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Considerations and concepts of case selection in the management of post-treatment endodontic disease (treatment failure)

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Dear Colleagues
I feel honoured and excited to participate in Endodontic Topics, the new review journal focusing on all aspects of the science and art of endodontics, and I hope you will join me in celebrating this first issue, wherever you are! In contrast to future issues, which will focus on one area each, this issue covers different areas, all reviewed by my fellow Associate Editors. I selected the following review for this issue because it touches on several topics that have been assigned to me to cover in the future. In this review, you will find reference to endodontic treatment outcome criteria, concepts of endodontic health and disease, decision-making, treatment outcome of apical surgery and orthograde re-treatment, post-operative pain associated with the aforementioned procedures, removal of crowns and posts, as well as broken instruments, perforation repair, retrograde re-treatment and more. All of these topics are dealt with in this article in the context of case selection in the management of post-treatment disease. In the future, however, you will see the focus shifting to examining each of these topics on their own, with many of them being reviewed in greater detail by those researchers and clinicians quoted in this review. So, to my mind, *this review is not just a review but a sign of things to come.*
I look forward to working with many knowledgeable colleagues in the future to develop good quality, comprehensive and critical reviews for your benefit. I hope you find these reviews exciting and useful.

Healing–disease vs. success–failure

The goal of endodontic treatment is to *prevent* and, when required, to *cure* endodontic disease, apical periodontitis (1). To attain this goal, endodontic treatment is based on a sound biological rationale, consisting primarily of exclusion of microorganisms from the root canal system (1). To what extent this goal is attainable has been the subject of many studies on the outcome of endodontic treatment (2). For the major part, these are prospective or retrospective follow-up studies of specific populations, in which the outcome is classified into 'success' and 'failure' categories. Because of differences in study material, treatment techniques and methodology, the outcomes reported in these studies vary considerably (2). One of the main reasons for the variability of reported outcomes is the inconsistent definition of 'success' (2):

- combined clinical and radiographic normalcy (no signs, symptoms or radiolucency present);
- clinical normalcy with reduced radiolucency; or
- clinical normalcy with persistent, stable radiolucency.

Just as researchers and clinicians appear to differ in their interpretation of endodontic treatment 'success–failure', patients, too, may have difficulties relating to these terms. The issue is further confused by the fact that the terms 'success–failure' are also being used to

describe the outcomes of other dental treatment procedures; the undiscerning use of these terms may confuse the patients when they consider different treatment alternatives. One focus of attention in recent years has been the implant-supported single-tooth replacement, for which the definition of 'success–failure' is quite different from that used in endodontics, and more consistent with the outcome category of 'survival' (3). Based on this definition, the reported 'success' rates for single-tooth implants are considerably higher than those for endodontic treatment (4). The patient weighing one 'success' rate against the other may erroneously assume their definitions to be comparable, and select the treatment alternative that appears to be offering the better chance of 'success'. **Clearly, then, the term 'success' used in the context of endodontic treatment outcome is ambiguous, and it cannot be used effectively as the basis for reliable communication among clinicians, and between clinicians and patients**.

When upon the follow-up examination teeth do not conform to the criteria of 'success', they are normally referred to as *'treatment failure'*. This term, too, is problematic – it is just as ambiguous as 'success', but in addition, it has a negative connotation (5). Furthermore, it is not specific enough to imply the necessity to pursue treatment or, in fact, any course of action. Therefore, the term 'failure' also does not promote effective communication in the context of endodontic treatment. In fact, Ørstavik (6) suggests that, in communication with patients, the value-laden terms 'success–failure' should be substituted with more neutral expressions, such as 'chance of healing' and 'risk of inflammation'.

In the majority of endodontic treatment 'failures', the radiolucency present, be it stable or reduced in size, is an expression of apical periodontitis – the same disease intended to be prevented or cured when initial endodontic treatment was performed. Giving it a different name (treatment failure) suggests that it is a different entity, whereas in fact it is not.

It is suggested therefore that, to promote effective communication within the profession and, most importantly, between clinicians and patients, the use of the terms 'success–failure' should be avoided when referring to the outcome of endodontic treatment. Instead, it is appropriate to use terms that are directly related to the goals of treatment, prevention or curing of disease. Therefore, **the outcome of treatment should be classified in terms of 'healing–disease'**. When upon follow-up examination there are no clinical signs, symptoms or radiolucency (combined clinical and radiographic normalcy), the tooth and surrounding tissues are classified as having *healed*. When the radiolucency has persisted without change or a new one has emerged, this is an expression of *disease,* even when there are no clinical signs and symptoms (clinical normalcy). To accommodate the fact that healing processes may require considerable time, often up to 4 years (6), reduced radiolucency combined with clinical normalcy can be interpreted as a suggestion of progressive *healing*.

It is this author's view that most patients can relate to the concept of 'disease–therapy–healing', unlike the concept of 'success–failure'. It is expected that each person, be it a patient or a doctor, will bring his or her individual values of health and disease into this consideration, as illustrated by Kvist and coworkers (7, 8). It would appear that the individual values of patients would again result in inconsistent responses to the outcome of any given endodontic treatment. However, assigning precedence and dominance to the patient's values is consistent with the current ethical principle of *patient autonomy* (8), and with the current legislative principles in many modern societies, which require the patient's *informed consent* and authorization for any treatment decisions made (9).

In summary, use of the terms 'healing–disease' to report the outcome of endodontic treatment is advisable, as this will minimize ambiguity, facilitate communication, and conform to ethical and legislative requirements. In this article, *disease* is used in lieu of 'treatment failure'.

