16

Restoration of Endodontically Treated Teeth

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CHAPTER OUTLINE

LEARNING OBJECTIVES

After reading this chapter, the student should be able to:

1. Describe the main factors involved in the survival of root-filled teeth.
2. Summarize factors contributing to loss of tooth strength and describe the structural importance of remaining tooth tissue.
3. Explain the importance of a coronal seal and how it is achieved.
4. Describe the requirements of an adequate restoration.
5. Outline postoperative risks to the unrestored tooth.
6. Discuss the rationale for immediate restoration.
7. Identify restorative options before root canal treatment is started.
8. Discuss the advantages and disadvantages of direct and indirect restorations.
9. Outline indications for post placement in anterior and posterior teeth.
10. Describe common post systems and the advantages and disadvantages of each.
11. Describe core materials and their placement.
12. Describe techniques for restoring an access opening through an existing restoration.

Endodontic therapy is predictable. However, for success the teeth need to be restored to their previous form and function. Before endodontic therapy, restorability must be determined; this involves careful evaluation of the existing tooth structure, including removal of all caries along with any existing restorations, both to reduce the risk of marginal leakage during treatment[1] and to reveal the amount of sound tooth structure.[2] Specific restorative options must be evaluated based on functional demand and remaining tooth structure.[2,3] This chapter will discuss the considerations needed to properly restore endodontically treated teeth.

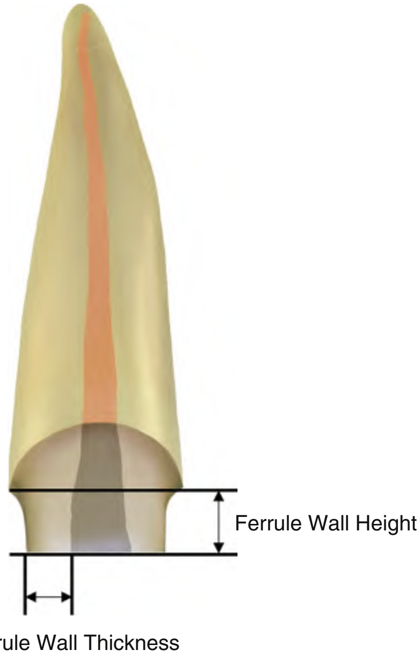
Criteria for a Restorable Tooth

A tooth must retain sufficient sound tooth structure after root canal therapy to allow predictable restoration. Evaluation of a tooth requires clinical, radiographic, and esthetic evaluation. The first step is to remove any existing caries and restorative materials. This process allows clear visualization of the remaining tooth structure and removes bacteria. A periodontal probe can be used to measure the height of the remaining tooth structure that will provide a ferrule; measure pocket depths, which can reveal periodontal status and possible signs of root fracture; and map the subgingival root morphology. A bitewing radiograph should be used to evaluate the remaining tooth structure, pulp chamber, and bone levels; and periapical radiographs should be used to evaluate tooth length and root morphology.

Amount of Remaining Coronal Tooth Structure

Most teeth requiring root canal treatment have been structurally compromised by caries and subsequent restorative procedures. Additional loss of tooth structure occurs during endodontic access, leading to further weakening of the tooth. When the access cavity

• **Fig. 16.1** Teeth requiring root canal treatment have commonly been structurally compromised by caries and restorative procedures. Endodontic access further compromises the tooth.



• **Fig. 16.2** Ferrule refers to the amount of cervical tooth structure available to resist tooth fracture and does not include any build-up material.

• **Fig. 16.3** Root canal–treated mandibular anterior teeth with a ferrule extending 2 mm beyond the core for optimal resistance to tooth fracture.

is surrounded by walls of dentin, it only has a minor weakening effect.[4] In a tooth already seriously compromised by caries, trauma, or large restorations, access preparation is more significant, particularly if some marginal ridges have been lost (Fig. 16.1).[5,6] Excessive coronal flaring of the access preparation also results in greater susceptibility to fracture.[7]

The formation of a ferrule around the remaining coronal tooth structure is important to prevent tooth fracture in endodontically treated teeth. Ferrule refers to the amount of cervical tooth structure, or the height of the remaining tooth structure under a crown, that is available to resist tooth fracture (Fig. 16.2). The more tooth structure present, the more resistant the tooth will be to fracture.

Ferrule Wall Height

The ferrule wall height is simply measured from the tooth preparation finish line to the coronal aspect of the remaining tooth structure.

The types of margin preparation or bevels on the remaining tooth structure are unimportant; the total height of the tooth structure is key.[8-12] The exact crown ferrule height required for success has been debated for many years; recommendations range from 1.0 mm to 3.0 mm heights.[10-14] We suggest that at least a 1.5 to 2.0 mm high circumferential wall of tooth structure be present above the crown finish line to ensure adequate fracture resistance and enhance the coronal seal provided by the final restoration (Fig. 16.3).

Ferrule Wall Thickness

Endodontic therapy requires the removal of tooth structure to gain access to the root canal system. The ferrule wall width refers to the amount of tooth structure remaining from the pulp chamber and/or access preparation to the external surface of the tooth. The amount of remaining ferrule wall thickness may be jeopardized by crown preparation. Decay and prior restoration may leave minimal ferrule wall thickness. The ability of a tooth to resist lateral forces is directly proportional to the thickness of remaining dentin.[15] More than 1.0 mm of dentin thickness around the root canal is needed for adequate resistance to fracture.[16-19]

Re-Establishing Coronal Tooth Structure

In a clinical situation where minimal tooth structure remains, the establishment of an adequate ferrule height can be challenging. In such situations, two factors are important to ensure success. First, it is important to reestablish a 1.5 mm to 2.0 mm ferrule and second to maintain the patient's biologic width. Biologic width refers to the junctional epithelium and connective tissue attachment present from the alveolar bone crest to the depth of the periodontal sulcus. It is suggested that the average biologic width is around 2 mm;[20] commonly the sulcus depth is also included in this measurement, resulting in a suggested measurement of 3 mm. However, the exact biologic width will vary from patient to patient. This suggests that approximately 5 mm of tooth height should remain coronal to the alveolar bone. When this is not available, height can be reestablished by means of surgical crown lengthening or orthodontic extrusion (see Chapter 21).

Surgical Crown Lengthening

Crown lengthening is a way to reestablish a ferrule by removing supporting periodontal structures to expose additional tooth structure. However, if a tooth has reduced bone support, short roots, a poor crown-to-root ratio, or if it could lead to an unacceptable esthetic result, crown lengthening would be contraindicated.[21] Additionally, the apical relocation of the finish line to a narrower part of the root exposes less cross-sectional area, predisposing to a weaker tooth[22] and potentially to furcation involvement. Therefore the ideal tooth for crown lengthening is a periodontally healthy, long, single rooted tooth, with minimal root taper.

