CHAPTER 8

Dentin

Learning Objectives

- Describe the various types of dentin and the structures they contain.
- Describe the dental process that lies in the dental tubules.
- Discuss the relationship of the enamel to the dentin at their junction.

Key Terms

Canaliculi
Dead tracts
Dentin: circumpulpal, globular, granular, interglobular, intratubular, mantle, peritubular, primary, reactionary/response, reparative, response, sclerotic, secondary, tertiary, transparent
Granular layer, granular layer of Tomes
Imbrication lines
Incremental lines
Interglobular spaces
Lines of von Ebner
Neonatal line
Osteodentin
Predentin
S curve
Smear layer

OVERVIEW

This chapter focuses on **dentin,** the hard tissue that constitutes the body of the tooth. Dentin is a living, sensitive tissue not normally exposed to the oral environment. Root dentin is covered by cementum, and crown dentin is covered by enamel. Dentin, like bone, is composed primarily of an organic matrix of collagen fibers and the mineral hydroxyapatite. It is classified as **primary, secondary,** or **tertiary** on the basis of the time of its development and the histologic characteristics of the tissue. Primary dentin is the major component of the crown and root and consists of **mantle** dentin, globular dentin, and **circumpulpal** dentin. Mantle dentin is deposited first, along the dentinoenamel junction, in a band about 150 μm wide and is mineralized by matrix vesicles and not a mineralization front. Mantle dentin does not contain dentin sialoprotein (DSP) or dentin phosphoprotein (DPP) in the mineralizing extracellular matrix. It is thought that mantle dentin is secreted by immature odontoblasts. The collagen fibers of this dentin are larger than those of the circumpulpal dentin, which forms later. Mantle dentin is separated from the circumpulpal dentin by a zone of disturbed dentin formation called **globular** dentin, which is noted because of the spaces between the globules, termed **interglobular spaces.** Globular dentin is believed to be a result of deficient mineralization caused during the final maturation of the odontoblast. Dentin continues to form, although the collagen fibers are smaller, until the teeth erupt and reach occlusion. As the teeth begin to function, the dentin is termed *secondary dentin* and is normal circumpulpal dentin. Dentin is responsive to the environment. When caries or mechanical trauma affects the pulp, dentin is deposited underlying that area and is termed **reactionary/response, reparative,** or *tertiary dentin.* This dentin is deposited to protect the pulp. Bordering the pulp is **predentin,** which is newly formed dentin before calcification and maturation. Predentin is composed of 90% type I collagen fibers and 10% noncollagenous proteins, which calcify within 24 hours as the odontoblasts deposit a new band of collagen fibers (**Box 8-2**).

In addition to classifying dentin, this chapter describes properties and characteristics of dentin. Like osteoblasts that form bone, the odontoblasts that form dentin lie on the surface of the forming hard tissue. Unlike bone, the odontoblastic processes exist in tubules and penetrate the dentin from the pulp to the dentinoenamel junction. Dentin, like bone, is deposited by appositional growth and produces incremental lines, but unlike bone, dentin does not remodel. In addition, a **granular** dentin anomaly appears along the root surface. This anomaly may also be caused by the cementum that forms adjacent to the root dentin during development. The odontoblasts may die because of trauma or old age, and **dead tracts** then develop in dentin. The tubules may later calcify as they fill with mineral. When this occurs, the dentin is termed **sclerotic** or **transparent** dentin.

PHYSICAL PROPERTIES

Dentin, which forms the bulk of the tooth, is yellowish in contrast to the whiter enamel. It appears darker if a root canal procedure has been performed. Dentin is composed of 70% inorganic hydroxyapatite crystals, 20% organic collagen fibers with small amounts of other proteins, and 10% water by weight. With 20% less mineral than enamel, dentin is softer, although it is slightly harder than bone or cementum. Therefore it is more radiolucent than enamel but much more dense or radiopaque than pulp. Dentin is resilient or slightly elastic, and this allows the impact of mastication to occur without fracturing the brittle overlying enamel. This resilience is partly the result of the presence throughout the matrix of tubules, which extend from the dentinoenamel junction to the pulp.

CLINICAL COMMENT

Metallic restorations, such as gold inlay, crown, or silver amalgam, are excellent thermal conductors. Therefore it is appropriate to place a cement base under these restorations to protect the pulp by minimizing pain conduction.

DENTIN CLASSIFICATION

Dentin includes primary, secondary, and tertiary dentin. Based on structure, primary dentin is composed of mantle and circumpulpal dentin. Examples of these classifications are given in **Fig. 8-1**, *A*. Fig. 8-1, *B*, shows the **S curve** of the dentinal tubules through primary and secondary dentin. Primary dentin forms the body of the tooth; secondary dentin forms only after tooth eruption and is a narrow band that borders the pulp. Tertiary or reparative dentin is formed only in response to trauma to the pulp (**Box 8-1**).

Primary Dentin

Mantle dentin is the first primary dentin formed. It is deposited first at the dentinoenamel junction (**Fig. 8-2**) and extends approximately 150 μm from the junction pulpward to the zone of **interglobular** or globular dentin. Mantle dentin is so named because it serves as a covering or mantle over the rest of the dentin. Normal circumpulpal dentin directly underlies mantle and globular dentin and comprises the bulk of the tooth's primary dentin. Circumpulpal dentin may be 6 to 8 mm thick in the crown and a little thinner in the roots.

Zones of dentin have structural differences. Mantle dentin is composed of large collagen fibers, some of which are 0.1 to 0.2 μm in diameter, in contrast to the circumpulpal dentinal matrix, which is 50 to 200 nanometers (nm). Thus the fibers in circumpulpal dentin are 10 times smaller than those in

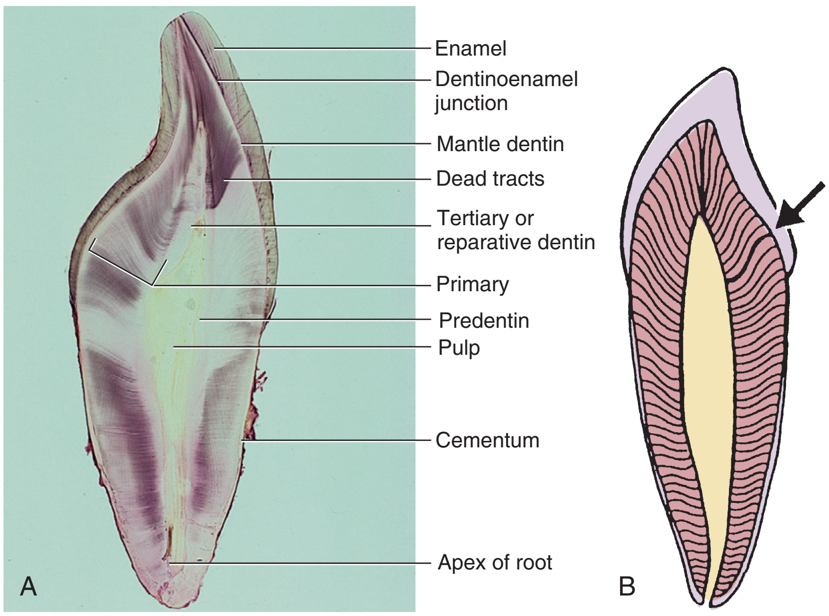

Fig. 8.1 Tooth section of enamel dentin and diagram of tooth. A, Incisor tooth section illustrating structures in enamel, dentin, and cementum. **B,** Diagram of dentin showing S curvature of the dentinal tubules, especially at the *arrow. (Modified from Avery JK:* Oral development and histology, *ed 3, Stuttgart, 2002, Thieme Medical.)*