Post-treatment endodontic disease

Epidemiology

In spite of the many inconsistencies, several of the aforementioned follow-up studies clearly demonstrate the excellent *potential outcome* of endodontic treatment, with apical periodontitis prevented or cured in over 80% of treated teeth (2, 10). Apparently, however, this excellent potential of endodontic treatment has not been corroborated in the majority of cross-sectional studies, generally considered as demonstrating the *realistic outcome* of endodontic treatment (11). In the cross-sectional studies of general popula-

tions in many countries, 20% to over 60% of endodontically treated teeth present with apparent radiolucency, suggestive of apical periodontitis (2, 12–18). Thus the cross-sectional studies indicate the true extent to which endodontically treated teeth in the population are associated with disease, and suggest the necessity to manage this condition on a far greater scale than suggested by the follow-up studies. For example, one Swedish study estimated the number of endodontically treated teeth associated with radiolucency at 2.5 million teeth (19).

Definition

The disease associated with radiolucency about endodontically treated teeth is apical periodontitis. However, as this disease has persisted despite treatment (Fig. 1), reoccurred after having healed at first (Fig. 2), or emerged during the follow-up period after treatment (Fig. 3), it would appear appropriate to characterize it as persistent, recurrent or emerged apical periodontitis. For simplicity, this author prefers to use the term *post-treatment disease* to include all persistent, recurrent and emerged apical periodontitis associated with endodontically treated teeth, while also differentiating these conditions from apical periodontitis associated with untreated teeth.

Etiology

Nair et al. (20) have convincingly demonstrated periapical pathological lesions consistent with apical periodontitis, caused by foreign bodies present within the periapical tissues. It is critically important to put these undisputed findings into a broad clinical perspective. In this context, it is relevant to recognize the origin of the root and periapical tissue specimens studied and analyzed by these researchers – they were derived from the population studied by the Umeå, Sweden, group (21). At the time of treatment, all teeth were microbiologically controlled with sophisticated methods, while subjected to antimicrobial intracanal procedures to

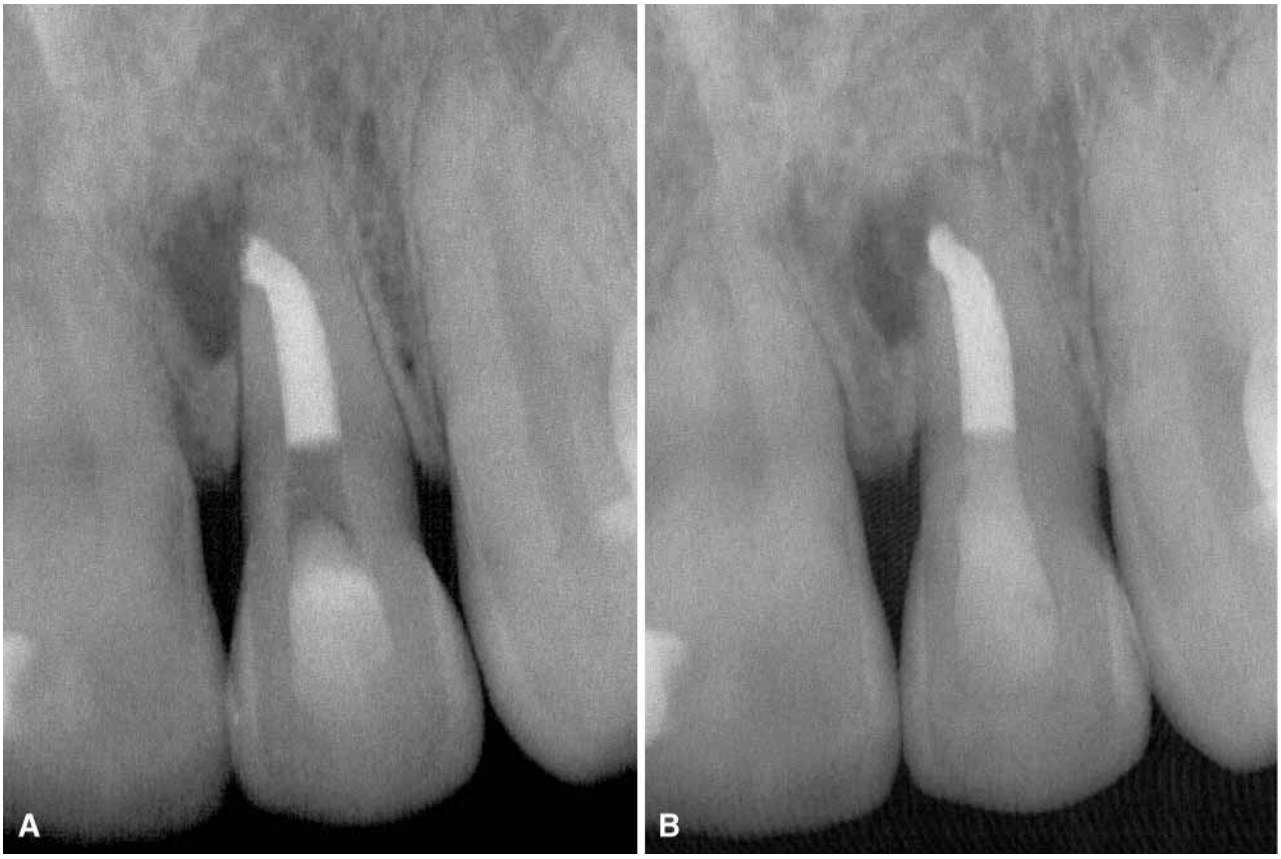

Fig. 1. Persistent disease after endodontic treatment. A. Immediate post-operative radiograph of maxillary lateral incisor with apical periodontitis. B. Persistent disease at 1 year.

eradicate root canal microorganisms. The canals were filled only when confirmed to be free of microorganisms. Twelve teeth (10%) presented with post-treatment disease upon follow-up, and nine were subjected to biopsy. Of these, in three teeth (33%) the researchers found foreign materials periapically, but not microorganisms in the canal. However, because exclusion of microorganisms is not routinely confirmed before root filling, the prevalence of non-microbial etiology in the general population should be much lower than that suggested by this study.