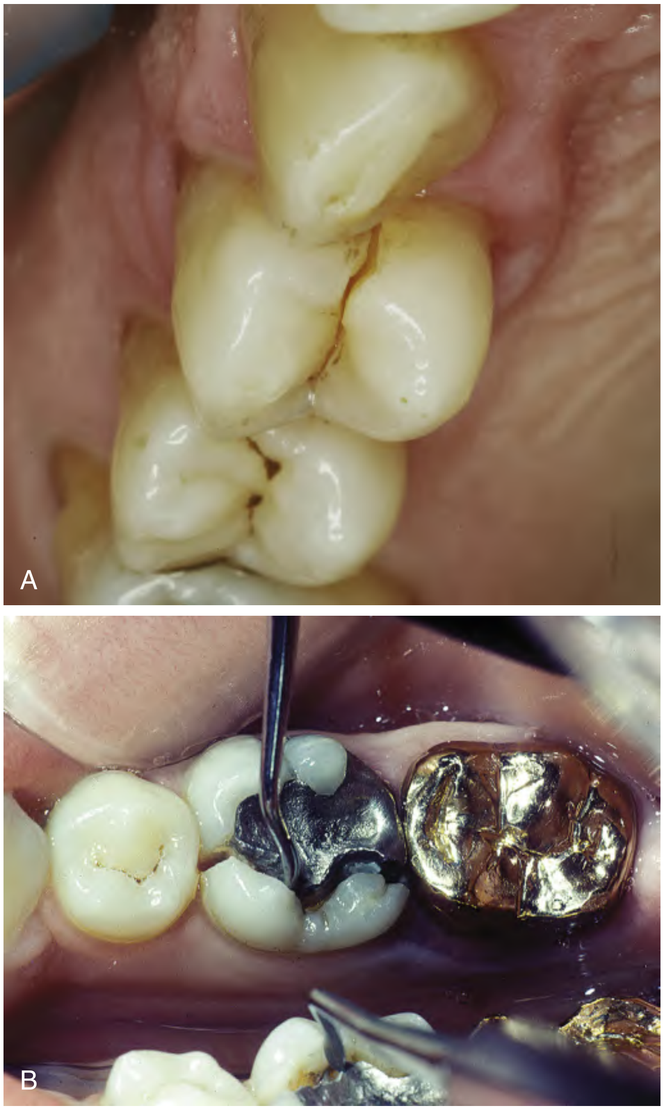
Orthodontic Extrusion

Orthodontic extrusion involves the forced eruption of a tooth. The eruption must be performed using rapid orthodontic extrusion allowing only the movement of the tooth. If slow orthodontic extrusion is performed, coronal migration of the bone and gingiva occurs, thereby not allowing the formation of the desired ferrule. It is also suggested to perform supracrestal fiberotomy and root planning to help minimize the coronal migration of bone and gingival tissues when rapidly extruding a tooth.[23] Rapid orthodontic extrusion involves 1 to 3 weeks of activation followed by 8 to 12 weeks of retention of the tooth before starting restoration.[24] However, when extruding a tooth with tapered roots, not only is the bone support reduced, the cross-sectional area is reduced, making an esthetic and structurally sound restoration more difficult.

Complications Associated with Endodontically Treated Teeth

Although root canal treated teeth are at greater risk of extraction than vital teeth,[25] their long-term survival rate is very high. Numerous studies investigating the survival of endodontically treated teeth have documented that at most 1% to 2% are lost per year,[26-29] and one very large study of almost 1.5 million cases reported that only 2.9% were lost after 8 years.[28] A recent meta-analysis showed a mean tooth survival of 87% after 8 to 10 years.[26] Factors that affect the survival of root-filled teeth include:

1. *Caries and periodontal disease.* Caries and periodontal disease are responsible for up to half of all extractions of root-filled teeth.[30-32] Emerging evidence suggests that root-filled teeth may be more susceptible to caries than vital teeth, though the reasons are unknown.[33,34]
2. *Lack of definitive restoration.* A surprisingly high percentage of teeth are not appropriately restored after root canal treatment.[27,31,35] In one study of U.S. insurance data,[6] almost 30% of teeth had not been restored 2 years after root canal treatment, and 11% of these teeth were extracted.
3. *Inadequate restoration.* Lack of coronal coverage for posterior teeth is a major restorative factor in their loss after root canal treatment.[26-28,36] A lack of cuspal protection, coronal coverage predisposes the tooth to unrestorable crown or root fracture. Direct restorations do not provide adequate protection for posterior teeth unless the access opening is very conservative.
4. *Occlusal stresses.* Teeth serving as abutments for fixed or removable prostheses are at significantly increased risk of loss, as are teeth lacking mesial and distal proximal support from adjacent teeth.[26,27,37]
5. *Endodontic factors.* Typically only about 10% of extractions of root canal treated teeth result from endodontic causes, such as persistent pain.[30-32,38] Endodontic pathology (development or persistence of a periapical lesion) is generally amenable to further management rather than extraction; likewise procedural complications, including perforation, may be managed.



• **Fig. 16.4** **(A)** Root fracture of a maxillary premolar without any existing restorations. **(B)** Crown-root fracture (split tooth) of a root canal–treated tooth restored with amalgam but lacking protection of undermined, weakened cusps. (Courtesy Dr. H. Colman.)

Structural, Esthetic, and Restorative Considerations

Teeth function in a challenging environment, with heavy occlusal forces and repeated loading at a frequency of more than 1 million cycles per year for many decades. Caries, restorative procedures, and occlusal stresses add to the risk of serious damage to teeth during normal function, and root canal treated teeth are at greater risk than intact teeth (Fig. 16.4). As noted previously, unrestorable crown fracture is a common sequel to inadequately protected root canal treated teeth.[36,39] It is important to understand the basis for this fracture susceptibility when planning the restoration.

Structural Changes in Dentin

It is now generally recognized that many mechanical properties of the dentin of endodontically treated teeth differ only to a minor extent from those of the dentin of vital teeth (strength, hardness, modulus of elasticity).[40,41] Prior studies were generally confounded by drying of studied teeth after extraction.[42-45]

Biomechanical Factors

Normal function generates large stresses that are capable of causing cusp fracture and even vertical root fracture in intact vital teeth.[46] Repeated functional loading and cyclic mechanical fatigue have the potential to weaken teeth over time, particularly after tooth structure has been lost to caries, restoration, and access preparation, which places even more stress upon the remaining diminished tooth structure.[4-6] The distribution of masticatory stresses in the restored root canal treated tooth is markedly and adversely changed from those in the intact, vital tooth.[44] Hence, the restoration must be designed to minimize and to protect against fracture.

Esthetic Considerations

Increasingly, patients wish to enhance the esthetic appearance of restorations; for endodontically treated teeth this often involves the use of crowns. Crown preparation necessitates further tooth reduction to provide adequate thickness of the ceramic material to provide a more natural appearance. The amount of required tooth reduction varies based on the material being used. Dark stained teeth may require additional tooth reduction to mask discoloration when translucent all-ceramic crowns are used, further weakening the tooth.

Requirements for an Adequate Restoration

The definitive restoration should (1) preserve as much tooth structure as possible, but not forget the appropriate thickness of the restorative material; (2) protect remaining tooth structure, cuspal coverage protecting posterior teeth; (3) satisfy function and esthetics; (4) provide a coronal seal; and (5) be completed in a timely manner. Care must be taken to ensure that esthetic demands do not lead to the weakening of teeth by excessive removal of remaining tooth structure.

Coronal Seal

Coronal leakage is a major cause of endodontic failure.[47,48] Even a well-obturated canal does not provide an enduring barrier to bacterial penetration[49]; we rely on the restoration for long-term integrity of the coronal seal. The restoration may provide the coronal seal either as a separate step (e.g., placing a barrier over canal orifices)[50,51] or, more commonly, as an integral part of the restoration. For direct restoration of a small access cavity, a bonded restoration provides the most reliable seal.[52] Experimental leakage studies consistently demonstrate that leakage occurs around posts, regardless of the type of post or luting cement.[53] However, a crown with an adequate ferrule and sound core foundation provides an effective barrier against coronal leakage.[54,55]

A frequently asked question with regard to lost or leaking restorations is, "How long can a root filling be exposed to oral fluids before it should be retreated?" The question has no clear answer. Experimental studies suggest that complete leakage along the length of the root filling occurs rapidly, within days or weeks.[56,57] A recent review, however, concluded that coronal leakage may be clinically less significant than is suggested by experimental laboratory leakage studies.[58] Clinically, bacterial invasion is often limited to the coronal third of the canal, and periapical lesions may take several years to develop.[59,60] One commonly accepted guideline is that the root canal should be retreated if it is exposed to oral fluids for more than 2 to 3 months.[47] Others suggest 2 to 3 weeks.[48] However, if the root filling has been performed to a high technical standard and periapical pathology is absent, it may be sufficient to replace the lost or leaking restoration rather than provide endodontic retreatment.[59] Of course, retreatment can be provided after pathology has eventually become evident, but the earlier bacteria are removed, the better the endodontic prognosis.

• **Fig. 16.5** Unrestorable fracture during root canal treatment. The lack of cuspal protection combined with deep anatomic grooves led to fracture within days of endodontic access.

Restoration Timing

Unless there are specific reasons for delay, definitive restoration is completed as soon as practical.[47,53,61,62] The core restoration should be placed at the time of obturation, before the rubber dam is removed.

If placement of the core restoration is to be delayed, orifice barriers can be placed at the time of obturation using composite resin[63] or glass ionomer or an adhesive cement. The gutta-percha is removed from the canal orifice 1 mm below the pulpal floor or 1 mm below the level of the cementoenamel junction (CEJ), creating a small depression. The tooth is etched and primer placed for composite resin or the tooth is conditioned for glass ionomer. One option is to seal the orifice with clear composite resin to allow easy visualization of the canal and gutta-percha should reentry into the canal ever be needed; another is to use an opaque white material so that it can easily be distinguished from natural tooth structure.

