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Endodontic Treatment Outcomes

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CHAPTER OUTLINE

LEARNING OBJECTIVES

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

1. Describe signs of successful and unsuccessful root canal treatment.
2. Describe the most common modalities used to determine success or failure.
3. State the approximate range of expected outcomes of routine, uncomplicated root canal treatment based on pretreatment conditions.
4. State predictors of success and failure.
5. Identify endodontic and nonendodontic causes of treatment failure.
6. State the outcomes of retreatment, endodontic surgery, and intentional replantation.
7. State the outcomes of fixed partial denture and single tooth implant treatments.
8. Approach treatment planning of root canal failure, recognizing the advantages and disadvantages of different treatment modalities.

Introduction

The primary goals of endodontic treatment are to provide patients with the best possible long-term outcomes regarding function, comfort, and esthetics. From a biologic perspective, this encompasses the prevention or cure of apical periodontitis. Prevention will be the focus for treating teeth presenting with pulpal inflammation, such as irreversible pulpitis. This can be achieved by maintaining aseptic conditions utilizing hygienic protocols and rubber dam isolation to prevent any oral microorganisms or bacteria present in caries from entering the root canal system during or after root canal treatment.

The objective for treating teeth with infection present within the root canal system is to significantly reduce the microbial load and to prevent recontamination.[1-3] This is achieved by a disinfecting phase, including thorough mechanical instrumentation, antimicrobial irrigation, and medication, as well as a sealing phase including root canal filling and placing permanent restoration. Complete root filling should largely eliminate the habitat for microorganisms, so that any residual microorganisms after treatment can be expected to perish as a result of the harsh environmental conditions of a well-sealed root canal root canal system, or at least rendered dormant. Finally, restorations preventing coronal leakage should disallow bacterial recontamination and achieve functional and esthetic rehabilitation.

Optimal outcomes are dependent on attaining these technical goals. However, as a result of the complexity of root canal systems,[4,5] less than perfect instrumentation, and root filling techniques, as well as the impossibility to render permanent restorations leakage free indefinitely, the guaranteed elimination of microorganisms from the root canal systems cannot be achieved under certain circumstances.

The purposes of this chapter are to (1) define success and failure, (2) describe methods used for the evaluation of endodontic outcomes, (3) provide outcome rates, including success and survival, (4) explain the signs and symptoms of negative outcomes, (5) discuss factors influencing outcomes, and (6) compare the outcomes of initial nonsurgical root canal treatment with those of nonsurgical retreatment, surgical retreatment (endodontic surgery), and alternative treatments, such as single tooth implants.

Definitions of Success and Failure

A successful outcome of root canal treatment may have a different meaning to different stakeholders involved in the treatment, including patients, dentists, and third-party payers.[6]

Patients will expect the elimination of symptoms, comfortable chewing function, satisfying esthetics, reassurance that symptoms may not recur, and that their tooth does not pose a risk of causing systemic disease. Insurance companies may judge the outcome by the access to care provided, the quality of care, cost efficiency, and the longevity of the treatment rendered.

Dentists are primarily concerned with the delivery of optimal care, predictable elimination of disease as measured clinically and radiographically, and fair compensation. In addition, they engage in aligning all stakeholders' expectations. Dentists should also reevaluate the technical quality of treatment and the long-term outcome in terms of preventing and eliminating apical periodontitis.

For endodontically treated teeth with previously vital pulps and no preexisting apical lesion, success entails that the tooth remains asymptomatic and no periapical pathosis develops after treatment. Failure will involve new symptoms and/or the appearance of a periapical lesion. For a tooth with a diagnosis of pulp necrosis, the outcome of the treatment is considered successful if the tooth remains asymptomatic and a preexisting apical periodontitis heals, respectively, no new apical lesion develops during follow-up. The presence of symptoms and/or a new or enlarging lesion is considered failure of the treatment.

Recently the American Association of Endodontists has proposed the following alternatives to the terms "success" and "failure":

- Healed—Functional, asymptomatic teeth with no or minimal radiographic periradicular pathosis.
- Nonhealed—Nonfunctional, symptomatic teeth with or without radiographic periradicular pathosis.
- Healing—Teeth with periradicular pathosis that are asymptomatic and functional, or teeth with or without radiographic periradicular pathosis that are symptomatic but for which the intended function is not altered.
- Functional—A treated tooth or root that is serving its intended purpose in the dentition.

Determination of success or failure may be difficult because of the nature and complexity of the periapical healing process itself and as a result of difficulties in observation. Many asymptomatic endodontically treated teeth demonstrate varying degrees of apical lesions radiographically. The clinician must judge whether a tooth is on a pathway to success or to failure and then decide together with the patient on a proper course of action if indicated.

When to Evaluate

Recommended follow-up periods have ranged from 6 months to 5 years.[7-12] Six months is a widely accepted and reasonable early follow-up interval for most situations. It is important to determine at what point of a healing process the outcome of treatment will be unlikely to reverse its course, and when treatment can be judged predictably as either success or failure, without a further need for follow-up.

A radiographic lesion that remains unchanged or increased in size after 1 year of follow-up is unlikely to ever resolve, and hence considered to be unsuccessful. If after 6 months a periapical lesion is still present, albeit smaller, it is likely to be in progress of healing, and further follow-up is indicated. Larger periradicular lesions will take longer to heal than smaller lesions. Unfortunately, apparent success may revert to failure later (often as a result of reinfection through coronal leakage), yet, late healing may also occur. Therefore an endodontic evaluation, including a patient history, clinical examination, and radiography of endodontically treated teeth should be part of every comprehensive patient examination.

Methods for Evaluation of Endodontic Outcomes

The evaluation process of successful endodontic therapy is complicated by the lack of direct correlation between measures of the disease process and its clinical manifestation. The clinician must therefore assimilate various metrics of information including patient history, clinical findings, and radiographic examinations to determine endodontic treatment outcomes. Evaluation of endodontic outcomes follows the same diagnostic pathway as for initial treatment (see Chapter 4). Biopsy of periradicular tissues during endodontic surgery provides a histologic diagnosis, another method for evaluation of success or failure of root canal treatment. This method is not routinely used and is an impractical approach to determine clinical outcomes of initial nonsurgical root canal treatments.

Patient History

Complaints of new, persistent, or worsening symptoms after root canal treatment has been completed may indicate failure. Persistence of signs (e.g., sinus tract opening) or symptoms long after endodontic therapy had been completed indicate primary and continuing disease. However, emergence of new signs or symptoms months or years after root canal treatment usually result from secondary posttreatment disease such as leakage secondary to absence of suitable coronal restoration. Symptoms related to discomfort or pain on chewing, aching, and so forth are generally an indication of periradicular inflammation or infection regardless of the evidence of radiographic lesion. It must be remembered that bony healing takes time and that a tooth that feels "different" on biting may be en route to healing; this should be confirmed clinically and radiographically. Pain on release may indicate a cracked tooth. A bad taste may indicate a draining abscess. Occasionally a patient reports sensitivity to cold or heat; this is most likely related to an adjacent untreated tooth but could be an indication of a missed vital canal in a treated tooth.

Clinical Examination

Presence of persistent signs or symptoms is usually an indication of disease and failure. However, absence of symptoms does not signify success. Periapical pathosis without significant symptoms is usually present in teeth before and after root canal treatment until healing has occurred.[13] There is little correlation between

the presence of pathosis and corresponding symptoms; yet when adverse signs or symptoms are evident, there is a strong likelihood that a pathosis is present.[14] Persistent signs (e.g., swelling, probing defect, or sinus tract) or symptoms usually indicate failure.

Common clinical success criteria include the following[14]:

- No signs of swelling, infection, or inflammation
- Disappearance of sinus tract (separate or through periodontal ligament space)
- No soft tissue defects or pathologic probing depths

As part of the overall assessment of the tooth after endodontic therapy it is crucial to evaluate the current restoration and the periodontal attachment apparatus. A defective/missing restoration as well as active periodontal disease have been significantly associated with loss of an endodontically treated tooth.[15]

Radiographic Findings

Based on the interpretation of radiographs, the outcome of each treatment can be classified as success, failure, or questionable status. To be able to accurately compare radiographs made at different times, it is important that they are made in a reproducible fashion and with minimal distortion. The best way to ensure reproducibility is with paralleling radiographic devices. Teeth with multiple roots or canals should be examined using both straight-on- and off-angle periapical views.

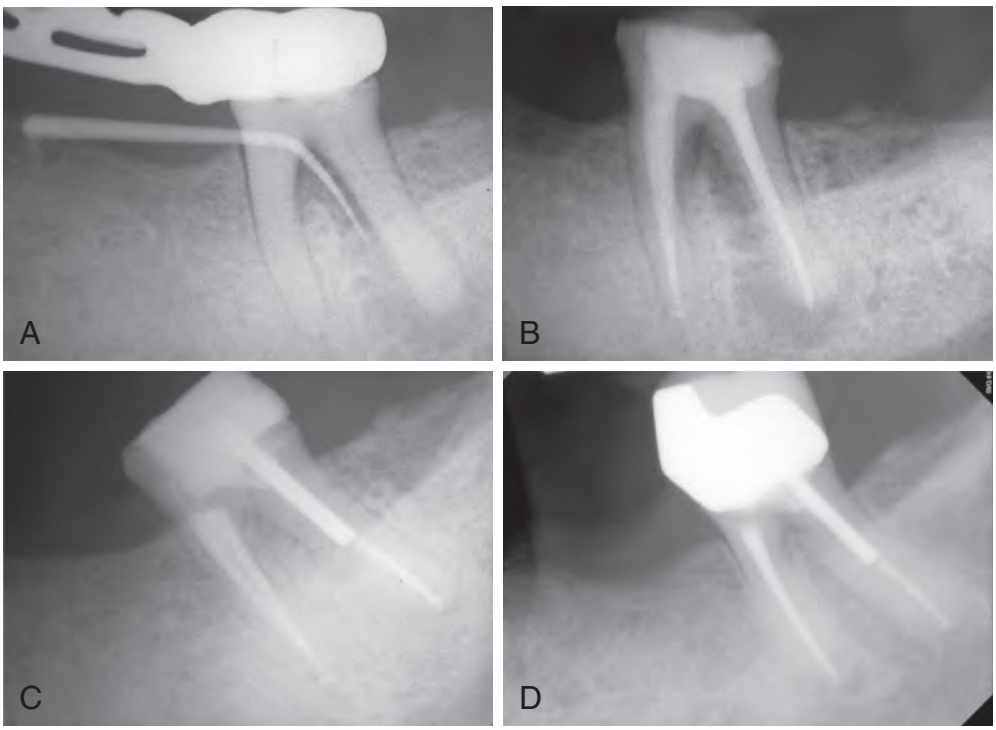
Radiographic success is the absence of an apical radiolucent lesion. This means that a resorptive lesion present at the time of treatment has resolved or, if there was no lesion present at the time of initial treatment, none has developed. Thus radiographic success is evident by the elimination or lack of development of an area of rarefaction for a minimum of 1 year after treatment (Fig. 22.1).

