formation, although the function of the cell-rich and cell-free zones in this process is still uncertain. In addition to the regions of the central and peripheral pulp is the area of the pulp horns. Here the odontoblasts are crowded and appear palisaded (pseudostratified) in contrast to their appearance in the remainder of the coronal area **(Fig. 9-6)**. In the middle area, root pulp odontoblasts are short and cuboidal.

Odontoblasts

Odontoblasts line the perimeter of the pulp from the time they begin organizing to form dentin to the time they are quiescent and no longer producing dentin at a rapid rate. Odontoblasts are small and oval when they first differentiate but soon become columnar **(Fig. 9-7)**. These cells then develop processes or extensions around which dentin forms. As the process lengthens, the amount of dentin thickens. Then the odontoblastic process develops many side branches that are contained within canaliculi. When these branches develop, space is provided in the dentin for them **(Fig. 9-8)**. Odontoblasts are larger in coronal pulp than in the root and appear columnar in pulp horns (see Fig. 9-6). These tall, columnar cells are about 35 µm long in the pulp horns, whereas in radicular pulp they are more cuboidal, and cells of the apical region appear flat. The process of the odontoblast is the largest part of the cell, extending from the pulp to the dentinoenamel junction. In the crown, the process could be several millimeters long, but it is shorter in the root.

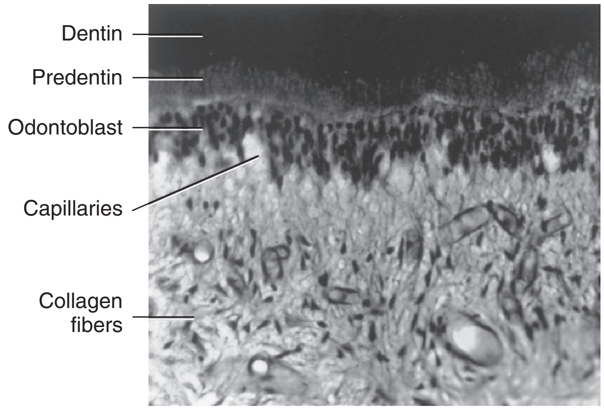

Fig. 9.6 Photomicrograph of odontoblasts in the coronal area of the pulp organ. Pulpal capillaries are shown among these cells.

The active cell has a large nucleus in its basal part and a Golgi apparatus in its apical part. Abundant rough-surface endoplasmic reticulum and numerous mitochondria are scattered through the cell body **(Fig. 9-9)**. The process arises from the odontoblast at the predentinal border, where the cell constricts as the process enters the dentinal tubule (see Fig. 9-8). The process passes through the predentin, where a few mitochondria are located. As