Most provisional restorative materials commonly used to seal the endodontic access opening allow substantial occlusal wear and loss of the coronal seal within weeks. The tooth has been weakened by access preparation and remains at risk until definitive restoration has been completed. The provisional restoration does not provide protection against masticatory forces, even when the

• **Fig. 16.6** Chamber and canal orifices retain an amalgam core, taking advantage of natural undercuts. The teeth can be prepared for crowns without removing the amalcore, or the amalgams may be definitive restorations if the cusps are adequately protected. (Courtesy D.P. Parashos.)

tooth is out of occlusion. Because nonrestorable fracture during or soon after treatment is all too common (Fig. 16.5), protection can be provided in the form of a well-made provisional crown.

For most teeth, it is both unnecessary and unwise to wait for radiographic evidence of healing before the definitive restoration is placed. Prompt restoration will improve the prognosis because it provides better protection against fracture and loss of the coronal seal.

When definitive restoration of the tooth is delayed, the provisional restoration must be durable and must protect, seal, and meet functional and esthetic demands. Provisional materials such as Cavit are inadequate.[64] For posterior teeth, some form of cuspal protection is desirable, even with provisional restorations.[65] A good long-term posterior provisional restoration will cover weakened cusps, thus providing functional and sealing protection. The definitive crown preparation can be completed later without removing the core (Fig. 16.6). Comparable anterior restorations are more challenging owing to esthetic demands and difficulties with the coronal seal.[53] A one-piece provisional postcrown is at risk of dislodgment, thereby compromising an adequate seal.[66] It is preferable to place a definitive post and core immediately after obturation when a provisional crown is indicated.[62,67]

Restoration Design

Guiding Principles

1. *Conservation of tooth structure.* Most anterior root canal treated teeth should be restored simply and conservatively using composite resin rather than with a more radical crown or a crown combined with a post and core.[68,69] Some data even indicate that molars that are intact (except for endodontic access openings) can be restored using only composite resin.[70] However, most root canal treated posterior teeth require crown placement so that the cusps and remaining tooth structure can be encompassed, minimizing the potential for tooth fracture.[36,39] The antiquated and unsound processes used by some practitioners of routinely creating a very large access preparation or decoronating an endodontically treated tooth and then rebuilding it are neither desirable nor in keeping with contemporary knowledge.
2. *Retention and resistance.* The definitive coronal restoration of a root canal treated tooth may consist only of a restorative filling in the endodontic access opening when it is retained by surrounding tooth structure. When the tooth is structurally compromised a crown is needed. It is retained by remaining dentin and a restorative material core that replaces missing tooth structure. Only if the core cannot be adequately retained by the remaining coronal tooth structure should a post be placed into the root canal to provide retention and resistance for the core. Because posts weaken teeth[71-75] and may produce root fracture or lead to root perforation during preparation of the root canal,[76] they should be used only when the core cannot be retained by any other means, such as mechanical and chemical bonding of a restorative material.[77,78]
3. *Protection of remaining tooth structure.* In posterior teeth, this applies to protecting weakened cusps by minimizing undue flexure and preventing fracture. The restoration is designed to encompass the cusps, thereby splinting the tooth and minimizing the chance of tooth fracture.

Planning the Definitive Restoration

A tooth that is intact except for the access preparation can simply be restored using amalgam or composite. All of the provisional restorative materials must be removed along with any cotton or foam pellet, the pulpal floor cleaned of any sealer or gutta-percha, and the round or oval obturations be clearly visualized, so that there will be no void between restoration and the pulpal floor or obturation.

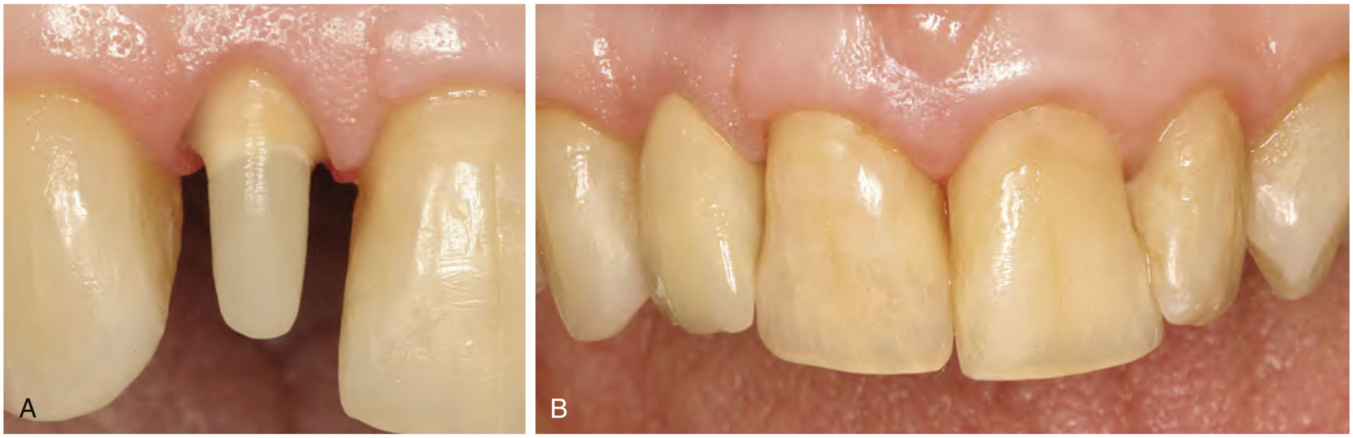
When the tooth requires a crown, the type of definitive treatment can be determined only after the existing restoration (or restorations) have been removed, to ensure that there is no caries present and to expose the remaining sound tooth structure. Therefore the specific crown material will be determined based on esthetic and functional demands.

Anterior Teeth

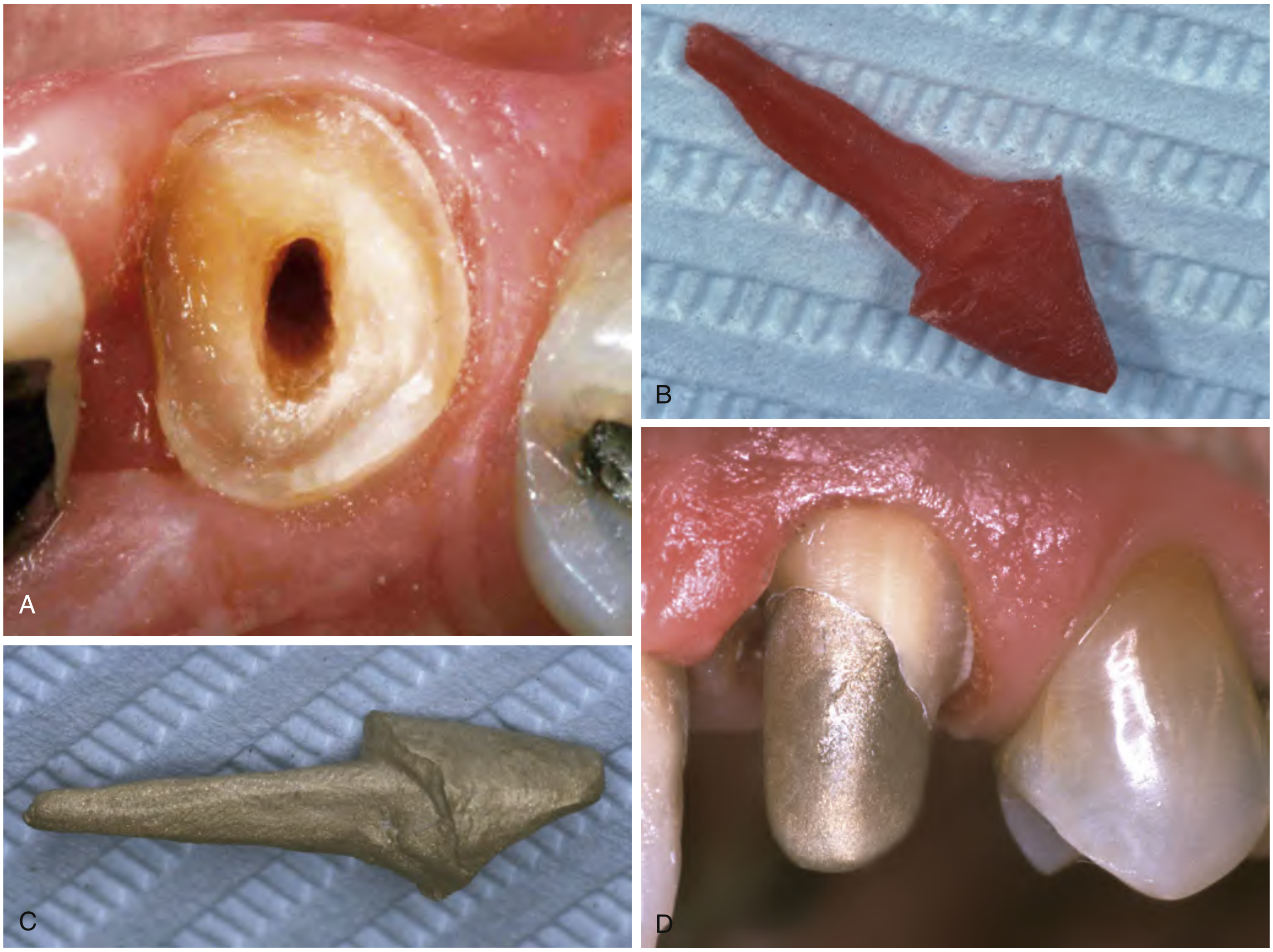
Whenever possible, direct restoration of the endodontic access opening (e.g., etched and bonded composite resin) is used. Further esthetic issues can be addressed conservatively through internal bleaching and the use of porcelain veneers. For grossly damaged anterior teeth, complete coronal coverage using a crown, or a crown retained by a post, may be necessary.