Radiographic failure is the persistence or development of pathosis radiographically. Specifically, whether this is a radiolucent lesion that has remained the same, has enlarged, or has developed since treatment (Fig. 22.2). Nonfunctional, symptomatic teeth with or without radiographic lesions are considered failure (nonhealed).

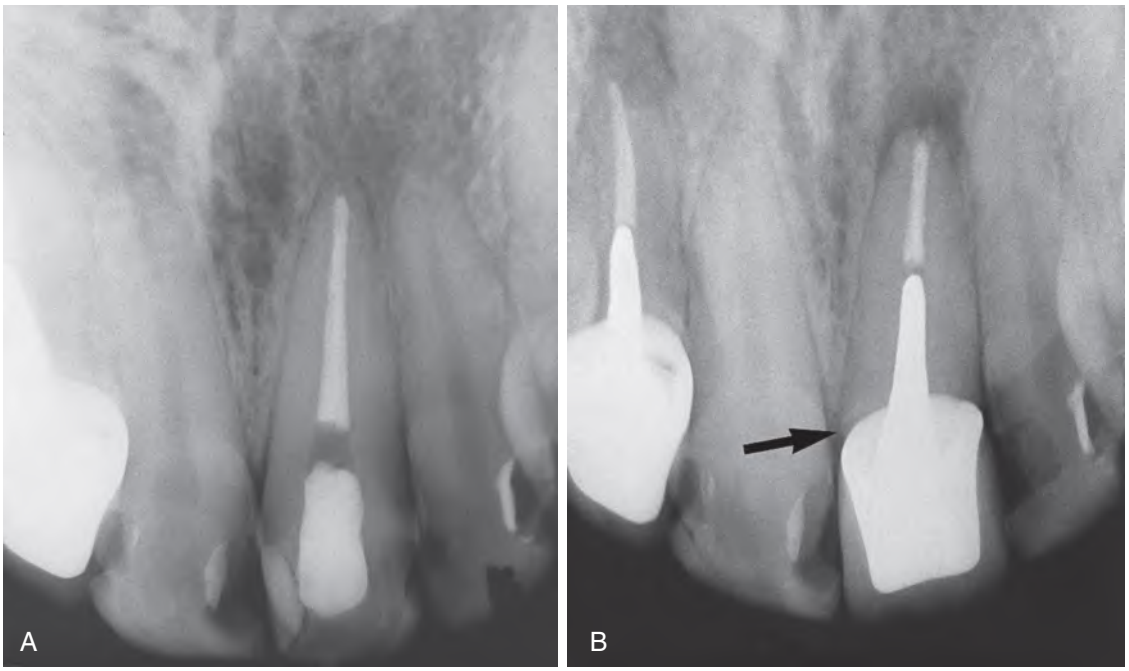
Radiographically unknown status indicates a state of uncertainty. This classification includes teeth with pathosis that are asymptomatic and functional. The radiolucent lesion in these teeth has neither become larger nor significantly decreased in size. Teeth with radiolucencies that were treated elsewhere and for which there are no prior radiographs for comparison are often assigned to this category (Fig. 22.3).

A shortcoming of radiographic evaluation is that radiographs may not be made or interpreted in standardized ways. As early as 1966, Bender et al.[14] noted that radiographic interpretation is often subject to personal bias and that a change in angulations can often give a completely different appearance to the lesion, making it appear either smaller or larger. Also, different observers may not agree on what they see in a radiograph and the same observer may disagree with himself if asked to review the same radiograph at a different lime period.[16]

Ørstavik et al.[17] suggested the use of the periapical index (PAI) for radiographic evaluation of the outcome of root canal treatment. The PAI relies on the comparison of the radiographs with a set of five radiographic images reported by Brynolf in 1967.[18] These images represent a radiographically healthy periapex (score 1) to a large periapical lesion (score 5). Each of the preoperative and recall radiographs is assigned a score according to its resemblance to one of the five reference images. The outcome of treatment using PAI can be classified as "healing" if the lesion size is reduced, "healed" if the lesion has been eliminated, or "developing" if a



• **Fig. 22.1** Success. **(A)** The initial radiograph shows the presence of bone loss from the crest of the ridge around the apex of the distal root. A sinus tract is traced. Periodontal probing demonstrates deep pocketing. There is no response to pulpal vitality tests. **(B)** Root canal treatment completed. **(C)** A 12-year recall radiograph shows resolution of the radiolucency, build-up, and post. **(D)** A 12-year recall radiograph demonstrates healthy apical tissues. The patient wears a removable partial denture.



• **Fig. 22.2** Failure. **(A)** Apparently adequate root canal treatment. The tooth was restored later with a post and core and crown. **(B)** The patient reports persistent discomfort after 2 years. A periradicular radiolucency indicates failure, probably a result of coronal leakage at a defective margin *(arrow)*.

new lesion has formed. Although accurate and reproducible, complete healing using the PAI may take up to 4 or 5 years especially after endodontic surgeries evidenced by a larger number of "slow" healers compared with the "late" failures. Others have commonly used the terms healed, healing, and diseased instead of success and failure because of the potential of the latter to confuse patients.[19]

Cone beam computed tomography (CBCT) with high resolution three-dimensional (3D) imaging technique has demonstrable value in diagnosis and outcomes assessment for endodontic patients (see Chapter 3). The 3D image allows a precise evaluation without the superimposition of surrounding anatomic structures. Recent studies comparing 2D and 3D images have reported a significant increase in uncertain healing and unsatisfactory healing at the 1-year follow-up period owing to higher and more precise detection of bone lesions that may not be visible with two-dimensional radiology.[20-22] Currently, the routine use of CBCT is not recommended[23-24] owing to its higher radiation dosage. However, with constant improvements in hardware and software algorithms CBCT will increasingly become an essential diagnostic and assessment tool for the clinician. The increased sensitivity and resolution may require a reevaluation of criteria for acceptable radiographic periapical healing.

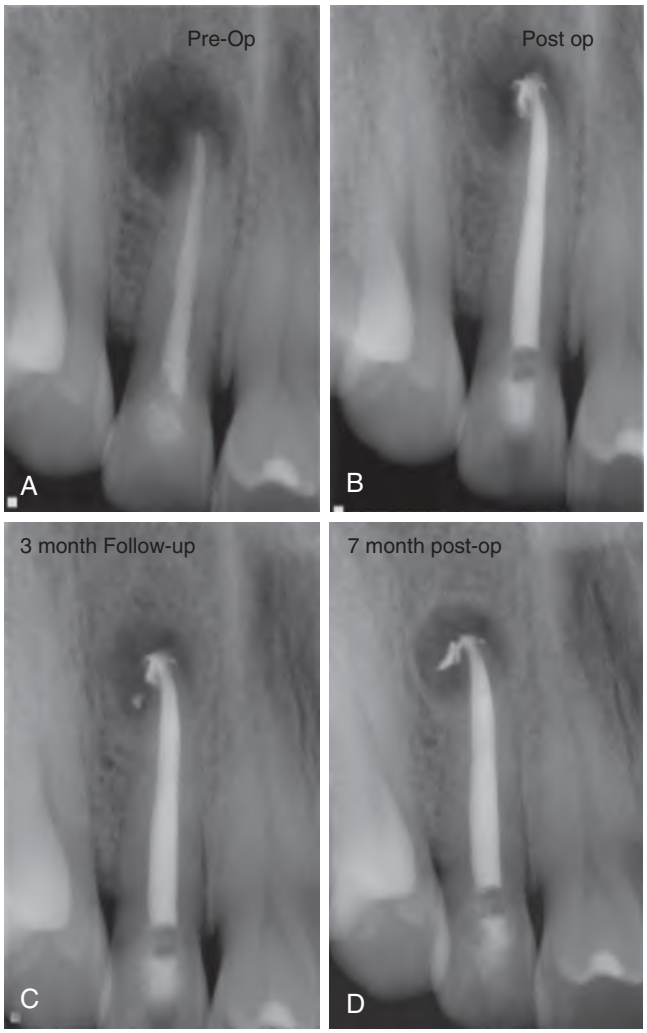
Histologic Examination

The ideal outcome through histologic assessment would necessitate reconstitution of periradicular structures and an absence of inflammation (Fig. 22.4). This is both impractical and impossible without surgery. Additionally, there is uncertainty about the degree of correlation between histologic findings and negative radiographic appearance. Two histologic investigations of teeth treated with root canals in cadavers reached very different conclusions. Brynolf[18] concluded that almost all root canal treated teeth showed some periradicular inflammation despite the appearance of successful treatment on radiographs. In contrast, Green el al.[25] observed that most root canal treated teeth with radiographically normal periapex were indeed free of inflammation histologically. Thus with current technology such as the noninvasive CBCT, the clinical and radiographic evaluation appear to be the more practical means of assessing degree of healing after endodontic treatment.

