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Diagnosis, prognosis and decision-making in the treatment of combined periodontal-endodontic lesions

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The pulp and periodontium are intimately related. As the tooth develops and the root is formed, three main avenues for communication are created: dentinal tubules, lateral and accessory canals, and the apical foramen.

Anatomic considerations

Dentinal tubules

Exposed dentinal tubules in areas of denuded cementum may serve as communication pathways between the pulp and periodontal ligament (Fig. 1). Exposure of dentinal tubules may occur due to developmental defects, disease, or periodontal procedures. In the root, dentinal tubules extend from the pulp to the dentinocemental junction (73). They run a relatively straight course and range in size from 1 to 3 μm in diameter (126). The diameter of the tubules decreases with age or as a response to a continuous low grade stimuli by the apposition of highly mineralized peritubular dentin. The number of dentinal tubules varies from approximately 8,000 at the dentinocemental junction to 57,000 per square millimeter at the pulpal end (126). In the cervical area of the root there are about 15,000 dentinal tubules per square millimeter (73). These tubules may be denuded of their cementum coverage as a result of periodontal disease, surgical procedures or developmentally when the cementum and enamel do not meet at the cemento-enamel junction (CEJ) thus leaving areas of exposed dentin. Patients experiencing cervical dentin hypersensitivity are an example of such a phenomena.

Scanning electron microscopic studies have demonstrated that dentin exposure at the CEJ occurrs in 18% of teeth in general and in 25% of anterior teeth in particular (132). Furthermore, the same tooth may have different CEJ characteristics with dentin exposure on one side while the other sides are covered with cementum (162). This area becomes important in assessing the progression of endodontic pathogens (Fig. 2), as well as the effect of root scaling and planing on cementum integrity, and bleaching-induced root resorption following the use of 30% hydrogen peroxide (50, 78, 153, 154).

Other areas of dentinal communication may be through developmental grooves, both palatogingival and apical (173).

Lateral and accessory canals

Lateral and accessory canals may be present anywhere along the root (Fig. 3). Their prevalence and location have been well documented in both animal and human teeth (26, 44, 69, 101, 115, 141, 155).

It is estimated that 30–40% of all teeth have lateral or accessory canals and the majority of them are found in the apical third of the root (73). DeDeus (44) found that 17% of teeth had lateral canals in the apical third of the root, about 9% in the middle third, and less than 2% in the coronal third. However, it seems that the prevalence of periodontal disease associated with lateral canals is relatively low. Kirkham (101) studied 1,000 human teeth with extensive periodontal disease and found only 2% had lateral canals located in a periodontal pocket.

Accessory canals in the furcation of molars may also be a direct pathway of communication between

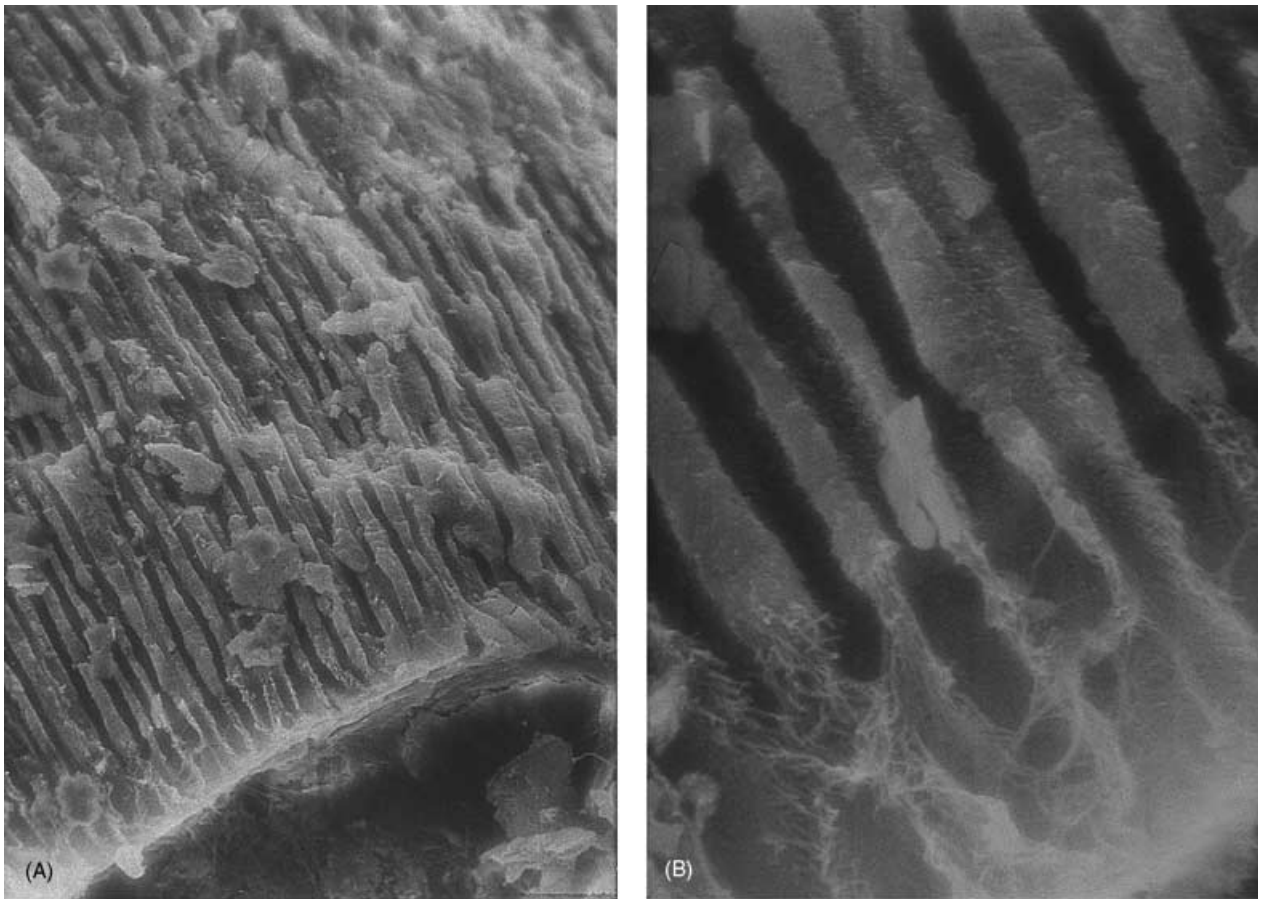

Fig. 1. (A) Scanning electron micrograph of open dentinal tubules. (B) Higher magnification. Note absence of odontoblastic processes.

the pulp and the periodontium (69, 115). The prevalence of accessory canals may vary from 23% to 76% (26, 64, 101). These accessory canals contain connective tissue and vessels that connect the circulatory system of the pulp with that of the periodontium. However, all these canals do not extend the full length from the pulp chamber to the floor of the furcation (64). Seltzer et al. (163) reported that pulpal inflammation may cause an inflammatory reaction in the interradicular periodontal tissues. The presence of patent accessory canals is a potential pathway for the spread of bacterial and toxic byproducts, resulting in a direct inflammatory process in the periodontal ligament (Fig. 4).

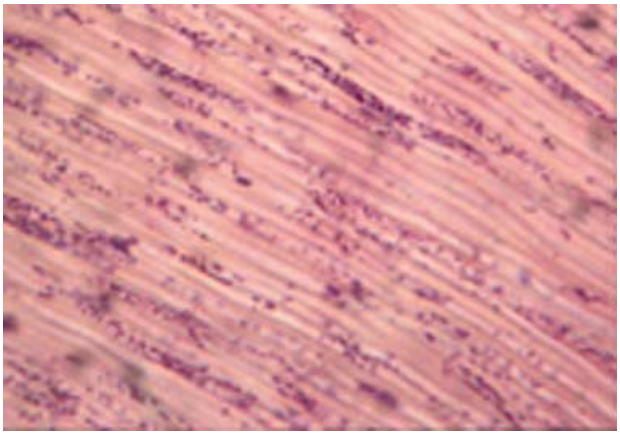

Fig. 2. Photomicrograph of bacteria in open dentinal tubules.

Apical foramen

The apical foramen is the principal and most direct route of communication between the pulp and periodontium. Bacterial and inflammatory byproducts may exit readily through the apical foramen to cause periapical pathosis. The apex is also a portal of entry of inflammatory byproducts from deep periodontal pockets to the pulp. Pulp inflammation or pulp necrosis extends into the periapical tissues causing a local inflammatory response accompanied with bone and root resorption (Fig. 5). Endodontic therapy is targeted to eliminate the intraradicular etiologic factors thus leading to healing of the periapical tissues.

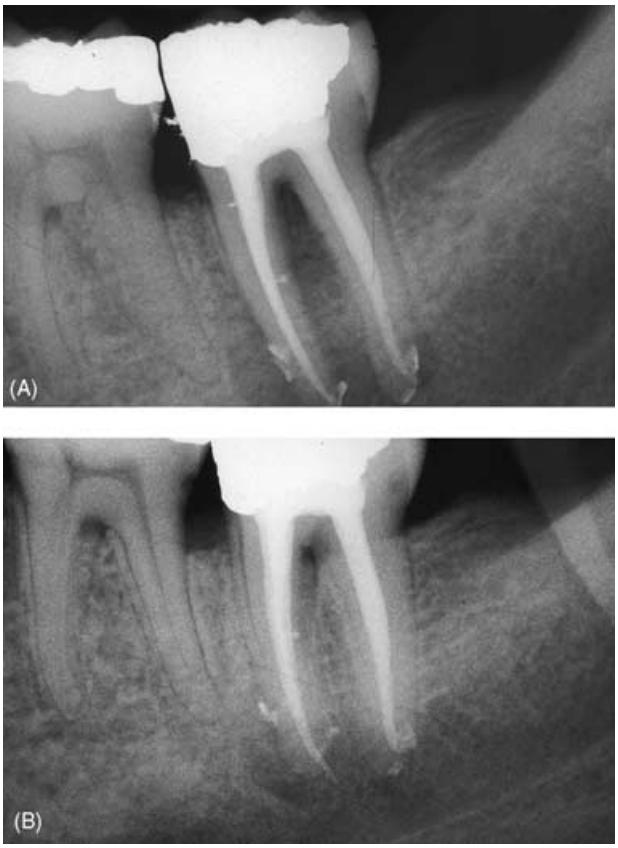

Fig. 3. (A) Postoperative radiograph showing multiple lateral canals in a mandibular second molar with apical and furcal radiolucencies. (B) One-year follow-up radiograph showing bony healing.

Endodontic disease and the periodontium

When the pulp becomes necrotic, there is a direct inflammatory response by the periodontal ligament at the apical foramen and/or opening of accessory canals (164) (Figs 4 and 5). Inflammatory byproducts of pulpal origin may leach out through the apex, lateral and accessory canals and dentinal tubules to trigger an inflammatory vascular response in the periodontium. Among those are living pathogens such as bacteria and their toxic byproducts, fungi and viruses (14, 40, 49, 70, 88, 91, 187), as well as nonliving pathogens (52, 133, 169, 181). Many of these are similar pathogens encountered in periodontal infections. In certain cases pulpal disease will stimulate epithelial growth that will affect the intergrity of the periradicular tissues (136, 170).

The effect of periodontal inflammation on the pulp is controversial and conflicting studies abound (2, 3, 17, 18, 38, 63, 122, 163, 183, 199). It has been suggested that periodontal disease has no effect on the pulp, at least until it involves the apex (38). On the other hand, several studies suggested that the effect of periodontal disease on the pulp is degenerative in nature including an increase in calcifications, fibrosis and collagen resorption, as well as a direct inflammatory affect (108, 118).

It seems that the pulp is usually not directly affected by periodontal disease until recession has opened an accessory canal to the oral environment. At this stage, pathogens penetrating from the oral cavity through the accessory canal into the pulp may cause a chronic inflammatory reaction and pulp necrosis. However, as long as the accessory canals are protected by sound cementum, necrosis usually does not occur. In addition, if the microvasculature of the apical foramen remains intact, the pulp will maintain its vitality (108). The effect of periodontal treatment on the pulp is similar during scaling and root planing or periodontal surgery if accessory canals are severed and/or opened to the oral environment. In such cases microbial invasion and secondary necrosis of the pulp can occur.

Etiologic factors

Live pathogens

Among the live pathogens encountered in a diseased pulp and periapical tissues are: bacteria (Fig. 6), fungi (Fig. 7), and viruses (Fig. 8). These pathogens and their byproducts may affect the periodontium in a variety of ways and need to be eliminated during root canal treatment.

Bacteria

Endodontic disease is caused by bacteria (58, 93, 146). The periapical tissues become involved when bacteria invade the pulp, causing either partial or total necrosis. The relationship between the presence of bacteria and pulpal and periapical diseases was demonstrated by Kakehashi et al. in a classic work (93). In that study, pulps of normal (conventional) rats were exposed and left open to the oral environment. Consequently, pulp necrosis ensued, followed by periapical inflammation and lesion formation. However, when the same procedure was performed on germ-free rats, not only did the pulps remain vital and relatively non-inflamed, but the exposure sites were repaired by dentin. The study demonstrated that without bacteria and their products, periapical lesions of endodontic origin do not occur. Möller et al. (127) confirmed these findings in monkeys. They

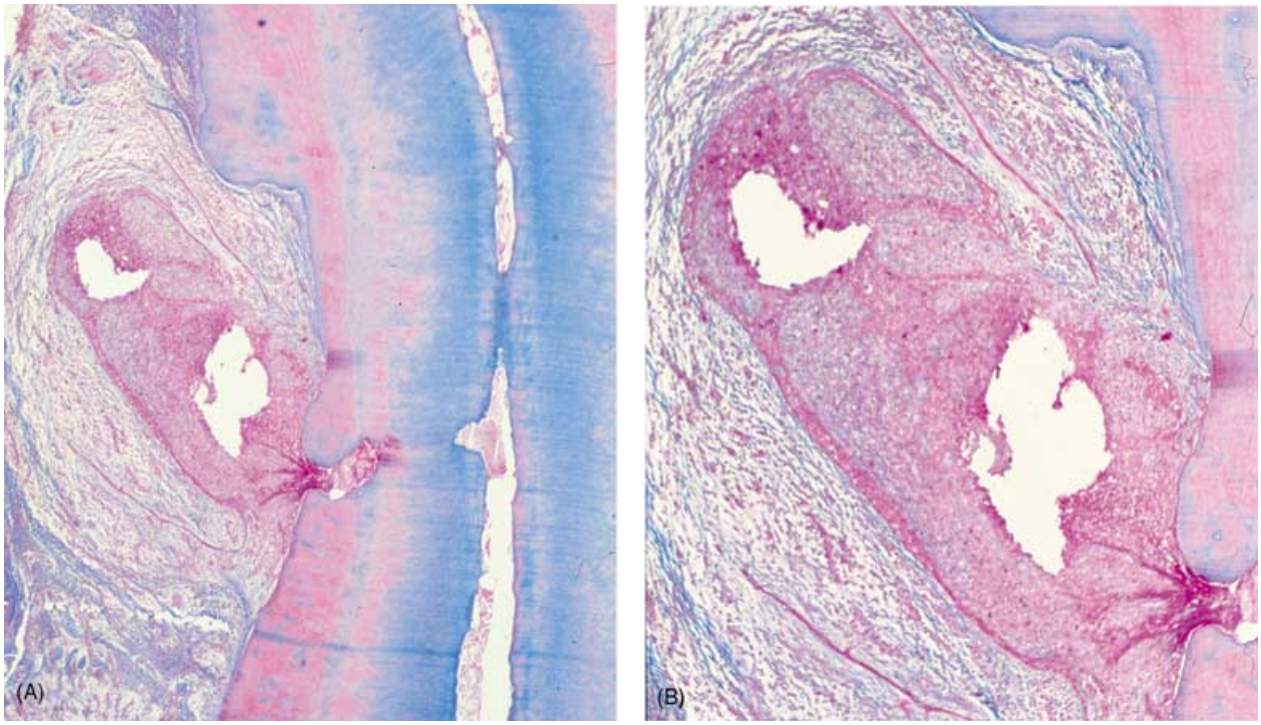

Fig. 4. Micrograph stained with Masson's Trichrome of a maxillary lateral incisor with a necrotic pulp associated with a lateral inflammatory process in the periodontal ligament. (A) Main canal, accessory canal, and the resultant inflammatory response in the periodontal ligament are evident. (B) Higher magnification of the area shows chronic inflammation with proliferating epithelium.

reported that non-infected necrotic pulp tissue did not induce periapical lesions or inflammatory reactions. However, once the pulp became infected, periapical lesions and inflammation in the apical tissues ocurred. Korzen et al. (105) reported similar results and suggested that pulpal infections are by nature usually mixed infections.

Blomlöf et al. (22) created defects on root surfaces of intentionally extracted monkey teeth with either open or mature apices. The canals were either infected or filled with calcium hydroxide and replanted back in their sockets. After 20 weeks, marginal epithelial downgrowth was found on the denuded dentin surface of the infected teeth. Jansson et al. (86) assessed the effects of endodontic pathogens on marginal periodontal wound healing of denuded dentinal surfaces surrounded by healthy periodontal ligament. Their results showed that in infected teeth, the defects were covered by 20% more epithelium, whereas the non-infected teeth showed only 10% more connective tissue coverage. Jansson et al. (87) concluded that pathogens in necrotic root canals may stimulate epithelial downgrowth along denuded dentin surfaces with marginal communication and thus augment periodontal disease. The same group of investigators (89), in a retrospective radiographic 3-year study, evaluated 175 endodontically treated single-rooted teeth of 133 patients. Patients who were more prone to periodontitis and exhibited evidence of endodontic treatment failures showed about a 3-fold increase in marginal bone loss as compared to patients without endodontic infection. Jansson & Ehnevid (86) also investigated the effect of endodontic infection on periodontal probing depth and the presence of furcation involvement in mandibular molars. They found that endodontic infection in mandibular molars was associated with more attachment loss in the furca. These authors suggested that endodontic infection in molars associated with periodontal disease may enhance periodontitis progression by spreading pathogens through accessory canals and dentinal tubules.

Proteolytic bacteria predominate in the root canal flora, which changes over time to a more anaerobic microbiota (55, 179). Rupf et al. (156) studied the profiles of periodontal pathogens in pulpal and periodontal diseases associated with the same tooth. Specific PCR methods were used to detect *Actinobacillus actinomycetemcomitans*, *Tannerella forsythensis*, *Eikenella corrodens*, *Fusobacterium nucleatum*, *Porphyromonas gingivalis*, *Prevotella intermedia*, and *Treponema denticola*. These pathogens were found in all endodontic samples and the same pathogens were found in teeth with chronic apical

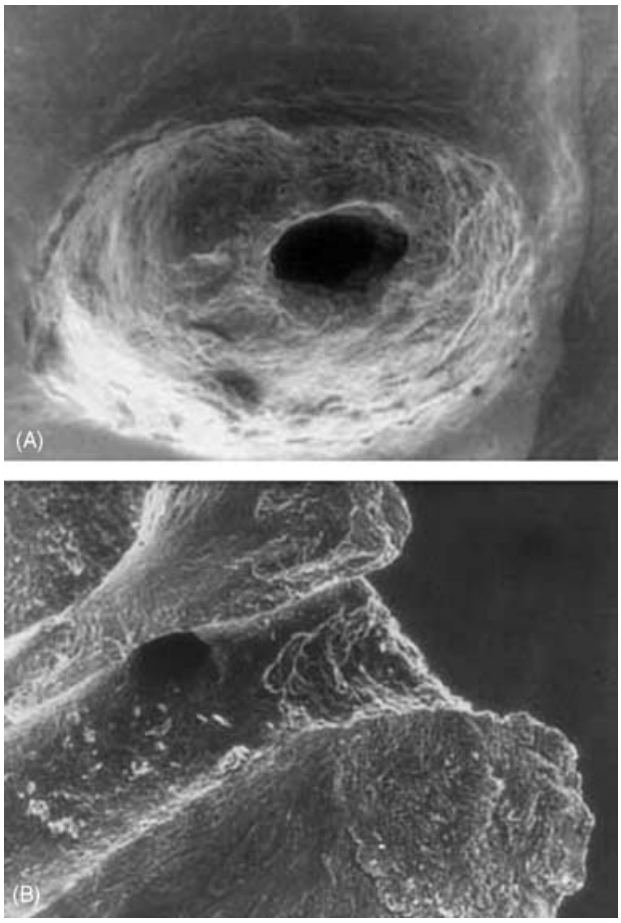

Fig. 5. (A) Scanning electron micrograph of the apical third of a root associated with a periapical inflammatory lesion. Multiple areas of external inflammatory root resorption are evident. (B) Section through the apex of a maxillary central incisor with pulp necrosis and periapical lesion. Note opening of accessory canal and dentinal resorption of the inner surface of the foramen.

periodontitis and chronic (adult) periodontitis. They concluded that periodontal pathogens often accompany endodontic infections and supported the idea that endodontic–periodontal interrelationships are a critical pathway for both diseases.