Either a prefabricated post with direct core buildup (see Fig. 16.7) or a cast post and core (see Fig. 16.8) can be used for anterior teeth. In esthetically demanding situations, discoloration of the crown by a metal post and core can be concerning. To prevent discoloration one can use prefabricated metal posts that are coated with a thin layer of opaque resin along with a tooth colored composite resin core. Alternatively, a cast post can be fabricated using a metal ceramic alloy that allows the application of opaque porcelain to mask the metallic color, thereby achieving better esthetic outcomes (Fig. 16.9). Tooth colored fiber or ceramic posts may also be considered.

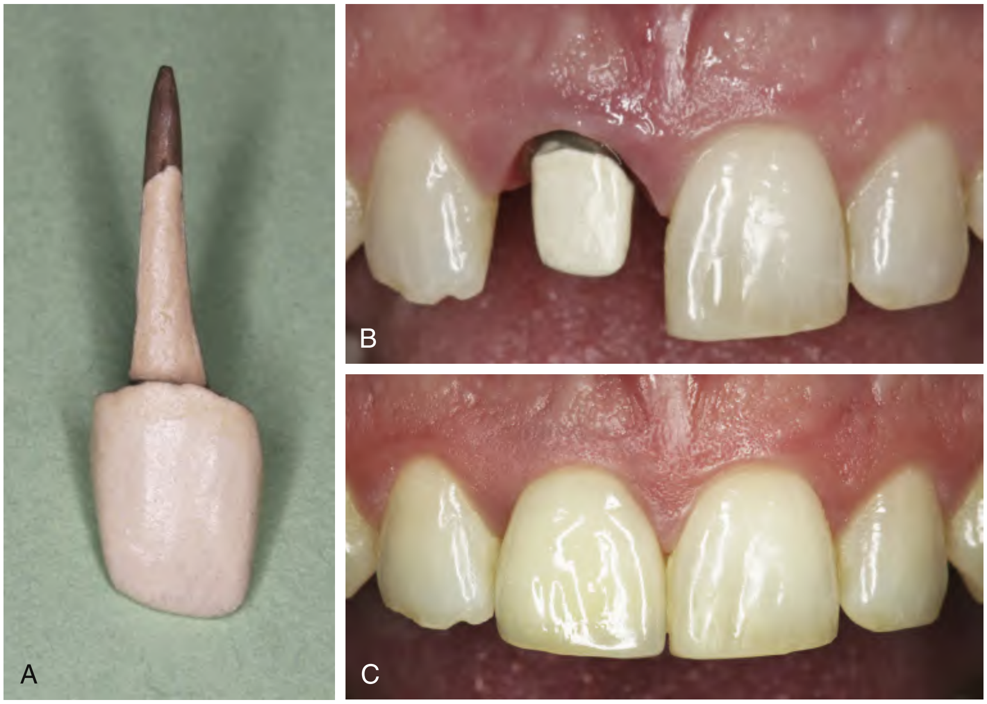
Anterior root canal treated teeth must withstand tipping and lateral forces from mandibular excursive movements which, if transmitted excessively via a post, can fracture the root. Consideration should be given to the occlusal scheme. Where possible, the excursive load should be limited, with more force being borne by adjacent, more structurally sound teeth.



• **Fig. 16.7** **(A)** Composite resin core buildup, with a ferrule incorporated into the preparation so that the crown can grasp the tooth structure cervical to the core. **(B)** The metal-ceramic crown as the definitive restoration.



• **Fig. 16.8** **(A)** Maxillary canine with oval root canal. This tooth is not morphologically suited for a prefabricated post because the post would contact only a small portion of the mesial and distal walls, or the tooth would have to be extensively prepared to a round form, weakening the tooth or possibly perforating it where the proximal root depressions are present. **(B)** A resin pattern was made directly in the tooth. **(C)** The pattern was invested and cast. **(D)** The cast post and core are cemented, and the tooth is ready for final preparation. (Courtesy Dr. J. Kan.)



• **Fig. 16.9** **(A)** Cast post and core fabricated using metal ceramic alloy with porcelain opaque layer applied. **(B)** Cast post and core cemented on central incisor. **(C)** Final restoration.

Study Questions

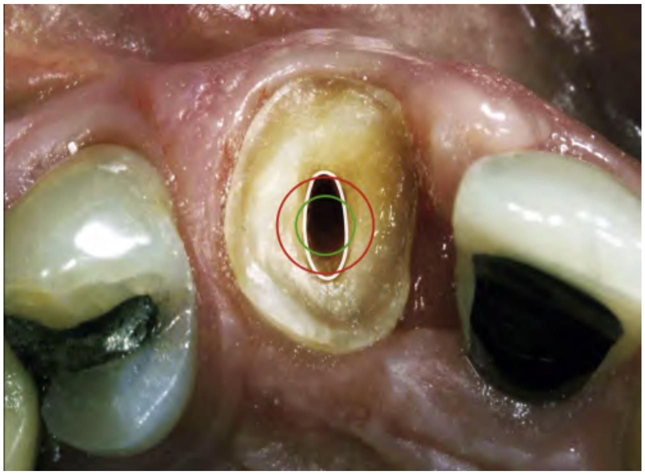
1. What is the most important determination before endodontic therapy?
   a. Length of root
   b. Curvature of root
   c. Restorability of tooth
   d. Location of tooth
2. Which of the following are criteria of a restorable tooth?
   a. Amount of remaining coronal tooth structure
   b. Ferrule wall height
   c. Ferrule wall thickness
   d. All of the above
3. What is the minimally suggested ferrule wall height?
   a. 1.0mm
   b. 2.0mm
   c. 3.0mm
   d. 4.0mm
4. Which of the following are contraindications to surgical crown lengthening?
   a. Reduced bone support
   b. Short roots
   c. Poor crown-to-root ratio
   d. Poor esthetic results
   d. All of the above
5. Which complications associated with endodontically treated teeth is the most comm?
   a. Caries and periodontal disease
   b. Lack of definitive restoration
   c. Inadequate restoration
   d. Occlusal stresses
   e. Endodontic factors
6. When restoring an anterior tooth with a conservative endodontic access and no existing restorations, the ideal restoration is a bonded composite
   a. True
   b. False

• **Fig. 16.10** A cast post and core provides the best foundation for restoring maxillary premolars.