In recent years, consistent and convincing evidence

Fig. 2. Recurrent disease after endodontic treatment. A. Immediate post-operative radiograph of maxillary second premolar with apical periodontitis. B. Apparent complete healing at 1 year. C. Recurred disease at 3 years.

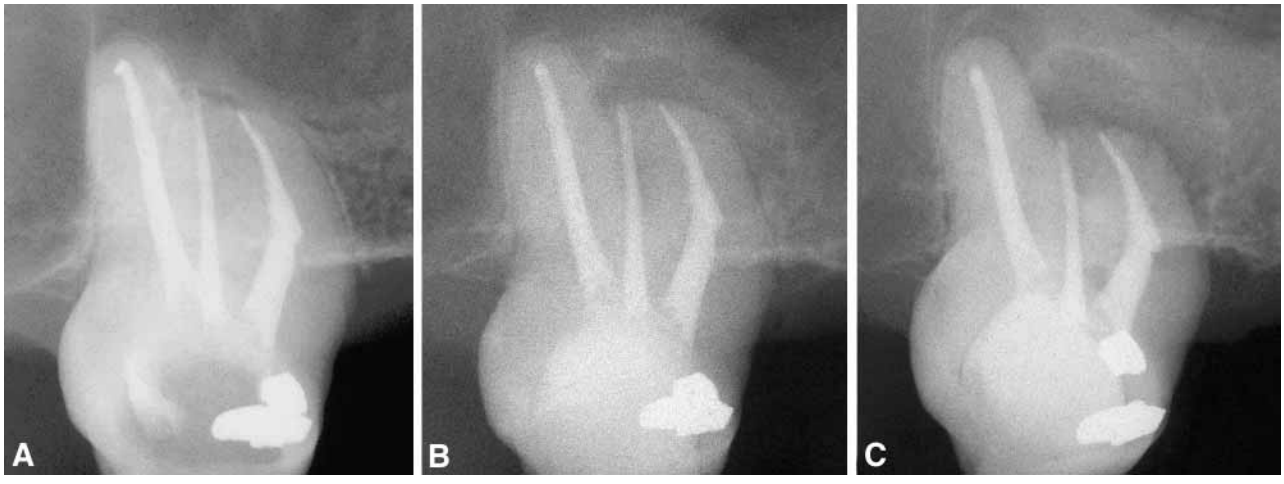

Fig. 3. Emerged disease after endodontic treatment. A. Immediate post-operative radiograph of maxillary second molar without evidence of apical periodontitis. B. Emerged disease at 3 years. C. Further expansion of disease at 6 years.

has been accumulated to confirm that post-treatment endodontic disease is primarily caused by infection (22). What appears to differ, and to some extent to stimulate a dispute, is the site in which microorganisms are harbored. **Most frequently the microorganisms are harbored in the *root canal system*** (23–31), when they have either survived the treatment and persisted (32), or invaded the filled canal space after treatment, possibly because of coronal leakage (33). Recent evidence has clearly demonstrated microorganisms of different species *harbored in the periapical tissues* (34–36). This recent evidence is an important addition to previous, well-established evidence confirming that specific microorganisms, particularly *Actinomyces israelii,* can become established in the periapical tissues and sustain the post-treatment disease (37). Collectively, microorganisms harbored outside the root canal are referred to as *extraradicular* (38). They may survive in cementum lacunae on the root surface (39, 40), in plaque-like microbial films on the apical root surface (38, 41–43), or in dentin debris inadvertently extruded periapically during treatment (44). **Clearly, different microbial species have the ability to survive in extraradicular sites, and this phenomenon appears to be far more common than was recognized a few years ago**. From the clinical perspective, however, the most important consideration is whether or not the extraradicular microorganisms observed in specimens from teeth with post-treatment disease did indeed sustain the disease process without dependence on microorganisms present in the root canal – a few microbial species have been shown to sustain extraradicular infection exclusively (37), but the ability of most other species to do so is still pending clarification. Until this aspect of exclusive extraradicular infection is elucidated, it should be regarded as a far less common occurrence than root canal infection, representing the minority of teeth associated with post-treatment disease.

Treatment – benefits and risks

Post-treatment disease, like other disease processes, can be resolved only if the etiological factor is eliminated or critically curtailed. To achieve this goal without having to extract the affected tooth, either orthograde *retreatment* or *apical surgery* can be performed. In accordance with the current guidelines regarding treatment decision making processes, the respective benefits and risks of both treatment alternatives have to be weighed (9).

Benefits

In general terms, 'a treatment procedure is beneficial to a patient if it is in some way conducive to his welfare, health, or both' (8). When considering treatment alternatives, therefore, factors should be taken into account that can potentially affect those two aspects of benefiting the patient.

Retreatment and apical surgery differ significantly in their ability to address the site where microorganisms are harbored. The following considerations are pertinent:

- *For root canal infection,* retreatment is an attempt to *exclude* the microorganisms, whereas apical surgery is an attempt to *confine* the microorganisms within the canal boundaries. Retreatment therefore offers a better chance to curtail root canal infection, and this is its *main benefit*. Surgery, on the other hand, has a limited capacity to curtail root canal infection, and therefore, it offers a lesser benefit.
- *For extraradicular infection,* surgery is an attempt to *exclude* the microorganisms by totally removing the infected site, whereas retreatment is an attempt to *isolate* the extraradicular microorganisms by cutting them off from possible, albeit unlikely, support from root canal microorganisms. Surgery therefore offers a better chance to curtail extraradicular infection, and this is its *main benefit*. Retreatment clearly offers a smaller benefit in this regard; however, its benefit cannot be dismissed entirely, as frequently there is uncertainty regarding the coexistence of extraradicular infection and root canal infection.