Spirochetes are another type of microorganism associated with both endodontic and periodontal diseases. Spirochetes are usually found more frequently in subgingival plaque than in root canals. Several studies revealed a large diversity of oral treponemes present in subgingival biofilms of periodontal pockets (29, 45, 95).

It has been suggested that the presence or absence of oral spirochetes can be used to differentiate between endodontic and periodontal abscesses (187). Today, the presence of spirochetes in the root canal system is well documented and has been demonstrated by different identification techniques such as darkfield and electron microscopy, checkerboard DNA–DNA hybridization analysis, and 16S rRNA gene profiles (24, 39, 40, 91, 92, 129, 150, 174).

The differences in the prevalence of spirochetes associated with endodontic disease reported by the various authors may be attributed to the different methodologies used. Recent studies demonstrated that the spirochete species most frequently found in root canals are *T. denticola* (150, 174) and *Treponema maltophilum* (92). The main virulence factor of *T. denticola* includes surface-expressed molecules with cytotoxic activities such as the major surface protein and the chymotrypsin-like protease complex, extracellular or membrane-associated proteolytic and hydrolytic enzymes, and metabolites (56). This organism possesses an array of virulence factors associated with periodontal disease and may also participate in the pathogenesis of periradicular disease (150). *T. maltophilum* is a small, motile treponeme with two periplasmic flagella. Although the virulence factors of this microorganism have not yet been fully studied, it has been proposed that the motility of *T. maltophilum*, caused by the rotation of its periplasmic flagella, might contribute to its pathogenicity (81). *T. maltophilum* has also been frequently isolated from patients with rapidly progressing forms of periodontitis (131).

It has also been suggested that L-form bacteria may have a possible role in periapical disease (172). Some bacterial strains can undergo morphological transition to their L-form after exposure to certain agents particularly penicillin (96). The L-form and the bacterium may appear individually or together and may transform from one variant to another with numerous intermediate L-form transitional stages. This may occur spontaneously or by induction in a cyclic manner. Under certain conditions, depending on host resistance factors and bacterial virulence, the L-forms revert to their original pathogenic bacterial form and may be responsible for acute exacerbation of chronic apical lesions (172).

Fungi (yeasts)

The presence and prevalence of fungi associated with endodontic disease is well documented (49). Yeast colonization associated with radicular pathosis has been demonstrated in untreated root caries (85, 198), dentinal tubules, (42, 99, 166), failing root canal treatments (128, 134, 142, 180), apices of teeth with asymptomatic apical periodontitis (114), and in periapical tissues (186). Many studies reported that the prevalence of fungi in cultured root canal systems varied from 0.5% to 26% in untreated root canals

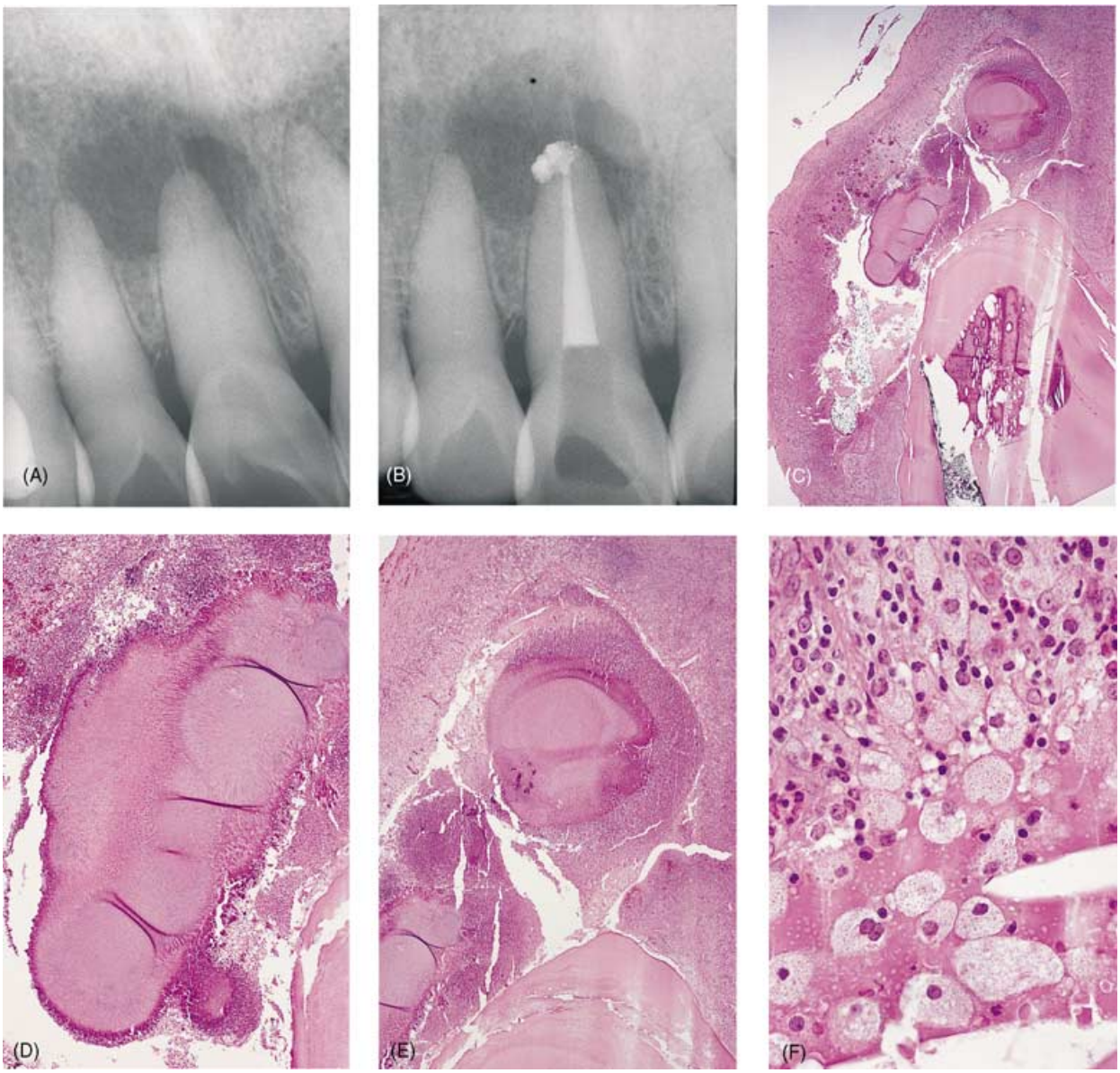

Fig. 6. Periapical *Actinomyces* infection. This case graphically shows the growth of bacteria past the apical foramen and its invasion of apical cementum and periapical tissues. (A) Radiograph of a maxillary central incisor with a necrotic pulp showing a large periapical lesion. (B) Nonsurgical endodontic therapy was done but the tooth continued to be symptomatic. (C) Apical surgery was then performed. Photomicrograph shows part of the root with the attached lesion. (D) Colonies of *Actinomyces* in the lumen of the lesion are evident. (E) Higher magnification shows large colony of *Actinomyces*. (F) Foamy macrophages attacking the bacteria. (G) Edge of the bacterial megacolony showing the absence of inflammatory cells that are unable to penetrate the colony. (H) Higher magnification of the bacterial colony. (I) Center of the colony untouched by the inflammatory cells. (J) Viable bacteria within the apical cementum.

(15, 65, 85, 98, 110) and from 3.7% to 33% in cases of previously treated canals (85, 128, 180, 186, 191). Several studies have demonstrated a higher prevalence of 40% to 55% (137, 166). The majority of the recovered fungi were *Candida albicans* (191). *C. albicans* has been detected in 21% of infected root canals using 18S rRNA directed species-specific primers (15). *C. albicans* also showed the ability to colonize canal walls and penetrate into dentinal tubules (144). Other species such as *Candida glabrata*, *Candida guillermondii*, and *Candida incospicia* (191) and *Rodotorula mucilaginosa* (49) were also detected.

Factors affecting the colonization of the root canal by fungi are not fully understood. It appears, however, that among the predisposing factors of this process are immunocompromising diseases such as cancer (42), certain intracanal medicaments (85), local and systemic antibiotics (121, 198), and previous unsuccessful endodontic therapy (176, 180). It has been hypothesized that the reduction of

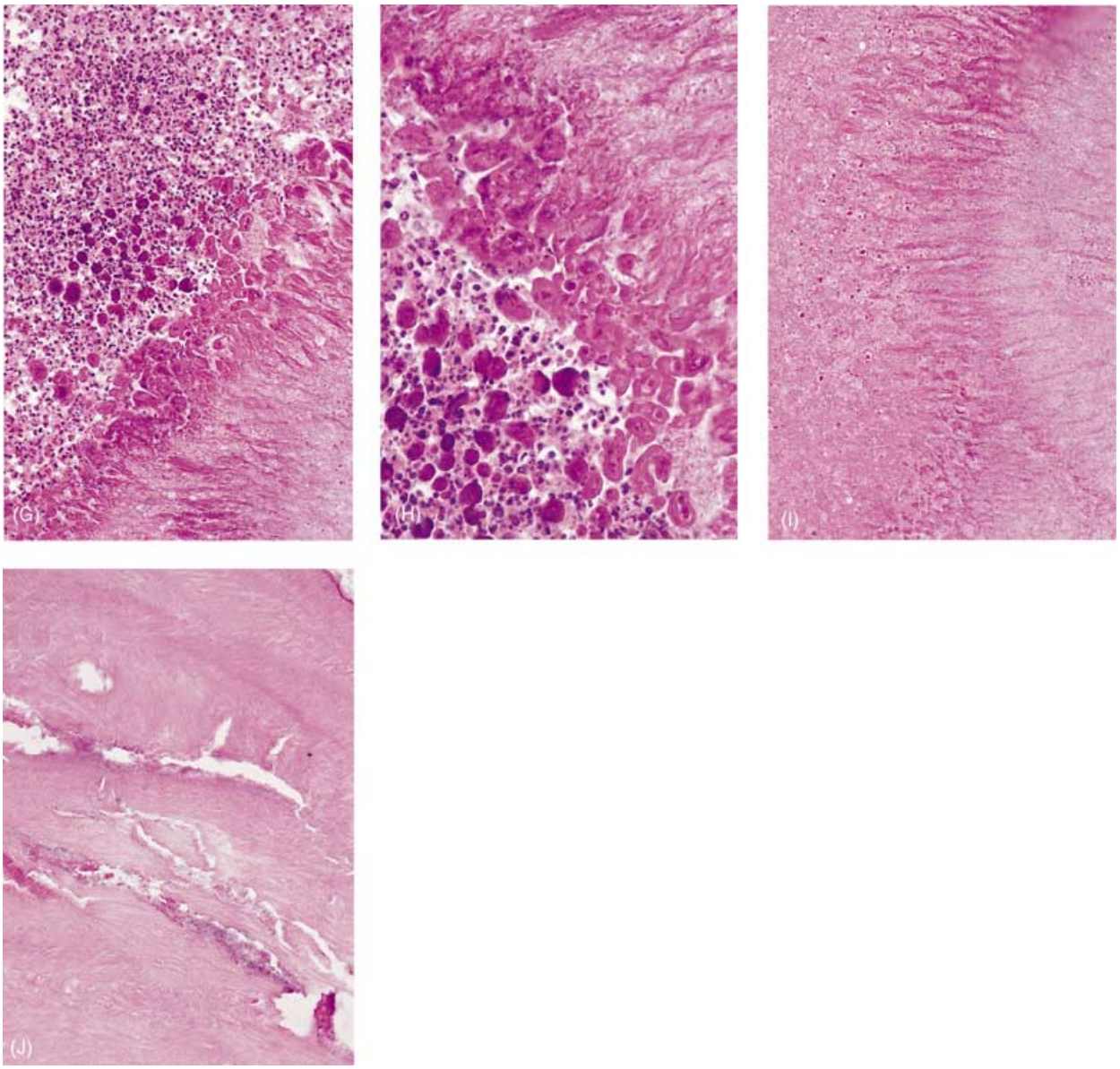

Fig. 6. continued

specific strains of bacteria in the root canal during endodontic treatment may allow fungal overgrowth in the low nutrient environment (176, 180). Another possibility is that fungi may gain access from the oral cavity during treatment as a result of poor asepsis. It has been found that approximately 20% of chronic periodontitis patients also harbor subgingival yeasts (41, 178). As in endodontic infections, *C. albicans* was also the most common species of fungi isolated (71).

Recently, it has been demonstrated that the presence of fungi in root canals is directly associated with their presence in saliva (49). These findings further stress the importance of using aseptic endodontic and periodontal techniques, maintaining the integrity of dental hard tissues, and covering the tooth crown as soon as practical with a well-sealed permanent restoration in order to prevent coronal leakage.

Viruses

There is increasing evidence to suggest that viruses play an important role in both endodontic and periodontal diseases. In patients with periodontal disease, herpes simplex virus is frequently detected in gingival crevicular fluid and in gingival biopsies of periodontal lesions (32, 34). Human cytomegalovirus was found in about 65% of periodontal pocket samples and in about 85% of gingival tissue samples (34). Epstein–Barr virus type I was detected in more than 40% of pocket samples and in about 80% of the

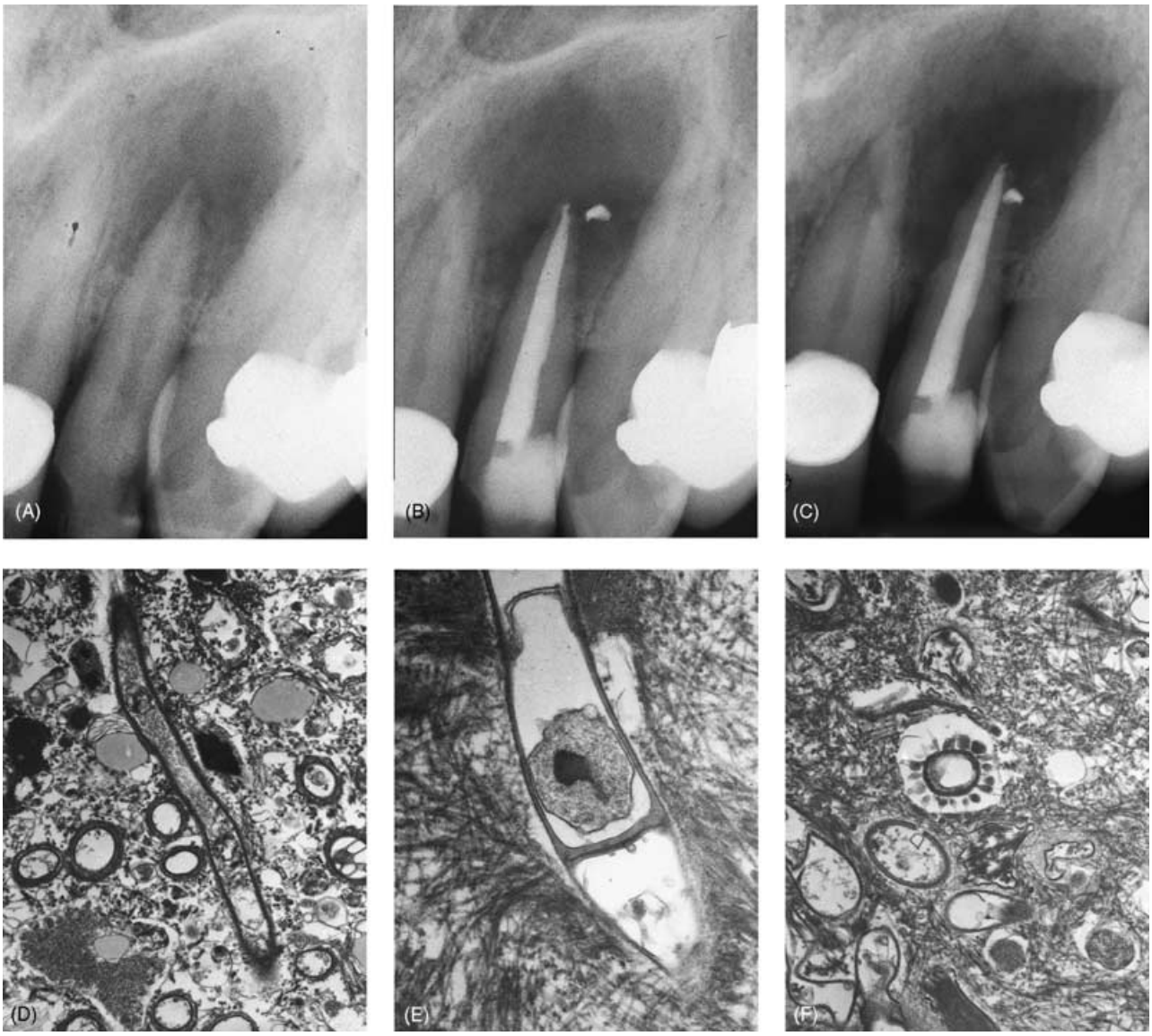

Fig. 7. Fungi in a persistent periapical lesion. (A) Radiograph of maxillary lateral incisor with necrotic pulp and periapical radiolucency. (B) Immediate postoperative radiograph showing good nonsurgical treatment. (C) At the 3-month recall the patient is still symptomatic and the periapical radiolucency is larger. (D) Transmission electron micrograph shows growing hyphae of a fungus. (E) Higher magnification of the hyphae showing the cell wall. (F) Reproductive fungi spores.

gingival tissue samples (34). Gingival herpesviruses were associated with increased occurrence of subgingival *P. gingivalis*, *T. forsythensis*, *P. intermedia*, *Prevotella nigrescens*, *T. denticola*, and *A. actinomycetemcomitans,* suggesting that they may play a role in promoting overgrowth of pathogenic periodontal bacteria (33).

In endodontics, the presence of viruses in the dental pulp was first reported in a patient with AIDS (62). DNA of HIV virus has also been detected in periradicular lesions (51). However, it has not been established that HIV virus can directly cause pulpal disease. Herpes simplex virus was also studied in relation to endodontic disease. However, unlike its role in periodontal disease, it appears that herpes simplex virus is not associated with endodontic disease (79, 148, 158). On the other hand, recent data suggest that other common types of human viruses may be involved in pulpal disease and in the development of periapical lesions. Sabeti et al. (157) suggested that human cytomegalovirus and Epstein–Barr virus play a role in the pathogenesis of symptomatic periapical lesions. It appears that active infection may give rise to production of an array of cytokines and chemokines with the potential to induce local immunosuppression or tissue destruction (31). Herpesvirus activation in periapical inflammatory cells may impair the host defense

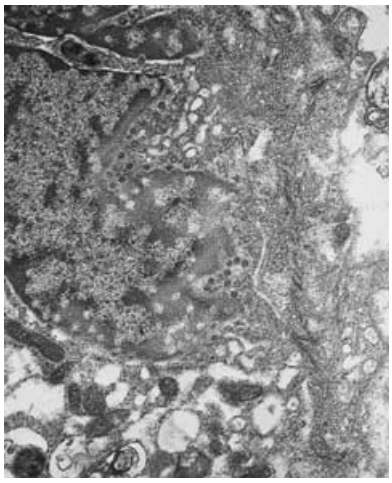

Fig. 8. Transmission electron micrograph of the nucleus of a macrophage in a periapical lesion showing a possible viral infection.

mechanisms and give rise to overgrowth of bacteria, as seen in periodontal lesions. Herpesvirus-mediated immune suppression may be detrimental in periapical infections due to already compromised host responses in the granulomatous tissue (119).

Alterations between prolonged periods of herpesvirus latency interrupted by periods of activation may explain some burst-like symptomatic episodes of periapical disease (158). Frequent reactivation of periapical herpesvirus may support rapid periapical breakdown. Absence of herpesvirus infection or viral reactivation may be the reason that some periapical lesions remain clinically stable for extended periods of time (158).

Non-living etiologic agents

Depending on their origin and nature, non-living etiologic agents can be either extrinsic or intrinsic.