Posterior Teeth

Premolars with substantial loss of coronal structure, missing buccal or palatal cusps, particularly maxillary premolars, often necessitate a cast post and core (Fig. 16.10). Premolar roots present many risks to post placement. Narrow mesiodistal root width and large developmental root concavities, coupled with tapered roots, may result in excessive removal of root structure or perforation when the tooth is prepared for a prefabricated post. Additionally, the mesiodistal thinness of the tooth may not permit adequate core thickness to allow strength when using a prefabricated post. Minimal enlargement during post space preparation is essential to preserve sufficient dentin thickness.[79] In maxillary premolars with two roots, the palatal canal is generally used for the post because the buccal root can frequently have a concavity on its furcal aspect.[79,80] A small, short (2 mm to 3 mm) post in the buccal canal can be used to provide some retention, resistance, and antirotation. As a rule of thumb, when a root canal is circular (Fig. 16.11) a

• **Fig. 16.11** **(A)** Maxillary lateral incisor with a circular canal is prepared for glass fiber post. **(B)** Fiber post bonded into prepared root canal. **(C)** Composite resin core and completed tooth preparation. **(D)** Cemented crown. **(E)** Radiograph showing the zirconia core with porcelain veneer and slightly radiopaque fiber post.



• **Fig. 16.12** An ovoid canal is prepared for a cast post and core (*white outline*), providing the best foundation for restoring maxillary premolars. If a prefabricated post space was created (*green outline*) the post would have minimal contact with the tooth, being retained primarily by cement. If a larger post space was created (*red outline*) the tooth would be structurally compromised, leading to perforation or fracture.

prefabricated post may be used. However, if the root canal is ovoid, a prefabricated post would be in close proximity to the mesial and distal walls of the canal whereas the facial and lingual areas would be filled with cement (Fig. 16.12). Therefore if the root canal is ovoid or ribbon shaped a custom cast post is suggested.

Most molars can be restored with a direct core foundation, gaining retention and resistance form from their relatively large pulp chambers, without the need of a post (Fig. 16.13). Additional core resistance and retention form is gained by extending the core material 1 mm to 2 mm into the canal orifices (see Figs. 16.6 and 16.13).[82] With fast-setting amalgam, the tooth may be prepared for the crown at the same visit, although preparation is easier when the material has fully hardened. A widely used alternative to amalgam is composite resin, which has a fracture resistance comparable to that of amalgam and produces more favorable tooth fracture patterns if failure occurs.[83,84] Composite resin has the advantage of allowing immediate crown preparation.[83] Glass ionomer does not have sufficient compressive strength for use as a core material. However, when minimal remaining coronal tooth structure is present and a small pulp chamber will not provide sufficient core retention, a post may occasionally be needed to provide retention for molar cores. The longest and straightest canal is preferred for the post, typically the palatal canal of maxillary molars and a distal canal in mandibular molars.[81] Even these roots can be hazardous; the palatal root typically curves toward the buccal, and the distal root of lower molars typically has large mesial and distal concavities. Other molar canals are generally even more problematic and generally should be avoided.

Considerations for Direct Restorations

Anterior teeth should generally be restored with direct restorations. Posterior teeth may be restored with direct restorations when they are largely intact, most of the marginal ridges remaining, along with a conservative access cavity and minimal overall loss of tooth structure.

Posterior teeth with substantial tooth structure loss may be restored with amalgam if it is esthetically acceptable and if unsupported cusps are adequately protected by the amalgam.[85] Some cuspal coverage amalgams have lasted for many years (Fig. 16.14), whereas others have fractured as a result of the presence of heavy occlusal forces. Assessment of occlusal forces and functional activity helps determine whether a cuspal coverage amalgam is a suitable restoration. A conventional Class II amalgam without cuspal coverage does not provide cuspal protection and ordinarily should not be used.[86] At a minimum, cusps adjacent to a lost marginal ridge should be onlayed with sufficient thickness of amalgam (at least 2.0 mm)[87] to resist occlusal forces (see Fig. 16.14). The amalgam should extend into the pulp chamber and canal orifices to aid retention. The amalgam may subsequently serve as a core for an indirectly fabricated restoration if indicated (see Fig. 16.13). Bonded amalgams have also been used, but their clinical performance in root-filled teeth has not been well documented, and bond failure is likely to be catastrophic in the presence of weakened, unprotected cusps.

The need for a tooth-colored restoration warrants the use of bonded composite resin restorations. The use of bonding continues to improve as materials and techniques improve, and good results have been reported in a long-term prospective clinical study of composite resin restorations.[88] Proximal leakage and recurrent proximal caries remain a concern, particularly when the restorations have subgingival margins and were placed without the use of a rubber dam. However, the ability to replace the missing tooth structure with a tooth colored, bonded restoration offers many benefits that should not be overlooked.

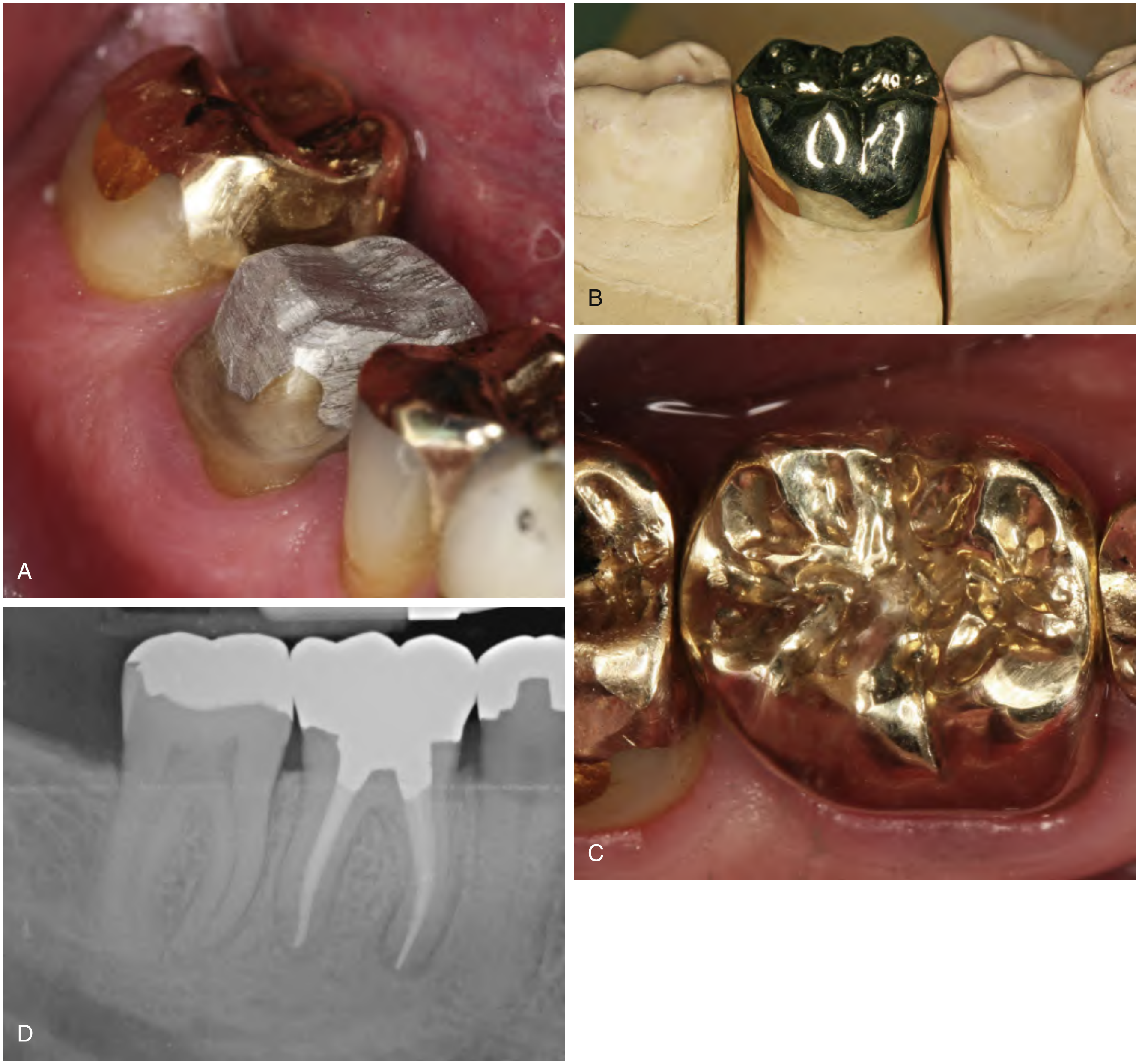
Considerations for Indirect Restorations

All-metal cast restorations (onlays and three-quarter and complete crowns) provide excellent occlusal protection and are optimal when the loss of tooth structure requires coronal coverage. The attractiveness of onlays is that the tooth preparation design is more conservative than complete coverage preparations, yet provides good cuspal coverage. The strength and toughness of gold allows conservative tooth reduction, with a reverse bevel providing effective cuspal coverage. Complete coverage all-metal crowns are used when there is insufficient coronal tooth structure present for a more conservative restoration or if functional or parafunctional stresses require the protective effect of complete coronal coverage.