Success Rates

As is the case for other dental and medical procedures, unfortunately, not all endodontic treatments are successful. Recognition, acceptance, and management of treatments that do not resolve and heal can be difficult and often involve a complex set of factors. Historically, the popular belief has been that the success and survival rates for root canal treatment are between 80% and 95%. However, general percentages should be taken with caution, and each case should be individually assessed to determine the percentage probability of success.

Torabinejad et al.[26] performed a systematic review of the literature pertaining to success and failure of nonsurgical root canal therapy and assigned levels of evidence (LOE) to the studies. In the previous 40 years, 306 articles have been published related to the outcome of nonsurgical root canal treatment. Fifty-one studies included at least 100 teeth; meta-analysis of these studies suggested an overall radiographic success rate of 81.5% over a period of 5 years. Others who assessed the 4- to 6-year outcomes of initial endodontic treatment have reported similar overall healing rates.[27] In another systematic review, Torabinejad and colleagues[28] compared the outcomes of endodontically treated teeth with those of single implant crowns, fixed dental prostheses (FPD), and no treatment after extraction. Success data in that review consistently ranked implant therapy as superior to endodontic treatment, which in turn was ranked as superior to FPD (Table 22.1).



• **Fig. 22.3** Uncertainty. **(A)** Obturation demonstrating voids and coronal leakage likely all contributed to failure. The tooth is suitable for nonsurgical retreatment and a new permanent restoration. **(B)** Postoperative image after retreatment. **(C)** Three-month recall, the patient reports absence of symptoms. The radiolucent lesion is decreasing in size but has not resolved. **(D)** Seven-month recall, despite a new restoration, the lesion has remained and stays in within the same proportions.

However, very different criteria for success are used in implant dentistry, endodontics, and prosthodontics; therefore such comparisons lack validity. Comparison of survival rates is much more meaningful and were recorded at 97% in same study.[28]

Survival Rates

Long-term survival rates for endodontically treated teeth include tooth retention or survival. Introduced by Friedman and Mor[19] in 2004 the term "functional retention" is frequently used to indicate retention of the tooth in the absence of signs and symptoms regardless of a radiographic lesion. Several very large studies have all reported extremely high long-term survival rates for teeth with root canal treatment: Lazarski et al.[29] reported 94% functional survival for 44,613 cases at 3.5 years in the United States; Salehrabi and Rotstein[30] reported 97% survival for 1.1 million patients at 8 years in the United States; and Chen and colleagues[31] reported 93% survival for 1.5 million teeth at 5 years in Taiwan. Teeth with root canal treatments have remarkably high long-term survival rates.

These rates of survival of endodontically treated teeth allow a better comparison with alternative treatments such as FPD and single implant-supported restorations. The previously mentioned systematic review shows that endodontic and implant treatments resulted in superior ≥6 year survival rates compared with extraction and replacement with an FPD.[28] Torabinejad et al.[28] as well as Iqbal and Kim[32] reported similar findings when they compared the survival rates of restored endodontically treated teeth with those of implant-supported restorations. Doyle and colleagues[33] additionally reported that although similar in failure rates, the implant group showed a longer time to tooth function and a higher incidence of postoperative complications requiring intervention. Furthermore, a recent systematic review reported that implant survival rates do not exceed those of even compromised but adequately root canal treated and maintained teeth.[34] Therefore the importance to maintaining the natural dentition through evidence-based dentistry cannot be overemphasized.

Patient-Based Outcomes

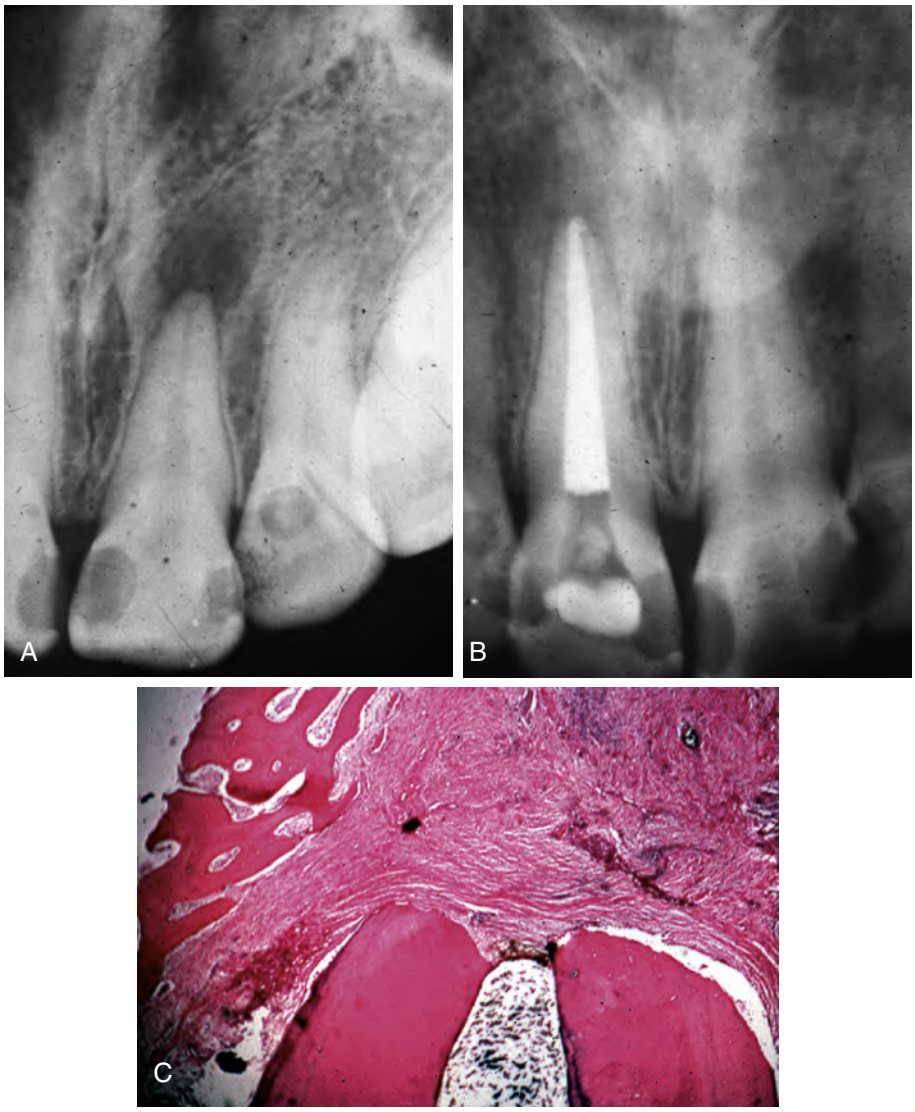
In the current age of patient-centered care, patients' perspectives of their health status are gaining importance in identifying needs, treatment planning, and ultimately in evaluating outcomes from health care. Today definitions of health include psychologic measures of well-being as well.[35] Anticipation and experience of root canal associated pain are major sources of fear for patients and a very important concern of dentists. A recent systematic review found that the severity of pretreatment root canal associated pain was moderate, dropped substantially within 1 day of treatment, and continued to drop to minimal levels in 7 days.[36] Overall satisfaction ratings for root canal treatment are extremely high, generally above the 90th percentile.[37] Satisfaction is higher when endodontic treatment is provided by specialists, probably a reflection of effective communication and efficient management. Initial costs for root canal treatment and restoration are substantially lower than for replacement with an implant single crown or FDP.[28,38]

Recent studies on patient-based outcomes have focused on the Quality of Life metrics. These instruments have mostly been adapted from medicine for application to dentistry, such as the Oral Health Related Quality of Life instruments (OHQoL). Liu et al.[39] reported a longitudinal study on the OHQoL for 279 patients after endodontic treatment using the Oral Health Impact Profile (OHIP) tool of assessment, which was shown to be both sensitive and responsive to endodontic treatment and useful in understanding patients' perspectives of outcomes.

A larger study involving over 1250 patients in a practice-based research network suggests that 3 to 5 years after initial root canal therapy a small percentage (5%) of patients experience persistent pain, of which <2% are not attributable to odontogenic causes that may adversely affect their quality of life.[40] Endodontic nonsurgical retreatment has also shown to significantly improve patients' quality of life and chewing ability over time, with a success rate of 90.4% after 2 years.[41] Future studies from patients' own perspectives could expand our understanding of the prognostic factors and the consequences of root canal treatment.

Postoperative Complications

As with all dental procedures, complications may occur after root canal treatment. However, the incidence of long-term postoperative complications appears to be lower than for the alternatives, single tooth implants and fixed dental prostheses.[33,42] The 10-year



• **Fig. 22.4** **(A)** A periapical radiograph revealed an apical radiolucency on the central incisor. **(B)** A periapical film taken 6 months later shows resolution of most of the apical radiolucency. Despite radiographic change, the patient remained symptomatic, and surgery had to be performed. **(C)** Histologic examination of this tooth shows resolution of most of the inflammatory cells near the apex. (Courtesy of Dr. A. Khayat.)

complication rate for retained root canal treated teeth is approximately 4%, compared with approximately 18% for retained single tooth implant restorations.[33] Typical complications include symptoms, swelling, and the need for retreatment.[33] In endodontics, complications are recorded as failures according to the criteria described previously; in other disciplines, complications are generally not recorded as failures.

Prognostic Indicators

The classic landmark study published by Larz Strindberg in 1956 related treatment outcomes to biologic and therapeutic factors.[43] Factors now considered to be predictors of success and failure include (1) apical pathosis, (2) bacterial status of the canal, (3) extent and quality of the obturation, and (4) quality of the coronal restoration. The role of these factors should be discussed with the patient before and after treatment.