Extrinsic agents

Foreign bodies

Foreign bodies are frequently found to be associated with inflammation of the periradicular tissues (Figs 9 and 10). Although endodontic and periodontal diseases are primarily associated with the presence of microorganisms, some treatment failures may be explained by the presence of certain foreign substances *in situ*. These include substances such as dentin and cementum chips (83, 200), amalgam (61, 104, 200), root canal filling materials (61, 97, 104, 200), cellulose fibers from absorbent paper points (53, 103, 104), gingival retraction cords (57), leguminous foods (125), and calculus-like deposits (72). A foreign-body response may occur to any of these substances and the clinical reaction may be either acute or chronic. Therefore, such conditions may be either symptomatic or asymptomatic. Microscopically, these lesions demonstrate the presence of multinucleated giant cells surrounding the foreign material in a chronic inflammatory infiltrate. Mechanical or surgical removal of the foreign bodies is usually the treatment of choice.

Intrinsic agents

Cholesterol

The presence of cholesterol crystals in apical periodontitis is a common histopathologic finding (20, 25, 135, 167, 189). With time, the cholesterol crystals would be dissolved and washed away, leaving behind the spaces they occupied as clefts. The reported prevalence of cholesterol clefts in periapical disease varies from 18% to 44% (25, 167, 189). It has been suggested that the crystals could be formed from cholesterol released by disintegrating erythrocytes of stagnant blood vessels within the periapical lesion (25), lymphocytes, plasma cells and macrophages, which die in great numbers and disintegrate in chronic periapical lesions (189), or by the circulating plasma lipids (167). However, it is possible that all of these factors may contribute to the accumulation, concentration and crystallization of cholesterol in a periapical lesion (Fig. 11).

Accumulation of cholesterol crystals in inflamed periapical tissues in some cases has been suggested to be one of the causes of failure of endodontic therapy (133, 135). It seems that the macrophages and the multinucleated giant cells that congregate around cholesterol crystals are not efficient enough to destroy the crystals completely. In addition, the accumulation of macrophages and giant cells around the cholesterol clefts in the absence of other inflammatory cells, such as neutrophils, lymphocytes and plasma cells, suggests that the cholesterol crystals induce a typical foreign-body reaction (133).

Russell bodies

Russell bodies can be found in most inflamed tissues throughout the body including the periradicular tissues (Fig. 12). These are small, spherical accumulations of an eosinophilic substance found within or near plasma cells and other lymphoid cells. The

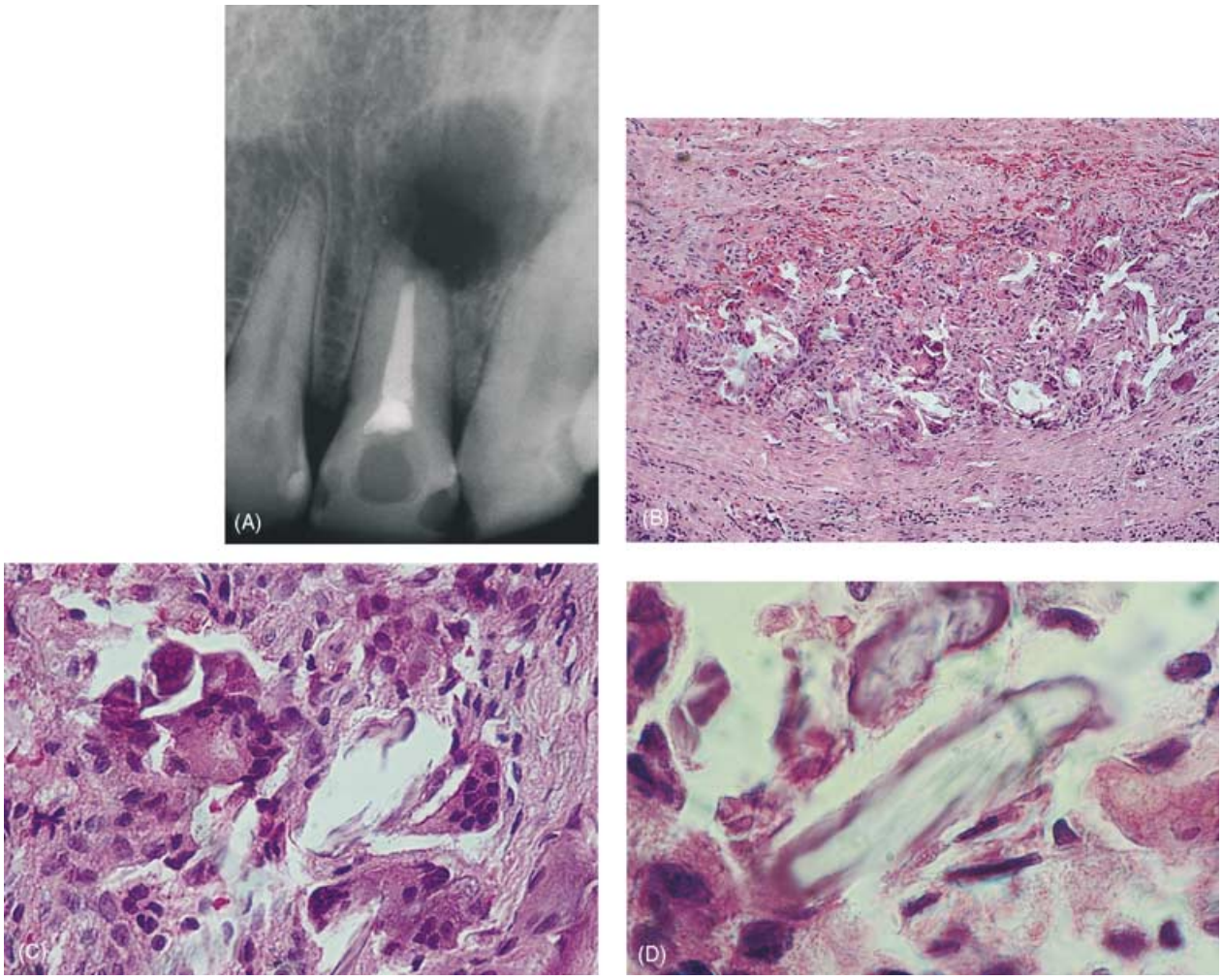

Fig. 9. Foreign-body particles in a periapical lesion. (A) Radiograph of a symptomatic maxillary central incisor with a large periapical lesion. Endodontic treatment was done 27 years ago. (B) Apical surgery was done and apical tissue submitted for histologic analysis. Photomicrograph shows foreign-body particles in the presence of giant cells. (C) Higher magnification of the foreign-body particles and giant cells. (D) Part of the foreign body. When put under polarized light, the presence of vegetable matter was apparent. The diagnosis was confirmed when parts of a paper point penetrated past the apical foramen.

presence and occurrence of Russell bodies in oral tissues and periapical lesions is well documented (60, 113, 120).

Several studies have indicated the presence of Russell bodies in about 80% of periradicular lesions. Recently, large intracellular and extracellular Russell bodies were found also in inflammatory pulpal tissue of carious primary teeth (181). It is hypothesized that Russell bodies are caused by the synthesis of excessive amounts of normal secretory protein in certain plasma cells engaged in active synthesis of immunoglobulins. The endoplasmic reticulum becomes greatly distended, producing large homogeneous eosinophilic inclusions (35). However, the prevalence of Russell bodies, the mechanisms of their production, and their exact role in pulpal inflammation have not yet fully elucidated.

Rushton hyaline bodies

The presence of Rushton hyaline bodies (RHB) is a feature unique to some odontogenic cysts. Their frequency varies from 2.6% to 9.5% (4). RHB usually appear within either the epithelial lining or the cyst lumen (Fig. 13). They have a variety of morphologic forms, including linear (straight or curved), irregular, rounded and polycyclic structures, or they may appear granular (4, 52).

The exact nature of RHB is not fully understood. It has been variously suggested that they are keratinous in nature (167), of hematogenous origin (82), a specialized secretory product of odontogenic epithelium (130), or degenerated red blood cells (52). Some authors suggested that RHB are material left behind from a previous surgical operation (124). It is not

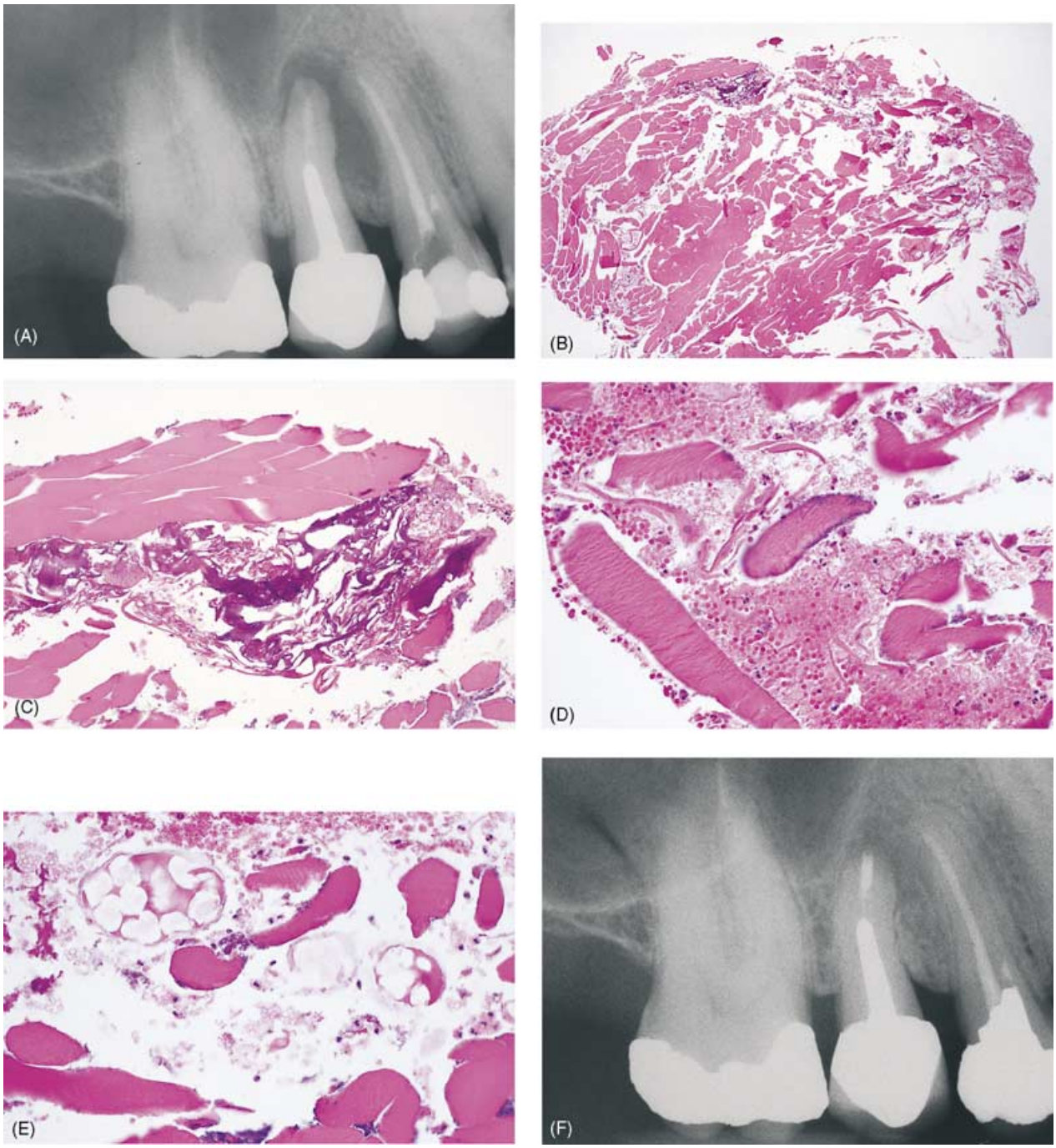

Fig. 10. Multiple etiologic reasons for non-healing of area past the apical foramen. (A) Radiograph showing treatment failure in a maxillary second premolar. The tooth was treated by intentional replantation during which the apical lesion was removed. (B) Photomicrograph of the lesion showing presence of foreign material. (C) Higher magnification shows purple unidentified foreign material and necrotic muscle tissue ("dead meat granuloma"). (D) A different area of the lesion showing necrotic muscle with bacterial colonies. (E) Necrotic muscle tissue infected by bacteria and presence of lentil beans (pulse granuloma). (F) One-year follow-up radiograph. The tooth is asymptomatic, firm and bony healing is evident.

clear why the RHB form mostly within the epithelium.

Charcot-Leyden crystals

Charcot-Leyden crystals (CLC) are naturally occurring haexagonal bipyramidal crystals derived from the intracellular granules of eosinophils and basophils (1, 182, 195). Their presence is most often associated with increased numbers of peripheral blood or tissue eosinophils in parasitic, allergic, neoplastic, and inflammatory diseases (1, 109, 195).

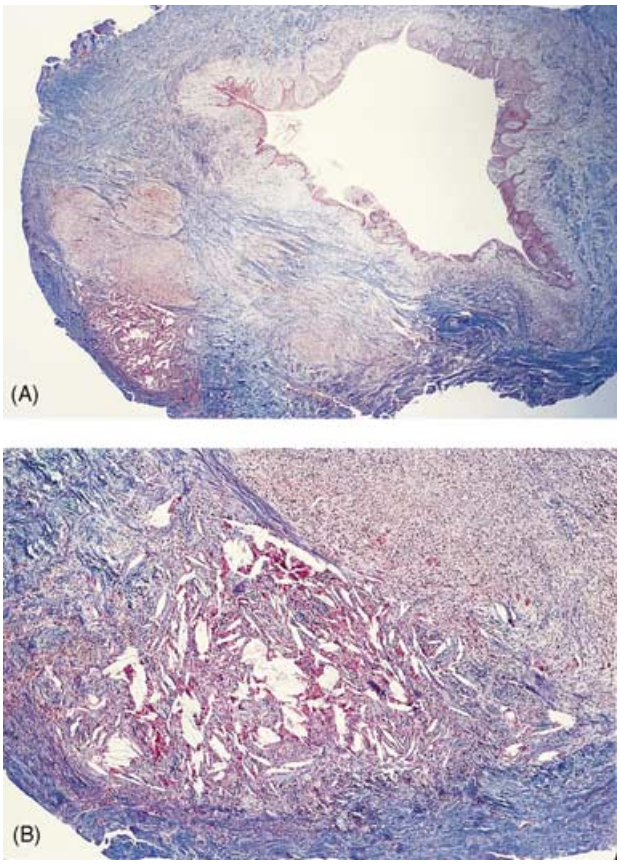

Fig. 11. Cholesterol clefts in a periapical lesion. (A) Photomicrograph stained with Masson's Trichrome of a cyst with a thick fibrous wall. Embedded in the wall is a large collection of cholesterol clefts. (B) Higher magnification showing empty clefts where cholesterol was dissolved during the histologic preparation.

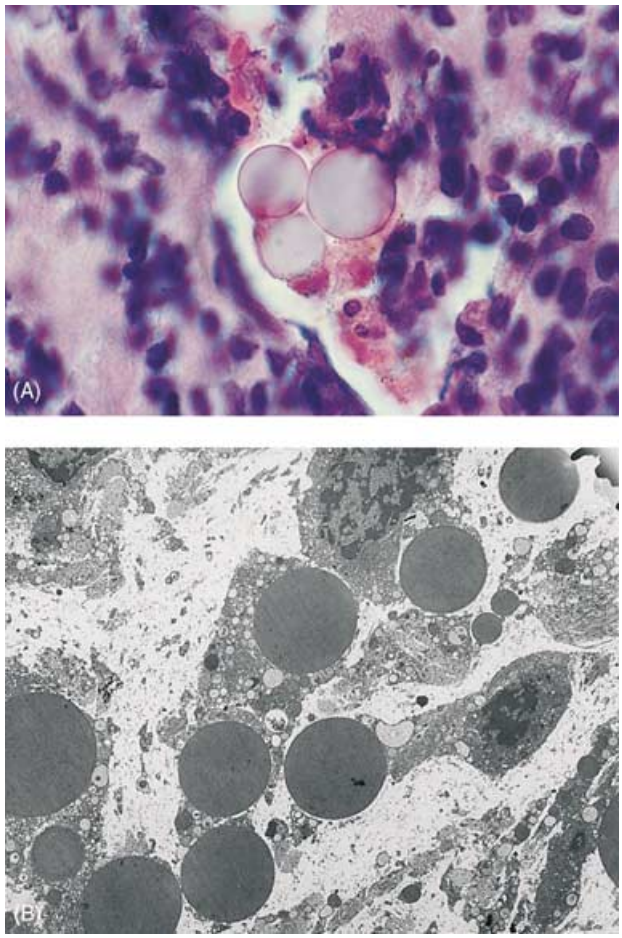

Fig. 12. (A) Photomicrograph of a periapical lesion showing presence of Russell bodies. (B) Transmission electron micrograph demonstrates the round amorphous shape of these bodies.

Activated macrophages were reported to have an important role in the formation of CLC in several disease processes (48, 109). CLC and damaged eosinophils, along with their granules, have been observed within macrophages (27, 48, 109). It has been proposed that after the degranulation of eosinophils, CLC protein could be phagocytized into acidified membrane-bound lysosomes (109). At some point, CLC protein would begin to crystallize, forming discrete particles increasing in volume and density over time. Ultimately, these crystals would be released via phagosomal exocytosis or by piercing through the membrane of the phagosome and macrophage cytoplasm, becoming free in the stromal tissue.

Recent findings support the theory that activated macrophages have a role in the formation of CLC (169). In addition, the presence of CLC can be detected within a periapical lesion that failed to resolve after conventional endodontic treatment (Fig. 14). Although the biological and pathologic role of CLC in endodontic and periodontal disease is still unknown, they may be associated with some cases of treatment failures.

Epithelium

Among the normal components of the lateral and apical periodontal ligament are the epithelial rests of Malassez. The term ''rests,'' is misleading in that it evokes a vision of discrete islands of epithelial cells. It has been shown that these rests are actually a fishnet-like, three-dimensional, interconnected network of epithelial cells. In many periapical lesions, epithelium is not present and therefore is presumed to have been destroyed (165). If the rests remain, they may respond to a stimulus by proliferating to wall off the irritants coming through the apical foramen. The epithelium is surrounded by chronic inflammation and is termed an epitheliated granuloma. If this lesion is not treated, the epithelium continues to

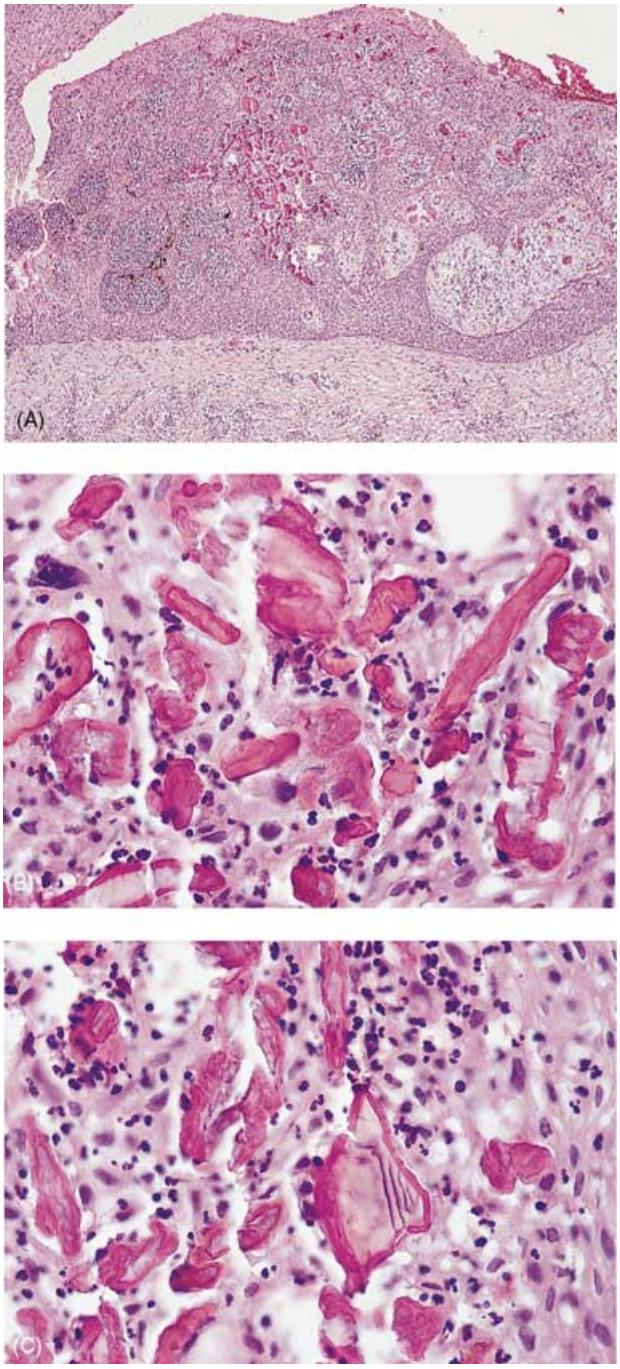

Fig. 13. (A) Photomicrograph showing Rushton hyaline bodies in the epithelial lining of a periapical cyst. (B, C) Higher magnifications demonstrating pleomorphism of these bodies.

proliferate in response to the bacteria and inflammatory products from the apical foramen.