When a tooth is prepared for a crown, the coronal access opening should be restored and sealed with an amalgam or a bonded composite resin as part of the core foundation for the crown. Glass ionomer can also be used to restore the access opening, as long as its purpose is to seal the opening and it is not forming a substantial portion of the axial walls that will be used for retention of the crown.

The esthetic requirements of many patients prevent the use of all-metal crowns. Metal-ceramic and all-ceramic crowns have become frequently used materials for root canal-treated teeth. Although all-ceramic crowns provide enhanced esthetics, metal-ceramic crowns can also be esthetic and they provide a reliable, strong restoration that protects against root fracture (Fig. 16.15).[78,89-92] However, root canal treatment may have required substantial tooth structure removal and that, coupled with the reduction needed for a crown, can necessitate placement of a core restoration and sometimes a post to retain the core.

To plan the core shape there must be complete exposure of the tooth's perimeter. Gingival retraction cord and sometimes soft tissue removal through electrosurgery or use of a laser are beneficial methods that help prevent undersized cores being made because of incomplete visualization of the tooth preparation finish line. When a core is used as a foundation for the crown without the use of a post, the material must be well retained into remaining tooth structure and must be of sufficient thickness so that the material will not fracture during function, resulting in crown failure (Fig. 16.16).



• **Fig. 16.13** **(A)** Amalgam core that covered the cusps has been prepared for a complete gold crown. **(B)** Complete crown on the working cast. **(C)** Occlusal view of the cemented crown. **(D)** Periapical radiograph of the cemented crown showing the amalgam core extended into the pulp chamber.

Posts

Coronal Tooth Preparation

Caries and prior restorations must be removed. Thin delicate spurs of tooth structure may be removed, but there is no need to make a flat uniform occlusal or incisal surface; the height of the remaining tooth structure should be maintained.

Ferrule

The use of a cervical ferrule that encompasses the tooth structure is the key to preventing tooth fracture and restoration loss (Fig. 16.17). Ferrules formed by a crown that extends cervically to engage the tooth structure apical to the core help teeth resist fracture, whereas ferrules created by the core overlapping the coronal tooth structure are generally not effective.[9-12] Crown ferrules that encompass more than 1 mm of tooth structure are the most effective in helping teeth resist fracture.[10] Ferrules that encompass 2 mm of tooth structure around the entire circumference of a tooth produce higher fracture resistance than ferrules that engage only part of the tooth circumference (see Fig. 16.10).[11,12]

Post Selection

A post is used to retain the core and provide resistance to lateral or tipping forces. The need for a post is dictated by the amount of remaining coronal tooth structure available to retain the core. A major disadvantage of posts is that they weaken teeth by additional removal of dentin and by creating stresses that predispose

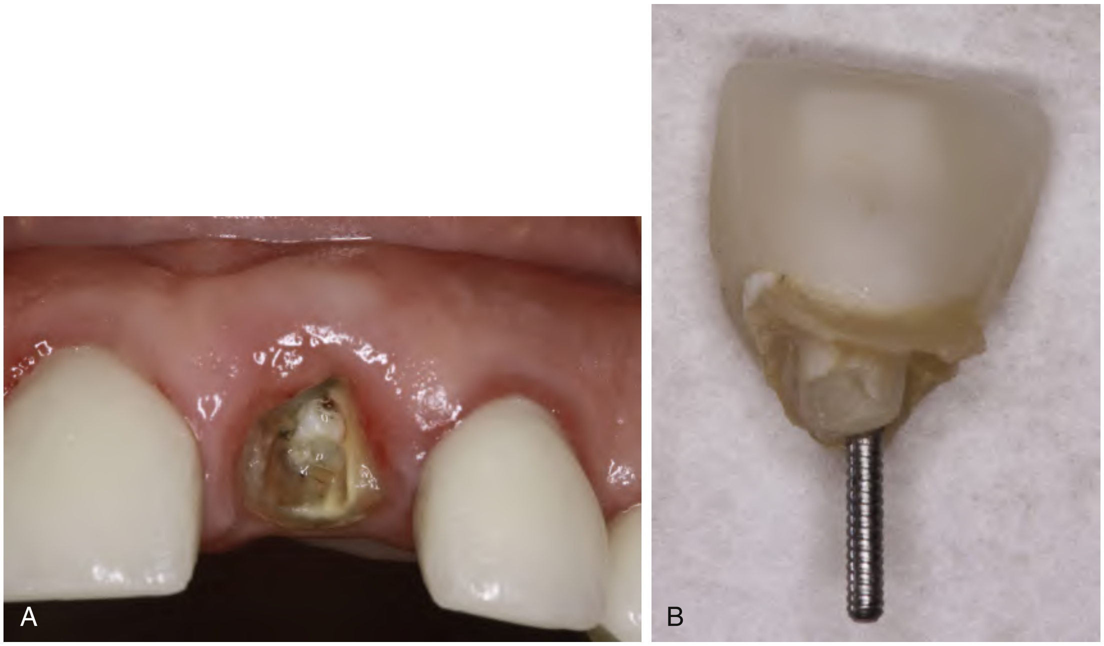
• **Fig. 16.14** Amalgam restoration replaced multiple cusps while also protecting mesiobuccal and lingual cusps with 2 mm of amalgam. It functioned well for more than 10 years, at which point the patient requested a crown on the tooth.

to root fracture.[77,78,83,93,94] Therefore posts are only used when the core cannot be retained in the tooth by any other means.

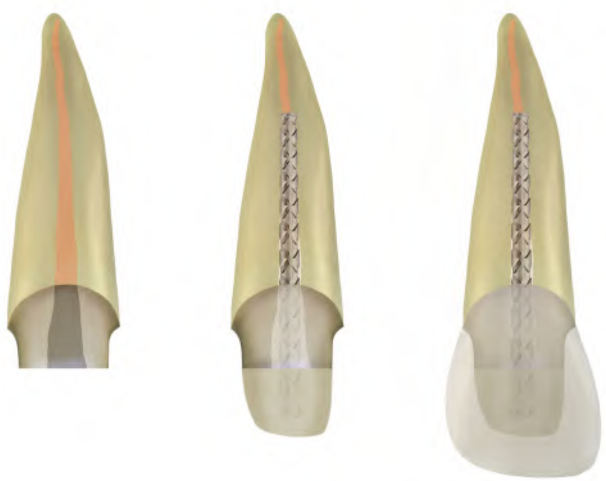
The tooth should not be prepared and adapted to the post system; rather, the post system and preparation design should be selected as appropriate to the tooth and its morphology. Therefore custom-cast posts and cores are preferred for roots that have very tapered root canals. Also, roots with substantial root concavities are best served by using cast posts and cores made to fit the existing morphology after root canal treatment rather than removing tooth structure to make the root fit the form of a prefabricated post. Prefabricated round posts may be particularly problematic in mandibular incisors, mandibular molars, maxillary first premolars, and all canals that are oval to ribbon-shaped (see Fig. 16.12).

Conservative round prefabricated round posts are well-suited for use in teeth that have round roots and round root canals because slight removal of some root structure to adapt the tooth to the post usually does not result in substantial weakening. A wide variety of passively seated prefabricated posts are available. Parallel-sided posts provide more retention than tapered posts. However, they require more apical post space preparation than tapered posts or cast posts

• **Fig. 16.15** **(A)** Endodontically treated maxillary first molar with amalgam core prepared for metal-ceramic crown. **(B)** Cemented crown. **(C)** Occlusal view of the crown. **(D)** Periapical radiograph showing the cemented crown and amalgam core.



• **Fig. 16.16** **(A)** The patient presented with crown failure caused by a lack of tooth ferrule. **(B)** The prefabricated post and composite core had minimal tooth structure with primarily cement retaining the entire crown. This was no match for the forces applied to anterior teeth.