Several investigations have reported factors that result in a slightly less favorable prognosis: the presence of periradicular lesions and larger lesion size;[38,44] the presence of bacteria in the canal before obturation;[45] and obturations that are short, long, contain voids, or lack density.[46-50] Some evidence suggests that the use of a calcium hydroxide intracanal medicament may improve the prognosis.[51-53] The quality of the coronal restoration plays a key role in the outcomes of root canal treatment.[54-56]

Factors such as the tooth type, age and gender of the patient, and obturation technique have minimal if any influence on the prognosis.[51-53,57] Most medical conditions have no significant bearing on the prognosis.[58] However, patients with insulin dependent diabetes mellitus have a significantly lower healing rate after root canal therapy in teeth with apical lesions.[59] Interestingly, diabetes mellitus, hypertension, and coronary artery disease are associated with an increased risk of extraction after root canal treatment.[60] Although this finding does not indicate causality, the systemic disease burden has broad effects on the patient's welfare, morbidity, and behavior. Obviously, a patient with a complex medical history, serious illness, or disability may present a high degree of difficulty in management and demands high levels of experience and

TABLE 22.1 Percentages of Pooled and Weighted Survival and Success Rates of Dental Implants, Root Canal Treatment, and Three- or Four-Unit Bridges Over 2 to 4, 4 To 6, And 6+ Years

Procedure	Success (%)	Survival (%)
2-4 years		
Dental implant (pooled)	98 (95-99)	95 (93-97)
Dental implant (weighted)	99 (96-100)	96 (94-97)
Root canal treatment (pooled)	90 (88-92)	94
Root canal treatment (weighted)	89 (88-91)	—
Three-unit bridge (pooled)	79 (69-87)	94
Three-unit bridge (weighted)	78 (76-81)	—
4-6 years		
Dental implant (pooled)	97 (96-98)	97 (95-98)
Dental implant (weighted)	98 (97-99)	97 (95-98)
Root canal treatment (pooled)	93 (87-97)	94 (92-96)
Root canal treatment (weighted)	94 (92-96)	94 (91-96)
Three-unit bridge (pooled)	82 (71-91)	93
Three-unit bridge (weighted)	76 (74-79)	—
6+ years		
Dental implant (pooled)	95 (93-96)	97 (95-99)
Dental implant (weighted)	95 (93-97)	97 (96-98)
Root canal treatment (pooled)	84 (82-87)	92 (84-97)
Root canal treatment (weighted)	84 (81-87)	97 (97-97)
Three-unit bridge (pooled)	81 (74-86)	82
Three-unit bridge (weighted)	80 (79-82)	—

expertise. However, root canal treatment may greatly benefit some patients by preventing the need for high-risk extractions or other surgical procedures; such patients include those with bleeding disorders, those who have undergone head and neck irradiation, and those treated with high-dose bisphosphonates.

Study Questions

1. Which of the following criteria WILL NOT be considered part of a truly successful outcome at a 1-year follow-up?
   a. No clinical signs of swelling, infection, or inflammation
   b. Disappearance of a sinus tract
   c. Decrease of a radiolucency in size
   d. No soft tissue defects or pathologic probing depths
   e. No clinical symptoms experienced by the patient
2. Which of the following statements about the radiographic detection of periapical pathosis is UNTRUE?
   a. The sensitivity of detecting apical periodontitis with CBCT imaging is higher than with conventional digital radiography
   b. Any apical periodontitis in the mandible will be detectable on radiographs if it exceeds 3 mm in diameter
   c. If radiographs at follow-up are taken at a different angulation than the postoperative control, the actual healing progression may be misjudged
   d. Different observers may disagree on the interpretation of periapical radiolucencies
   e. The same observer may disagree with him/herself on the interpretation of periapical radiolucencies if viewed at different times
3. Based on systematic reviews and meta-analyses, which of the following outcome ranges does not reflect the associated procedure?
   a. Success of root canal treatment with a diagnosis of irreversible pulpitis: 90% to 100%
   b. Success of root canal treatment with a diagnosis of apical periodontitis: 75% to 85%
   c. Success of nonsurgical retreatment: 75% to 85%
   d. Success of endodontic microsurgery: 55% to 65%
   e. Survival of single-unit implants: 90% to 100%
4. Which of the following factors WOULD NOT be considered to be a predictor of success and failure for endodontic treatment?
   a. Type of root filling material
   b. Presence or absence of apical pathosis
   c. Extent and quality of the root filling
   d. Bacterial status of the root canal system
   e. Quality of the coronal restoration
5. Which of the following statements about the PAI is INCORRECT?
   a. The PAI relies on the comparison with a set of five radiographic images reported by Brynolf in 1967
   b. The outcome of treatment using PAI can be classified as “healing” if the lesion size is reduced
   c. The outcome of treatment using PAI can be classified as “healed” if the lesion has been eliminated
   d. The outcome of treatment using PAI can be classified as “developing” if a new lesion has formed
   e. The PAI grades in 4 stages from healthy periapex (score 1) to a large periapical lesion (score 4)

Causes of Nonhealed, Failed Root Canal Treatment

The outcome of endodontic therapy largely depends on the management of infection.

The presence of newly introduced, persistent, or recurrent microorganisms is the primary cause of endodontic pathology.[61] Ideally, after chemomechanical instrumentation, the root canal system should be free of microorganisms.[62]

The prevention of microbial infection of the root canal system is the primary goal for the treatment of teeth with a vital pulp status. This necessitates proper isolation, disinfection of the operative field, and aseptic root canal treatment techniques to reduce the risk of contamination and to achieve a superior prognosis. If the pulp was necrotic, or the tooth previously endodontically treated, and an apical pathology was present, the removal of microorganisms, toxins, metabolites, antigens, and byproducts is essential but may be challenging.

The location and nature of the microorganisms, the complexity of the root canal system, technical aspects of endodontic treatment, and the quality of the permanent restoration all play an important role as potential reasons for treatment failure.

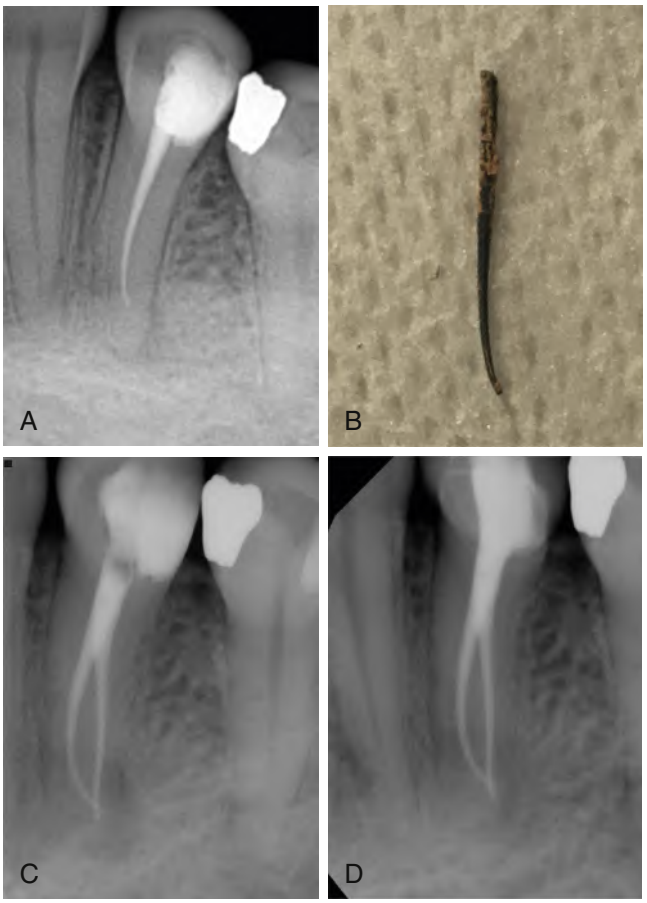
Unfortunately, the complexity of the root canal system with all its ramifications may make microorganisms inaccessible to mechanical disruption or the antimicrobial effects of disinfectants, medications, and root canal filling materials.[63,64] The larger part of infected root canal systems may probably contain residual microorganisms after root canal treatment; however, the environmental conditions of a well-sealed root canal system after appropriate chemomechanical débridement are expected to eliminate them, or at the least leave them in a dormant state.

Hence, chemomechanical disinfection will primarily aim at a reduction of microbial counts by a combination of mechanical instrumentation with copious and frequent disinfecting solutions, such as sodium hypochlorite.[65] Interappointment medication with calcium hydroxide may further reduce the number of microorganisms,[66] accelerate healing, and reduce inflammation.[51,52]

Common errors leading to persistent microbial presence and ultimately failure include (1) errors in diagnosis and treatment planning; (2) lack of knowledge of pulp and/or root anatomy, resulting in missing canals or other areas of the root canal during treatment; (3) inadequate débridement and/or disinfection of the root canal system; (4) operative errors; (5) deficiencies of the root filling; (6) the absence of cuspal coverage in posterior teeth, allowing for increased fracture rates; (7) excessive removal of tooth structure, predisposing teeth to fracture; and (8) coronal leakage through inadequate temporary or permanent restorations. Understanding these preoperative, operative, and postoperative factors plays an essential role in assessing the reasons for treatment failure and the best options for its management.