The term ''bay'' cyst has been introduced for the microcopic representation of this situation (170). This is a chronic inflammatory lesion that has epithelium lining surrounding the lumen, but the lumen has a direct communication with the root canal system through the foramen (Fig. 15). On the other hand, a ''true'' cyst is the completion of the epithelial proliferative lesion. It is a three-dimensional, epithelium-lined cavity with no communication between the lumen and the canal system (Fig. 16). When periapical lesions are studied in relation to the root canal a clear distinction between these two entities should be made (136, 170).

There has been some confusion in the diagnosis when lesions are studied only on curetted biopsy material. Since the tooth is not attached to the lesion, orientation to the apex is lost. Therefore the criterion used for diagnosis of a cyst is a strip of epithelium that appears to be lining a cavity. It is apparent that curetting both a bay cyst and a true cyst could lead to the same microscopic diagnosis. A bay cyst could be sectioned in such a way that it could resemble or give the appearance of a true cyst. This distinction between a bay and a true cyst is important from the standpoint of healing (37). It may be that true cysts must be surgically removed, but bay cysts that communicated with the root canal may heal with nonsurgical root canal therapy. Since root canal therapy can directly affect the lumen of the bay cyst, the environmental change may bring about resolution of the lesion. The true cyst is independent of the root canal system; therefore conventional therapy may have no effect on the lesion.

The formation of a cyst and its progression from a bay cyst to a true cyst occurs over time. Valderhaug (190), in a study done in monkeys, showed no cyst formation until at least 6 months after the canal contents became necrotic. Thus the longer a lesion is present, the greater the chance of becoming a true cyst. However, the incidence of true cysts is probably less than 10% (170).

Contributing factors

Poor endodontic treatment

Correct endodontic procedures and techniques are key factors for treatment success. It is imperative to completely clean, shape and obturate the canal system in order to enhance successful outcomes. Unfortunately, poor endodontic treatments are often found associated with periradicular inflammation. Poor endodontic treatment allows canal reinfection, which may often lead to treatment failure (143). Clinical signs and symptoms as well as radiographic evidence of periradicular lesions are usually associated with endodontic failure.

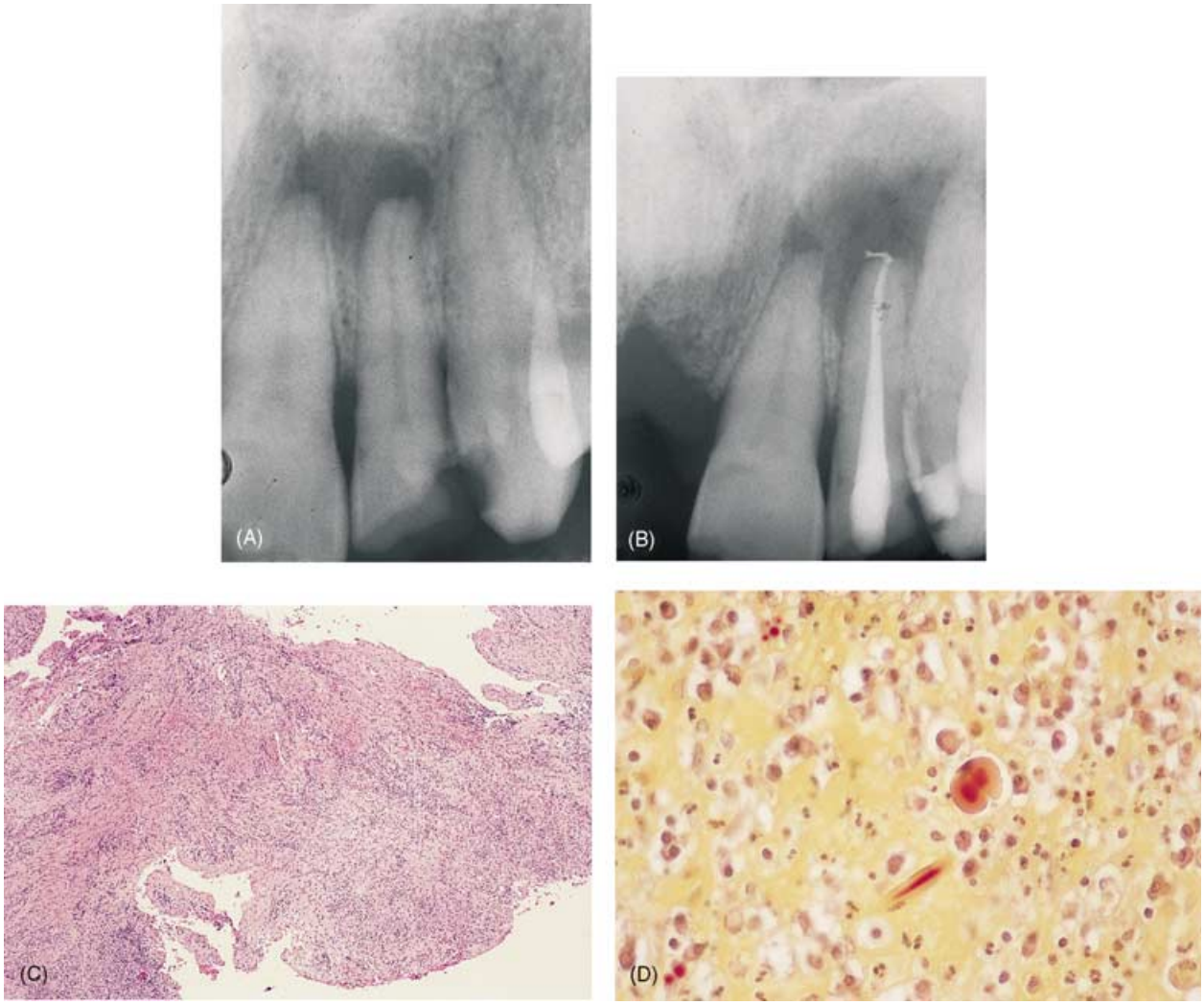

Fig. 14. Charcot-Leyden crystals in a periapical lesion. (A) Maxillary lateral incisor with necrotic pulp and periapical lesion. (B) Nine months after endodontic treatment the tooth is symptomatic and the lesion is larger. (C) Apical surgery was done and the lesion submitted for microscopic analysis. Photomicrograph stained with hematoxylin & eosin shows only acute and chronic inflammatory infiltrate. (D, F, H) May-Grunwald-Giemsa stain reveals the presence of Charcot-Leyden crystals. (E, G) Polarized light demonstrates refraction of the Charcot-Leyden crystals.

Endodontic failures can be treated by either orthograde or retrograde retreatment with good success rates (Figs 17 and 18). It seems that the success rate is similar to that of initial conventional endodontic treatment if the cause of failure is properly diagnosed and corrected (19). In recent years, retreatment techniques have improved dramatically due to use of the operating microscope and development of new armamentarium.

Poor restorations

Coronal leakage is an important cause of failure of endodontic treatment. Root canals may become recontaminated by microorganisms due to delay in placement of a coronal restoration and fracture of the coronal restoration and/or the tooth (160). Madison & Wilcox (116) found that exposure of root canals to the oral environment allowed coronal leakage to occur, and in some cases along the whole length of the root canal. Ray & Trope (147) reported that defective restorations and adequate root fillings had a higher incidence of failures than teeth with inadequate root fillings and adequate restorations. Teeth in which both the root fillings and restorations were adequate had only 9% failure, while teeth in which both root fillings and restorations were defective had about 82% failure (147). Saunders & Saunders (159) showed that coronal leakage was a significant clinical problem in root-filled molars. In an *in vitro* study, they found that packing excess gutta-percha and sealer over the floor of the pulp chamber, after completion of root canal filling, did not seal the root canals. It was therefore recommended that excess

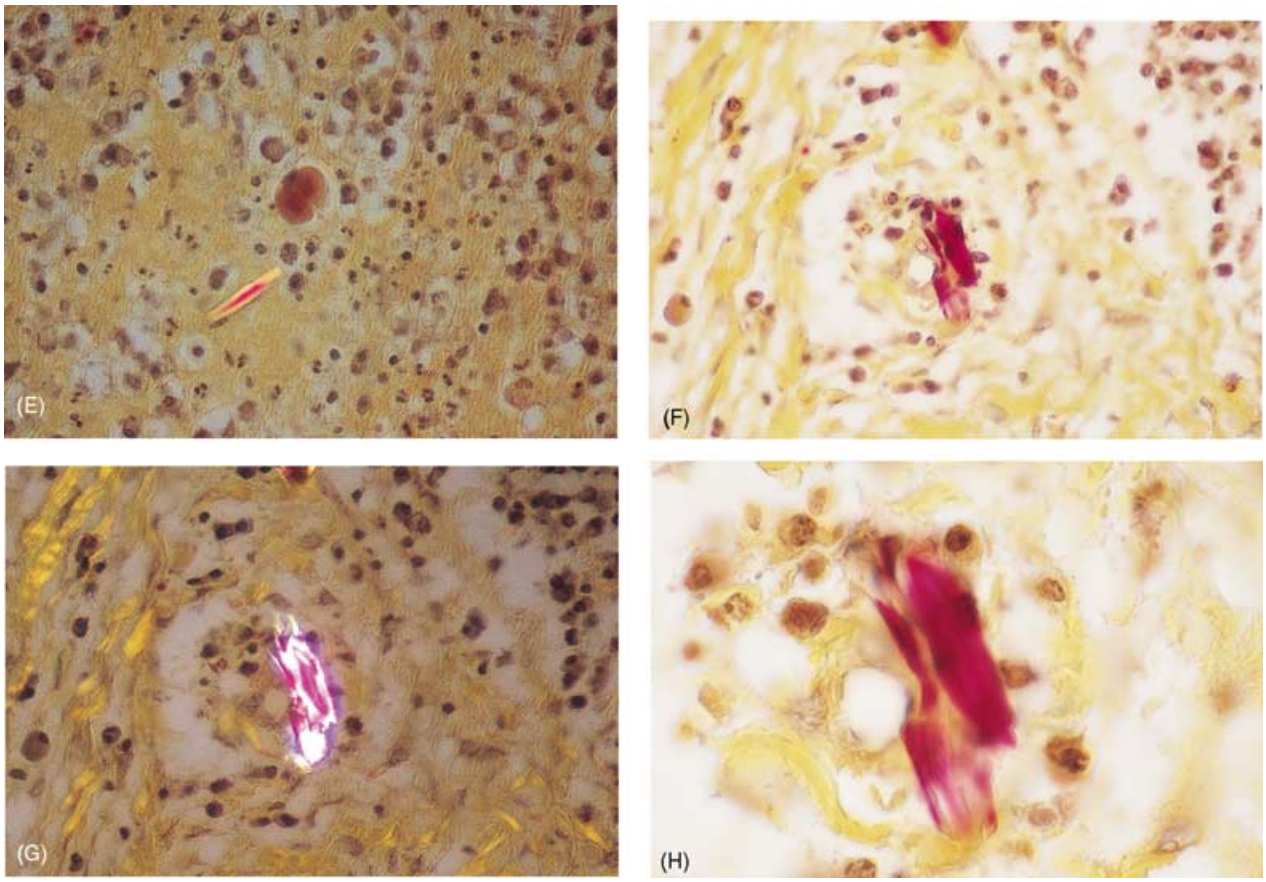

Fig. 14. continued

of gutta-percha filling should be removed to the level of the canal orifices and that the floor of the pulp chamber be protected with a well-sealed restorative material (159).

Coronal restoration is the primary barrier against coronal leakage and bacterial contamination of endodontic treatment. Therefore it is essential that the root canal system be protected by good endodontic

Fig. 15. Photomicrograph showing a bay cyst associated with a root canal that opens directly into the lumen of the lesion.

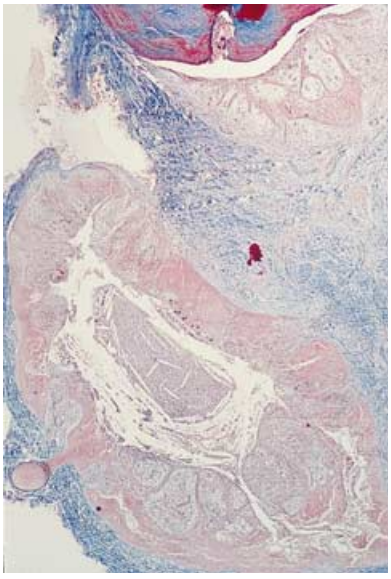

Fig. 16. Photomicrograph of a true inflammatory cyst stained with Masson's Trichrome showing a 3-dimensional epithelial-lined lesion with no connection to the root canal system and apical foramen in serial sections.

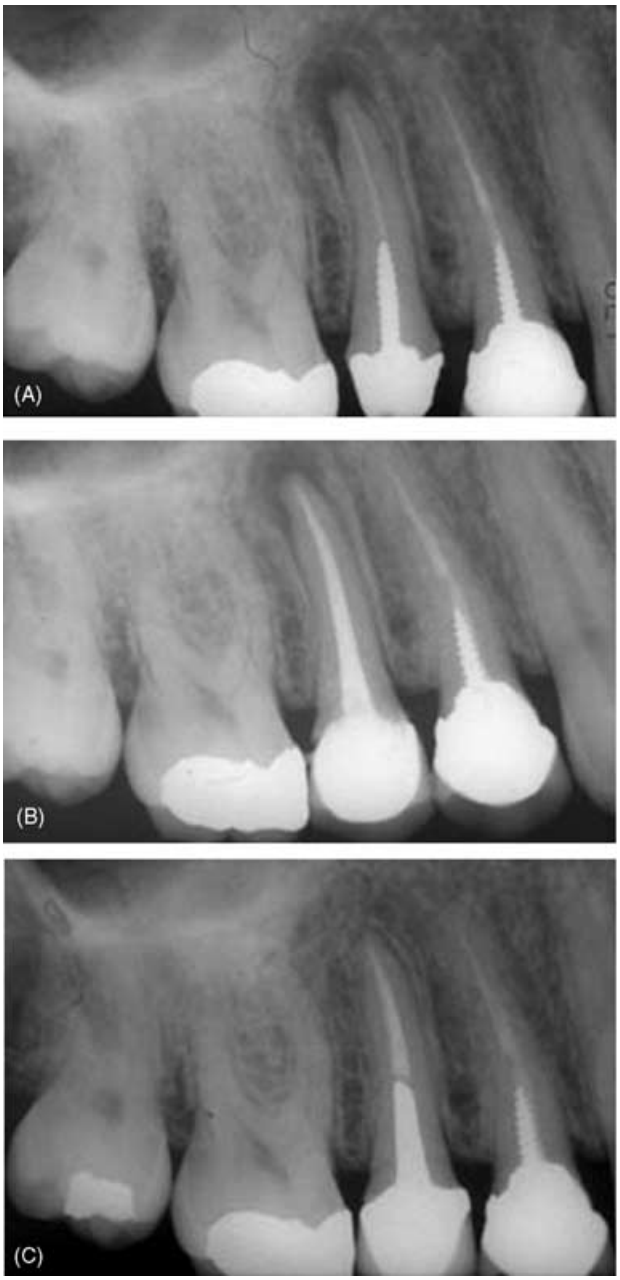

Fig. 17. Non-healing due to insufficient root canal preparation and obturation in a maxillary second premolar. (A) Radiograph showing periapical radiolucency associated with the tooth involved. (B) Postoperative radiograph immediately following endodontic retreatment. (C) Two-year follow-up radiograph showing evidence of bony healing. The tooth was restored with post and crown.

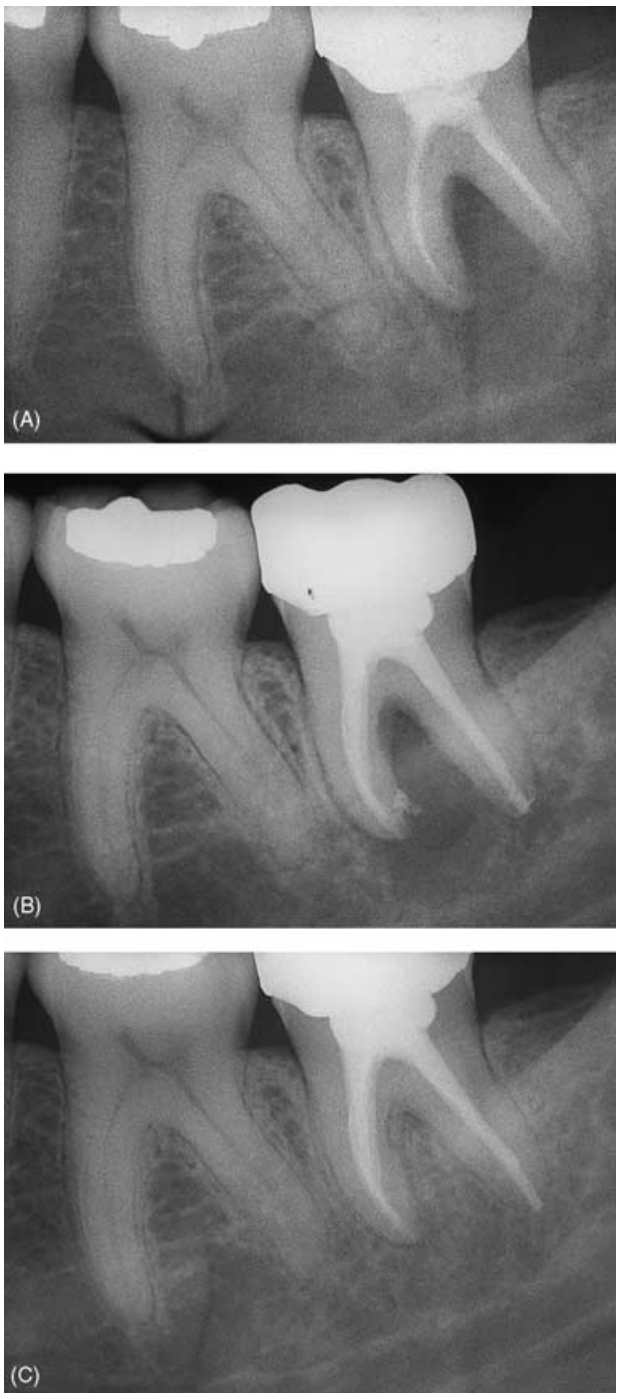

Fig. 18. Non-healing due to insufficient root canal preparation and obturation in a mandibular second molar. (A) Radiograph showing a large periapical and furcal radiolucency. (B) Radiograph taken immediately following endodontic non-surgical retreatment. (C) Three-year follow-up radiograph showing evidence of bony healing.

obturation and a well-sealed coronal restoration (Fig. 19). However, even popular permanent restorative materials may not always prevent coronal leakage (197). Cemented full crowns (68, 196) as well as dentin-bonded crowns (140) also showed leakage.

Heling et al. (80) performed an extensive review of the literature to determine the factors associated with long-term prognosis of endodontically treated teeth and drew the following conclusions:

- Post space preparation and cementation should be performed with rubber-dam isolation.
- The post space should be prepared with a heated plugger.
- A minimum of 3 mm of root canal filling should remain in the preparation.