Box 8-1 Types of Dentin

Primary dentin (prior to eruption)
- Mantle dentin
- Interglobular dentin
- Circumpulpal dentin
- Peritubular dentin
- Intertubular dentin

Secondary dentin
- Normal circumpulpal dentin (after eruption)

Tertiary dentin
- Reactionary/response
- Reparative
- Osteodentin
- Sclerotic dentin

Fig. 8.2 Histologic section of mantle dentin. Area bounded by dentinoenamel junction above and interglobular dentin below.

mantle dentin. Mantle dentin is also slightly less mineralized and contains fewer defects than circumpulpal dentin. Mantle dentin is nearly free of developmental defects. It interdigitates with enamel at the scalloped dentinoenamel junction peripherally and in the zone of globular dentin centrally. The area of globular dentin usually exists only in the crown but may extend into the root. Such a zone of dentinal matrix is not completely mineralized, and the area of globular calcospherites has not fused correctly (see Fig. 8-2 and **Fig. 8-3**, *C*).

Globular dentin contains hypomineralized areas between the globules, termed *interglobular spaces*. Fig. 8-3 shows examples of various structures in dentin. Interglobular spaces are not true spaces but are less mineralized areas between the calcified globules. The dentinal tubules run without interruption through this zone, indicating a defect in mineralization, not a defect in matrix formation (see Fig. 8-2). Interglobular dentin is especially noticeable with vitamin D deficiency, which affects mineralization of teeth and bones. Primary dentin constitutes the bulk of dentin in crowns and roots of teeth. It is characterized by the continuity of tubules from pulp to dentinoenamel junction and by incremental lines that indicate a daily rhythmic deposition pattern of approximately 4 μm of dentin.

Box 8-2 Components of the Extracellular Matrix of Dentin

Collagens
- Type I
- Type I trimer
- Type V
- Type III
- Type VI, IX, X, XI, XII

Proteoglycans
- Decorin (PG II)
- Biglycan (PG I)
- Chondroitin, 4- & 6-sulphate containing
- Dermatan sulphate
- Keratan sulphate
- Perlecan (heparan sulphate)

Lipids
- Phospholipids (phosphatidylcholine, phosphatidylethanolamine)
- Cholesterol
- Cholesterol ester
- Triacylglycerols

Proteolytic enzymes, etc.
- Enamelysin
- Matrix metalloproteinase (MMPs)
- Tissue inhibitors of matrix metalloproteinases (TIMPs)
- Gelatinases

Glycoproteins/sialoproteins
- Osteonectin
- Dentine sialoproteins (DSPs)
- Dentine phosphoproteins (DPPs)
- Bone sialoprotein
- Osteopontin
- Bone acidic glycoprotein 75
- Syndecan 2
- Alpha-2-HS-glycoprotein (AHSG)
- Laminin

Serum-derived proteins
- Albumin
- Fibronectin
- Immunoglobulins

Phosphoproteins
- Dentine matrix protein 1, 2
- γ-Carboxyglutamate A
- Osteocalcin
- Matrix Gla protein

Growth factors
- Transforming growth factors (TGFs)
- Chondrogenic-inducing factor
- Bone morphogenic proteins (BMPs 2, 4, 7)
- Fibroblast growth factors (FGFs)
- Insulin-like growth factors (IGFs)
- Amelin-1 transient expression

CLINICAL COMMENT

The sensitivity of dentin is an important clinical consideration after placement of a restoration that conducts heat or cold. Dentin responds to such stimuli by deposition of reparative dentin and by changes in the dentin tubules underlying the restoration. The sensitivity of the tooth will diminish after a few weeks because of these changes.

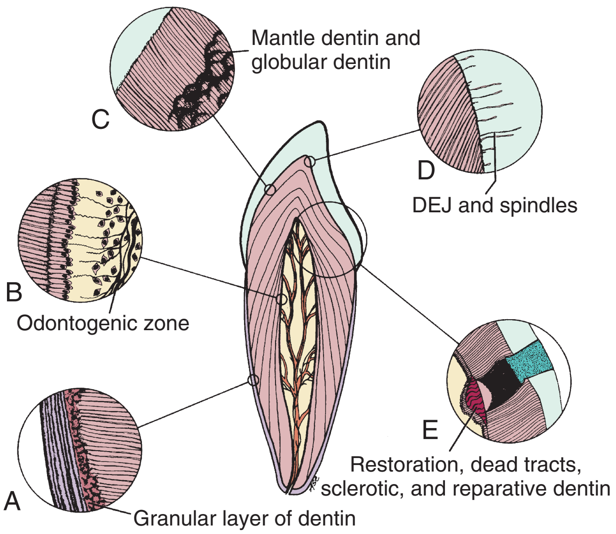

Fig. 8.3 Various structures in dentin. A, Granular layer of dentin and adjacent cementum. **B,** Odontogenic zone and predentin. **C,** Mantle dentin and interglobular or globular dentin. **D,** Dentinoenamel junction and spindles. **E,** Restoration, dead tracts, sclerotic dentin, and reparative dentin.

Secondary Dentin

Secondary dentin forms internally to primary dentin of the crown and root. It develops after the crown has come into clinical occlusal function and the roots are nearly completed **(Fig. 8-4)**. This dentin is deposited more slowly than primary dentin, and its incremental lines are only about 1.0 to 1.5 μm apart. Dental scientists theorize that after the crown begins clinical function, the brain signals the dentin to slow the rate of production. This keeps the pulp from being obliterated by the previous rapid rate of dentin formation. The tubules of primary and secondary dentin are generally continuous unless the deposition of secondary dentin is uneven. In molar teeth, for example, more secondary dentin is deposited on the roof and floor of the coronal pulp chamber than on the lateral walls. This leads to protection of the pulpal horns as occlusal function occurs.