Preoperative Causes

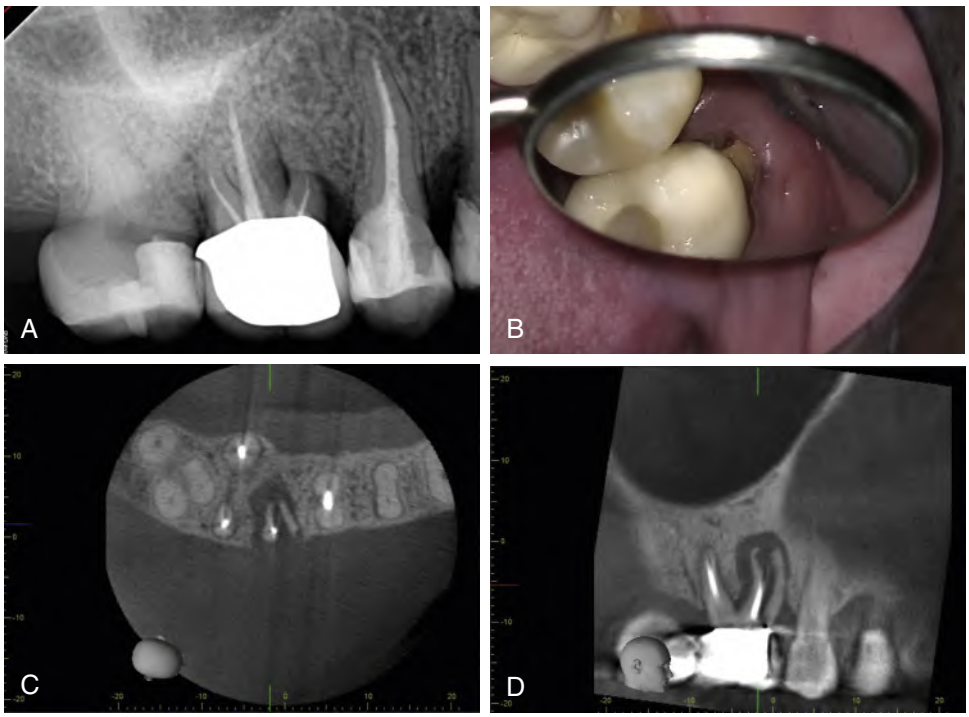
Misdiagnosis, errors in treatment planning and decision making, inadequate case selection (i.e., treatment beyond a clinician's skill levels and expertise), as well as the treatment of a tooth with a poor initial prognosis may be a reason for failure of endodontic treatment. Diagnosis should be based on all available information: the patient's medical and dental history, chief complaint, signs and symptoms, as well as a current, comprehensive endodontic evaluation, including visual inspection, percussion, palpation, probing, sensitivity tests, and radiographic evaluation (see Chapter 4). The radiographic evaluation should include periapical films from different mesiodistal angulations and may include bite wing radiographs or three-dimensional projections, such as a limited field of view CBCT (see Chapter 3). Together with the clinical examination, the radiographic evaluation may aid in identifying complexities in the root canal system, such as additional canals (Fig. 22.5) and canal anatomy, root dilacerations and curvatures, fractures (Fig. 22.6), external or internal resorption, periodontal defects, and/or the presence of periapical pathologies.



• **Fig. 22.5** **(A)** Double periodontal ligament visible mesially in the mandibular first premolar indicates the presence of a division in the canal or the root or additional canals. **(B)** Original root filling material with plastic carrier removed. **(C)** A postoperative radiograph revealed a midroot split and two canals. **(D)** Six-month recall, permanent restoration and resolution of apical periodontitis, indicative of healing.

Particular microorganisms, such as *Enterococcus faecalis*, demonstrate special survival qualities, including the ability to form biofilms.[67-69] The arrangement of bacteria in biofilms may pose significant challenges for effective elimination,[70] with an estimated 1000-fold greater resistance to antimicrobial agents than corresponding planktonic forms of bacteria.[71] Although apical periodontitis is usually in response to intraradicular infection, there are situations, such as an acute apical abscess, where microorganisms are present in the periapical tissues. In certain situations, extraradicular biofilms or cohesive bodies within the periapical lesion itself can be found, rendering these microorganisms inaccessible to intraradicular treatment strategies, with actinomyces,[72] or *Propionibacterium propionicum*[73] being common examples.

Lastly, the nature of the periapical lesion may play a role in the healing process. Most periapical pathologies are inflammatory in



• **Fig. 22.6** Indicators of vertical root fracture. **(A)** Isolated bone loss on mesiobuccal root. **(B)** Clinical observation of fracture line. **(C)** Cone beam computed tomography (CBCT) confirmation of separated root fragments. **(D)** CBCT confirmation of J-shaped lesion. (CBCT acquisition for treatment planning of root resection; courtesy of Dr. Rami Elsabee.)

kind,[74] histologically 50% being described as granulomas, 35% as abscesses, and 15% as cysts. Of the cysts, approximately 40% were identified as pocket cysts, where the epithelial-lined cavity is connected to the root canal system through the apical foramen. These lesions are expected to heal after nonsurgical endodontic treatment.[74] However, the remaining 60% are true cysts, which are more likely to heal only after extraction or surgical endodontic treatment, as they are disconnected from the root canal system and enclosed by epithelial lining in its entirety.[74] It is currently not possible to differentiate clinically between periapical cysts and granulomas, nor between periapical pocket and true cysts. Nevertheless, larger lesions (radiographically 200 mm^2 or greater) were shown more likely to be cysts.[75,76]

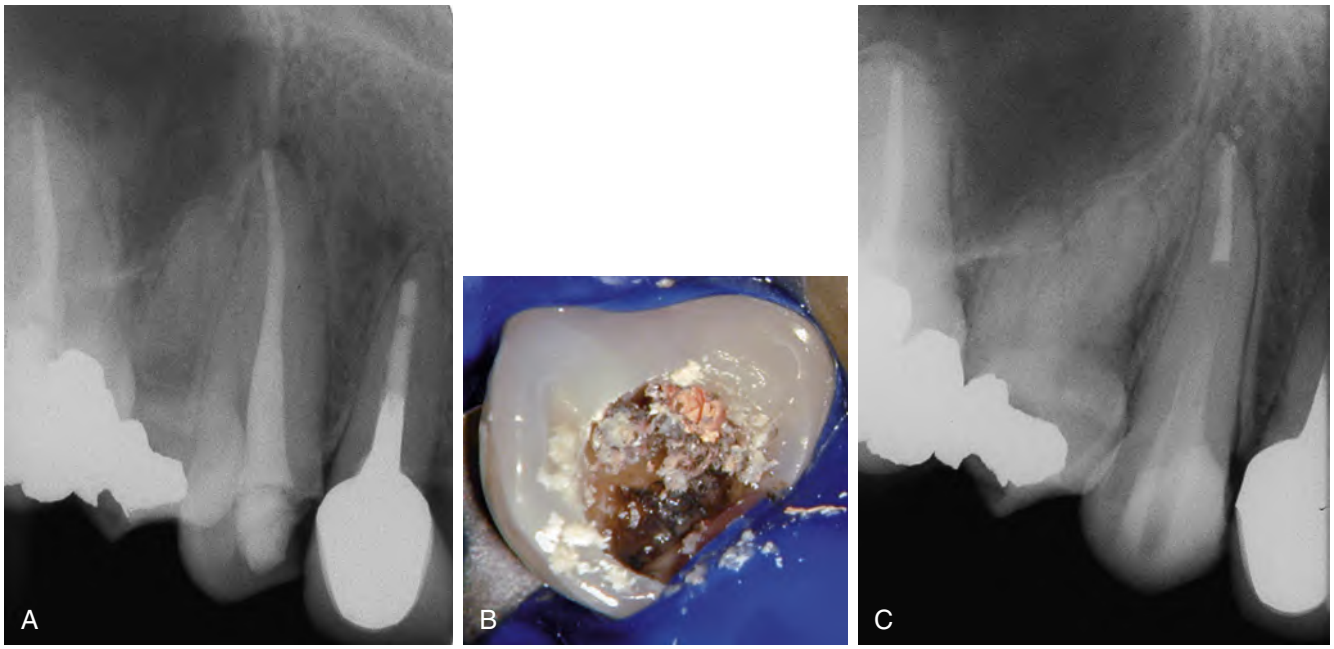
Operative Causes

Many failures result from errors in operative procedure (see Chapter 18). The thorough débridement and/or disinfection of the root canal system in its entirety together with a well sealing root filling and permanent restoration are the means during endodontic treatment to prevent or eliminate apical periodontitis and to achieve success. Advancements in endodontic instruments and techniques have greatly improved the ease and completeness of chemomechanical cleaning. Rotary nickel-titanium file systems and new activation techniques for irrigation solutions have helped to clean more predictably. In comparison to stainless steel hand instrumentation rotary nickel-titanium files are more flexible and prepare root canals more centered and rounder. However, clinicians must follow proper protocols to avoid failure. A straight-line access cavity allowing for unobstructed approach to the canal orifices provides for safer canal instrumentation and reduces the risk of missing canals. If pulp horns are not removed, pulpal tissues, bacteria, debris, and filling materials may remain in the coronal pulp space and may result in persistent infection or tooth discoloration. Underextended access preparations may limit instrument maneuverability, posing a risk of insufficient cleaning and instrument fracture. However, overly large access cavities should also be avoided to reduce excessive loss of tooth structure, which may weaken the tooth, increase the risk of fracture and perforation, and complicate restoration.[77-78]

The difficulty level of the endodontic treatment may strongly affect the quality of the outcome. Significant deviations from the normal tooth or root form, extreme (>30°) or S-shaped curvatures, canal division in the middle or apical third, or very long roots (>25 mm) may increase the likelihood of perforations with subsequent leakage or mechanical irritation, and development of a lesion.[79] Although perforations have had a better prognosis since repair materials such as mineral trioxide aggregate (MTA) or bioceramics became available,[80] some may require endodontic surgery.[81] Other possible complications may be related to open apices (>1.5 mm in diameter), decreased canal visibility on radiographs, calcified canals, internal and external resorptions, as well as history of trauma.