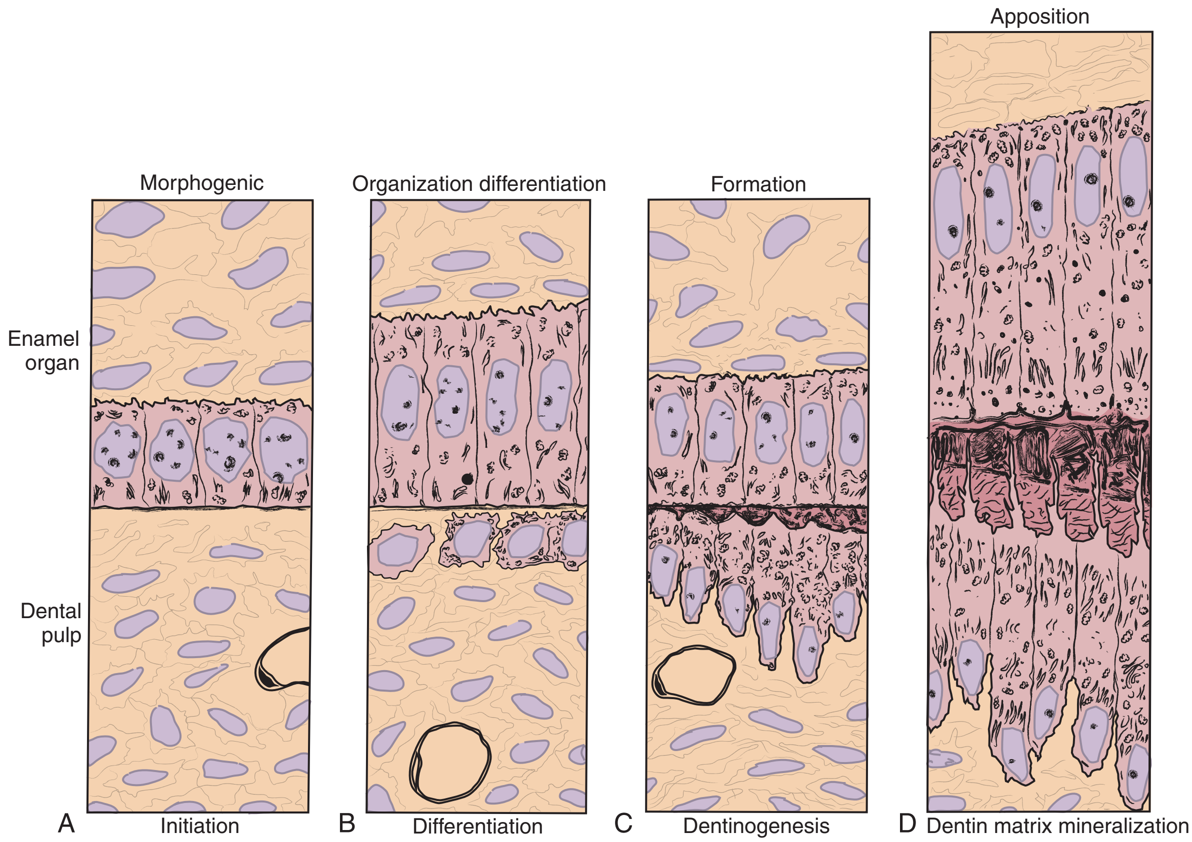

Fig. 9.7 Changes in an odontoblast during its differentiation from a preodontoblast (A) to beginning function (D). In the enamel organ, an ameloblast differentiates first and an odontoblast second, but an odontoblast then forms dentin before an ameloblast forms enamel.