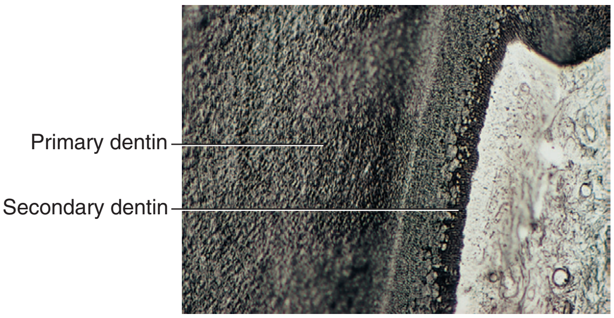

Fig. 8.4 Primary dentin *(left)* and secondary dentin *(right)*. Note the demarcation between the two. *(From Bhaskar SN, editor:* Orban's oral histology and embryology, *ed 11, St. Louis, 1991, Mosby.)*

Tertiary Dentin: Reactionary/Response and Reparative

Reparative or tertiary dentin results from pulpal stimulation and forms only at the site of odontoblastic activation. Whether the formation is the result of attrition, abrasion, caries, or restorative procedures, this dentin is deposited underlying only those stimulated areas **(Figs. 8-5** and **8-6)**. It may be deposited rapidly, in which case the resulting dentin appears irregular with sparse and twisted tubules and possible cell inclusions (Fig. 8-6, *B* to *E*). Odontoblasts, fibroblasts, and blood cells have been found in this type of dentin. In contrast, if it is formed slowly because of fewer stimuli, the dentin appears more regular, much like primary or secondary dentin (Figs. 8-5 and 8-6, *A*). Reparative dentin at times resembles bone more than dentin and is then termed **osteodentin** (Fig. 8-6, *C*). It can also appear as a combination of several types (Fig. 8-6, *E*). Recent terminology suggests that the term *reactionary/response dentin* be used when the original odontoblasts function in deposition and that *reparative dentin* be used when newly recruited odontoblasts begin depositing dentin. The latter case occurs with a more severe injury to the tooth such as a pulp exposure, which then necessitates recruitment of progenitor cells that then differentiate into new odontoblasts. It is interesting to speculate why the newly recruited odontoblasts do not recapitulate development and produce mantle dentin but instead produce various other types of dentin, including osteodentin initially and at a much later time during the pulpal healing sequence, tubular dentin. Perhaps this is because of the urgency of protecting the pulp from further damage and thereby forming a "scar," which then seals the pulp during dentin bridge formation.

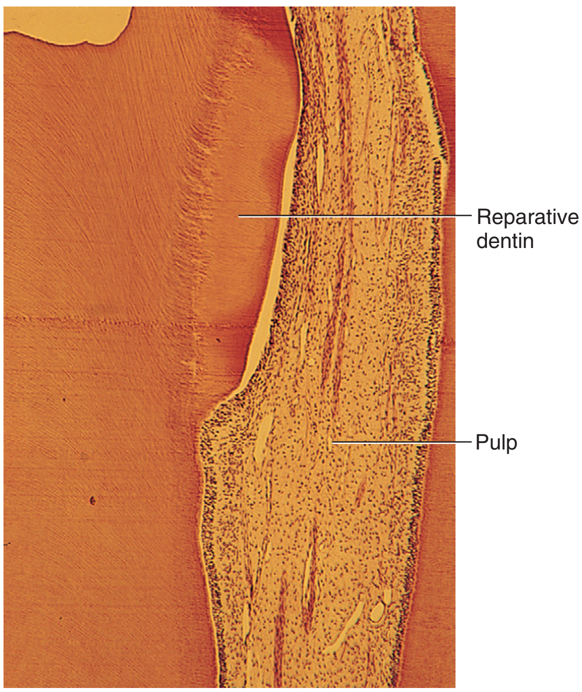

Fig. 8.5 Reparative dentin. Reparative dentin formed in localized area under cavity preparation. Open tubules underlying the cavity floor caused the response of reparative dentin.

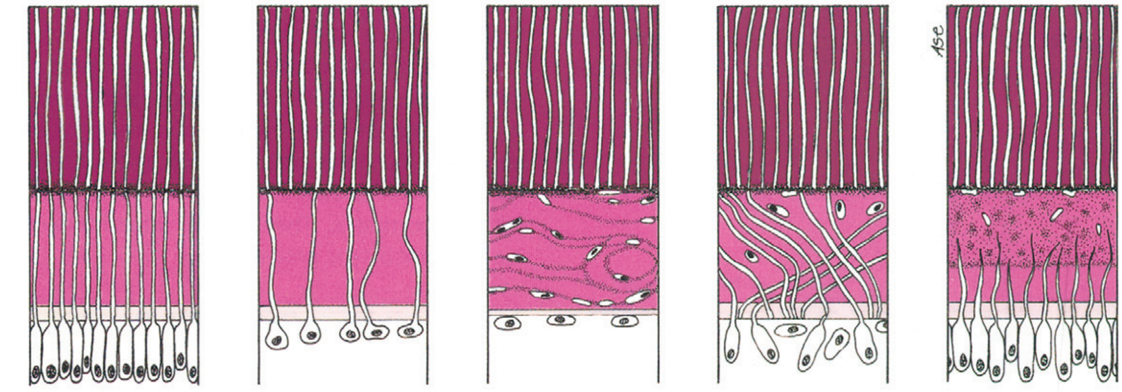

Fig. 8.6 Normal and reparative dentin. A, Normal dentin. **B** to **E,** Reparative dentin: **B,** Decrease in number of tubules; **C,** Cell inclusions; **D,** Irregular and twisted tubules; **E,** Combination of types.

CONSIDER THE PATIENT

Case 1: A patient complains of pain in a tooth after placement of a large gold crown. The tooth is very sensitive to hot or cold fluids or foods. Why?

PREDENTIN

Predentin is a band of newly formed, unmineralized matrix of dentin at the pulpal border of the dentin (**Fig. 8-7**). Predentin is evidence that dentin forms in two stages: first, the organic matrix is deposited, and second, an inorganic mineral substance is added. Mineralization occurs at the predentin–dentin junction at the mineralization front where predentin becomes a new layer of dentin. During primary dentin formation, 4 µm of predentin is deposited and calcified each day. After occlusion and function, this activity decreases to 1.0 to 1.5 µm per day.

TUBULAR AND INTERTUBULAR RELATIONS

Primary and Secondary Tubules

As dentin is formed by odontoblasts, space is provided for the lengthening process of the odontoblast that moves pulpward from the dentinoenamel junction (DEJ). The tubules normally begin at this junction but may extend into the forming enamel matrix. The process begins forming before either enamel or

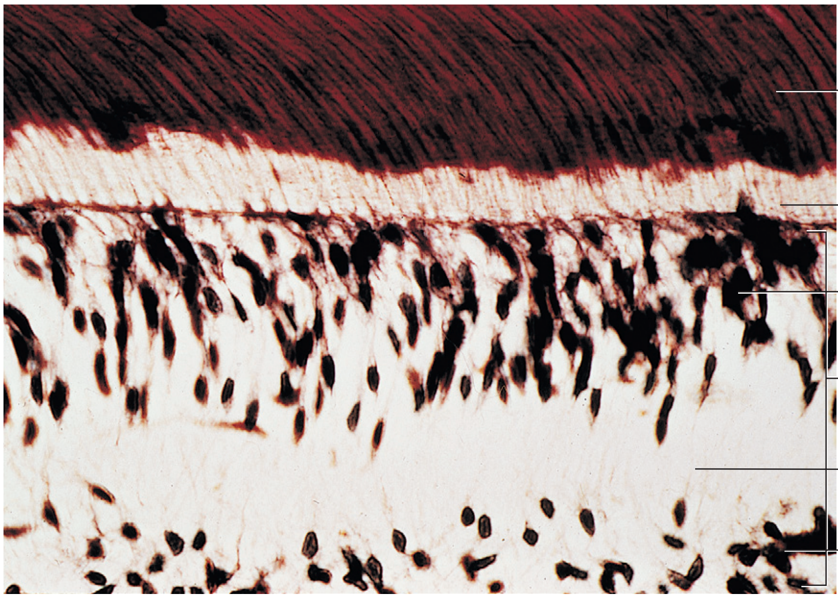

Fig. 8.7 Photomicrograph of predentin zone that borders pulp with mature dentin above. Odontogenic zone is below predentin and comprises odontoblasts and cell-free and cell-rich zones.