Calcified and/or missed canals may be difficult to visualize on periapical radiographs; however, the use of CBCT imaging may allow for a clear detection. Clinically, the pulp floor should be carefully inspected after removal of decay and any existing restoration to identify missed or calcified canals.

Sjögren et al. demonstrated a 94% periapical healing rate in teeth with apical periodontitis if the root filling was extended to within 0 to 2 mm of the radiographic apex.[11] Confining endodontic procedures and materials to within the canal space facilitates repair of periradicular tissues.[46,82] However, if the apical area was underinstrumented more than 2 mm from the root-end, this outcome decreased



• **Fig. 22.7** **(A)** Lack of coronal seal resulted in clinical symptoms and a periapical lesion in the maxillary right cuspid. **(B)** A clinical photograph shows lack of permanent restoration and coronal decay. **(C)** After retreatment of the previous root canal treatment and placement of a C-fiber post, the coronal access to the root canal treated tooth was sealed permanently. (Courtesy of Dr. D. Roland.)

to 68%.[11,50] On the other hand, overinstrumentation with overfilling of root canal filling materials may also promote foreign-body reactions,[83] periradicular hemorrhage, and induce extraradicular infection by transferring microorganisms from the canal to the periapical tissues, possibly compromising the outcome.[84]

Postoperative Causes

The restoration of the tooth after root canal treatment should be with a high-quality, durable coronal restoration that permanently protects and seals the tooth, preventing ingress and apical percolation of microorganisms and salivary contaminants (Fig. 22.7).[50-56,62-66,85-89]

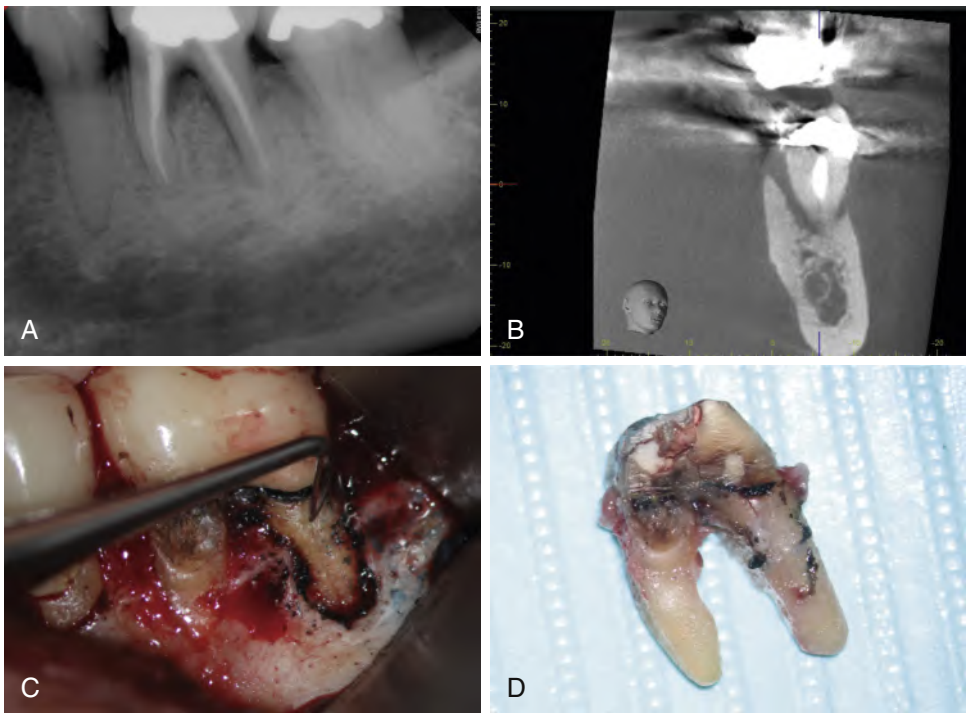
Coronal leakage at any time after the completion of the root canal treatment may pose the risk of recontamination and subsequently failure of the endodontic procedure. The coronal seal must be guaranteed by a temporary restoration immediately after the completion of the root canal treatment and then for the lifetime of the tooth by a permanent restoration.

The permanent restoration may be placed immediately after the root filling is completed, or as early as possible thereafter. Rubber dam isolation in a saliva-free environment must be used whenever the actual root filling is exposed during the restoration process. Orifice sealants or barrier materials may be useful to minimize any risk of recontamination during the restoration process.[90] Any temporary restorations and cotton pellets must be completely removed before restoration.[61] Gutta-percha and sealer should be removed from the floor of the access cavity. No space should remain between the root filling and the buildup and/or restoration, as any such space provides a potential habitat for bacterial colonization and growth.

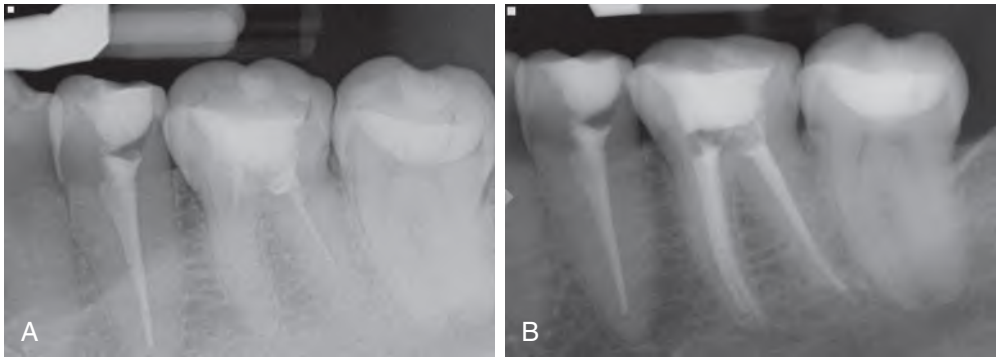
Errors throughout this restorative process may compromise success. This may include excessive dentin removal during instrumentation or for posts weakening the teeth and increasing its susceptibility to fracture (Fig. 22.8),[77] or perforations occurring during placement of the post. Full coronal coverage (i.e., with a crown or an onlay) has been shown to improve the prognosis for posterior teeth by reducing the incidence of fracture. However, for anterior teeth with enough tooth structure remaining, full coronal coverage does not increase the longevity of the tooth. On the contrary, preparing anterior endodontically treated teeth for a crown may remove too much remaining tooth structure, weaken the tooth, and result in a less favorable prognosis. Composite restorations and/or ceramic veneers are preferred for anterior teeth.

Outcomes of Treatments After Failure of Initial Nonsurgical Endodontics

For decades the primary goal of dentistry was to preserve the natural dentition, trying to save teeth with pulpal and/or periodontal diseases and, if hopeless teeth needed to be extracted, to replace them with fixed or removable prostheses. Although this may seem to lay out straight-forward decision making, treatment planning arguably has become more complex with the availability of dental implants. Both the preservation of endodontically treated teeth with appropriate permanent restoration as well as implant restorations demonstrate excellent and predictable outcomes to maintain the patient's oral health and dentition. The clear majority of teeth with endodontic treatment will heal without any further intervention. In case of failure of primary endodontic treatment, however, clinicians have the following treatment options: (1) nonsurgical retreatment, (2) surgical retreatment, (3) extraction and replacement with a single tooth implant, (4) extraction and replacement using a fixed dental prosthesis, (5) intentional replantation or autotransplantation, and (6) extraction without replacement.[91]



• **Fig. 22.8** **(A)** Overenlargement of the coronal thirds. Bone loss in furcation and along distal root. **(B)** Cone beam computed tomography (CBCT) confirmation of extent of vertical bone loss. **(C)** Clinical confirmation after flap elevation. **(D)** Extracted tooth. (Courtesy of Dr. Rami Elsabee.)



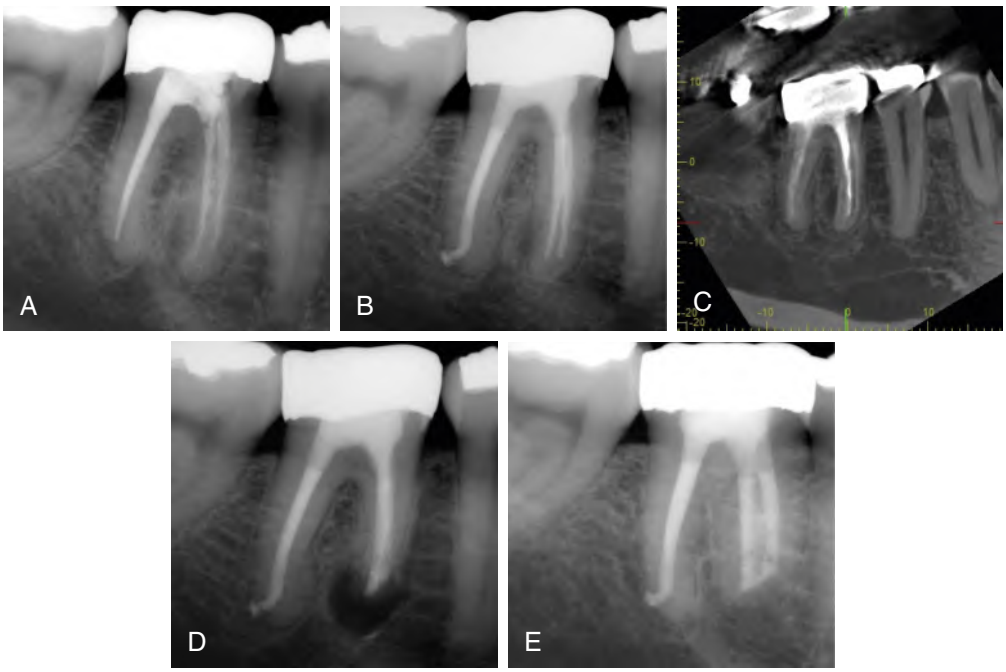
• **Fig. 22.9** **(A)** A preoperative periapical radiograph shows the first mandibular molar with inadequate root canal treatment. The patient presents with clinical symptoms. **(B)** Postoperative radiograph after nonsurgical retreatment; patient is asymptomatic.