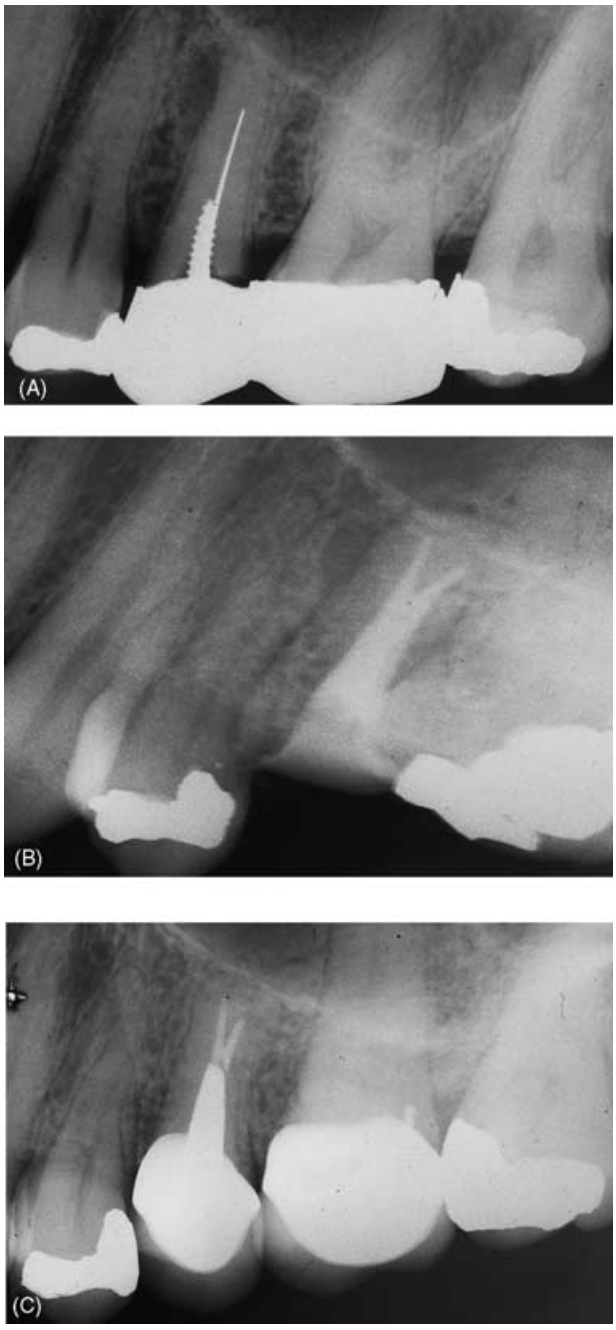

Fig. 19. Poor coronal seal in a maxillary second premolar. (A) Radiograph showing inadequate coronal restoration and root canal treatment. Note the lateral apical lesion associated with the tooth. (B) Radiograph taken upon completion of endodontic retreatment. The old restoration was removed and the canal system properly prepared and obturated. (C) Five-year follow-up radiograph showing bony repair. The tooth was adequately restored with post and crown.

- The post space should be irrigated and dressed as during root canal treatment.
- Leak-proof restorations should be placed as soon as possible after endodontic treatment.
- Endodontic retreatment should be considered for teeth with a coronal seal compromised for longer than 3 months.

Trauma

Trauma to teeth and alveolar bone may involve the pulp and the periodontal ligament. Both tissues can be affected either directly or indirectly. Dental injuries may take many shapes but generally can be classified as enamel fractures, crown fractures without pulp involvement, crown fractures with pulp involvement, crown–root fracture, root fracture, luxation, and avulsion (11). Treatment of traumatic dental injuries varies depending on the type of injury and it will determine pulpal and periodontal ligament healing prognosis (10).

Enamel fracture involves the enamel only and includes chipping and incomplete fractures or cracks. Treatment usually includes grinding and smoothing the rough edges or restoration of the missing enamel structure. In cases where only the enamel is involved, the pulp usually maintains its vitality and the prognosis is good.

Crown fracture without pulp involvement is an uncomplicated fracture that involves enamel and dentin without pulp exposure. Treatment may include conservative restoration with composite resin or reattachment of the separated fragments. It has been reported that reattachment of dentin–enamel crown fragments is a conservative possibility for crown restoration (9).

Crown fracture with pulp involvement is a complicated fracture involving enamel and dentin and exposure of the pulp. The extent of the fracture helps to determine the necessary pulpal and restorative treatments (11). A small fracture may indicate vital pulp therapy followed by acid-etched composite restoration. A more extensive fracture may require root canal treatment as well. The stage of tooth maturation is an important factor in choosing between pulpotomy and pulpectomy (11). The amount of time elapsed from the injury often affects pulpal prognosis. The sooner the tooth is treated, the better the prognosis.

Crown–root fractures are usually oblique and involve both crown and root. They include enamel, dentin, and cementum and may or may not include the pulp. Crown–root fractures often include molars and premolars, but anterior teeth can also be affected. A cusp fracture that extends subgingivally is a common finding and often presents a diagnostic and clinical challenge (11). Treatment depends on the severity of the fracture and may vary from only removing of the fractured tooth fragment and restoration to endodontic treatment, periodontal treatment and/or surgical procedures. Sometimes

the prognosis is poor and the tooth needs to be extracted. Due to the complexity of this injury, a team approach involving endodontists, periodontists, orthodontists, and prosthodontists is highly recommended (11).

Root fractures involve cementum, dentin, and pulp. They may be horizontal or transverse. Clinically, root fractures may often present mobility of the involved teeth as well as pain on biting. Often, a periodontal defect or a sinus tract is associated with the fractured root. Radiographically, a root fracture can only be visualized if the X-ray beam passes through the fracture line. Horizontal and oblique root fractures are easier to detect radiographically while the diagnosis of vertical root fractures is more challenging.

Treatment, when feasible, usually includes repositioning of the coronal segment and stabilization by splinting (11). A flexible splint using orthodontic or nylon wire and acid-etched resin for periods of up to 12 weeks will enhance pulpal and periodontal repair (8). Teeth with fractured roots do not necessarily require root canal treatment if healing takes place with no evidence of pulp disease (201).

Luxations include several different types of tooth displacement injuries such as concussion, subluxation, extrusive luxation, lateral luxation, and intrusive luxation. Generally, the more severe the luxation injury, the greater the damage to the periodontium and to the dental pulp (11).

In concussion injuries the tooth is only sensitive to percussion. There is no increase in mobility, and no radiographic changes are found. The pulp may respond normal to vitality tests and no immediate treatment is usually necessary (11).

In subluxation injuries the teeth are sensitive to percussion and also have increased mobility (11). Often sulcular bleeding is present, indicating damage to the periodontal ligament. Radiographic findings are unremarkable and the pulp may respond normally to vitality tests (11). No treatment is usually required for minor subluxations. If mobility is severe, stabilization of the tooth is necessary.

In extrusive luxations the teeth have been partially displaced from the socket and increased mobility is found. Radiographs also show displacement. The pulp usually does not respond to vitality tests and requires root canal treatment once irreversible pulpitis is diagnosed (11). The tooth requires repositioning and splinting usually for a 2–3-week period.

In lateral luxations the tooth has been displaced away from its long axis. Percussion sensitivity may or may not be present. A metallic sound upon percussion indicates that the root has been forced into the alveolar bone (11). Treatment includes repositioning and splinting. Lateral luxations that involve bony fractures usually require up to 8-week splinting periods. Endodontic therapy should be performed only when a definite diagnosis of irreversible pulpitis or pulp necrosis is established.

During intrusive luxations the teeth are forced into their sockets in an axial direction. They have decreased mobility and resemble ankylosis (11). Treatment depends on root maturity. If the root is not completely formed and have an open apex the tooth may re-erupt. In such cases root canal therapy is not necessary as the pulp may revascularize (6). If the tooth is fully developed, active extrusion is indicated. In such cases root canal treatment is indicated since pulp necrosis develops in almost all cases (6).

Avulsion is when the tooth is totally displaced from its alveolar socket. If the tooth is replanted soon after avulsion, the periodontal ligament has a good chance of healing (11). Extra-alveolar time and the storage media used to transport the tooth are critical factors for successful replantation. The degree of recovery of the periodontal ligament cells will determine long-term success.

Resorptions

Root resorption is a condition associated with either a physiologic or a pathologic process resulting in a loss of dentin, cementum and/or bone (5). It may be initiated in the periodontium and affect initially the external surfaces of the tooth (external resorption) or it may start within the pulp space affecting primarily the internal dentin surfaces (internal resorption). If not diagnosed and treated, external root resorption may invade cementum, dentin and ultimately the pulp space. In cases of untreated internal resorptions the process may advance and perforate to the external root surface.

External root resorption may be divided into three main categories (185):

1) progressive inflammatory resorption
2) invasive resorption (non inflammatory)
3) replacement resorption (non inflammatory).

Progressive inflammatory root resorption is caused by stimuli such as pulpal infection and sulcular infection. It may occur following traumatic displacement injuries, tumors, cysts, certain systemic diseases, periodontal disease, or as a result of pulp inflammation and necrosis. Practically all teeth with apical periodontitis will exhibit a certain degree of inflammatory root resorption (Fig. 20). This can be

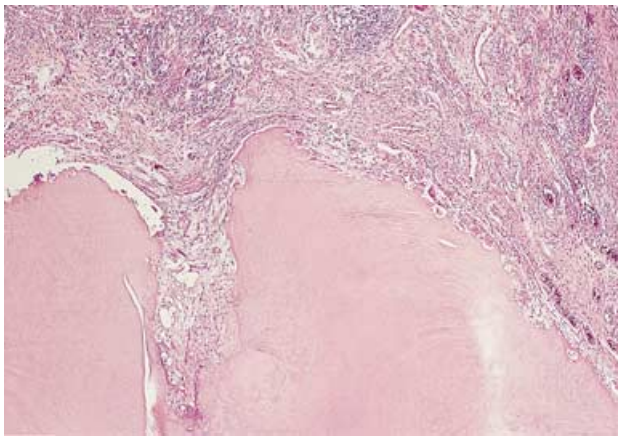

Fig. 20. Photomicrograph of a tooth with a periapical lesion showing multiple resorptive areas, inflammatory infiltrate, and osteoclasts.

located on either the apical or lateral aspects of the root but is more frequent at the apex. During the initial stages the resorption cannot be detected radiographically; however, it is evident in histologic sections. If allowed to progress, the resorptive process may destroy the entire root. If detected and treated early, the prognosis is good. Removal of the inflamed pulpal tissue and obturation of the root canal system is the treatment of choice (36, 177).

Invasive root resorption, also known as invasive cervical resorption, is a relatively uncommon form of external root resorption (74–76). It is characterized by its cervical location and invasive nature (Fig. 21). Invasion of the cervical region of the root is predominated by fibrovascular tissue derived from the periodontal ligament. The process progressively resorbs cementum, enamel, and dentin and later may involve the pulp space. There may be no signs or symptoms unless it is associated with pulpal or periodontal infection. Secondary bacterial invasion into the pulp or periodontal ligament space will cause an inflammation of the tissues accompanied with pain. Frequently, however, the resorptive defect is only detected by routine radiographic examination. Where the lesion is visible, the clinical features vary from a small defect at the gingival margin to a pink coronal discoloration of the tooth crown (74). Radiographically, the lesion varies from well delineated to irregularly bordered radiolucencies. A characteristic radiopaque line generally separates the image of the lesion from that of the root canal, because the pulp remains protected by a thin layer of predentin until late in the process (74).

The etiology of invasive cervical resorption is not fully understood. It seems, however, that potential predisposing factors are trauma, orthodontic treatment and intracoronal bleaching with 30% hydrogen peroxide (75, 153). Treatment of the condition presents clinical problems because the resorptive tissue is highly vascular and the resulting hemorrhage may impede visualization and compromise placement of a restoration (76). Successful treatment relies upon the complete removal or inactivation of the resorptive tissue. This is difficult to obtain in more advanced lesions characterized by a series of small channels often interconnecting with the periodontal ligament apical to the main lesion. In most cases, surgery is necessary to gain access to the resorptive defect and often may cause loss of bone and periodontal attachment. Topical application of a 90% aqueous solution of trichloracetic acid, curettage and sealing of the defect has proved successful in most cases (76). Large defects associated with advanced stages of this condition have a poor prognosis.

Replacement resorption or ankylosis occurs following extensive necrosis of the periodontal ligament with formation of bone onto a denuded area of the root surface (185). This condition is most often seen as a complication of luxation injuries, especially in avulsed teeth that have been out of their sockets in dry conditions for several hours (Fig. 22).

Certain periodontal procedures have been reported to induce replacement root resorption (117). The potential for replacement resorption was also associated with periodontal wound healing (94). Granulation tissue derived from bone or gingival connective tissue may induce root resorption and ankylosis (23). It seems that the culprit is the lack of ability to form connective tissue attachment on a denuded root surface. The only cells within the periodontium that seem to have this ability are the periodontal ligament cells (23). In general, if less than 20% of the root surface is involved, reversal of the ankylosis may occur (7). If not, ankylosed teeth are incorporated in the alveolar bone and will become part of the normal remodeling process of bone. This is a gradual process and the speed by which the teeth are replaced by bone varies depending mainly on the metabolic rate of the patient. In most cases, it may take years before the root is completely resorbed.

Clinically, replacement root resorption is diagnosed when lack of mobility of the ankylosed teeth is determined (7). The teeth will also have a metallic sound upon percussion, and after a period of time will be in infraocclusion. Radiographically, absence of a periodontal ligament space is evident and the ingrowth of bone into the root will present a characteristic ''moth-eaten'' appearance (185).

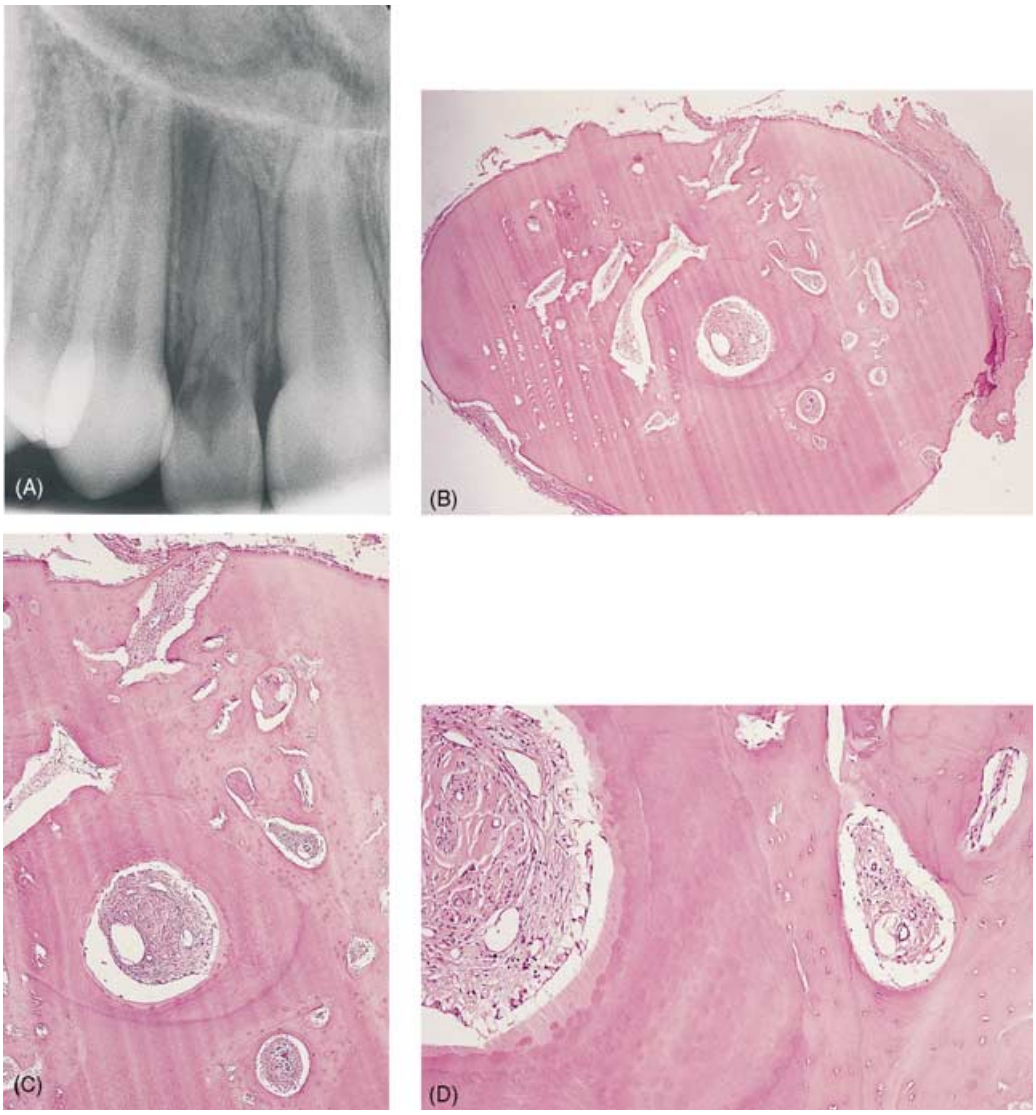

Fig. 21. Invasive root resorption in a maxillary lateral incisor. (A) Radiograph shows a large diffuse resorptive defect in the cervical region. The tooth was extracted and submitted for microscopic analysis. (B–D) Photomicrographs of a horizontal cross-section of the resorptive area. Note the multiple resorption bays as well as bone-like material deposited directly on dentin (ankylosis). Also note the absence of inflammation.

Internal root resorption occurs as a result of multinucleated giant cell activity in an inflamed pulp (Fig. 23). The origin of this condition is not fully understood but it appears to be related to chronic pulpal inflammation associated with an infected coronal pulp space (193). Internal resorption will only take place in the presence of granulation tissue and if the odontoblastic layer and predentin are affected or lost (185, 194).

Causes for internal resorption are usually trauma, but bacteria may play a role in the process (193). Traumatic factors can be either mechanical, chemical, or thermal. Extreme heat has been suggested as a possible cause for this type of resorption (188). Therefore, the clinician must use sufficient irrigating solutions when performing root scaling with ultrasonic devices as well as when using cauterization during surgical procedures.

Internal root resorption is usually asymptomatic and diagnosed during a routine radiographic examination. Early diagnosis is critical for the prognosis (Fig. 23). When diagnosed at an early stage endodontic treatment of such lesions is usually uneventful (Fig. 24). The radiographic appearance of the resorptive defect discloses a distorted outline of the root canal. A round or an oval-shaped enlargement of the root canal space is usually found. In most cases, resorption of the adjacent bone does not occur unless large parts of the pulp become infected. Histologically, pulpal granulation tissue with multinucleated giant cells and coronal pulp necrosis are commonly found.

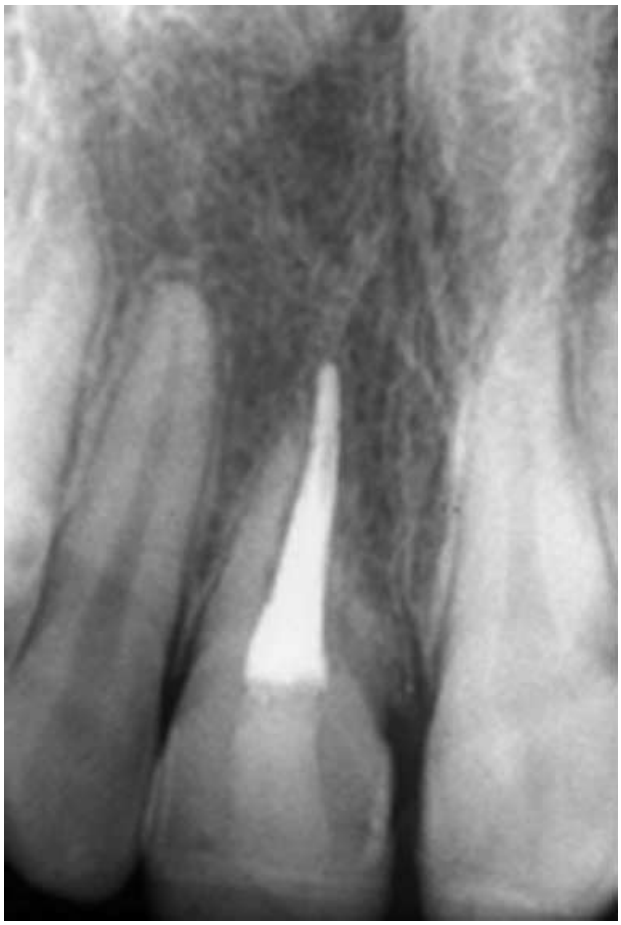

Fig. 22. Radiograph showing replacement root resorption in a maxillary central incisor that was avulsed and remained 2 h out of its socket.