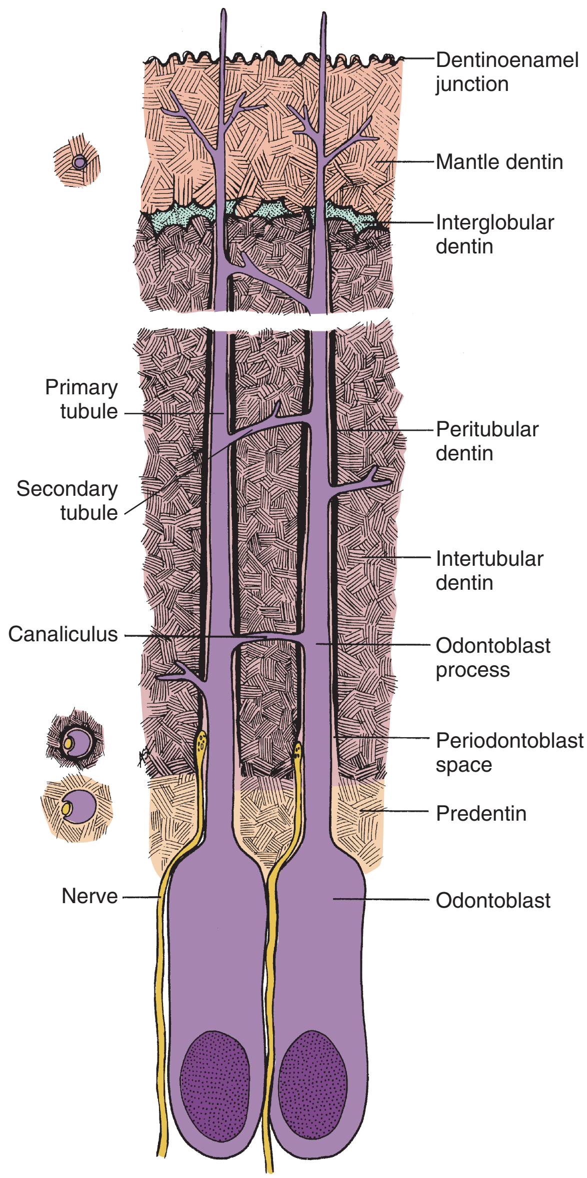

Fig. 9.8 Odontoblast and process extend through the entire thickness of dentin into the inner enamel, as noted at the top of the picture. Side branches of odontoblastic process are shown, and cross section of tubules is at the *left*. *(Modified from Bhaskar SN, editor:* Orban's oral histology and embryology, *ed 11, St. Louis, 1991, Mosby.)*

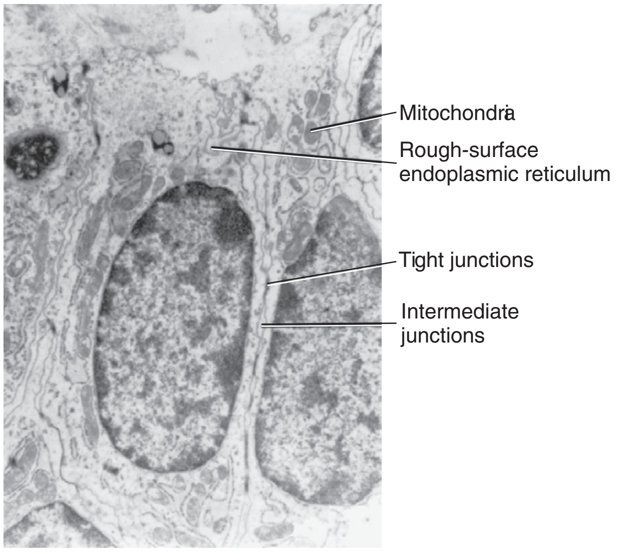

Fig. 9.9 Electron micrograph of tight, intermediate, and gap junctions, which are located between odontoblasts. Cell organelles may also be seen above the region of nuclei. *(From Avery JK:* Oral development and histology, *ed 3, Stuttgart, 2002, Thieme Medical.)*

it continues into the mineralized dentin, the process is devoid of major organelles but contains filaments, membrane-bound vesicles, and microtubules throughout its length to the dentino-enamel junction. How far the process extends into the dentin has been the subject of much discussion. Recent evidence indicates that it extends all the way to, and in some instances through, the dentinoenamel junction and into the enamel as spindles (see Fig. 9-8).

Three types of junctional complexes are found between adjacent odontoblasts: **tight (zonula occludens), gap,** and **intermediate junctions** (**Fig. 9-10**). Each junction has a different function. Adhering junctions or desmosomes are beltlike areas around these cells that possibly function in maintaining positional relationship between cells. This also prevents substances in the pulp from passing into the dentin. Gap junctions are openings between odontoblasts for communication of cell electrical impulses and passage of small molecules (see Fig. 9-10 and **Fig. 9-11**). In this manner, the odontoblasts can have synchronous activity. If stimuli reach the odontoblasts, this information spreads throughout the cell layer by gap junctions, which allow molecules less than a kilo Dalton to pass from one cell to another (paracrine; i.e., calcium, cyclic adenosine monophosphate [cAMP], which are important intercellular signaling molecules). Although odontoblasts are generally believed to live as long as the tooth is viable, inactivity and aging of the odontoblasts result in loss of organelles and a reduction of cell size.

Fibroblasts

Fibroblasts are the most numerous cells in pulp because they are located throughout pulp. These cells are characterized by their functional state. In young pulp, fibroblasts produce collagen fibers and ground substance. At that time, they have a large oval nucleus that is centrally located and has multiple processes (**Fig. 9-12**). Higher magnification of a fibroblast illustrates a Golgi apparatus, adjacent abundant rough-surface endoplasmic reticulum, and mitochondria (**Fig. 9-13**). This fibroblast is a protein-producing cell. In aging, these cells appear smaller and

CLINICAL COMMENT

The pulp horns recede with age. This is a protective measure performed by the pulp cells. Also, reparative dentin forms under cavity preparations or other areas of trauma. Cells in the pulp can be called on to become new odontoblasts and to form dentin at required sites.