• **Fig. 16.17** (*Left*) Root canal-treated tooth with adequate ferrule. (*Middle*) Post space has been created, post cemented (note white cement between post and canal walls), and composite core build-up. (*Right*) Outline of the final crown and components of a root canal-treated tooth restored with a prefabricated post and core.

and cores; matching post size to canal size is important to minimize dentin removal and cement thickness. The post should closely approximate the root canal walls without binding, but it need not contact dentin throughout its entire length. Threaded, active, posts should be avoided; passive posts are preferred.[94,116,117] Serrations and vents allow the post to be seated without undue pressure and the set cement to grip the post.

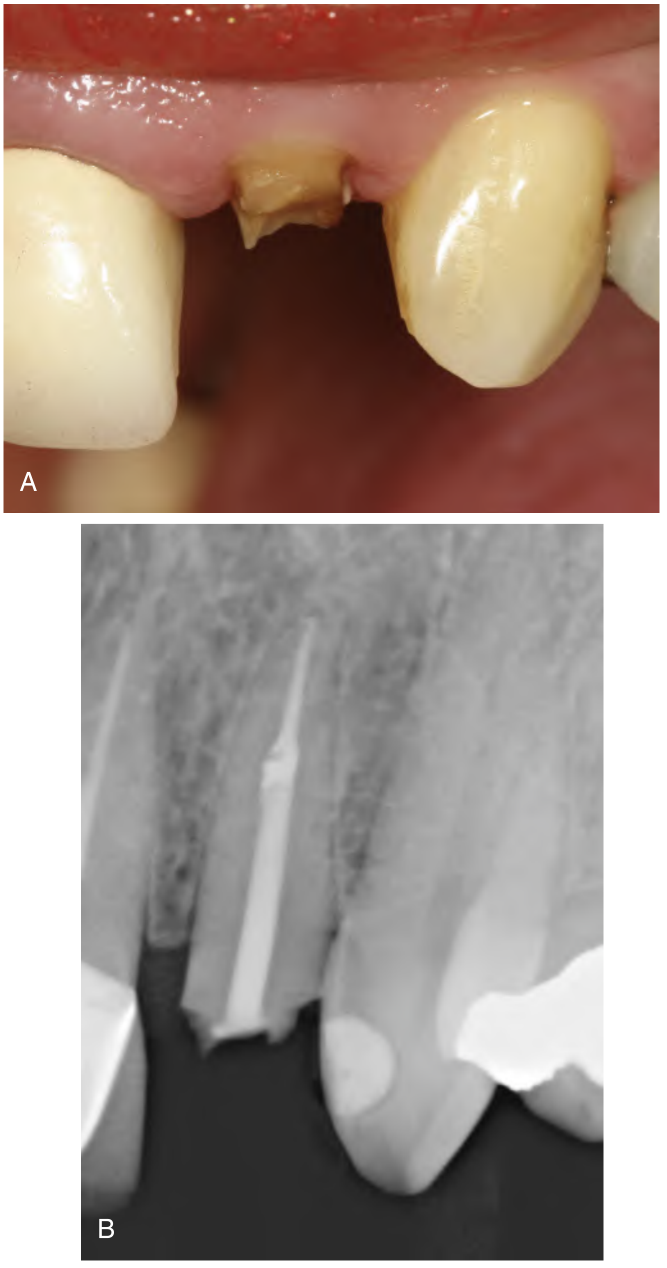
There has been a debate regarding how the post should interact with the tooth under load and whether the post material should be similar in stiffness to root dentin (quartz fiber), somewhat stiffer (carbon fiber, titanium, and gold), or much stiffer (zirconia, stainless steel, and cobalt-chromium alloys).[95] Stiff posts have been successfully used for decades, help to protect restorations, but they may lead to a slightly increased risk of tooth fracture, whereas the more flexible posts deform with the tooth and may tend to fail more frequently but without fracturing the tooth.[96] Long-term clinical trials are needed to determine how posts should interact with teeth and what degree of stiffness functions best.

Tooth-colored post and core materials are needed beneath all-ceramic crowns to prevent discoloration and to allow some light transmission through the crown and tooth; this situation has created increased interest in fiber posts (see Fig. 16.11). The desire to have posts flex in concert with tooth structure has also raised interest in fiber posts. Quartz fiber posts appear to be advantageous with regard to root fracture potential.[97-112] However, these types of posts were less retentive than metal posts in laboratory tests,[113] indicating the need for optimal post length. Clinical results with fiber posts have been mixed; many studies have reported high levels of success, but other, longer term studies[103,111,112] have reported higher failure rates.[103,110,112] Post loosening, post fracture, and even root fracture have been reported. Hence, it is proposed that fiber posts be used cautiously when post length is less than optimal (Fig. 16.18), when peripheral walls are missing (Fig. 16.19),[114] or when heavy occlusal forces or parafunctional habits are present.[115]

Post Space Length

When a post is required for core retention, the minimum post space (length, diameter, and taper) should be prepared under rubber dam. Preparation consists of removing gutta-percha to the required length, followed by the least amount of enlargement and shaping needed to receive the post (see

• **Fig. 16.18** Excessively short fiber post that rapidly failed and resulted in fracture of the remaining facial tooth structure, visible inside the crown. (Courtesy Dr. N. Baba.)



• **Fig. 16.19** **(A)** Fiber post that fractured. Note the lack of peripheral walls to help support the post. **(B)** Radiograph showing the fractured fiber post. (Courtesy Dr. N. Baba.)

Fig. 16.17). Caution is required because excessive removal of gutta-percha results in a defective apical seal.[118,119] Because there is evidence that longer posts are more retentive[119,120] and have less potential to cause root fracture than do short posts,[120-124] optimizing post length is appropriate as long as the apical seal is not compromised.

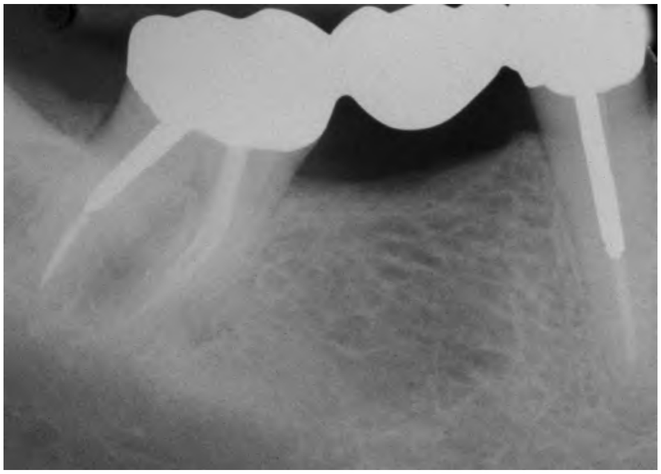
In order to protect the apical seal it is recommended that at least 5.0 mm of apical gutta-percha be retained and the post extended to that level (see Fig. 16.17). For molars, the length is determined by the potential for root thinning or perforation and root curvature.[125] Posts should be extended only 5.0 mm into the root canal and only in the straightest widest molar root (distal root of the mandibular molars and palatal root of the maxillary molars) (Fig. 16.20).

Radiographs may be deceptive as a guide to root curvature and diameter by disguising root concavities and curves in the faciolingual plane; off-angle radiographs are helpful in understanding faciolingual curvature.[81] As a general rule, the post diameter should be minimal, particularly apically, and not more than one quarter to one third of the root diameter (see Fig. 16.20).[79] Tapered post preparations minimize the amount of tooth structure removed apically and thereby reduce the amount of tooth structure removed. However, tapered posts have been shown to be less retentive and cause more stress on the tooth as a result of a wedging effect.[126,127]

Removal of Gutta-Percha

Whenever possible, gutta-percha is removed under rubber dam isolation immediately after obturation, and the tooth is robustly provisionalized before rubber dam removal, to ensure apical and coronal sealing.[128] At this stage, the dentist is most familiar with the canal features, including shape, length, size, and curvature. Gutta-percha is removed to the desired length using a hot instrument. The remaining gutta-percha is then vertically condensed before the sealer has set. A radiograph confirms that sufficient gutta-percha remains (5 mm) for the apical seal.[128,129]

Gutta-percha removal at a subsequent appointment is also an appropriate process.[128-130] A safe procedure is the use of a heated instrument. Gutta-percha is removed in increments to the desired length using a heated plugger that has sufficient heat capacity. Solvents should not be used for removing gutta-percha to create a post space because of messiness and unpredictable depth of penetration. Rotary instruments may be used, but caution is required, because they can create a channel that does not follow the root canal, causing root thinning or, worse yet, perforation. Gates-Glidden drills are less likely to go off track or perforate than Peeso reamers. Rotary instruments may also “grab” and displace the apical gutta-percha. Nickel-titanium rotary instruments specially designed for preparing post spaces are available; these have a noncutting tip.