Perforations

Root perforations are undesirable clinical complications that may lead to treatment failure (184). When root perforation occurs, communications between the root canal system and either periradicular tissues or the oral cavity may often reduce the prognosis of treatment. Root perforations may result from extensive carious lesions, resorption, or from operator error occurring during root canal instrumentation or post preparation (106, 184).

Treatment prognosis of root perforations depends on the size, location, time of diagnosis and treatment, degree of periodontal damage as well as the sealing ability and biocompatibility of the repair material (59). It has been recognized that treatment success depends mainly on immediate sealing of the perforation and appropriate infection control. Among the materials that have been recommended to seal root perforations are mineral trioxide aggregate, Super EBA, intermediate restorative material, Cavit®, glass-ionomer cements, composites, and amalgam (12, 43, 90, 112, 139, 149).

Developmental malformations

Teeth with developmental malformations tend to fail to respond to treatment when they are directly associated with an invagination or a vertical developmental radicular groove. Such conditions can lead to an untreatable periodontal condition. These grooves usually begin in the central fossa of maxillary central and lateral incisors crossing over the cingulum, and continuing apically down the root for varying distances. Such a groove is probably due to the failure of the tooth germ to form another root. As long as the epithelial attachment remains intact, the periodontium remains healthy. However, once this attachment is breached and the groove becomes contaminated by bacteria, a self-sustaining infrabony pocket can be formed along its entire lengh. This fissure-like channel provides a nidus for accumulation of bacterial biofilm and an avenue for the progression of periodontal disease. Radiographically, the area of bone destruction follows the course of the groove.

From a diagnostic standpoint, the patient may present symptoms of a periodontal abscess or a variety of asymptomatic endodontic conditions. If the condition is purely periodontal, it can be diagnosed by visually following the groove to the gingival margin and by probing the depth of the pocket, which is usually tubular in form and localized to this one area, as opposed to a more generalized periodontal problem. The tooth will respond to pulp-testing procedures. Bone destruction that vertically follows the groove may be apparent radiographically. If this entity is also associated with an endodontic disease, the patient may present clinically with any of the spectrum of endodontic symptoms.

The prognosis of root canal treatment in such cases is guarded, depending upon the apical extent of the groove. The clinician must look for the groove since it may have been altered by a previous access opening or restoration placed in the access cavity. The appearance of a teardrop-shaped area on the radiograph should immediately arouse suspicion. The developmental groove may actually be visible on the radiograph. If so, it will appear as a dark vertical line. This condition must be differentiated from a vertical fracture, which may give a similar radiographic appearance.

Treatment consists of buring out the groove, placing bone substitutes, and surgical management of the soft tissues and underlying bone. Radicular grooves can result in self-sustaining infrabony pockets and therefore scaling and root planing will not

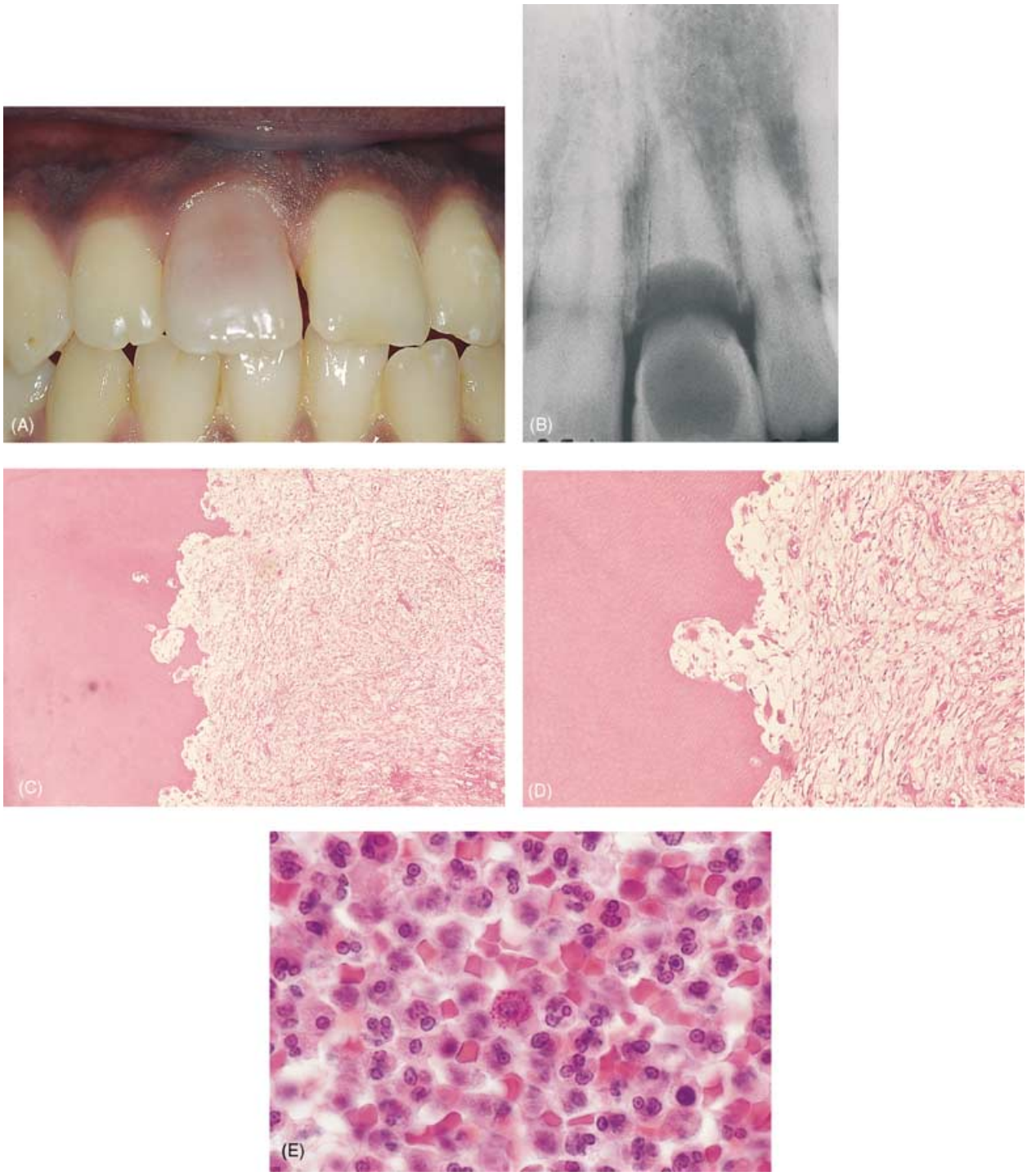

Fig. 23. Internal root resorption in a maxillary central incisor. The patient reported that a small lesion was diagnosed 2 years previously and was left untreated. (A) Clinical view. Note a large ''pink spot'' defect in the crown. (B) Radiograph showing a large internal resorptive defect in the crown and cervical area. Note that the defect has perforated into the surrounding periodontal ligament. (C–E) Histologic section of the internal resorptive area showing chronically inflamed connective tissue and dentin resorption by multinucleated giant cells.

suffice. Although the acute nature of the problem may be alleviated initially, the source of the chronic or acute inflammation must be eradicated by a surgical approach. Occasionally, the tooth needs to be extracted due to a poor prognosis.

Differential diagnosis

For differential diagnostic purposes the ''endo-perio lesions'' are best classified as endodontic,

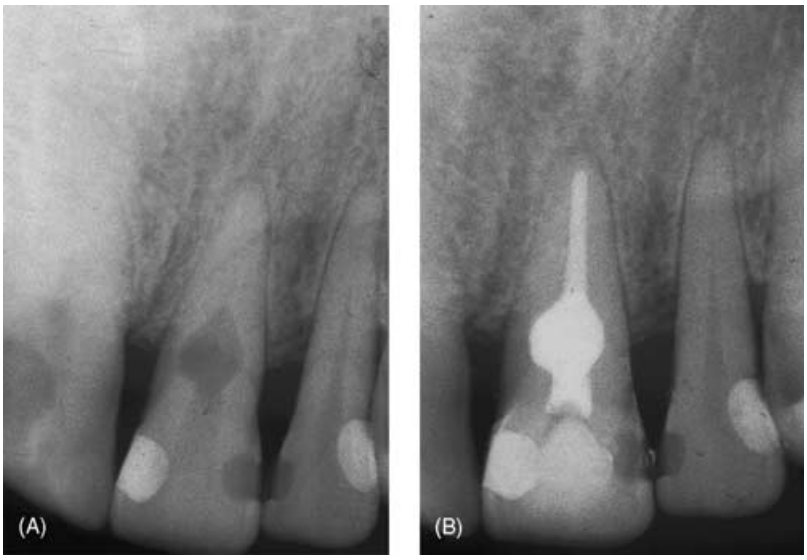

Fig. 24. (A) Radiograph showing an internal inflammatory resorptive defect in the coronal third of the root canal of a maxillary central incisor. The tooth tested positive to pulp sensitivity tests. (B) Postoperative radiograph showing obturation of root canal and resorptive defect.

periodontal or combined diseases (171). They can also be classified by treatment depending on whether endodontic, periodontal or combined treatment modalities are necessary. They include: primary endodontic disease, primary periodontal disease, and combined diseases. The combined diseases include: primary endodontic disease with secondary periodontal involvement, primary periodontal disease with secondary endodontic involvement, and true combined diseases.

Primary endodontic disease

An acute exacerbation of a chronic apical lesion on a tooth with a necrotic pulp may drain coronally through the periodontal ligament into the gingival sulcus. This condition may mimic clinically the presence of a periodontal abscess. In reality, it is a sinus tract from pulpal origin that opens through the periodontal ligament area. For diagnosis purposes, it is imperative for the clinician to insert a gutta-percha cone into the sinus tract and to take one or more radiographs to determine the origin of the lesion. When the pocket is probed, it is narrow and lacks width. A similar situation occurs where drainage from the apex of a molar tooth extends coronally into the furcation area. This may also occur in the presence of lateral canals extending from a necrotic pulp into the furcation area.

Primary endodontic diseases usually heal following root canal treatment (Fig. 25). The sinus tract extending into the gingival sulcus or furcation area disappears at an early stage once the necrotic pulp has been removed and the root canals are well sealed (Fig. 26). It is important to recognize that failure of any periodontal treatment will occur when the presence of a necrotic pulp has not been diagnosed, and endodontic treatment has not followed.

Primary periodontal disease

These lesions are caused primarily by periodontal pathogens. In this process, chronic periodontitis progresses apically along the root surface. In most cases, pulp tests indicate a clinically normal pulpal reaction (Fig. 27). There is frequently an accumulation of plaque and calculus and the pockets are wider.

The prognosis depends upon the stage of periodontal disease and the efficacy of periodontal treatment. The clinician must also be aware of the radiographic appearance of periodontal disease associated with developmental radicular anomalies (Fig. 28).

Combined diseases

Primary endodontic disease with secondary periodontal involvement

If after a period of time a suppurating primary endodontic disease remains untreated, it may become secondarily involved with periodontal breakdown (Fig. 29). Plaque forms at the gingival margin of the sinus tract and leads to plaque-induced periodontitis in the area. When plaque or calculus is detected, the treatment and prognosis of the tooth are different that those of teeth involved with only primary endododntic disease. The tooth now requires both endodontic and periodontal treatments. If the endodontic treatment is adequate, the prognosis depends on the severity of the plaque-induced periodontitis and the

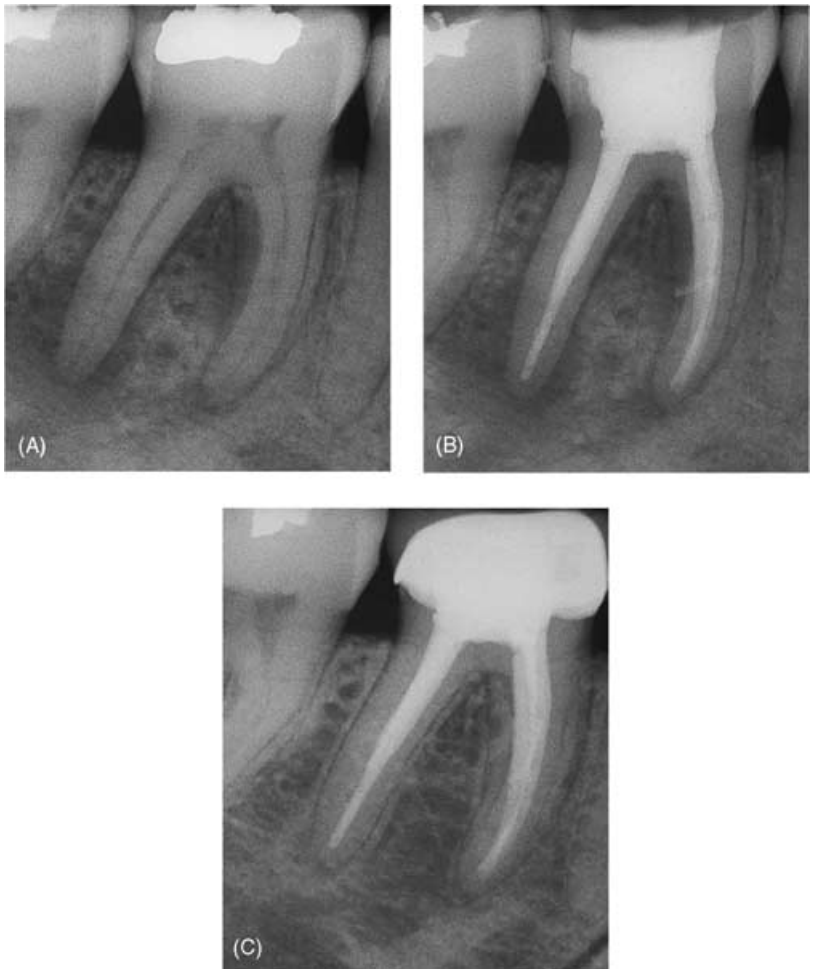

Fig. 25. Primary endodontic disease in a mandibular first molar with a necrotic pulp. (A) Preoperative radiograph showing periapical and interradicular radiolucencies. (B) Radiograph taken upon completion of root canal treatment. (C) Two-year follow-up radiograph showing evidence of bony healing.

efficacy of periodontal treatment. With endodontic treatment alone, only part of the lesion will heal to the level of the secondary periodontal lesion. In general, healing of the tissues damaged by suppuration from the pulp space can be anticipated.

Primary endodontic lesions with secondary periodontal involvement may also occur as a result of root perforation during root canal treatment, or where pins or posts have been misplaced during coronal restoration. Symptoms may be acute, with periodontal abscess formation associated with pain, swelling, pus or exudate, pocket formation, and tooth mobility. A more chronic response may sometimes occur without pain, and involves the sudden appearance of a pocket with bleeding on probing or exudation of pus. When the root perforation is situated close to the alveolar crest, it may be possible to raise a flap and repair the defect with an appropriate filling material. In deeper perforations, or in the roof of the fucation, immediate repair of the perforation has a better prognosis than management of an infected one. Use of mineral trioxide aggregate has resulted in cemental healing following immediate repair (145).

Root fractures may also present as primary endodontic lesions with secondary periodontal involvement. These typically occur on root-treated teeth, often with post and crowns. The signs may range from a local deepening of a periodontal pocket to more acute periodontal abscess formation. Root fractures have also become an increasing problem with molar teeth that have been treated by root resection (107, 151).

Primary periodontal disease with secondary endodontic involvement

The apical progression of a periodontal pocket may continue until the apical tissues are involved. In this case the pulp may become necrotic as a result of infection entering via lateral canals or the apical foramen. In single-rooted teeth the prognosis is usually poor. In molar teeth the prognosis may be better. Since not all the roots may suffer the same loss of supporting tissues, root resection can be considered as a treatment alternative.

The effect of the progression of chronic periodontitis on the vitality of the pulp is controversial

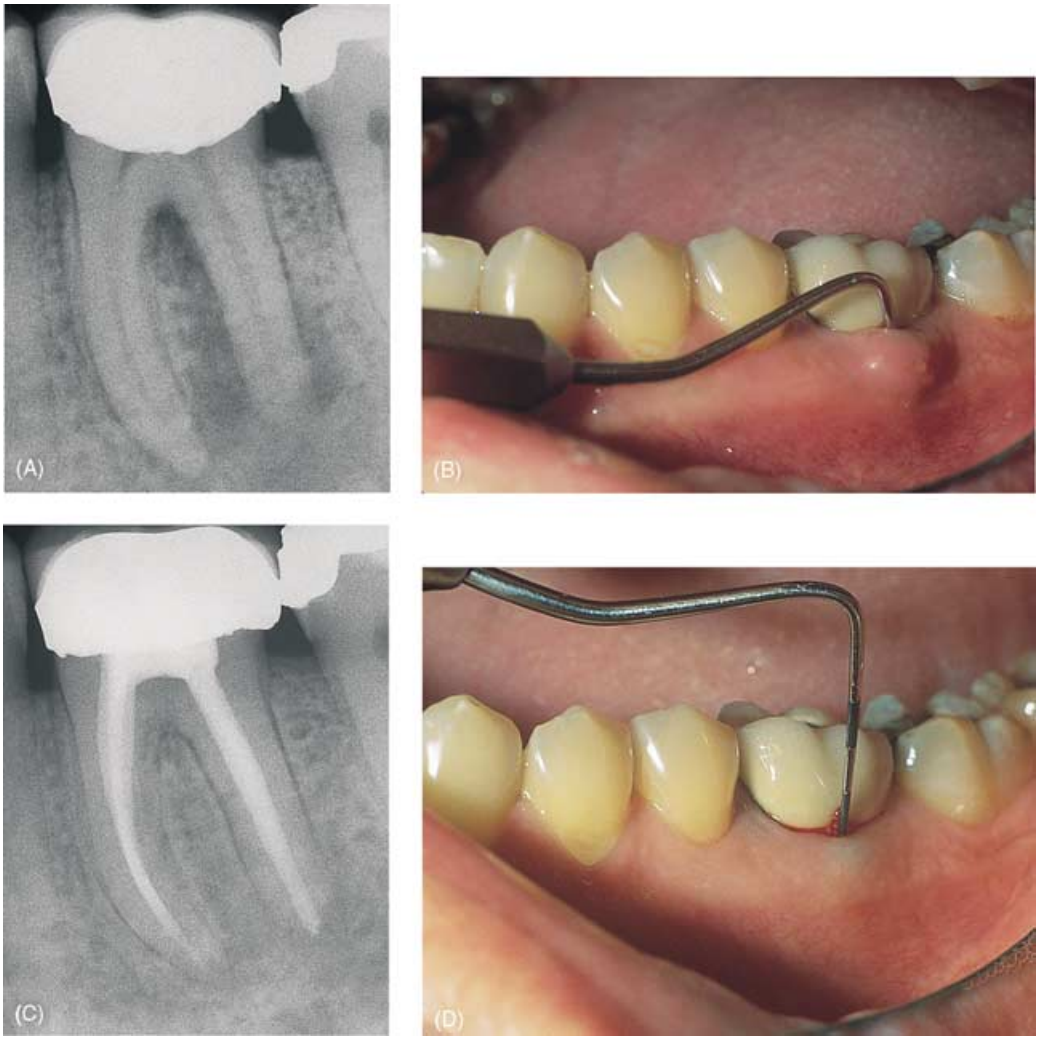

Fig. 26. Primary endodontic disease in a mandibular first molar with a necrotic pulp. (A) Preoperative radiograph showing large periradicular radiolucency associated with the distal root and furcal lucency. (B) Clinically, a deep narrow buccal periodontal defect can be probed. Note gingival swelling. (C) One year following root canal therapy, resolution of the periradicular bony radiolucency is evident. (D) Clinically, the buccal defect healed and probing is normal.

(2, 3, 108). If the blood supply circulating through the apex is intact, the pulp has good prospects for survival. It has been reported that pulpal changes resulting from periodontal disease are more likely to occur when the apical foramen is involved (108). In these cases, bacteria originating from the periodontal pocket are the most likely source of root canal infection. A strong correlation between the presence of microorganisms in root canals and their presence in periodontal pockets of advanced periodontitis has been demonstrated (100, 102). Support for this concept has come from research in which cultured samples obtained from the pulp tissue and radicular dentin of periodontally involved human teeth showed bacterial growth in 87% of the teeth (2, 3).