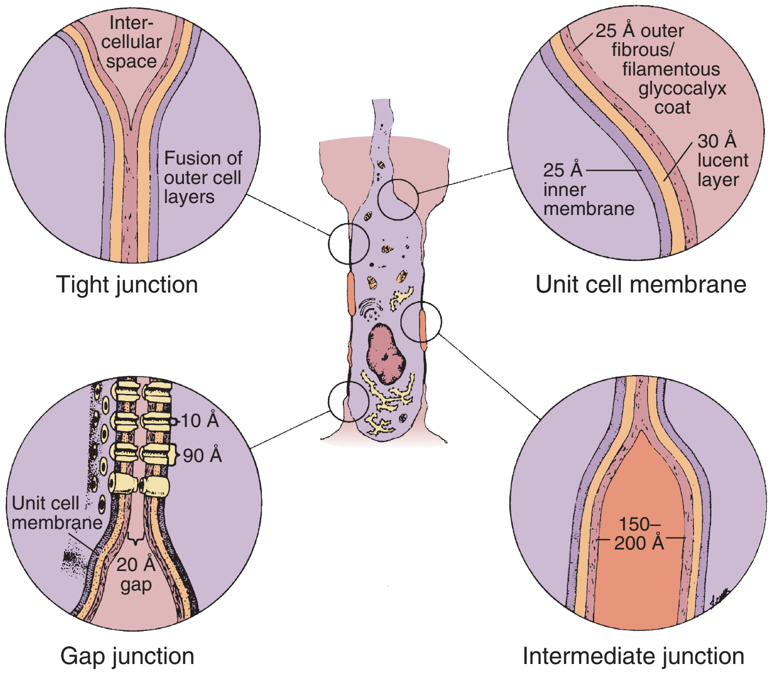

Fig. 9.10 Diagram of the three types of junctional complexes found between adjacent odontoblasts. Their locations can be noted in central diagram, and an illustration of a unit membrane is at *upper right*. *(Modified from Bhaskar SN, editor:* Orban's oral histology and embryology, *ed 11, St. Louis, 1991, Mosby.)*

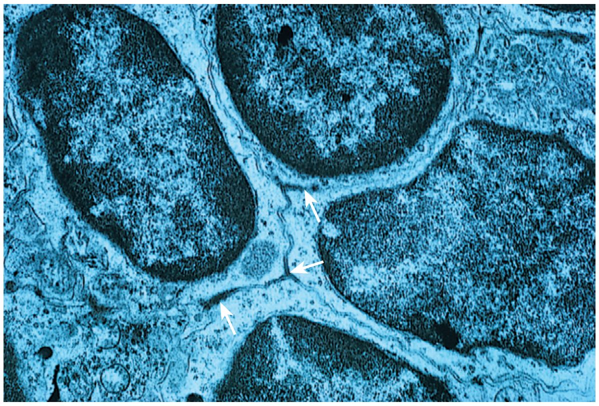

Fig. 9.11 Electron micrograph of junctions between four odontoblasts in the region of cell nuclei. Cell membranes meet at thickened dense-staining zones where junctions are formed, as indicated by *arrows.* These dark zones are gap junctions that allow passage of small molecules between odontoblasts.