Nonsurgical Retreatment

Nonsurgical endodontic retreatment is the first treatment choice for most failed endodontic cases. The success rate of nonsurgical retreatment ranged between 40% and 100% according to a systematic review that identified 31 clinical studies since 1970 (Fig. 22.9).[92] The prospective Toronto study reported a "healed" rate of endodontic retreatment cases of 81%.[93] A systematic review and meta-analysis of nonsurgical retreatment reported an overall weighted pooled success rate of 77.2% based on data from 17 studies from 1961 to 2005.[94] In teeth with apical periodontitis the overall success was reduced to 65%, and of those with lesions larger than 5 mm in diameter to 41%.[94] However, it was mentioned that the follow-up periods for larger lesions might not have been long enough to demonstrate complete healing.[94] The technical quality of the initial endodontic treatment may negatively affect the outcome of nonsurgical retreatment if the entire root canal system is not accessible for complete reinstrumentation and disinfection during retreatment caused by obstacles left behind from the initial root canal treatment.[95] Unfortunately, to date, no higher level evidence outcome study on nonsurgical retreatment exists that included today's standard modern treatment techniques, such as nickel-titanium instrumentation, the dental operating microscope, or modern diagnostic tools such as CBCT imaging. Hence, it is unknown if there are changes in the success rates with recent endodontic technologies.

Endodontic Surgery

A systematic review of studies investigating the outcome of surgical endodontics found success rates ranging from 37% to 91%, depending on the operator and the specific techniques used for



• **Fig. 22.10** **(A)** Insufficient root canal treatment of a first mandibular lower molar. **(B)** Cone beam computed tomography (CBCT) for treatment planning. **(C)** Patient remains symptomatic 3 months after nonsurgical retreatment. **(D)** Postoperative radiograph after endodontic microsurgery. **(E)** A recall radiograph 18 months later shows complete resolution of the periradicular lesion. The patient remained asymptomatic since the surgical procedure. (Courtesy of Dr. Tom Schloss.)

the surgical procedures.[96] Unfortunately, many studies reporting the success and failure of periapical surgery were identified as case series or other studies with a low level of evidence.[97] Torabinejad and colleagues performed a systematic review comparing the clinical and radiographic outcomes of nonsurgical retreatment with those of surgical retreatment.[98] The study concluded that nonsurgical retreatment provided more favorable long-term outcomes than endodontic surgery.[98]

A number of systematic reviews and meta-analyses have since then documented that the outcome of surgical retreatment very much depends on the techniques used for the procedures. Traditional, now obsolete techniques using a straight surgical handpiece, beveled root resection, and often a retrograde filling with amalgam demonstrated weighted pooled success rates of 59.0%.[99] On the other hand, the use of loupes, ultrasonic root-end preparation, and more biocompatible filling materials such as intermediate restorative material (IRM), SuperEBA, or MTA increased this outcome to 86% of periapical healing.[100] Endodontic microsurgery, which uses the same tools and techniques, but replaces loupes with a dental operating microscope capable of providing high magnification, demonstrated even higher success rates ranging from 91.4% to 94.4% for true endodontic lesions based on several meta-analyses (Fig. 22.10).[99,101-103] However, another systematic review and meta-analysis described lower outcome rates for teeth undergoing endodontic surgery compared with single unit implants.[104] Moreover, if the tooth is also periodontally compromised, surgical outcome was also reported to be significantly lower.[105]

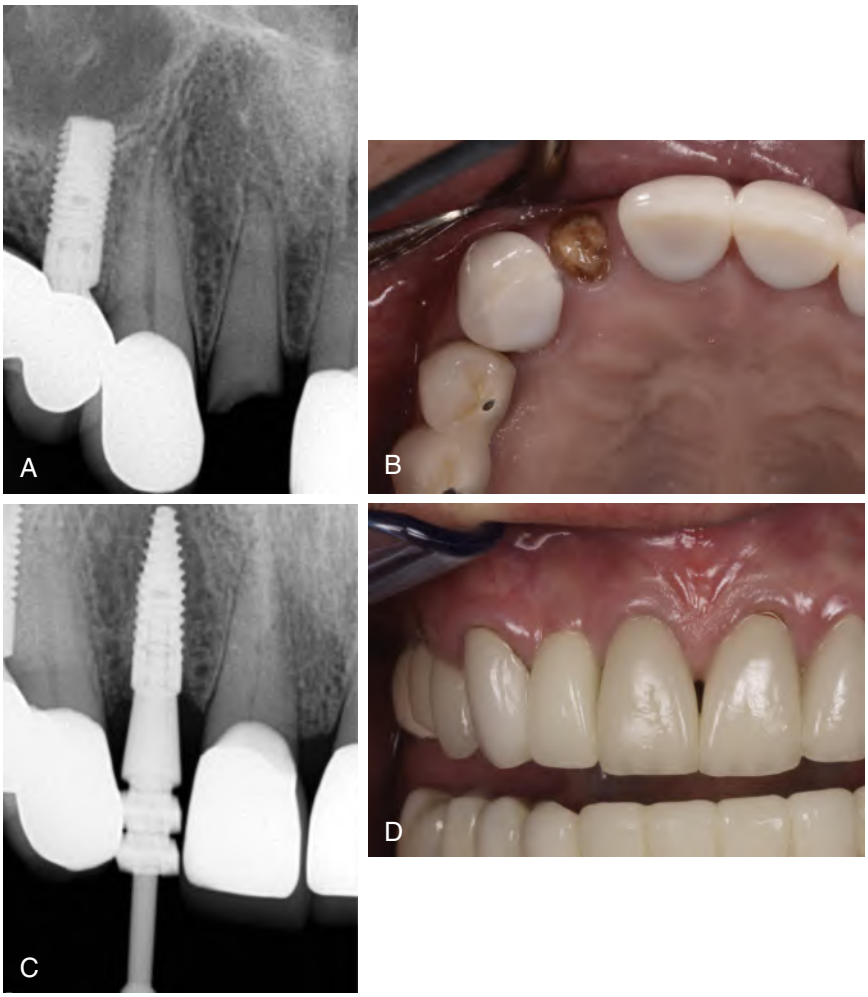
Endodontic surgery should be reserved for teeth with failed nonsurgical retreatment, or situations where nonsurgical retreatment may be precluded for technical reasons,[98] as it appears that the success rate for a conventional retreatment is very high.[106]

Single Tooth Implant

The introduction of dental implants into modern dentistry provided great benefits for patients and allowed for functional, durable, and esthetic tooth replacement, leading to significant changes in endodontic, periodontic, and prosthodontic treatment planning and decision-making.[107] Implant-supported restorations have obviated the need for crown preparations on intact abutment teeth for fixed partial dentures (Fig. 22.11), and allowed fixed prosthodontic restorations even in the absence of suitable natural teeth as abutments.[108,109]

Comparisons between the outcome of endodontically treated teeth and dental implants are challenging as a result of the multifactorial nature of both treatment modalities, short-term versus long-term outcome, and the differences in outcome assessment. The implant field lacks a singular definition of success. Guidelines of the Academy of Osseointegration described "the desired outcome of successful implant therapy" as "not only the achievement of the therapeutic goal but the maintenance of a stable, functional and esthetically acceptable tooth replacement for the patient."[110] As a substitute of defined outcome criteria, survival of the implant unit is used frequently.[107]

Success and survival rates for single tooth implants are now generally very high. The aforementioned systematic review and meta-analysis by Iqbal and Kim included 55 studies investigating dental implants and 13 studies investigating endodontically treated teeth with various follow-up periods.[32] At the earliest point of comparison at 1 year, implant survival was higher at 97.5% compared with tooth survival of 96.9%. This trend showed reversal at long-term after 6 years when implant survival had declined to 94.2% and endodontically treated teeth were retained at 97.2%. However, over all time periods, 95.0% of implants and 94.0% of endodontically treated teeth survived.[32] Torabinejad et al. also have reported survival rate of 97% for both procedures.[28]



• **Fig. 22.11** **(A)** A periapical radiograph shows a maxillary right lateral incisor with extensive loss of coronal tooth structure, insufficient crown-to-root ratio, and unfavorable, tapered root form. **(B)** Corresponding clinical image demonstrates tooth structure loss at soft tissue level. The tooth was deemed nonrestorable. Note narrow space between central incisor and canine. **(C)** Radiograph showing ideal implant positioning and transfer abutment alignment. **(D)** Clinical situation at 1-year recall. (Courtesy of Dr. Santiago Jané Ceballos.)