• **Fig. 16.20** Molar abutment for fixed partial denture has a post in the distal root that extends 5 mm beyond the base of the pulp chamber into the root canal. The post was prepared with a tapered form to minimize tooth reduction. In the premolar abutment, a parallel-wall post was used because of the more favorable root morphology and dimensions.

They can be effective[131] and pose low risks of ledging or canal transportation.[132,133]

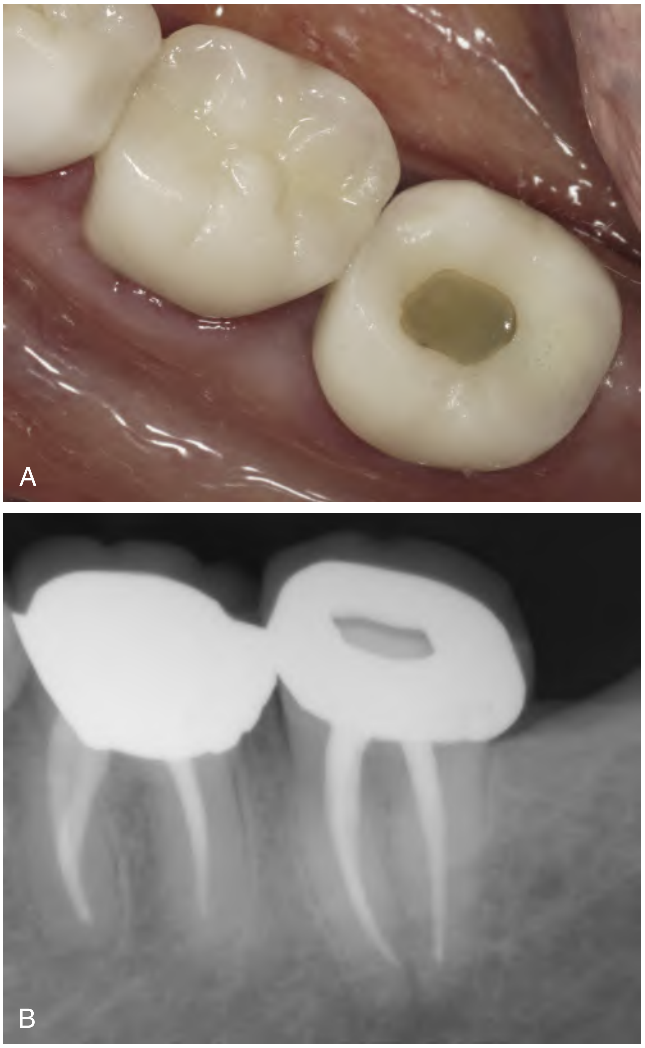
Completing the Post Space Preparation

After the post length and diameter have been established, the post space may need further refinement to eliminate small undercuts. After gutta-percha has been removed, rotary instruments can be used for final post space shaping; however, as stated previously, they should be used carefully to avoid excessive tooth removal that weakens the root or causes a perforation. Post spaces for prefabricated posts should be finished using the manufacturer's recommended drill. Final shaping can also be performed using hand manipulation of the rotary instruments because only small amounts of tooth need to be removed in most situations. After a post space has been made, a robust provisional restoration must be used to exclude oral bacteria, and a calcium hydroxide intracanal medicament will provide further protection until the post has been cemented.

Post Cementation

Proper post cementation is vital; the recommended procedures are:

1. Rubber dam isolation is needed before removal of the provisional restoration and intracanal medicament.
2. The post should be fitted to the canal and the seating verified radiographically. Custom cast posts can be adjusted to achieve a passive fit using a silicone disclosing medium (e.g., Fit Checker), then air particle abraded using 50-µm aluminum oxide, before being cleaned.
3. The walls of the post space should be disinfected using sodium hypochlorite; the smear layer removed using ethylenediaminetetraacetic acid (EDTA); rinsed with water; and dried using paper points, not by blowing air.
4. After referring to the cement procedural instructions, properly mix or activate the cement and place cement in the canal system. Depending on the specific cement used, a slow-speed handpiece and lentulo spiral turning clockwise may be used to uniformly disperse the cement throughout the canal system. Some cements preclude the use of a lentulo spiral because it speeds up their setting time.



• **Fig. 16.21** **(A)** Access through existing crown that has been sealed with composite. **(B)** Radiograph showing root canal treatment through crown.

5. Place cement onto the post and carefully seat the post. Remove excess cement once it has set enough for the cement to come off in solid pieces.
6. Allow complete setting of the cement before using any rotary instruments to shape or refine finish lines to avoid potential weakening of the cemented post caused by vibration. Depending on the cement used this may require provisional restoration of the tooth and returning at another appointment to refine the interface between post and tooth.
7. Build-up of the core is performed for the prefabricated posts using a definitive restorative material (composite resin, amalgam). The tooth with core build-up is then refined for the final restoration and an impression made, or the prepared tooth scanned.

Restoring Access Through an Existing Restoration

Occasionally, pulps undergo irreversible pulpitis or necrosis after placement of a crown, requiring root canal treatment (Fig. 16.21).[76,93,134] Access through the restoration, with subsequent definitive repair of the opening, is preferable to making a new crown.

For the restoration to remain functional, four conditions must be met: (1) The restoration must be proved to be without leakage, preferably recently placed; (2) the interface between the restoration and the repair material must provide a good coronal seal; (3) retention of the crown must not be compromised; and (4) the final core structure must support the restoration against functional or minor traumatic stresses. Access, particularly if overextended, may leave only a thin shell of axial dentin, especially in anterior teeth and premolars. Retention then depends almost entirely on the repair material. Fortunately, the chamber and canal are available to create a core that provides adequate retention and support in many instances. Placement of a post through an access opening in an existing crown into the root canal adds little additional support and retention and is rarely indicated.

The repair material should have high compressive and shear strength. Amalgam is an excellent material that maintains (and even improves) its seal with time and is easily condensed into the entire chamber and access opening as a single unit. Composite resins are usually the material of choice in tooth-colored crowns.[83] Glass ionomer and other cements do not have the required shear, tensile, or compressive strength.

Essential Precepts

Key points in retaining and restoring all root canal-treated teeth by any method include:

1. Careful preoperative assessment regarding the amount of remaining tooth structure and planning for the definitive restoration;
2. Conservation of tooth structure during access preparation and restorative procedures;
3. Use of rubber dam isolation until after a definitive core restoration or post has been placed;
4. Use of coronal coverage to bind the cusps together on most posterior teeth;
5. Avoidance of crowns on anterior teeth, unless absolutely necessary;
6. Avoidance of posts unless there is no other way to provide resistance or retention for the final restoration;
7. Prompt restoration without delay.

Study Questions

7. When restoring a mandibular molar with a large pulp chamber which of the following is the preferred technique?
   a. Post cemented in the distal root
   b. Direct core placed in pulp chamber and crown
   c. Occlusal composite filling
   d. Cast post and core with crown
8. Posterior endodontically treated teeth should primarily be restored with what type of definitive restoration?
   a. Crown
   b. Direct composite filling
   c. Direct amalgam filling
   d. Inlay
9. What is the primary purpose of a post?
   a. Strengthen the tooth
   b. Retain the core build-up
   c. Compensate for minimal ferrule
   d. Improve esthetics
10. What is the minimum amount of gutta percha required to maintain an apical seal?
    a. 3.0mm
    b. 4.0mm
    c. 5.0mm
    d. 6.0mm
11. Which of the following are key elements that an existing crown must display prior to accessing through an existing restoration?
    a. The restoration must be proven to be without leakage
    b. The interface between the restoration and the repair material must provide good coronal seal
    c. Retention of the crown must not be compromised
    d. The final core structure must support the restoration against functional or minor traumatic stresses
    e. All of the above

ANSWERS

Answer Box 16

1 c. Restorability of tooth
2 d. All of the above
3 b. 2.0mm
4 e. All of the above
5 a. Caries and periodontal disease
6 a. True
8 b. Direct core placed in pulp chamber and crown
7 a. Crown
9 b. Retain the core build-up
10 c. 5.0mm
11 e. All of the above

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