dentin matrix begins forming. Thus the spindles that are extensions of the odontoblastic process extend a short distance into enamel. The odontoblastic process then forms an S curve, which extends to the pulp. The odontoblasts initially have multiple processes when they first differentiate but withdraw them at the junction of the globular/circumpulpal interface when the cell undergoes the final differentiation process. As the process elongates, it branches, and its secondary processes appear at nearly right angles to the main process (**Fig. 8-8**) and are contained within **canaliculi** located perpendicular to the dentinal tubule. These cells and their processes give the dentin vitality. The surface area ratio of the dentinoenamel junction to the pulpal surface is about 1:5. Therefore the tubules are farther apart at the dentinoenamel junction than at the pulpal surface (see Figs. 8-1 and 8-8). In addition, the tubules are smaller in diameter in the outer dentin (1 μm) than at the pulpal border (3 to 4 μm). The ratio of the number of tubules at the dentinoenamel junction to the number at the pulpal border is about 4:1. This relates to the odontoblast's gradual increase in size as its process grows in length. Also, more tubules are in the crown than in the root. Approximately 30,000 to 50,000 tubules per square millimeter exist in the dentin near the pulp. The lateral branches of the odontoblastic processes are seen throughout dentin, crown, and root. These lateral branches are termed *canaliculi, secondary branches,* or *microtubules* (see Fig. 8-8) and are less than 1 μm in diameter. Some of these lateral branches lead to an adjacent dentinal tubule, and some appear to terminate in the intertubular matrix. Each of these secondary tubules contains branches of the odontoblastic process that contact the adjacent odontoblasts allowing intercellular communication through gap junctions.

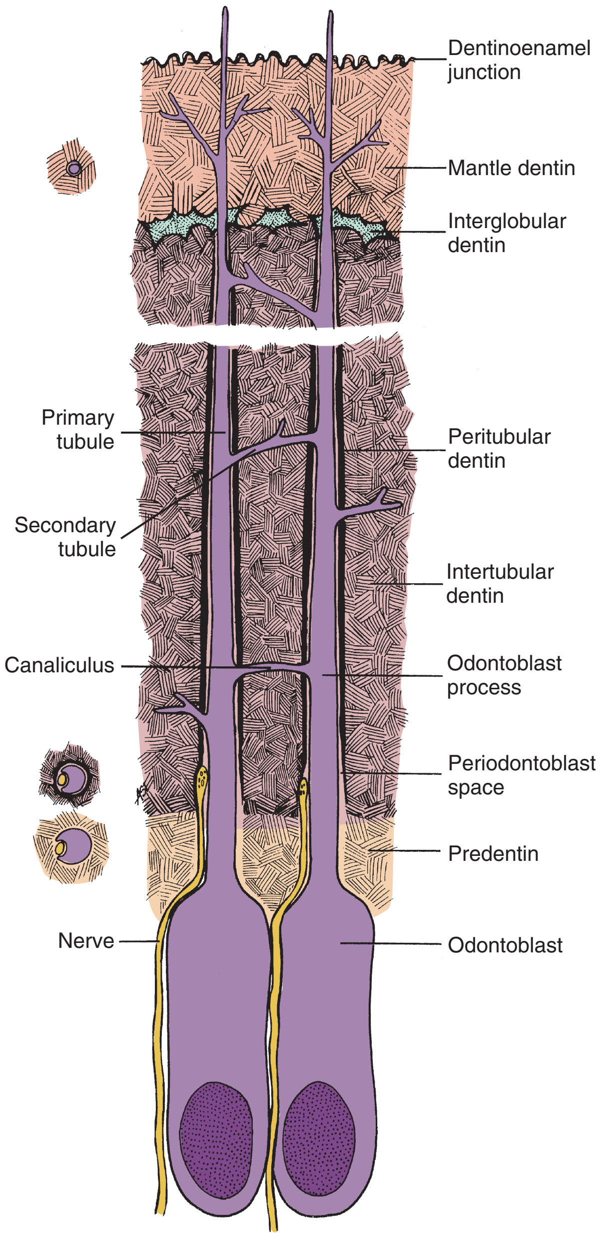

Fig. 8.8 Odontoblast process in the dentinal tubule and extending from the dentinoenamel junction above to the pulp below. Side branches of odontoblast processes in tubules are in inner dentin called *secondary tubules* and in outer dentin termed *canaliculi. (From Bhaskar SN, editor:* Orban's oral histology and embryology, *ed 11, St. Louis, 1991, Mosby.)*

Intratubular or Peritubular Dentin and Sclerotic Dentin

The dentinal matrix that immediately surrounds the dentinal tubule is termed **intratubular** or **peritubular** dentin (**Fig. 8-9**). Peritubular dentin is present in tubules throughout dentin except near the pulp. It is called *peritubular* because it is a hypermineralized collar surrounding the tubules. However, because it is formed within and at the expense of the tubules,

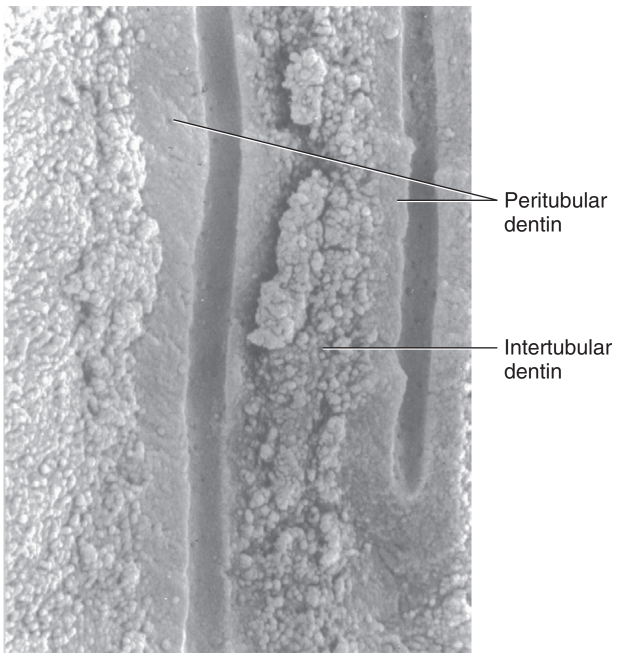

Fig. 8.9 Diagram of dentinal tubules showing peritubular and intertubular dentin. Note that side branches of dentinal tubules are in the intertubular dentin. *(From Berkovitz BKB, Holland GR, Moxham BJ:* Oral anatomy, histology, and embryology, *ed 4, St. Louis, 2009, Mosby.)*