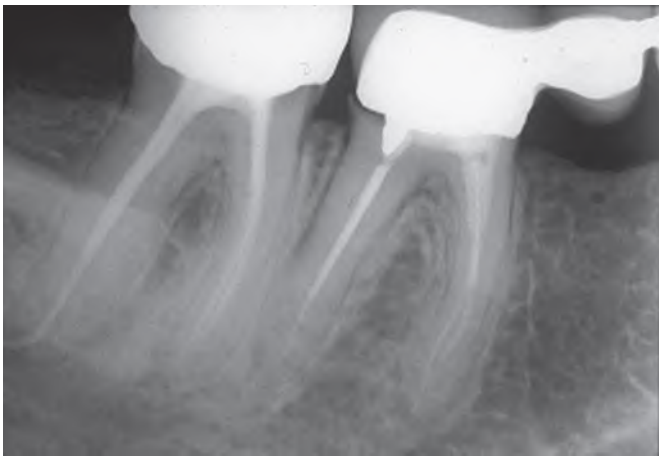
In Doyle et al.'s study, 196 single implants were matched with 196 endodontically treated teeth, followed-up for up to 10 years, and then compared based on the outcome variables 'success', 'survival with intervention', 'survival without intervention', as well as 'failure'.[33] Results demonstrated identical failure rates at 6.1%. Tooth success was reported at 82.1%, and dental implants success at 73.5%. The rate for survival with need for intervention was higher for dental implants (17.9%) than for natural teeth (2.6%), confirming high complication rates often observed for implant restorations. Although overall degrees of satisfaction with minimal pain and discomfort have been generally observed for both procedures,[111] it is now agreed upon that restored natural teeth outlast dental implant restorations in comparable situations, Endodontic and implant success and survival rates are, however, substantially superior to those for fixed dental prostheses (Table 22.1). Vahdati et al. recently compared the survival outcome of nonsurgical root canal treatment and single-tooth implants in 170 patients who received both treatments.[112] The study confirmed Doyle and coworkers, with both treatments demonstrating a 95% survival rate with a mean 7.5-year follow-up, and a significantly higher number of adjunct and additional treatments, number of appointments, elapsed time before the final restoration, number of prescribed medications, as well as cost of treatment for single-tooth implants compared with nonsurgical root canal treatment.[112]

Both options, the preservation of a natural tooth and implant (re-)placement, should be seen as complementary and not as competing procedures.[32]

The decision to retain or to extract an individual tooth will be based on findings regarding the endodontic status, periodontal condition, remaining tooth structure, caries, root morphology, the condition of the adjacent teeth and the opposing arch, the occlusion, and esthetic parameters.[113] If in the long-term a tooth is potentially compromised in regard to prosthodontic, periodontal, or endodontic reasons, it needs to be taken into consideration that multiple risk factors may accumulate and that the risk of long-term failure may increase.[114]

Fixed Dental Prostheses

Before implant dentistry the preparation of teeth as abutments for fixed or removable partial dentures was common after the extraction of hopeless teeth. However, an increased incident rate for caries as well as pulpal and periodontal problems was



• **Fig. 22.12** Restored mandibular right molars have developed pulpal and periapical problems, in addition to caries under the margins of the crowns. Coronal leakage likely contributed to the development of the new periapical lesions.

reported, in addition to complications such as ceramic or root fractures (Fig. 22.12).[115] Success and survival rates for fixed dental prostheses have been reported as 48% to 95%. A meta-analysis of the literature demonstrated a 10-year survival of 87% and a 15-year survival rate of 69% for fixed dental prostheses.[116] Other reports also demonstrated similar results.[28,117,118] A systematic review comparing endodontically treated teeth with implant single crowns and fixed dental prostheses reported a success rate of only 82% at more than 6 years (see Table 22.1). As discussed previously, treatment planning in prosthodontics has changed significantly since the introduction of dental implants.[119] Implant-supported prostheses are now broadly preferred to tooth-supported prostheses.

Replantation and Transplantation

Replantation is the reinsertion of a tooth into its alveolus after careful, deliberate extraction of the tooth for the purpose of extraoral surgical retreatment.[120] Replantation is indicated when there is no other treatment alternative to maintain a strategic tooth, particularly in situations where the proximity of anatomic details, such as the infra-alveolar nerve or adjacent root structures prohibit direct endodontic surgery (Fig. 22.13). Replanted teeth are often successful long-term[103,121-123] but require careful case selection (see Chapter 21).

Transplantation is the transfer of a tooth from one alveolar socket to another in the same patient.[120,124,125] The clinical procedures involved include socket preparation, extraction, transplantation, and stabilization. When transplantation is appropriately indicated and performed, these teeth may have a good prognosis.[91,126-129] Ankylosis and resorption are the most common failure modes of intentionally replanted and autotransplanted teeth.

Extraction Without Replacement

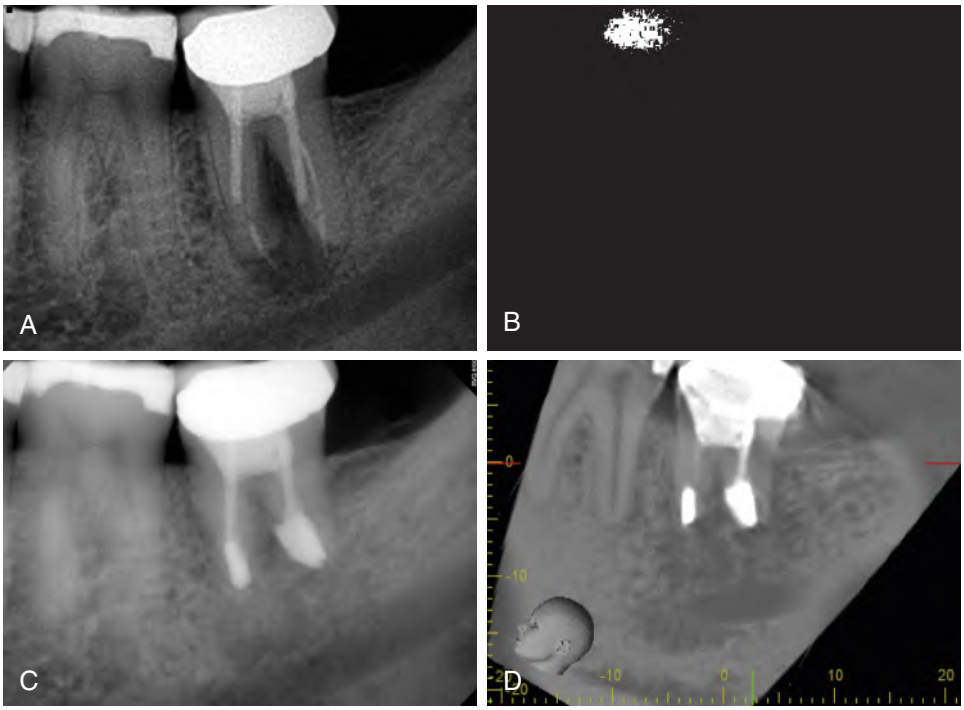
Limited information is available about beneficial or harmful effects of extracting and not replacing individual teeth, including any potential psychosocial and/or economic effect. Few adverse effects were described for a shortened or even an interrupted dental arch. However, it is undebated that the loss of visible teeth without replacement has a tremendous adverse psychosocial effect.[28]

Reasons for Extraction of Endodontically Treated Teeth

Only a small proportion of endodontically treated teeth are extracted. Of these, very few are extracted for endodontic reasons.[29-31] Common reasons for extraction are decay, periodontal disease, nonrestorability, prosthodontic failure, and tooth or root fracture.[15,29-31,130] Added complexity of any additional adjunctive procedure may also result in further complications and higher associated risks, which may increase treatment costs and compromise a patient's willingness to accept endodontic treatment and tooth preservation.[131] However, after the belief that dental implants provide for better long-term prognosis compared with natural teeth has now been rejected by various comparative studies, a renewed call to revisit the long history of successful tooth maintenance for the preservation of the natural dentition has emerged.[132] After all, a missing tooth will be irreversibly gone, and extraction should be only considered after thorough deliberation.[107] Thus it is critical

Study Questions

6. Which one of the following factors WILL NOT complicate adequate disinfection of the root canal system?
   a. Virulence of the microorganisms
   b. Complexity of the root canal system
   c. Choice of rotary file system
   d. Separated instrument in the root canal system
   e. Quality of the permanent restoration all play an important role in as potential reasons for treatment failure
7. Errors that can lead to persistent microbial presence and endodontic failure include all of the following EXCEPT one. Mark this EXCEPTION.
   a. Inaccurate diagnosis
   b. Presence of tertiary dentin
   c. Missed canals
   d. Inadequate débridement and/or disinfection of the root canal system
   e. Inadequate temporary or permanent restorations
8. What is the most significant challenge posed by the presence of bacteria in a biofilm?
   a. Reduced immune response from host
   b. Increased bacterial load in apical area
   c. File separation from torsional fatigue
   d. Greater resistance to antimicrobial agents
   e. Higher potential for type I allergic reaction
9. What is the LEAST common reason for extraction of endodontically treated teeth?
   a. Inadequate endodontics
   b. Periodontal disease
   c. Prosthodontic failure
   d. Root fracture
   e. Higher success for implants compared with natural teeth
10. Vahdati et al. recently compared the survival outcome of nonsurgical root canal treatment and single-tooth implants in 170 patients who received both treatments. What was the significance noted with single-tooth implants?
    a. Higher number of adjunct and additional treatments
    b. Longer elapsed time before the final restoration
    c. Higher number of prescribed medications
    d. Higher cost of treatment
    e. All the above



• **Fig. 22.13** **(A)** A periapical radiograph shows a mandibular second left molar with periradicular radiolucency. The previous root filling is overextended in both roots, the position of the post in the distal root and the extent of the bone loss are indicative of a post perforation. **(B)** Situation after intentional replantation using bioceramic putty as root-end filling and post perforation repair material during the extraoral procedure. **(C)** A radiograph 24 months later shows complete healing of the periradicular tissues. **(D)** Cone beam computed tomography (CBCT) confirmation of the periradicular healing.

ANSWERS

Answer Box 22

1 c. Decrease of a radiolucency in size
2 b. Any apical periodontitis in the mandible will be detectable on radiographs if it exceeds 3 mm in diameter
3 d. Success of endodontic microsurgery: 55% to 65%
4 a. Type of root filling material
5 e. The PAI grades in 4 stages from healthy periapex (score 1) to a large periapical lesion (score 4)
6 c. Choice of rotary file system
7 b. Presence of tertiary dentin
8 d. Greater resistance to antimicrobial agents
9 a. Inadequate endodontics
10 e. All the above

that the current situation as well as all potential future risk factors are being carefully considered during comprehensive patient assessment and treatment planning.[113,131,133]

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