provided by Golgi-derived vesicles. Unlike in metazoans, however, vesicle transport to the bud neck does not require microtubules but instead depends on myosin-dependent transport along actin filaments.

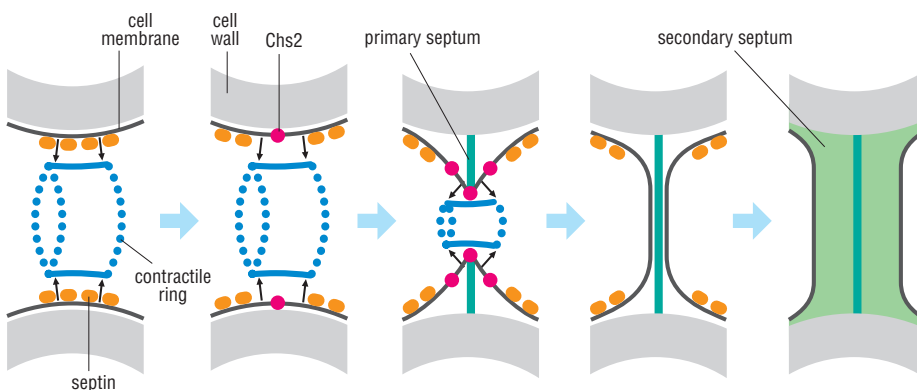
Transport of vesicles to the cleavage site also delivers proteins that help organize the contractile ring and serve other functions in cell separation. In budding yeast, for example, Golgi-derived vesicles that fuse with the bud-neck membrane contain the transmembrane enzyme chitin synthase, Chs2, which synthesizes chitin, the complex polysaccharide that forms the primary septum between mother and daughter cells (see Figure 8-10).

The connection between daughter cells is finally severed when the inwardly moving membranes contact and fuse with each other. This poorly understood process requires the removal of the contractile ring and, in animal cells, depends on the construction of a large protein complex called the **midbody** at the division site. The final membrane fusion event depends on machinery like that involved in membrane fusion events in the secretory pathway.

## Membrane addition occurs in parallel with actin–myosin contraction

Membrane deposition generally occurs in parallel with the contraction of the actin–myosin ring, so that new membrane is added at a rate that matches the rate at which the ring moves inward. It is not clear how membrane addition and ring contraction are coordinated with each other. One simple possibility is that the two processes are independent but occur in parallel because they are both triggered by the same upstream regulatory mechanism. Dephosphorylation of Cdk targets, for example, may be an important mechanism for initiating both processes.

Another possibility is that the membrane deposition machinery and the contraction machinery are physically coupled in some way, so that the progression of each process depends on the other. There is good evidence for this in both budding and fission yeasts, in which inhibition of membrane vesicle delivery or cell wall synthesis causes defects in ring contraction. In animal cells, however, there is less evidence for direct coupling, and it seems that membrane addition and ring contraction are at least partly independent. Inhibition of actin polymerization or Rho activation, for example, blocks the formation of the contractile ring in *Xenopus* embryonic cells but does not affect membrane insertion. Conversely, inhibition of membrane insertion (by depolymerization of microtubules in the furrow microtubule array, for example) does not prevent contractile ring formation and the initiation of contraction—although full inward contraction of the ring cannot occur without the addition of new membrane.



**Figure 8-10 Septation in budding yeast**

These diagrams represent cross-sections of the bud neck during the final stages of cytokinesis. A ring of septins (gold) lies beneath the cell membrane, while unknown proteins (black arrows) link the actin–myosin ring (blue) to the membrane. Delivery of membrane vesicles (not shown) results in the appearance of Chs2 (red), a transmembrane chitin synthase, in the cell membrane adjacent to the contractile ring. As the actin–myosin ring begins to contract, Chs2 constructs a primary septum (green) behind the inwardly moving membranes, which eventually fuse to generate two separate cells with a primary septum between them. Other chitin synthases then construct a thick secondary septum. Separation of mother and daughter occurs when chitinases digest the primary septum (not shown). Interestingly, Chs2 and the actin–myosin ring are not absolutely essential for cytokinesis in budding yeast; in their absence, an abnormal but effective septum is constructed by the chitin synthases that normally synthesize the secondary septum. Adapted from Cabib, E.: *Arch. Biochem. Biophys.* 2004, **426**:201–207.