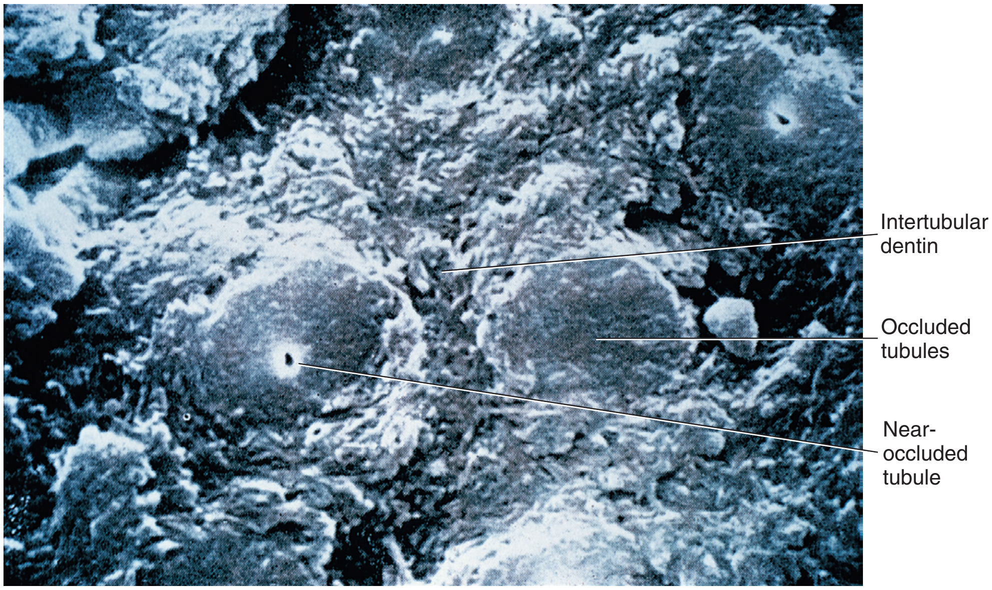

Fig. 8.10 Scanning electron micrograph of sclerotic dentinal tubules. The micrograph shows the minute size of nearly occluded dentinal tubules and some completely occluded tubules. Tubule occlusion is a mechanism to protect the pulp. *(From Avery JK:* Oral development and histology, *ed 3, Stuttgart, 2002, Thieme Medical.)*

intratubular dentin is a more accurate term. Intratubular dentin is missing from the dentinal tubules in interglobular dentin. This is an area of deficient mineralization like the area of predentin, which is also not calcified. In some areas, the hypermineralized intratubular dentin completely fills the tubules, as in the area near the dentinoenamel junction overlying the pulp horns. This condition is also found in the peripheral tubules of the root near the cementum. These are areas of very small tubules and areas where external stimulation may play a role. *Sclerotic dentin* or *transparent dentin* **(Fig. 8-10)** is the term for dentin with tubules that are completely obliterated. The name is derived from the transparent nature of dentin in its appearance under a light microscope, which manifests itself when the tubules are no longer present. Sclerotic dentin increases in amount with age and is believed to be another mechanism to protect the pulp, like reactionary/response and reparative dentin. Permeability to the pulp is eliminated in these areas, and sclerotic dentin is found in areas of attrition, abrasion, fracture, and caries of the enamel.

Intertubular Dentin

The main body of dentin is located between or around the dentinal tubules. Intertubular dentin is the body of dentin, which comprises the crown and root. This dentin consists of the same type of organic matrix fibers (type I collagen fibers and inorganic crystals of hydroxyapatite) as that of intratubular dentin. Intertubular dentin, however, is less highly calcified and changes little throughout life. The collagen fibers of the matrix form a meshwork oriented nearly perpendicular to the intratubular dentin. They exhibit a typical 640-Angstrom (Å) cross banding similar to those of bone or cementum.

CLINICAL COMMENT

Dentinal tubules increase in size by the loss of intratubular or peritubular dentin. This dentin is subject to decalcification by caries or acid cleansing of the cavity, which removes the smear layer. This dentin is about 40% more highly calcified than the remainder of the dentin.

CLINICAL COMMENT

Dentin is a permeable hard tissue with tubules leading from the dentinoenamel junction to the pulp. Therefore, in cavity preparation, sealing of dentinal tubules is a requisite for effective restorative dentistry.

INCREMENTAL LINES

All dentin is deposited incrementally, which means that as a certain amount of matrix is deposited daily, a hesitation in activity follows. This hesitation in formation results in an alteration of the matrix known as **incremental lines, imbrication lines,** or **lines of von Ebner.** Although daily lines are difficult to distinguish, lines formed by increments over several days (possibly every 5 days), resulting in 20-µm lines, are believed to be the ones von Ebner described **(Fig. 8-11)**. Analysis of soft x-ray films has shown these lines to represent hypocalcified bands, at least in the primary teeth and the permanent first molars, indicating that dentin is formed before birth. Prenatal dentin and postnatal dentin are separated by an accentuated contour line known as the **neonatal line** **(Fig. 8-12)**. This line reflects the abrupt change in environment that occurs at or near birth.

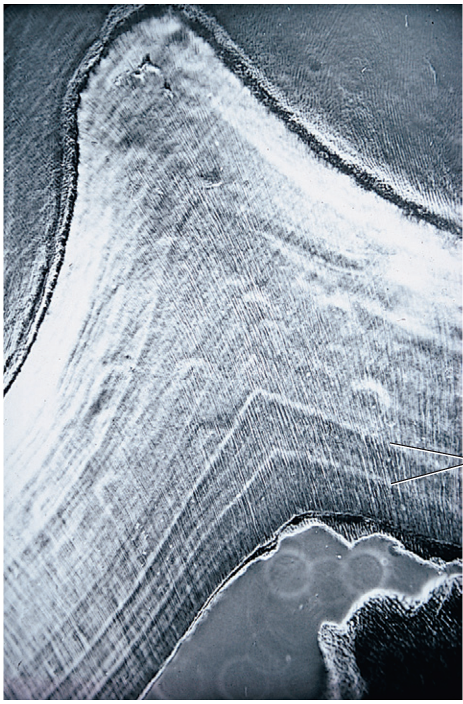

Fig. 8.11 Microradiograph of 20-μm incremental lines (lines of von Ebner) in dentin. Fine daily incremental lines can be seen microscopically between the 20-μm lines.