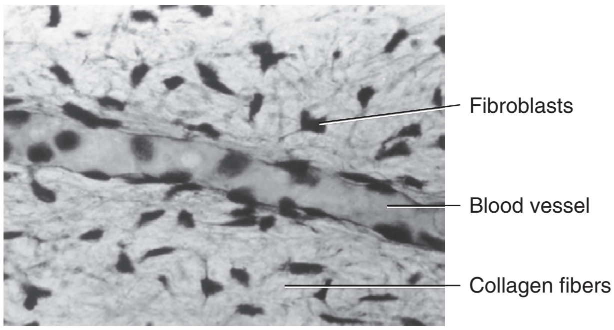

Fig. 9.12 Pulp fibroblasts, collagen fibers, and blood vessels in young pulp. *(From Avery JK:* Oral development and histology, *ed 3, Stuttgart, 2002, Thieme Medical.)*

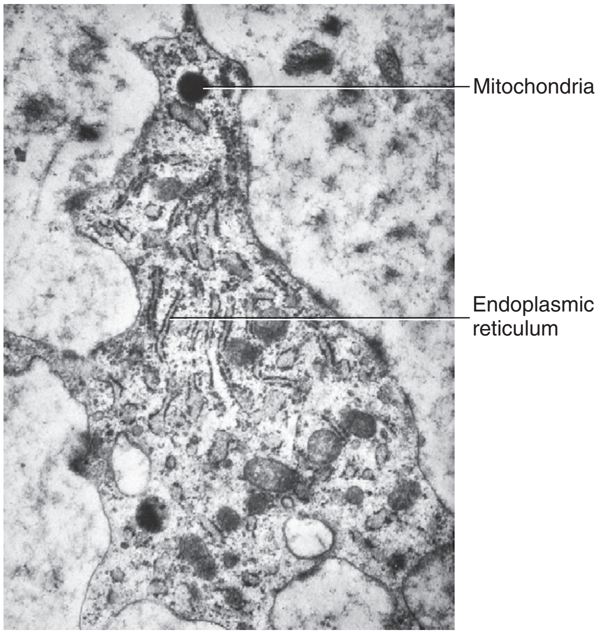

Fig. 9.13 Electron micrograph of pulp fibroblasts showing rough-surface endoplasmic reticulum and mitochondria. *(From Bhaskar SN, editor:* Orban's oral histology and embryology, *ed 11, St. Louis, 1991, Mosby.)*

shaped like a spindle, with few organelles. Although many cells in the pulp proper resemble fibroblasts, it is difficult to determine what their exact role is in pulpal homeostasis, maintenance, turnover and repair/regeneration, and it remains an active area of scientific investigation.

Other Pulpal Cells

Nerve cells in the pulp include **Schwann cells** (**Fig. 9-14**). These cells form the myelin sheath of nerves and are associated

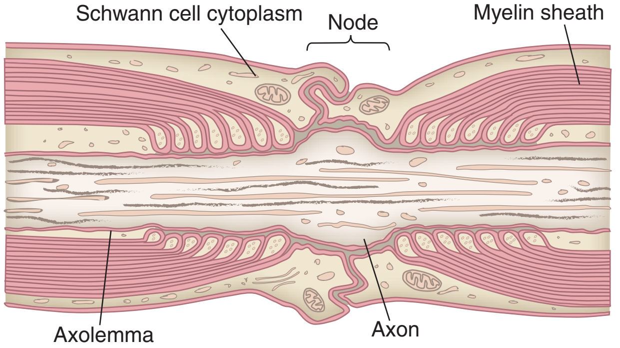

Fig. 9.14 Pulpal nerve axon surrounded by Schwann cell cytoplasm.

with all pulp nerves. In addition, **endothelial cells** lining the capillaries, veins, and arteries of the pulp can be visualized **(Fig. 9-15)**. Accompanying most blood vessels are **pericytes** and perivascular cells and numerous **undifferentiated cells** found in normal pulp. They function as a cell pool and are called into action when new odontoblasts or fibroblasts are needed. For example, this may happen when reparative dentin is needed for pulp exposure. **Macrophages,** normal constituents of the pulp, function in pulp maintenance because of the turnover of cells in pulp **(Fig. 9-16)**. **Lymphocytes,** both T and B, are also found in pulp-free spaces and function in an immune capacity for the pulp. **Erythrocytes, leukocytes, eosinophils,** and **basophils** are found in pulp blood vessels.