The treatment of periodontal disease can also lead to secondary endodontic involvement. Lateral canals and dentinal tubules may be opened to the oral environment by scaling and root planing or surgical flap procedures. It is possible for a blood vessel within a lateral canal to be severed by a curette and for microorganisms to be pushed into the area during treatment, resulting in pulp inflammation and necrosis (Fig. 30).

True combined disease

True combined endodontic–periodontal disease occurs less frequently than other endodontic–periodontal problems. It is formed when an endodontic disease progressing coronally joins with an infected periodontal pocket progressing apically (163, 171). The degree of attachment loss in this type of lesion is invariably large and the prognosis guarded (Fig. 31). This is particularly true in single-rooted

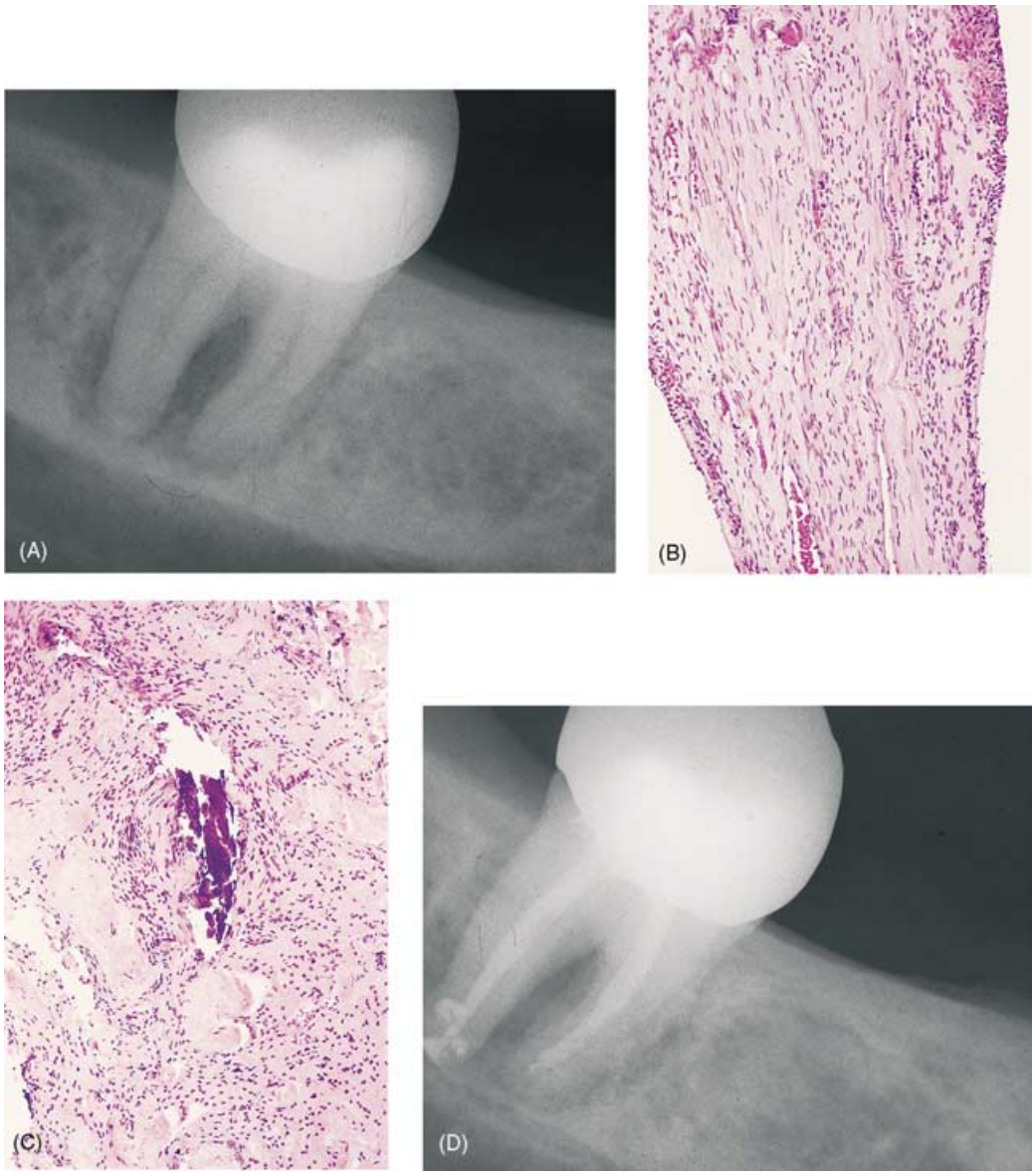

Fig. 27. Primary periodontal disease in a mandibular second molar. Patient was referred for endodontic therapy. (A) Preoperative radiograph showing periradicular radiolucency; however, the response of the tooth to pulp sensitivity tests was normal. The referring dentist insisted that endodontic therapy be done. (B) Photomicrograph of the pulp tissue removed during treatment. Note normal appearance of the pulp. (C) Higher magnification shows normal cellular components as well as blood microvasculature. (D) Postoperative radiograph. The tooth was subsequently lost to periodontal disease. A periapical lesion of endodontic origin will not occur in the presence of a normal vital pulp.

teeth (Fig. 32). In molar teeth, root resection can be considered as a treatment alternative if not all roots are severely involved. Sometimes, supplementary surgical procedures are required (Fig. 33). In most cases periapical healing may be anticipated following successful endodontic treatment. The periodontal tissues, however, may not respond well to treatment and will depend on the severity of the combined disease.

The radiographic appearance of combined endodontic-periodontal disease may be similar to that of a vertically fractured tooth. A fracture that has invaded the pulp space, with resultant necrosis, may also be labeled a true combined lesion and yet not be amenable to successful treatment. If a sinus tract is present, it may be necessary to raise a flap to determine the etiology of the lesion.

Clinical diagnostic procedures

Clinical tests are imperative for obtaining correct diagnosis and differentiating between endodontic

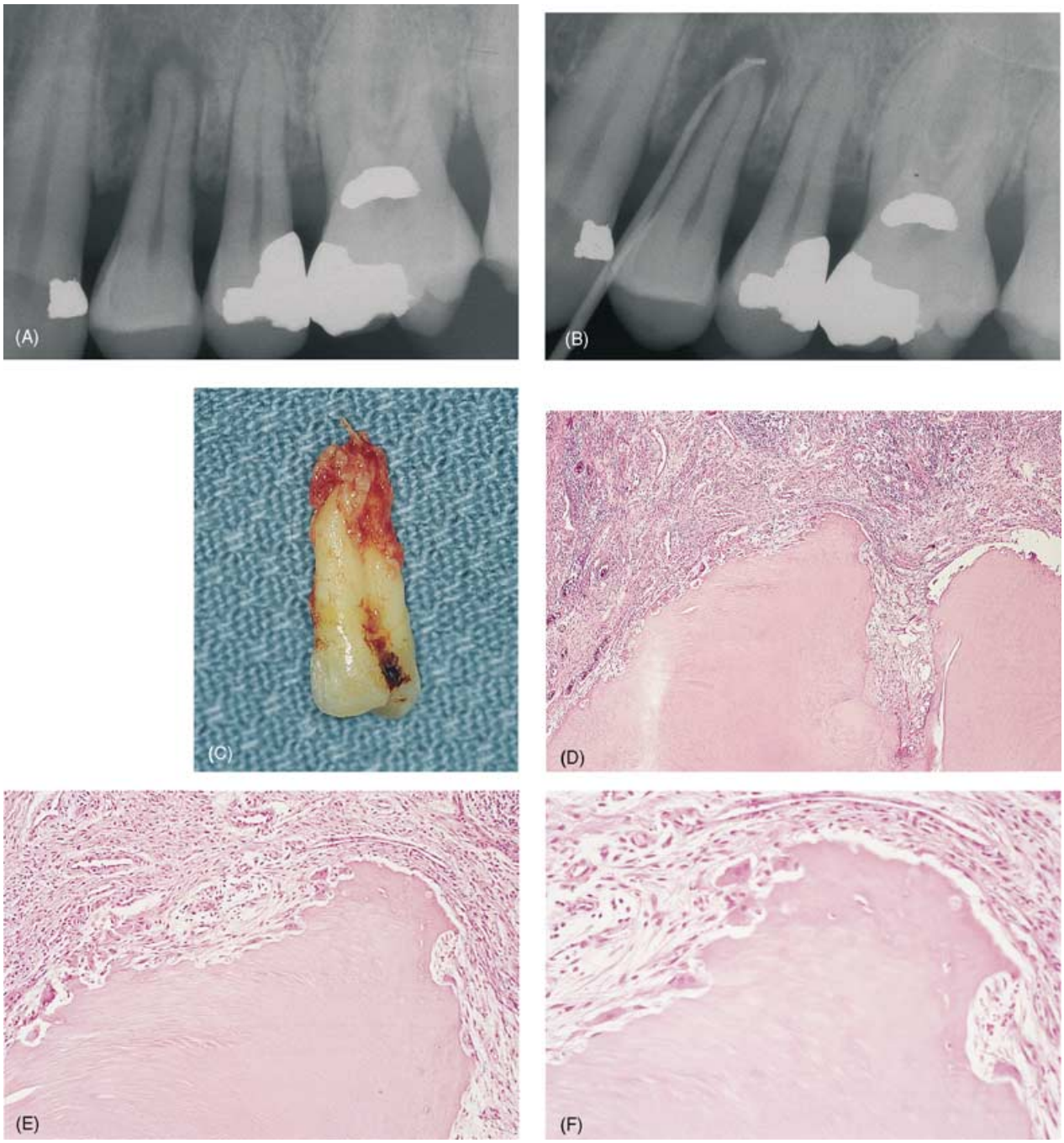

Fig. 28. Primary periodontal disease in a maxillary second premolar. (A) Radiograph showing alveolar bone loss and a periapical lesion. Clinically, a deep narrow pocket was found on the mesial aspect of the root. There was no evidence of caries and the tooth responded normally to pulp sensitivity tests. (B) Radiograph showing pocket tracking with gutta-percha cone to the apical area. It was decided to extract the tooth. (C) Clinical view of the extracted tooth with the attached lesion. Note a deep mesial radicular developmental groove. (D) Photomicrograph of the apex of the tooth with the attached lesion. (E, F) Higher magnification shows the inflammatory lesion, cementum and dentin resorption, and osteoclasts. (G, H) Histologic sections of the pulp chamber shows uninflamed pulp, odontoblastic layer, and intact predentin.

and periodontal disease. The extraoral and intraoral tissues are examined for the presence of any abnormality or disease. One test is usually not sufficient to obtain a conclusive diagnosis.

Visual examination

A thorough visual examination of the lips, cheeks, oral mucosa, tongue, palate and muscles should be

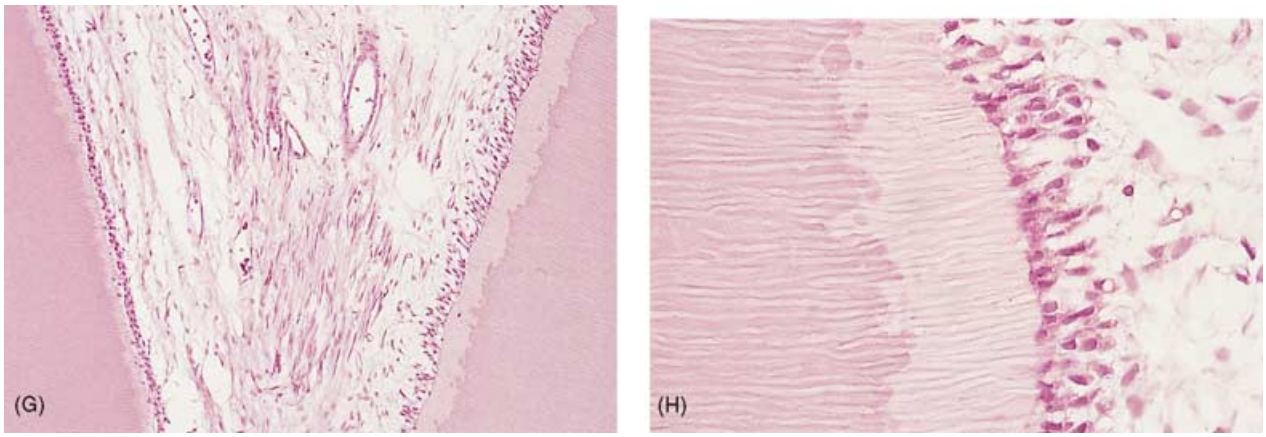

Fig. 28. continued

done routinely. Digital examination of the same tissues is performed simultaneously. The alveolar mucosa and attached gingiva are examined for the presence of inflammation, ulcerations, or sinus tracts. Frequently, the presence of a sinus tract is associated with a necrotic pulp (See below in section on ''fistula tracking'').

The teeth are examined for abnormalities such as caries, defective restorations, erosions, abrasions, cracks, fractures, and discolorations. A discolored permanent tooth may often be associated with a necrotic pulp. A ''pink spot'' detected in the tooth crown may indicate an active internal resorption process. A conclusive diagnosis for pulpal disease cannot be achieved by visual examination alone. It therefore must always be accompanied by additional tests.

Visual examination is dramatically improved by the use of enhanced magnification and illumination.

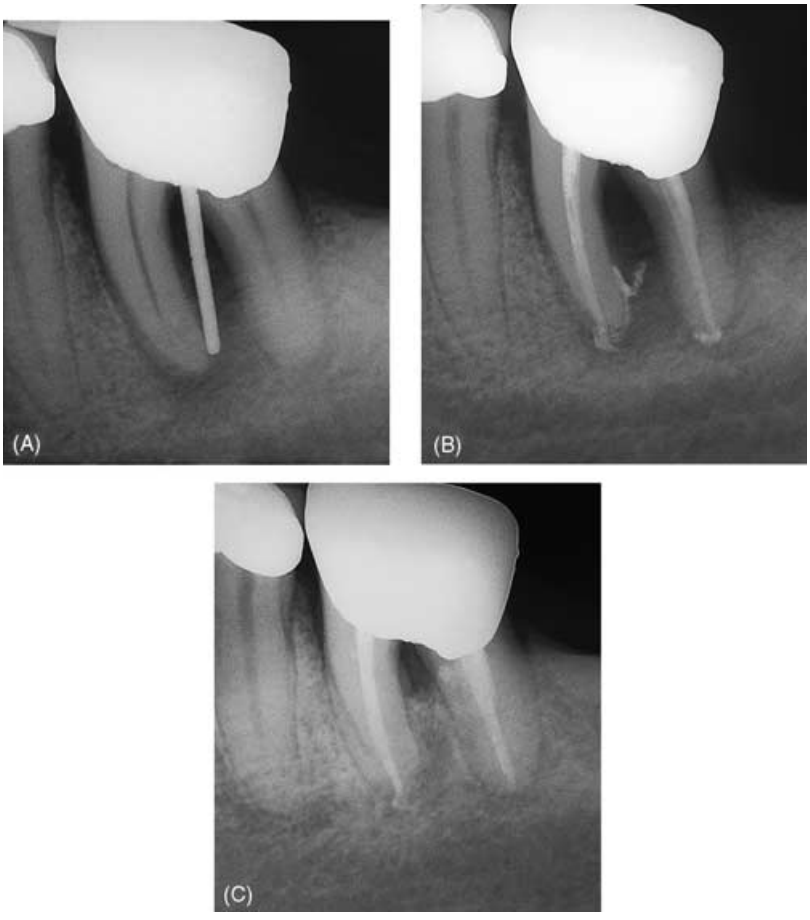

Fig. 29. Primary endodontic disease with secondary periodontal involvement in a mandibular first molar. (A) Preoperative radiograph demonstrating interradicular defect extending to the apical region of the mesial root. (B) Radiograph taken upon completion of root canal therapy. (C) One year follow-up radiograph showing resolution of most of the periradicular lesion, however, a bony defect at the furcal area remained. Note that endodontic treatment alone did not yield complete healing of the defect. Periodontal treatment is necessary for further healing of the furcal area and inflamed gingival tissues.

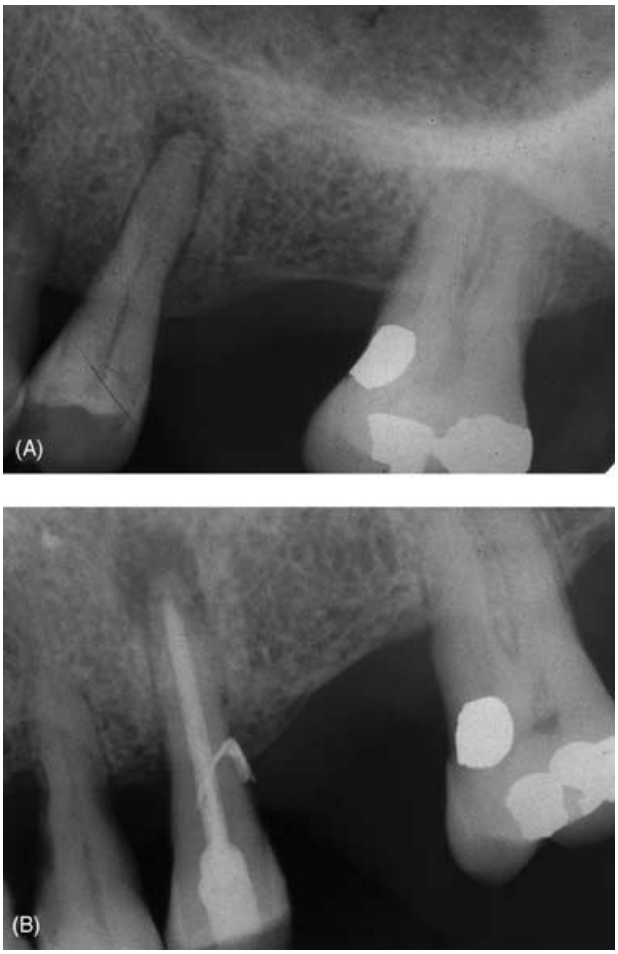

Fig. 30. Primary periodontal disease with secondary endodontic involvement in a maxillary premolar. (A) Radiograph showing a bone loss in one-third of the root and a separate periapical radiolucency. The crown was intact but pulp sensitivity tests were negative. (B) Radiograph taken immediately following root canal therapy showing lateral canal that was exposed to the oral environment due to bone loss. Exposed lateral canal is one of the possible pathways of infection of the root canal.

Magnifying loops and the operating microscope are currently widely used among dental professionals (Fig. 34). These accessories facilitate the location of calculus, caries, coronal and radicular fractures, developmental defects, and areas of denuded dentin mainly at the cementum–enamel junction.

Palpation

Palpation is performed by applying firm digital pressure to the mucosa covering the roots and apices. With the index finger the mucosa is pressed against the underlying cortical bone. This will detect the presence of periradicular abnormalities or ''hot'' zones that produce painful response to digital pressure. A positive response to palpation may indicate

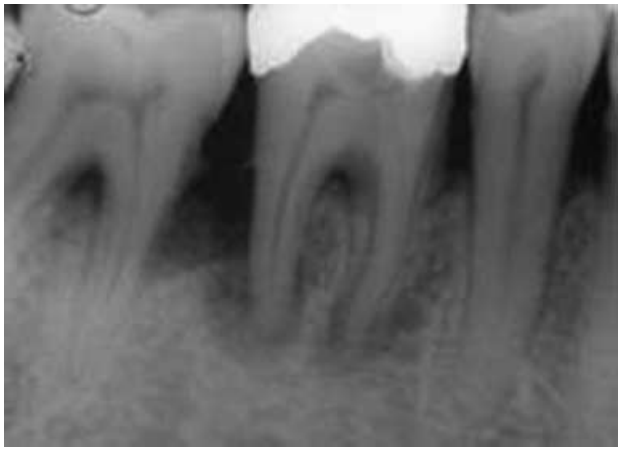

Fig. 31. True combined endodontic–periodontal disease in a mandibular first molar. Radiograph showing separate progression of endodontic disease and periodontal disease. The tooth remained untreated and consequently the two lesions joined together.

active periradicular inflammatory process. However, this test does not indicate whether the inflammatory process is of endodontic or periodontal origin. Also, as with any other clinical test, the response should be compared to control teeth.