To summarize, root canal infection is far more common than exclusive extraradicular infection, and it should be considered as representing the majority of teeth associated with post-treatment disease. Therefore, it is appropriate to consider that **generally the benefits of retreatment, the procedure that best curtails root canal infection, outweigh those of apical surgery.** When clinical evidence or case history supports the **diagnosis of extraradicular infection, the benefits of apical surgery outweigh those of retreatment.** In either case, both procedures may be carried out in conjunction to exclude microorganisms harbored in all possible sites and thus maximize the benefit. In this manner the

treatment outcome is better than that of either procedure alone (2) because 'infection is eliminated and re-infection is prevented' (45). However, in teeth where the root canal is accessible for retreatment, apical surgery should be avoided to prevent its inherent risks; therefore, the combination of both procedures is not common (2).

The better ability of retreatment to curtail root canal infection should theoretically translate into the most important benefit of all – an *improved treatment outcome*. Although the respective outcomes of retreatment and apical surgery have been reported in follow-up studies of either alternative (2), the most appropriate comparison between the two alternatives is on the basis of randomized controlled trials. To date, two such clinical trials have been reported (46, 47), and both conclude that the outcome of both alternatives does not differ significantly. However, it would be a mistake to consider these two trials in isolation from the many other outcome studies available. It is interesting to note that, for apical surgery, the complete healing rate of just under 60% reported in both trials is consistent with the weighted average rate of 67% calculated from the outcomes in other studies reported in the past decade (2, 10, 48, 49). In contrast, for retreatment, the healing rates of 28% (46) and 55% (47) fall considerably short of the weighted average rate of 80% calculated from other studies reported in the past decade (2, 50–58). It is difficult to speculate why the outcome of retreatment is poorer than usual in these two trials. Possibly, the randomization requirement that was the basis for the experimental design resulted in retreatment performed in teeth in which complicating factors were present, such as root canal obstacles, extruded filling materials or perforations. The mention in one of the studies (47) of 17% of the retreated teeth having extruded root fillings may be a hint to that effect. Comparisons between the outcome of retreatment and apical surgery beyond these two randomized controlled trials are not appropriate; therefore, **the treatment outcome benefit of the two alternative procedures cannot be clearly defined (8)**.

Risks

Both retreatment and apical surgery require considerable manipulation, and should be considered invasive procedures associated with inherent risks. For retreatment, the inherent risk depends on the type of restoration that is present, and the type of root canal filling or other obstacles that have to be eliminated. At most, the patient is at risk of losing the tooth because of fracture or a significant complication, such as an irreparable perforation (59). Other complications, such as instrument breakage or marked canal transportation represent a lesser risk, although they can compromise the outcome of treatment. The following considerations may be used as suggestive of the risk associated with retreatment:

- *Coronal restoration* – Only removal of full coverage restorations (crowns, bridges) is associated with a risk; the tooth may be rendered non-restorable if its coronal portion is severed.
- *Post restoration* – Post removal is associated with a risk of root fracture, proportional to the retention of the post within the root. Post retention depends on its size, type and the material with which it is cemented—it is the greatest when the post is large, long and has parallel walls (60), and when it is cemented with dentin-bonded composite resin, such as Panavia (61). Nevertheless, when the appropriate armamentarium is used with adequate skill, the risk of root fracture is very small, and should not be considered to exceed 1% (62) (Fig. 4). Also, post removal may occasionally be avoided in multirooted teeth, when post-treatment disease is associated with roots other than the one supporting the post (59, 63) (Fig. 5).
- *Root canal obstacles* – Attempts to eliminate insoluble materials, such as zinc-phosphate cement or broken instruments, are associated with a risk of root perforation. The more apical the location of the obstacle, the greater the risk. Nevertheless, root perforations can frequently be successfully repaired *in situ* (64); therefore, unlike in the past, perforations should no longer result in imminent tooth loss, although they may compromise the outcome of treatment.

For apical surgery, the inherent risk depends on the location of the treated tooth in proximity to sensitive anatomic structures such as nerves, major blood vessels, sinuses, muscles or roots of adjacent teeth, and on the accessibility of the roots as determined by the thickness of the buccal alveolar bone plate and depth of the buccal vestibule. At most, the patient is at risk of nerve damage or sinus complications requiring additional invasive procedures. Other complications, such as perforation of the lingual alveolar bone plate or exposure of a root dehiscence, may compromise