Fibers and Ground Substance

Collagen fibers exist in the extracellular matrix, which surrounds the cells. Collagen originates from the pulpal fibroblasts throughout pulp. Both type I and type III collagen have been found in pulp. Type I is produced by odontoblasts because this is the type of collagen found in dentin, the tissue that the odontoblasts produce. Type III is produced by pulp fibroblasts in the maintenance of the pulp proper. In young pulp, fibers are relatively sparse and the tissue appears delicate (see Fig. 9-12). Around the fibers is the ground substance of pulp. This substance is the environment that provides life for cells in pulp and throughout the body. If pulp is irritated, fibers may accumulate rapidly. However, older pulp contains more collagen of both bundle and diffuse types **(Fig. 9-17)**. Type IV collagen is found in the pulp associated with basement membrane surrounding blood vessels. Other types of collagen are also found in

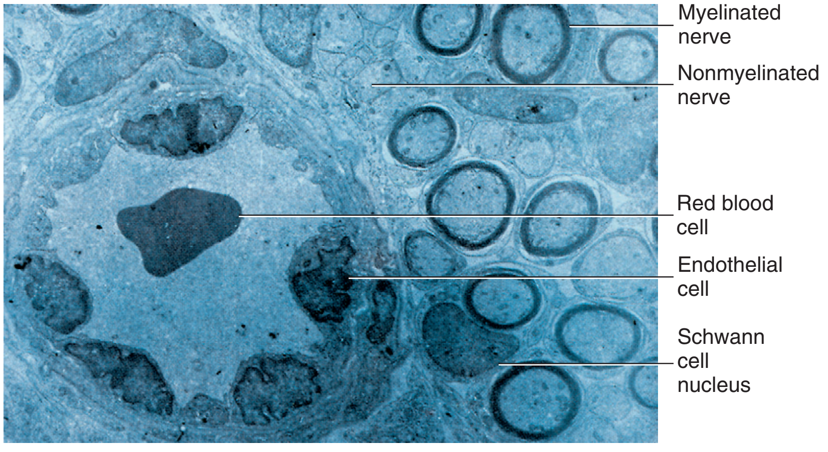

Fig. 9.15 Electron micrograph of an arteriole in the central pulp. The lumen is surrounded by endothelial cells forming the intimal layer and of muscle cells forming the media. At *right* are myelinated nerves; large nuclei belong to accompanying Schwann cells. *(From Avery JK: Oral development and histology, ed 3, Stuttgart, 2002, Thieme Medical.)*

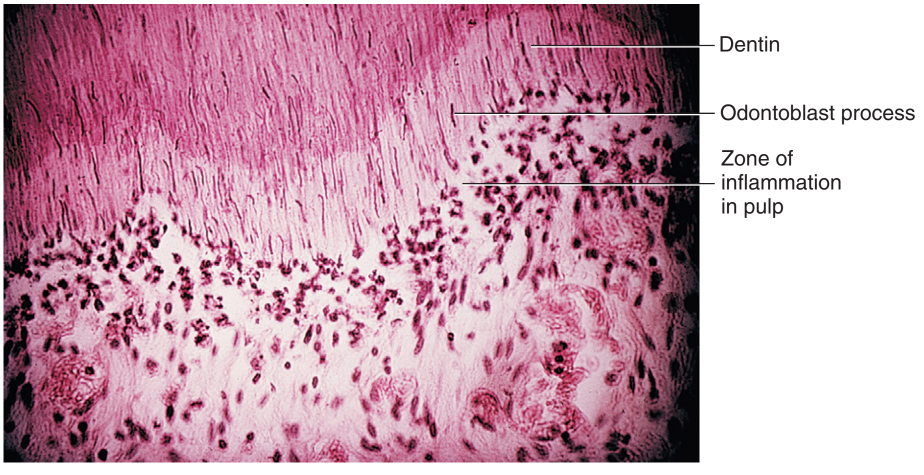

Fig. 9.16 Area underlying dentin with leukocytes, lymphocytes, and macrophages apparently responding to an irritant that resulted in inflammation. The odontoblastic processes in dentinal tubules are degenerating.