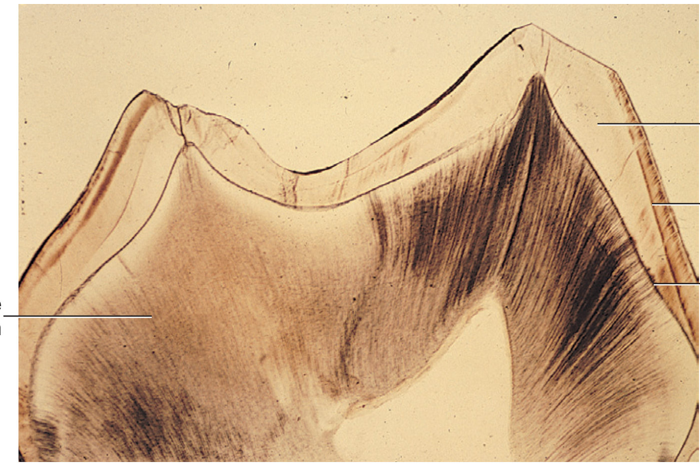

Fig. 8.12 Neonatal line is seen at birth in both enamel and dentin because the prenatal enamel has fewer defects than postnatal enamel. The neonatal line is more easily seen in enamel because of the color change between prenatal and postnatal enamel. Dentin has a neonatal line that is difficult to see at this magnification, but is located midway through dentin.

GRANULAR LAYER

When a thin, calcified section of root is studied under transmitted light, a granular-appearing layer of dentin is seen underlying the cementum that covers the root. This layer is known as the **granular layer** or **granular layer of Tomes** (**Fig. 8-13**). This zone increases slightly in width, proceeding from the cementoenamel junction to the root apex. The zone is believed to be the result of a coalescing and looping of the terminal portions of the dentinal tubules. It is possible that the odontoblast is initially disoriented as it begins dentin formation. The odontoblast turns at right angles to the root surface and proceeds pulpward, causing the dentinal matrix in this area to be defective (**Fig. 8-14**). This disorientation of the odontoblasts could be the result of the initial incomplete information transmitted by the inner root sheath cells resulting in the granular layer. In the crown, ameloblasts direct this process more efficiently, although on occasion odontoblasts cross the dentinoenamel junction and come back leaving enamel spindles on the enamel side of the dentinoenamel junction.

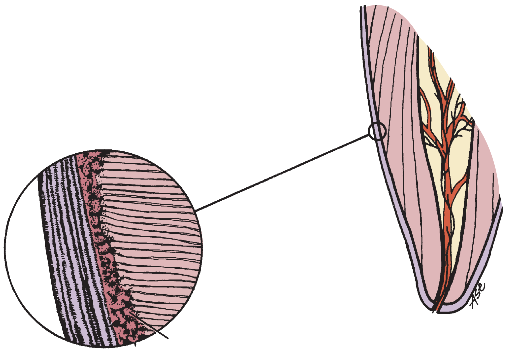

Fig. 8.13 Diagram of the appearance and location of the granular layer of dentin along the cementodentinal junction of the root.

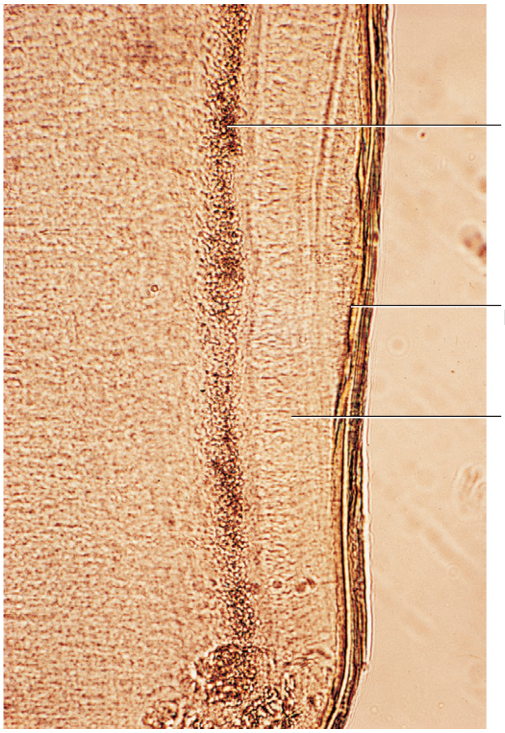

Fig. 8.14 Histologic appearance of the granular layer of dentin *(center)* and cementum *(right),* with periodontal ligament remnants *(far right).*

ODONTOBLASTIC CELL PROCESSES

Odontoblastic cell processes are cytoplasmic extensions of the cell body that are positioned at the pulp–dentin border. Opinions vary about whether these processes extend through the entire thickness of dentin. This difference in opinion is caused in part by the difficulty in preserving and visualizing these processes. Recently, improved techniques of immunofluorescence labeling, freeze fracture, and polymer replacement have revealed that these processes extend to the dentinoenamel junction (**Fig. 8-15**). In some instances, they also extend into the enamel for a short distance as enamel spindles (**Fig. 8-16**). The odontoblastic processes are largest in diameter near the pulp (3 to 4 μm) and taper to 1 μm near the dentinoenamel junction. During development, these processes were divided near the dentinoenamel junction into branched processes (**Fig. 8-17**), but as the odontoblast matured, the processes were retracted and formed a single main process.

Periodically along the odontoblastic process, lateral branches arise at nearly right angles to the main odontoblastic process, extend into the intertubular dentin, and where they contact adjacent odontoblast processes and form gap junctions (**Fig. 8-18**). Within the odontoblastic process are microtubules, small filaments, occasional mitochondria, and microvesicles that can be

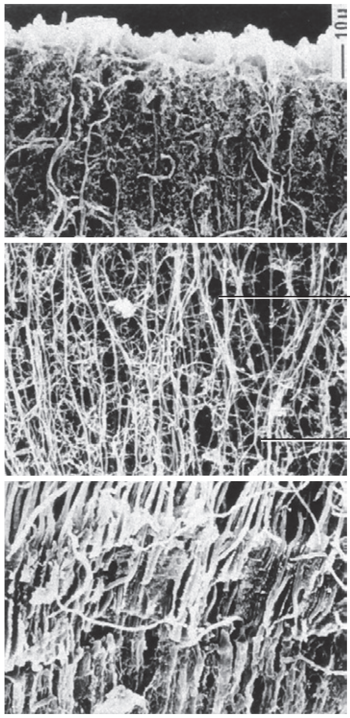

Fig. 8.15 Photomicrograph of odontoblasts *(bottom)* with their processes intact and extending upward to dentinoenamel junction *(top).* Peritubular and intertubular dentinal matrix has been removed, exposing odontoblastic processes.

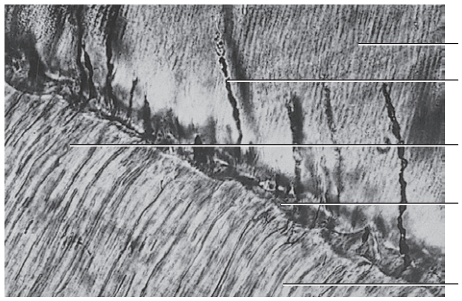

Fig. 8.16 Spindles, which are extensions of dentinal tubules, pass across the dentinoenamel junction into inner enamel.