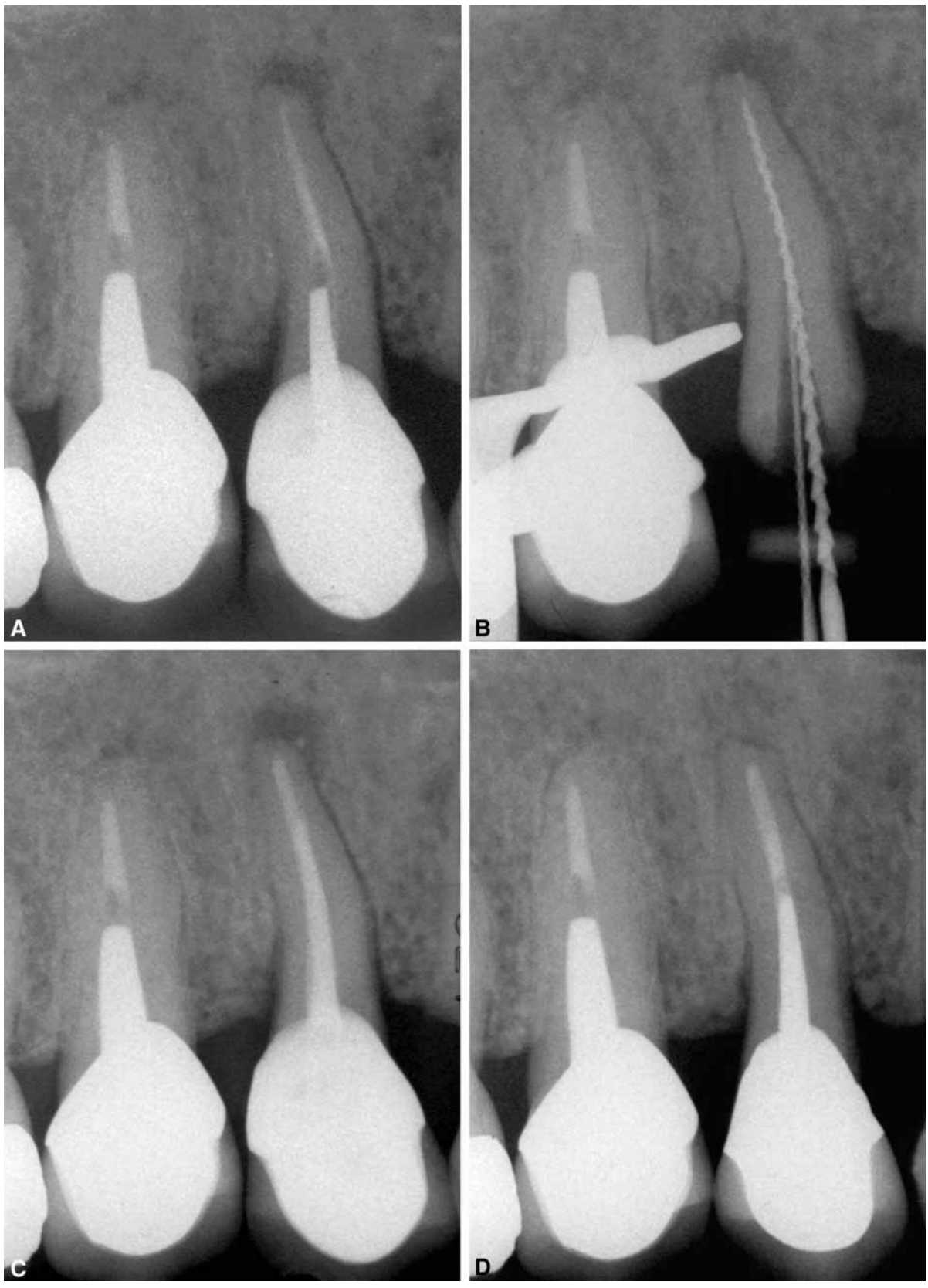

Fig. 4. Retreatment in posterior tooth with a cast post. A. Cast post and crown in maxillary first premolar with post-treatment disease. B. Crown was removed reversibly, the post was extracted with the Gonon device, and retreatment is underway. C. Completed retreatment with the original crown recemented in place. D. Complete healing at 4 years.