Percussion

Percussion is performed by tapping on the incisal or occlusal surfaces of the teeth either with the finger or with a blunt instrument such as the back end of a mirror handle. The tooth crown is tapped vertically and horizontally. Although this test does not disclose the condition of the pulp, it indicates the presence of a periradicular inflammation. An abnormal positive response indicates inflammation of the periodontal ligament that may be either from pulpal or periodontal origin. The sensitivity of the proprioceptive fibers in an inflamed periodontal ligament will help identify the location of the pain. This test should be done gently, especially in highly sensitive teeth. It should be repeated several times and compared to control teeth.

Mobility

Mobility testing can be performed using two mirror handles on each side of the crown. Pressure is applied in a facial–lingual direction as well as in a vertical direction and the tooth mobility is scored. Tooth mobility is directly proportional to the integrity of the attachment apparatus or to the extent of inflammation in the periodontal ligament (30). Teeth with extreme mobility generally have little

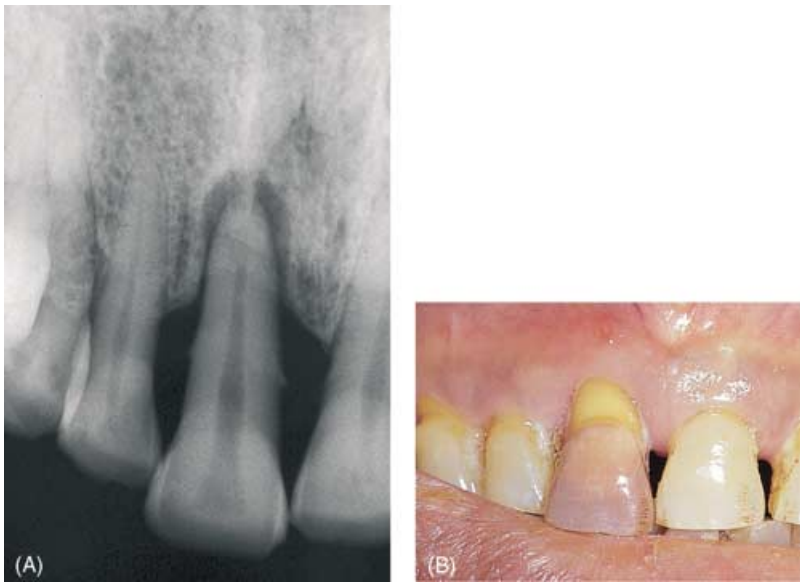

Fig. 32. True combined endodontic-periodontal disease. (A) Radiograph showing bone loss in two-thirds of the root with calculus present and a separate periapical radiolucency. (B) Clinical examination revealed coronal color change of the tooth involved and pus exuding from the gingival crevice. Pulp sensitivity tests were negative indicating pulp necrosis.

periodontal support, indicating that the primary cause may be periodontal disease.

Fractured roots and recently traumatized teeth often present high mobility. Frequently, however, a periradicular abscess of pulpal origin may cause similar mobility. This can only be verified if other tests indicate pulp necrosis or if mobility improves a short time after completion of endodontic therapy. Pressure exerted by an acute apical abscess may cause transient tooth mobility (84). This may also occur as a result of orthodontic movement and pulp necrosis of previously traumatized teeth (152).

Radiographs

Radiographs are essential for detection of anatomic landmarks and a variety of pathological conditions. In addition, radiographs are of utmost importance for documentation and legal purposes. Radiographic examination will aid in detection of carious lesions, extensive or defective restorations, pulp caps, pulpotomies, previous root canal treatment and possible mishaps, stages of root formation, canal obliteration, root resorption, root fractures, periradicular radiolucencies, thickened periodontal ligament, and alveolar bone loss.

The integrity of the dental pulp cannot be determined by radiographic images alone. Radiographic changes will only be detected once the inflammation or bacterial byproducts originating from the dental pulp cause sufficient demineralization of the cortical bone. Often, the initial phases of periradicular bone resorption from endodontic origin is confined only to cancellous bone. Therefore it cannot be detected unless the cortical bone is also affected (16, 111). Also, certain radiographic features are susceptible to multiple interpretations (66, 67). On the other hand, periodontal disease causing alveolar bone loss can be effectively detected by radiographs. For purposes of differential diagnosis, periapical and bitewing radiographs should be taken from several angles. Sometimes, other types of radiographs are also required.

A number of radioloucent and radiopaque lesions of non-endodontic and non-periodontal origin may simulate the radiographic appearance of endodontic or periodontal lesions. Therefore, clinical signs and symptoms as well as findings from the other clinical tests should always be considered at the time of radiographic evaluation.

Pulp vitality testing

These tests are designed to assess the response of the pulp to different stimuli. An abnormal response may indicate degenerative changes in the pulp. In general, no response indicates pulp necrosis, and moderate transient response indicates normal vital pulp. A quick painful response may often indicate reversible pulpitis and lingering painful response indicate irreversible pulpitis. Since some of these tests may provoke a painful reaction they should be carefully performed and their nature and importance explained to the patient. When correctly performed and adequately interpreted these tests are reliable in differentiating between pulpal disease and periodontal disease. The most commonly used pulp vitality tests are: cold test, electric test, blood flow tests, and cavity test (192).

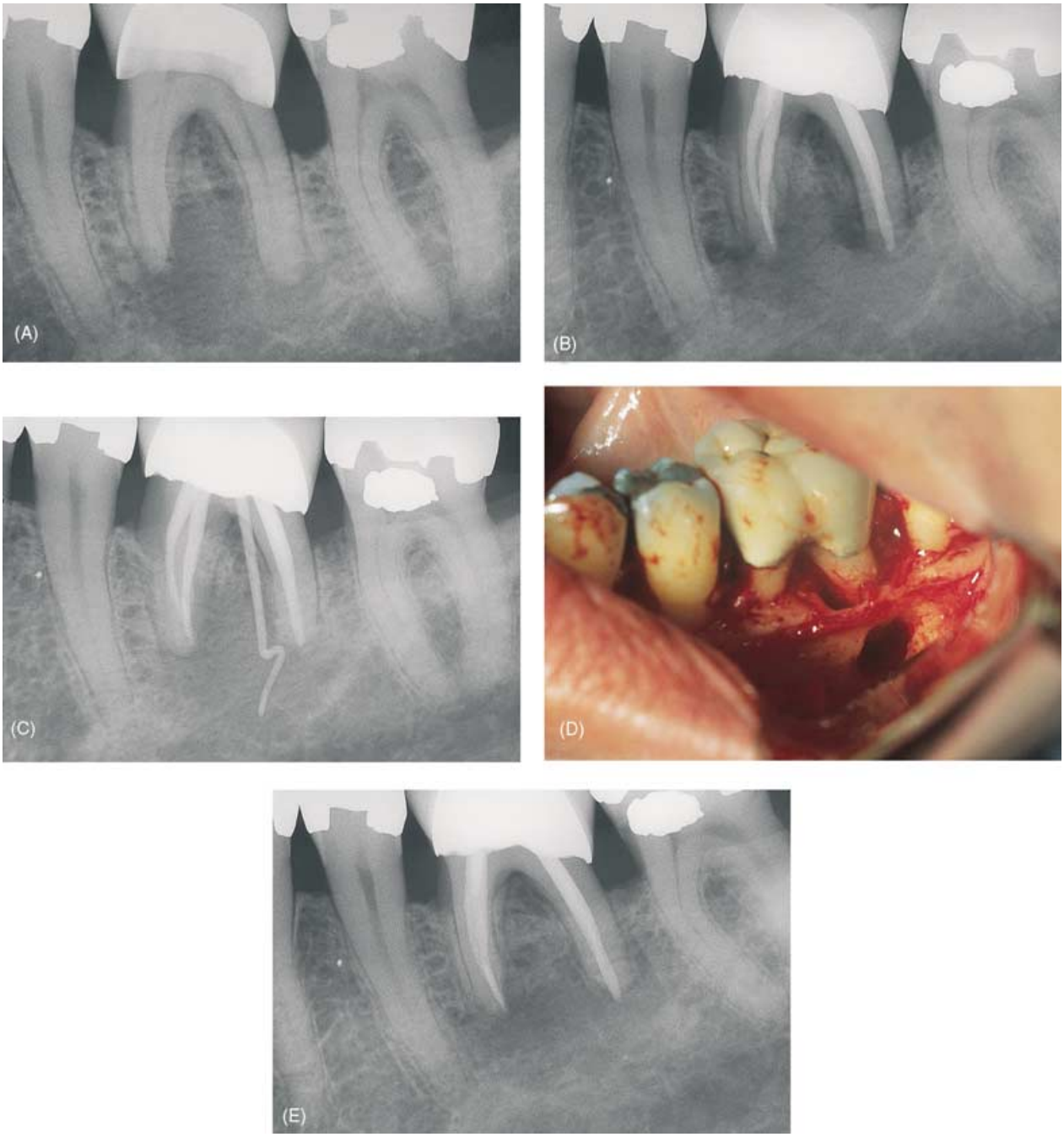

Fig. 33. True combined endodontic-periodontal diseases in a mandibular first molar. (A) Preoperative radiograph showing periradicular radiolucencies. Pulp sensitivity tests were negative. (B) Immediate postoperative radiograph of nonsurgical endodontic treatment. (C) Six-month follow-up radiograph showing no healing. Gutta-percha cone is inserted in the buccal gingival sulcus. (D) Clinical photograph showing treatment of the root surfaces and removal of the periradicular lesion. (E) One-year follow-up radiograph demonstrating healing.

Cold test

This test is performed by applying a cold substance, or agent, to a well-isolated tooth surface. Tooth isolation can be achieved by drying the crown surfaces with cotton rolls, gauze and a very gentle air blast. Several cold methods are used: ice sticks, ethyl chloride, carbon dioxide (dry ice), and refrigerants such as dichlorodifluoromethane (DDM). Carbon dioxide (–78 °C) and DDM (–50 °C) are extremely cold and are only used when the pulp does not respond to less cold agents. Extremely cold agents may cause crazing and infraction lines on the enamel.

Teeth with vital pulps will react to cold with sharp brief pain response that usually does not last more than a few seconds. An intense and prolonged pain

Fig. 34. The operating microscope provides enhanced magnification and illumination of the working field. It is used for both diagnosis and treatment purposes.

response often indicates abnormal pulpal changes and irreversible pulpitis. Lack of response may indicate pulp necrosis. When adequately performed, this test is reliable in determining whether the pulp has undergone irreversible damage. However, false-positive and false-negative responses may occur, especially in multiradicular teeth where not all roots are affected or in teeth with calcified root canals.

Electric test

This test is performed by applying an electric stimulus to the tooth using a special pulp tester device. The tooth is first cleaned, dried and isolated. A small amount of toothpaste is placed on the electrode of the pulp tester, which is then put into contact with the clean tooth surface. Only sound tooth structure should be contacted. Electric current is gradually applied until the patient reports sensation. Many devices are currently available; all are effective and used in a similar manner (Fig. 35). The purpose of the test is to stimulate the sensory nerve fibers of the pulp to produce a response. No response frequently indicates pulp necrosis. A positive response may be interpreted as either intact vital pulp or partially necrotic pulp. However, the electric test does not provide any information about the condition of the vascular supply of the pulp.

While interpreting the results the clinician must take into consideration the various false-positives and false-negatives of this test (144). The most common causes for false-positive responses are: partial pulp necrosis, patient anxiety, ineffective isolation, and inadvertent contact with metallic restorations.

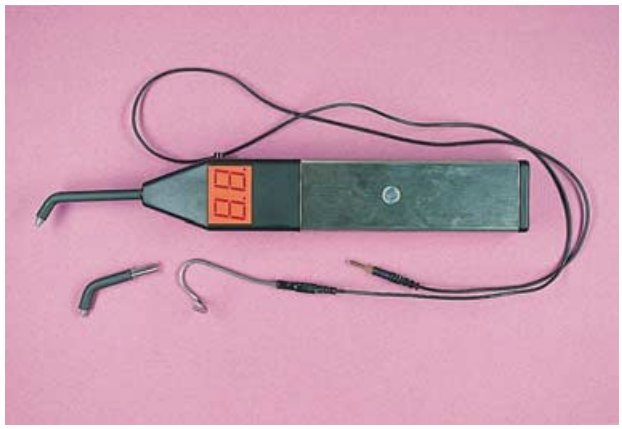

Fig. 35. An example of a popular pulp tester device. It produces a low electric current to stimulate the sensory nerve fibers of the pulp.

The most common causes for false-negative responses are: obliterated root canals, recently traumatized teeth, teeth with immature apices, patient taking drugs that elevate the pain threshold, and poor electrode–tooth contact. In general, however, the electric pulp test is easy to perform and provides accurate determination of pulp necrosis in adult teeth.

Blood flow test

This test is designed to determine the vitality of the pulp by measuring its blood flow rather than the response of its sensory nerve fibers. Different systems such as dual wavelength spectrophotometry, pulse oximetry, and laser Doppler have been developed to measure either oxyhemoglobin, low concentration of blood, or pulsation of the pulp (46, 54, 138, 161). Sensors are applied to the external surfaces of the crown and the pulp blood flow is recorded and compared to controls. The procedure is non-invasive and painless. These tests are relatively new and are not used routinely.

Cavity test

This test is highly reliable in determining the vitality of the pulp. It basically consists of creating a cavity in the tooth without anesthesia. A high-speed handpiece with a new sharp bur is generally used. A positive response indicates presence of vital pulp tissue, while a negative response accurately indicates pulp necrosis. If no response is obtained, the cavity is extended into the pulp chamber and endodontic treatment is initiated.

This test is not routinely performed since it may produce pain in cases where the pulp is vital. It should only be limited to cases where all other tests proved inconclusive and a definitive diagnosis of the pulp condition could not be established.

Restored teeth testing

Testing teeth with extensive coronal restorations is somewhat more challenging. Whenever possible, the restoration should be removed to facilitate pulp testing. In cases where restoration removal is not feasible, a small access opening is made through the restoration until sound tooth structure is reached. Cold test and cavity test will give the most reliable results. In most instances electric pulp testing will not prove beneficial.

Access through full gold crowns can usually be done without affecting the strength and stability of the restoration. Access repair is done with amalgam, or another permanent filling material (123). Access for pulp testing can be done through porcelain restorations as well. In such cases, access is done slowly and with copious water irrigation.

Pocket probing

Periodontal probing is an important test that should always be performed when attempting to differentiate between endodontic and periodontal disease. A blunt calibrated periodontal probe is used to determine the probing depth and clinical attachment level. It may also be used to track a sinus resulting from an inflammatory periapical lesion that extends cervically through the periodontal ligament space. A deep solitary pocket in the absence of periodontal disease may indicate the presence of a lesion of endodontic origin or a vertical root fracture.

Periodontal probing can be used as a diagnostic and prognostic aid (192). For example, the prognosis for a tooth with a necrotic pulp that has developed a sinus track is excellent following adequate root canal therapy. However, the prognosis of root canal treatment in a tooth with severe periodontal disease is dependent on the success of the periodontal therapy. Therefore, correct identification of the etiology of the disease, whether endodontic, periodontal or combined, will determine the course of treatment and long-term prognosis.

Fistula tracking

Endodontic or periodontal disease may sometimes develop a fistulous sinus track. Inflammatory exudates may often travel through tissues and structures of minor resistance and open anywhere on the oral mucosa or facial skin. Intraorally, the opening is usually visible on the attached buccal gingiva or in the vestibule. Extraorally, the fistula may open anywhere on the face and neck. However, it is most commonly found on the cheek, chin, and angle of the mandibule, and occasionally also on the floor of the nose (78). If the etiology is pulpal, it usually responds well to endodontic therapy.

The identification of the sinus tract by simple visual examination does not necessarily indicate the origin of the inflammatory exudate or the tooth involved. Occasionally, the exudate exists through the periodontal ligament, thus mimicking a pocket of periodontal origin. Identifying the source of inflammation by tracking the fistula will help the clinician to differentiate between diseases of endodontic and periodontal origin.

Fistula tracking is done by inserting a semi-rigid radiopaque material into the sinus track until resistance is met. Commonly used materials include gutta-percha cones or presoftened silver cones. A radiograph is then taken that will reveal the course of the sinus tract and the origin of the inflammatory process.

Cracked tooth testing

Transillumination

This test is designed to aid in the identification of cracks and fractures in the crown. A fiberoptic connected to a high-power light source is used to illuminate the crown and gingival sulcus. The contrast between the dark shadow of the fracture and the light shadow of the surrounding tissue will clearly reveal the size and orientation of the fracture line. An existing restoration may need to be removed to enhance visibility.

Wedging

This technique aids in the identification of vertical crown fractures or crown–root fractures. Such fractures cause a painful response to the patient at the time of chewing. During the test, wedging forces are created as the patient is instructed to chew on a cottonwood stick or other firm material. This test is fairly reliable in identifying a single tooth causing pain during mastication. Many of these fractures involve only the tooth crown and terminate in the pulp chamber. Such cases are treated successfully with endodontic therapy.

Staining

Staining identifies lines of fracture in the crown and root and is often used in conjunction with the wedging test. The tooth crown is dried and a cotton pellet soaked with methylene blue dye is swabbed on the occlusal surface of the tooth. The patient is asked to

bite on a stick and perform lateral jaw movements. This way the dye penetrates well into the zone of the fracture. The dye is then rinsed from the tooth surfaces and visual examination with magnifying loops or the microscope will reveal a distinctive fracture line darkened with dye.

Selective anesthesia test

This test is useful in cases where the source of pain cannot be attributed to a specific arch. Disappearance of pain following a mandibular block will confirm the source of pain originating from a mandibular tooth. The periodontal ligament injection is often used to narrow down the zone in question, however, it cannot anesthetize a single tooth without affecting adjacent teeth (47). In the maxillary arch the test may be more focused to a specific tooth by injecting a small amount of anesthetic solution in an anterior–posterior direction at the root apex level. No conclusive diagnosis differentiating between endodontic and periodontal disease can be made using this type of test.

Treatment decision-making and prognosis

Treatment decision-making and prognosis depend primarily on the diagnosis of the specific endodontic and/or periodontal disease. The main factors to consider are pulp vitality and type and extent of the periodontal defect. Diagnosis of primary endodontic disease and primary periodontal disease usually present no clinical difficulty. In primary endodontic disease the pulp is infected and nonvital. In primary periodontal disease the pulp is vital and responsive to testing. However, primary endodontic disease with secondary periodontal involvement, primary periodontal disease with secondary endodontic involvement, or true combined diseases are clinically and radiographically very similar. If a lesion is diagnosed and treated as primarily endodontic disease due to lack of evidence of plaque-induced periodontitis, and there is soft-tissue healing on clinical probing and bony healing on a recall radiogragh, a valid retrospective diagnosis can then be made. The degree of healing that has taken place following root canal treatment will determine the retrospective classification. In the absence of adequate healing, further periodontal treatment is indicated.

The prognosis and treatment of each endodontic–periodontal disease type varies. Primary endodontic disease should only be treated by endodontic therapy and has a good prognosis. Primary periodontal disease should only be treated by periodontal therapy. In this case, the prognosis depends on severity of the periodontal disease and patient response. Primary endodontic disease with secondary periodontal involvement should first be treated with endodontic therapy. Treatment results should be evaluated in 2–3 months and only then should periodontal treatment be considered. This sequence of treatment allows sufficient time for initial tissue healing and better assessment of the periodontal condition (28, 141). It also reduces the potential risk of introducing bacteria and their byproducts during the initial healing phase. In this regard, it was suggested that the periodontal healing was adversely affected by aggressive removal of the periodontal ligament and underlying cementum during interim endodontic therapy (21). Areas of the roots that were not aggressively treated showed unremarkable healing (21). Prognosis of primary endodontic disease with secondary periodontal involvement depends primarily on the severity of periodontal involvement, periodontal treatment and patient response.

Primary periodontal disease with secondary endodontic involvement and true combined endodontic–periodontal diseases require both endodontic and periodontal therapies. It has been demonstrated that intrapulpal infection tends to promote epithelial downgrowth along a denuded dentin surface (22). Additionally, experimentally induced periodontal defects around infected teeth were associated with 20% more epithelium than non-infected teeth (88). Non-infected teeth showed 10% more connective tissue coverage than infected teeth (88). The prognosis of primary periodontal disease with secondary endodontic involvement and true combined diseases depends primarily upon the severity of the periodontal disease and the response to periodontal treatment. Cases of true combined disease usually have a more guarded prognosis than the other types of endodontic–periodontal problems. In general, assuming the endodontic therapy is adequate, what is of endodontic origin will heal. Thus the prognosis of combined diseases rests with the efficacy of periodontal therapy.

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