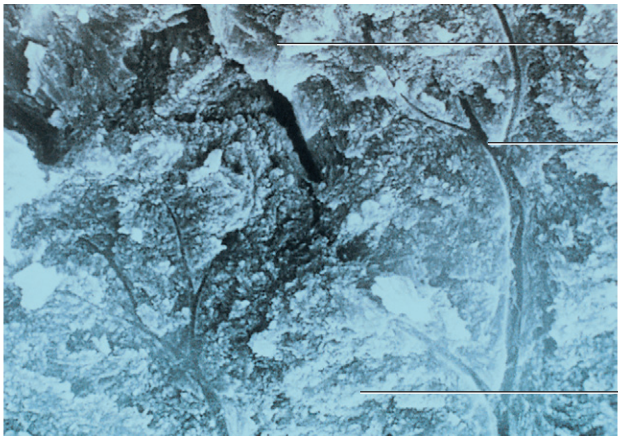

Fig. 8.17 Scanning electron micrograph of dentinal tubules branching near the dentinoenamel junction.

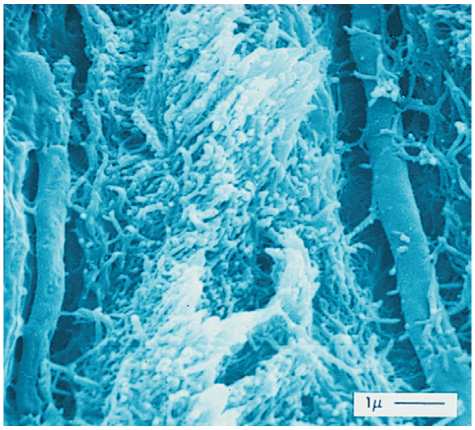

Fig. 8.18 Scanning electron micrograph of dentin near the dentinoenamel junction, illustrating the odontoblastic processes. Side branches of the odontoblastic process extend into intertubular dentin.

visualized using the transmission electron microscope (TEM). Organelles (i.e., mitochondria) are not normally found in the odontoblast process but are found within the cell body. All these structures are indicative of the protein-synthesizing character of the odontoblast. Collagen is deposited along the predentinal border and to a lesser extent along the tubule wall. Nerve terminals can be seen close to the odontoblastic cell body and within the dentinal tubule in the region of the predentin. These are described in Chapter 9. Loss of the odontoblastic process usually results in the appearance of dead tracts in dentin. In the dentin underlying an area of attrition or a carious lesion, odontoblasts may die and processes disintegrate, producing a group of open tubules that contain debris and spaces. If these tubules are open to overlying caries, bacteria may enter them and migrate to the pulp, causing inflammation. The areas of dead tracts may appear black when the teeth are sectioned and viewed by transmitted light because of the additive properties of light rays and because air may penetrate these tubules and create this appearance (**Fig. 8-19**).

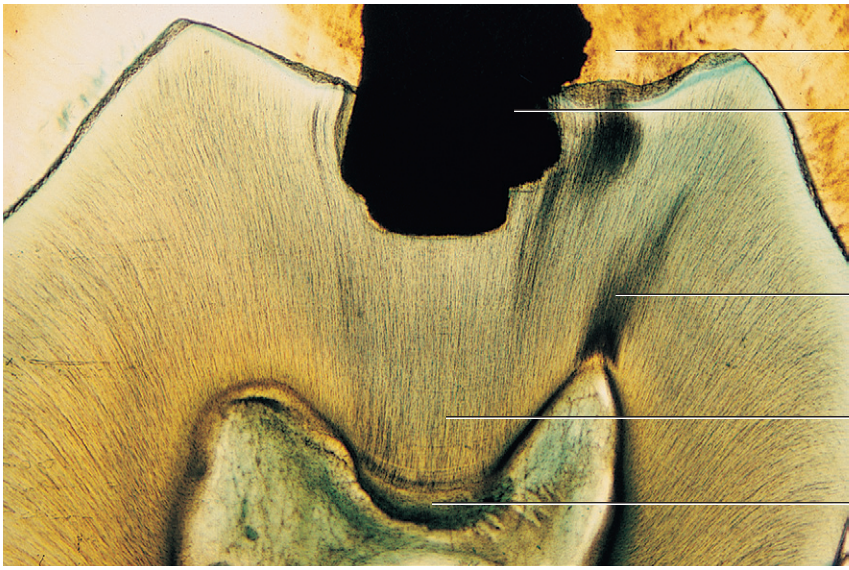

Fig. 8.19 Black dead tracts (open tubules) underlie a black (dense) restoration that appears associated with sclerosed dentinal tubules. Tubules lie adjacent to the reparative dentin, which is seen on the roof of the pulp chamber. Each of these tubules probably resulted from stimulation from the overlying restoration.

CONSIDER THE PATIENT

Case 2: A patient asks why carious dentin does not elicit pain during its removal.

CLINICAL COMMENT

A carious attack can sometimes result in the death of the odontoblast underlying the surface lesion. The dentinal tubules normally contain a living odontoblast process, dentinal fluid, and sometimes a nerve terminal. After the odontoblast dies, the dentinal fluid will crystallize and fill the dentinal tubule with sclerotic dentin (transparent dentin), thus preventing further insult to the pulp.

DENTINOENAMEL JUNCTION

The junction between dentin and enamel, termed the *dentinoenamel junction,* is scalloped, which enhances contact and adherence of the two structurally different tissues. This can be seen microscopically in Figs. 8-13 and 8-16. Scalloping has been found to be accentuated in the cusps where the incisal or occlusal contact is greatest. Features in addition to scalloping that characterize the dentinoenamel junction are enamel spindles and fine branching of the terminal dentinal tubules in the mantle dentin (see Figs. 8-16 and 8-17). The odontoblastic processes extend to the dentinoenamel junction unless stimulation has caused a change in the tubule and its contents. Fig. 8-18 shows the processes with their side branches, and Fig. 8-19 gives an example of changes in dentin underlying a restoration. Loss of tubular contents results in dead tracts *(black streaks)* that indicate air in the tubules. Below the dead tract area in Fig. 8-19 is sclerosed dentin, which protects the pulp from bacteria or bacterial products in the tubules underlying the restoration.

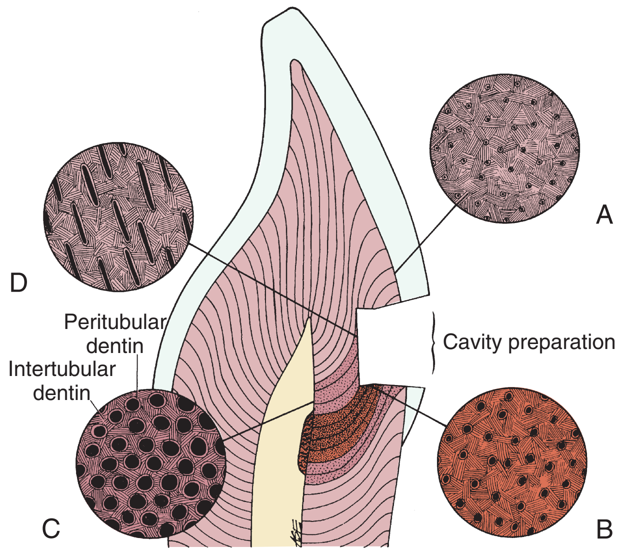

Fig. 8.20 Location and differences in size of dentinal tubules at the dentinoenamel junction **(A)** and at pulp **(C)** and relationship between tubules in cavity floor **(B** and **D)** and the pathway of caries through dentin. Size of tubules at the pulp border **(C)** can be compared with those in the floor of the cavity **(B** and **D)** and at the dentinoenamel junction **(A).** Deposition of reparative dentin underlies invading caries. *(Modified from Avery JK:* Oral development and histology, *ed 3, Stuttgart, 2002, Thieme Medical.)*