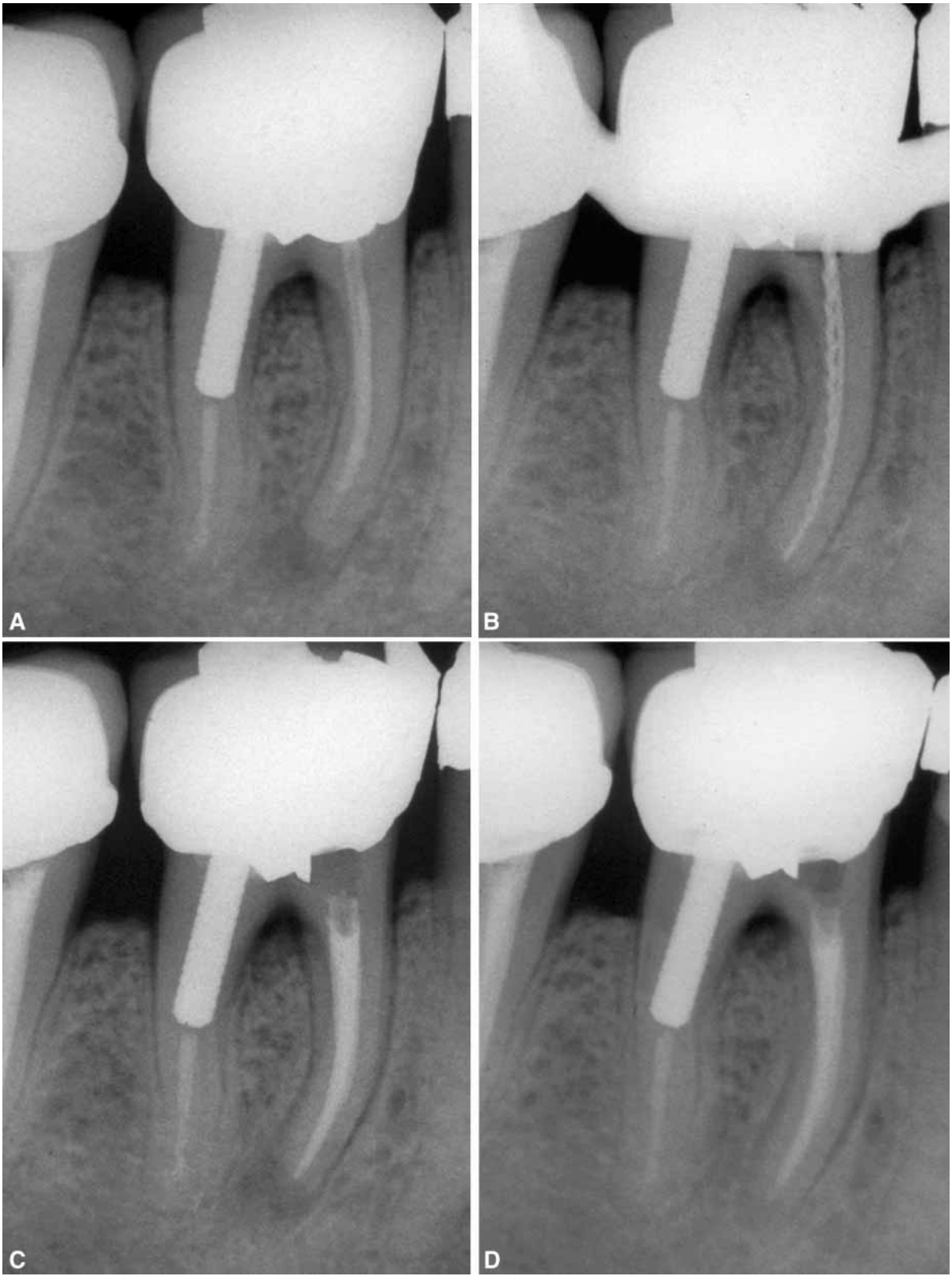

Fig. 5. Retreatment through crown without post removal. A. Large prefabricated post in distal root of mandibular first molar with post-treatment disease associated with mesial root. Removal of the post and retreatment of the distal canals would have the benefit of preventing potential disease and the risk of root crack; therefore, it is avoided. B. Access to mesial canals was prepared through the crown and core without disturbing the post and distal aspect of core; retreatment is in progress. C. Completed retreatment of mesial canals. D. Complete healing at 6 months. (Reprinted with permission from (63)).

the outcome of treatment (45). Minor sinus exposure usually represents a lesser risk, because its sequelae are either transient in nature or treatable (65, 66). Another treatable complication is an inadvertent resection of an adjacent root tip. Although the textbooks on apical surgery do not elaborate on potential risks, the following considerations may suggest risks associated with apical surgery:

- *Proximity to the inferior alveolar nerve* – Operation on mandibular premolars and molars is associated with a risk of paresthesia or dysesthesia, mainly resulting from manipulation and inadvertent nerve damage. This risk is greatest when the mandibular canal or the mental foramen is radiographically observed in close proximity to the surgery site. Although the altered sensation is often transient, it may be permanent.
- *Proximity to the maxillary sinus* – Depending on their proximity to the sinus, operation on maxillary premolars and molars, and less frequently, on maxillary canines, may be associated with the risk of misplacing the resected root apex into the sinus (67), which may necessitate further surgical intervention. To a large extent this risk is avoidable, but it is not entirely preventable. Another risk is development of sinusitis after the surgical procedure (66). In most cases, the sinusitis can be resolved by an antibiotic regimen; lasting complications or necessity to extract the tooth are uncommon (66).
- *Accessibility* – Operation on difficult to access teeth is associated with a greater risk of procedural complications, such as lingual bone plate perforation or inadvertent resection of an adjacent root, than is operation in easily accessible areas. Although procedural complications may compromise the prognosis (45), to a large extent they are treatable.

To summarize, it is impossible to generalize whether the risks associated with either alternative outweigh those associated with the other. **This assessment can only be made by taking in account the characteristics of the individual tooth** that requires management of post-treatment disease.

Another potential risk associated with treatment are the postoperative sequelae of *pain and swelling*. According to Kvist & Reit (68), retreatment provoked postoperative pain and swelling in 26% and 15% of patients, respectively, whereas apical surgery provoked similar reactions in 90% and 100% of the patients, respectively. The symptoms subsided faster after retreatment, with only 4% of the patients still having some swelling after 1 week, compared to 66% of patients that had apical surgery. **The pertinence of these findings is subject to individual interpretation by each and every patient** – some may consider this critical, while others may not. It should be noted, however, that the postoperative discomfort may indirectly influence another consideration that is key to the selection between retreatment and apical surgery, that of cost. For example, in the same study (68), 23% of the patients who received apical surgery, but none of those who received retreatment, required sick leave because of swelling. This may have resulted in loss of income, thus increasing the indirect cost associated with apical surgery (68).

Unique dilemmas

As explained above, without clear evidence of extraradicular infection, it is appropriate to consider retreatment as the *principal treatment of choice* in the management of post-treatment disease, unless the foreseen risks of retreatment of the specific tooth in question appear to outweigh those of apical surgery. Accordingly, apical surgery is a *compromise*, unless infection is assumed to be extraradicular, retreatment is unfeasible or restricted, or a previous retreatment attempt has not resulted in healing (5). According to this rationale, retreatment should be much more frequently performed than apical surgery. However, apical surgery appears to be as prevalent as retreatment, and, in some parts of the world, even more prevalent (69). The reasons for this disparity between theory and practice appear to be founded in the unique dilemmas that affect clinicians' decisions when they are required to manage teeth with post-treatment disease.

One complicating factor is the considerable difference between retreatment and the more 'routine' initial endodontic treatment. Although these two root canal treatment procedures share similar biologic principles and objectives, the following considerations are unique to retreatment (70):

- An extensive restoration may have to be sacrificed and later remade, which considerably increases the overall cost of the entire treatment.
- Morphologic alterations resulting from the previous treatment may present unusual technical and therapeutic challenges (71).

- Root filling and possibly restorative materials must be removed from the root canals, increasing the associated risk.
- The healing rate is generally recognized to be lower than after initial treatment (2), undermining the confidence of both the patient and the clinician.
- Patients may be more apprehensive than with the 'routine' initial treatment.

Inconsistent management

The unique dilemmas highlighted above may be the main reason for the inconsistent management of post-treatment endodontic disease, as demonstrated in several studies (72–74). After having reviewed treatment plans submitted for a Swedish population of 1094 patients, which included 874 teeth with post-treatment endodontic disease, Petersson et al. (74) report that extraction was planned in 23% of the teeth, apical surgery in 3% and retreatment in 20%, but in the remaining 54% of the teeth, no intervention was planned. In another report (73), 351 patients were examined in successive cross-sectional studies performed 11 years apart; it was revealed that 22% of the teeth that presented with post-treatment disease in the first study were extracted and 18% were subjected to retreatment or apical surgery, but 60% remained untreated in spite of the evident pathosis. A comparable distribution was observed by Friedman et al. (72) in a long-term follow-up study after apical surgery: 31% of the teeth in which healing had not occurred were extracted and 16% were treated again, while 53% remained unattended from one follow-up period to the next, and remained in limbo up to 8 years in some cases.