PERMEABILITY

The outer surface of dentin is approximately five times larger in surface area than the inner surface. Because the tubule diameter is only 1 µm near the dentinoenamel junction, the tubules are farthest apart at this junction. They are, however, much closer together at the pulpal surface, because the tubules are larger (3 to 4 µm) and the dentinal surface is five times smaller **(Fig. 8-20)**. The tubules are consequently cone shaped and permit increased permeability from the cavity wall or floor to the pulp. The system of branching tubules increases the permeability. Also, because the peritubular dentin is more highly calcified than is the intertubular dentin, the etching of a cavity causes an increase in the diameter of the tubule. The only feature that protects the pulp is that it has higher osmotic pressure than the area of the dentinoenamel junction. Fluid is constantly being forced outward by this increased pressure of the pulp. Therefore, when some dentinal tubules are cut, a small vesicle of fluid appears on the cut surface of the cavity preparation. Against the direction of this flow, minute particles such as bacteria or bacterial products percolate down the dentinal tubules to the pulp. Again, loss of the odontoblastic process, which produces a dead tract, results in increased permeability. For these reasons, the permeability factor is a major consideration in cleansing of the cavity preparation and the placement of a cavity liner to prevent microleakage. In Fig. 8-20, the shaded area indicating caries signifies that bacteria find the shortest distance to the pulp along the dentinal tubules. The figure also shows the deposition of reparative or reactionary/response dentin to the cavity preparation.

The tubules of dentin are effectively blocked by the production of a smear layer on the floor or walls of the cavity during preparation. The **smear layer** is composed of the fine particles of cut dentinal debris that are produced by cavity preparation. These particles enter the tubules as smear plugs at the cut surface of the cavity preparation. The effectiveness of the plug is dependent on the size of the tubules and the size of the cut particles of dentin.

CLINICAL COMMENT

Dentin is a vital tissue that contains living cell processes. Because these branching processes permeate the dentin so completely, it is not possible to touch a cavity preparation in dentin with an explorer without inflicting pain.

REPAIR PROCESS

Dentin is laid down throughout life. Pathologic effects of dental caries, attrition, abrasion, and cavity preparation cause changes in dentin. The changes are described as odontoblastic degeneration, formation of dead tracts, calcification of tubules leading to sclerosis, and tertiary or reparative dentin formation.

Fig. 8.21 Thin section of two human mandibular molar teeth in situ with gold crowns. The pulp of the first molar appears normal with no sign of sclerotic dentin or dead tracts.

Stimulation of the odontoblasts leads to increased dentinogenesis underlying an area of pathologic change. If the stimulation is mild enough for the odontoblast to survive, reactionary/response dentin will be formed. This is believed to be a protective mechanism of the pulp to maintain its vitality. A second situation arises after death and degeneration of the odontoblast. When dead tracts appear, sclerosis of the dentin may occur, and further reparative dentin secreted by replacement odontoblast in the pulp forms. In this instance, the pulp is again protected by this walling off action, which blocks the tubules underlying the area of trauma (see Figs. 8-19 and 8-20). With appropriate coverage, pulps can maintain their vitality. Dead tracts and sclerosis of dentin do not occur if leakage is prevented. An example of this is shown in **Fig. 8-21** in which the pulp is vital in the first molar under a full crown. The pulp in the second molar is not visible because the crown was not cut through its center. This unusual section shows teeth and the surrounding supporting bone.

CLINICAL COMMENT

The pulp is covered by smear layer dentinal particles, which block the tubules and aid in walling off the pulp, and by the formation of reparative dentin.

CONSIDER THE PATIENT

Discussion 1: Metals are good conductors of heat and cold. (Similar complaints may result after placement of an amalgam or an inlay.) However, the clinician can offer the patient assurance that the tooth will respond to the pain with internal healing. The clinician knows that reactionary/response dentin forms slowly and eventually will insulate the pulp nerves from the metal restoration. Within 6 months or a year following such a restoration, the patient may note that the pain no longer exists. This indicates that the reactionary/response dentin has formed.
Discussion 2: The odontoblastic process is believed to function in pain conduction in dentin and is nonliving in carious dentin. During cavity preparation, pain arises only from the adjacent living dentin.

Self-Evaluation Questions

1. Name the type of dentin that comprises the greater part of the crown and root.
2. Name the newly formed area of collagen matrix that borders the pulp.
3. Describe the location and composition of the granular layer of dentin.
4. Name several factors that affect the permeability of the dentin.
5. What are the location and composition of mantle dentin?
6. What is the smear layer and what is its importance to permeability of dentin?
7. Why is dentin considered a vital tissue?
8. What is sclerotic dentin and where is it most likely to be seen?
9. What is secondary dentin and when does it form?
10. What is interglobular dentin and how does it form?

QUANDARIES IN SCIENCE

The extracellular matrix (ECM) of predentin and dentin is highly evolved and contains many substances that potentially function during development, wound healing, and repair/regeneration. On stimulation, soluble molecules can be released from the ECM that have the ability to recruit cells necessary for repair/regeneration and induce progenitor cells to differentiate into replacement odontoblasts. How these molecules participate in the maintenance of dentin and how it is maintained by the odontoblast are still the subjects of many dental scientists who are studying this interesting tissue. Whether the dentist of the future use natural substances to affect repair of the dentin and maintain pulp vitality is a question that only science and time will answer.

SUGGESTED READING

Bleicher F, Couble ML, Buchaille R, et al: New genes involved in odontoblast differentiation, *Adv Dent Res* 15:30–33, 2001.

Boskey A: The role of extracellular matrix in dentin mineralization, *Crit Rev Oral Biol Med* 2:369–388, 1991.

Holland GR: The odontoblast process: form and function, *J Dent Res* 64:499–514, 1984.

Linde A: Structure and calcification of dentin. In Bonucci E, editor: *Calcification in biological systems,* Boca Raton, FL, 1992, CRC Press.

Pashley DH: Dentin permeability and dentin sensitivity, *Proc Finn Dent Soc* 88(S1):31–38, 1992.

Pashley DH: Smear layer: overview of structure and function, *Proc Finn Dent Soc* 88(S1):225–242, 1992.

Priam F, et al: New cellular models for tracking the odontoblast phenotype, *Arch Oral Biol* 50(2):271–277, 2005.

Szabo J, Trombitas K, Szabo I: The odontoblast processes branches, *Arch Oral Biol* 29(4):331–333, 1984.

Trowbridge HO, Franks M, Korostoff E, et al: Sensory response to thermal stimulation in human teeth, *J Endocrinol* 6(1):405–412,1980.

Yamamoto T, et al: The structure of the cemento–dentinal junction in rat molars, *Ann Anatomy* 182(2):185–190, 2000.