The inconsistent management is not unique to post-treatment endodontic disease; it has been documented in other disciplines of dentistry and in medicine (8). Nevertheless, its foundations require exploration, in an attempt to more consistently provide patients with the best treatment and greatest benefit. It appears from the extensive research efforts of the Gothenburg, Sweden, group (8) that the inconsistent management stems from:

- weak evidence base to support decisions;
- subjective, unreliable and unstable values of periapical health and disease;
- subjective values of the utility, or benefit of treatment (retreatment/surgery) relative to persistent disease.

All of the above result in considerable intra- and inter-individual variations in decision making among clinicians, observed even in surveys referring to radiographs or drawings and case histories, but not involving actual treatment of patients (8, 75–85). It is amazing to note that, although there were neither patients to treat nor real risks to be concerned about, the 'treatment' prescribed by the surveyed clinicians varied considerably – retreatment in 25% of the teeth, apical surgery in 15–20%, but no treatment in 53–60% of the teeth (76, 80).

Such apparent reluctance of clinicians to implement treatment indicates unease with the management of post-treatment disease. The unease of the clinicians is frequently confounded by the patient's reluctance to accept retreatment, a procedure interpreted as a repetition of the 'same thing'. In contrast, apical surgery may be interpreted as a different procedure, thus not stirring similar sentiments. To foster confidence and appropriate management, definitive criteria are required to select cases for extraction, retreatment and apical surgery.

Diagnosis

Presence or absence of endodontic disease is determined according to clinical and radiographic findings. As mentioned above, opinions regarding diagnosis have varied among clinicians and even researchers from as far back as some 70 years ago (86). This variability is greatest when symptoms are absent (2). However, apical periodontitis is frequently asymptomatic and diagnosed primarily by the radiographic appearance. The rather low prevalence of clinical signs and symptoms in conjunction with apical periodontitis has been suggested by a number of treatment outcome studies. For example, of all the teeth with periapical radiolucency included in two studies on the outcome of endodontic treatment, only 18% (87) and 24% (10) also presented clinical symptoms.

Clearly then, **the absence of symptoms at a follow-up examination of endodontically treated teeth is immaterial when the radiographic appearance is suggestive of post-treatment disease**; therefore, it should not be used as an argument to defer treatment or to avoid it altogether (2). Fur-

thermore, when infected teeth present with apical periodontitis for initial endodontic treatment they are consistently treated because of radiographic signs of disease, although the majority are not symptomatic. If radiographs still suggest the same disease post-treatment, this should not be considered a satisfactory outcome, even if symptoms are absent (2).

This dilemma of disease vs. symptoms can be resolved simply by asking the patient upon consultation whether he/she expects *healing of the disease*, or only *relief of the symptoms*? The specific answer may serve as a guideline for the clinician and the patient as to which expectation is the most important.

Non-endodontic disease, vertical root fracture or healing in progress should all be carefully considered as a differential diagnosis (88). In this regard, the *case history* is reviewed, noting previous radiographs when these are available, past occurrences of symptoms, the time elapsed since previous treatment (to recognize healing in progress and thus avoid premature diagnosis) and previous attempts at retreatment or apical surgery (may be suggestive of vertical fracture) (70, 89).

Selection of treatment

Selection of extraction, retreatment or apical surgery appears to be an area that has not been clearly described in articles and textbooks until fairly recently. Almost uniformly, this area had been referred to by outlining indications for apical surgery, as follows (5, 71, 89, 90):

- persistence of symptoms after endodontic treatment;
- poor or suspect quality of the root filling (assessed radiographically or upon clinical inspection);
- presence of post-supported restorations, inaccessible canals and irretrievable root filling materials;
- procedural complications during endodontic treatment;
- diagnostic procedures such as biopsy and verification of a fracture or crack.

The approach to retreatment had been mostly intuitive and subjective, which may be one of the reasons why clinicians educated during that period demonstrate such variability and inconsistency in selecting between retreatment and apical surgery. Another reason may be the reluctance to remove posts, primarily to avoid the risks, but also because of previously experienced unsuccessful attempts at post removal (69).

Friedman & Stabholz (70) were the first to suggest systematic criteria for case selection in the management of post-treatment disease. At that time, society expected clinicians to assume a paternalistic approach to clinical decision making (8); it was the clinician's responsibility to select and then provide the most appropriate treatment; therefore, for the most part, the outlined criteria referred to the case history and the tooth under consideration. The patient was mentioned briefly, to suggest he/she 'should be informed about alternative treatments and possibly be allowed to participate in deciding the choice of treatment' (70). The clinician, too, was mentioned briefly, and advised to 'evaluate each case according to his capability' and, in doubtful cases, to 'consult an endodontist whom he may consider more experienced than himself' (70). Perhaps the weakest aspect of this case selection system was the assessment of the 'feasibility' of gaining a coronal access to the root canals; this introduced subjectivity and bias at the most critical juncture of deciding between retreatment and apical surgery. Nevertheless, this system has gained wide acceptance, possibly because it categorically regarded retreatment as a preferred treatment alternative, and focused on identifying clinical conditions, that would justify an alternative treatment such as tooth anatomy, root filling, iatrogenic factors and potential complications.

Reit and coworkers (7, 8, 47, 68, 77–84, 91) have systematically studied the decision making process with regards to the management of post-treatment disease in an attempt to understand the various factors that underlie this process and to develop a decision making strategy. They suggest that this process involves the interaction of scientific, psychological and sociological considerations and that it relies mostly on the associated values of the utility of treatment (retreatment or surgery) for a disease that is not life threatening (80). Thus far it appears that the monumental work of these researchers has been extremely helpful in underscoring the many factors involved, from timing and interpretation of follow-up radiographs to personal ethical and utility values. They suggest a follow-up strategy, whereby patients should be assessed for the outcome of treatment 1 year postoperatively and, if in doubt, recalled again 3 years later (91). However, they have not yet been able to suggest a systematic strategy

that, if universally taught to clinicians, would facilitate the selection between retreatment and apical surgery and would make it more consistent.

As stated above, the current ethical and legislative requirements of the society dictate that *the patient selects the treatment*; the clinician's responsibility has evolved from making treatment decisions to communicating the pertinent information and thus facilitating the patient's decision making process, and providing the treatment selected by the patient. The following case selection strategy, suggested by Friedman (63), is consistent with this modern concept.

Case selection

Retreatment and apical surgery are usually performed to treat *existing disease*, presenting with definitive radiographic changes and possibly clinical signs and symptoms. However, even in the absence of disease, retreatment may be indicated to prevent the *potential emergence of disease* in the future (5, 70).

Treatment of existing disease

As explained above, whenever post-treatment disease is diagnosed and treatment (tooth retention) is preferred over extraction, both orthograde retreatment and apical surgery should be considered. Because retreatment appears to offer a *greater benefit* – better ability to eliminate the disease's etiology (root canal infection) with minimal invasion, and a *lesser risk* – significantly less postoperative discomfort (68) and less chance of injuring anatomic structures, it should be generally considered ***the principal treatment of choice***; however, it is not always feasible. At times, retreatment can be more time-consuming and costly than surgery, particularly when an extensive restoration must be replaced. Also, the ability to materialize the full benefit of retreatment may be restricted by a variety of clinical factors (70). Moreover, clinicians' capability to perform retreatment and surgery varies considerably.

To summarize, orthograde retreatment is generally selected because of its greater benefit and lesser risk in comparison with apical surgery. Therefore, the case selection strategy suggested below is based on considerations that either preclude retreatment altogether, or restrict it in a way that may decrease the potential benefits and increase the risks; the resulting *modified benefit–risk balance may no longer outweigh that of apical surgery.* These considerations focus on:

- the patient,
- the tooth in question,
- the clinician,
- the previous treatment attempts.

Patient considerations

The attitude of patients and clinicians towards periapical disease and the utility of treating it differ significantly (83). Moreover, the motivation to retain every tooth and to pursue the best long-term treatment outcome may vary, as do the motivation and ability to allocate time and finances. All these general attitudes influence the patient's treatment preferences; therefore, they are primary considerations in the case selection process (Table 1).

Motivation to retain the tooth

The considerable effort associated with both retreatment and apical surgery is justifiable only by the potential to retain the diseased tooth. For the unmotivated patient, extraction is recommended.

Motivation to pursue the best long-term outcome

For the patient who is receptive to a compromise in terms of the long-term outcome, the easier apical surgery procedure is recommended when retreatment is expected to be very elaborate, unless surgery is contraindicated on the grounds of health, anatomy or accessibility.

Critical time concerns

For the time-restricted patient who is receptive to a compromise in order to minimize his or her time commitment, the quicker apical surgery procedure is recommended. However, the associated postoperative discomfort and recovery may impose loss of work time and income (68), and therefore should be taken into account.

Critical financial concerns

For the financially restricted patient who is receptive to a compromise in order to minimize cost, apical

surgery is recommended when the combined cost of retreatment and restoration is considered prohibitive. Again, the potential loss of income resulting from postoperative discomfort and recovery should be taken into account (68).

Following the simple strategy described above, the patient is prompted to relate the treatment alternatives to some of his or her values and priorities. This may be helpful in preparing the patient to make a decision regarding the selected treatment.

Tooth considerations

When, following the above, the patient indicates a preference for retreatment, the tooth and surrounding tissues are scrutinized with the aim of identifying clinical conditions that might adversely affect the prognosis. Particular attention should be directed towards the recognition of obstacles that might limit the clinician's ability to materialize the full benefit of retreatment, or that might increase the level of risk when attempts are made to overcome obstacles. In specific cases, the modified benefit–risk balance no longer justifies the preference of retreatment over surgery.

'Site of infection'

As explained above, infection by root canal microorganisms is best eliminated by retreatment (2), whereas infection by extraradicular (periapical) microorganisms is best eliminated by apical surgery (43). In contrast, infection associated with a vertical root crack or fracture cannot be predictably eliminated by either procedure (92). A diagnostic process is therefore required to differentially establish the likely 'site of infection'. To facilitate this process, one should recognize the frequent manifestation of extraradicular actinomycosis, more than one sinus tract (37), and that of a vertical root crack/fracture, an isolated, narrow defect along the root (92). Comparison of older and recent radiographs may also be helpful in some cases (70, 89).

Root canal obstacles

To materialize the full benefit of retreatment, elimination of root canal infection, the canal must be renegotiated throughout. Obstacles that restrict the clinician's ability to totally renegotiate the canal decrease the potential benefit of retreatment, while attempts to overcome the obstacles increase the risk of procedural complications (transportation, perforation). The main obstacles that should be considered are (Fig. 6):

- calcification;
- diverging root canal system;
- suspected ledge;
- hard-setting cement;
- broken instrument.

The feasibility of overcoming these obstacles must be assessed; consequently, the benefit–risk balance may or may not change in favor of the surgical alternative.

In many teeth the canals are obstructed with posts. In the past, presence of a post was the main indication for apical surgery (5, 71, 89, 90). Currently, however, cumulative clinical experience (62) and research data (60, 61) have helped establish confidence among many clinicians that posts can be removed predictably with minimal risk (Fig.s 4 and 7). Therefore, presence of a post should not be considered to change the benefit–risk balance in favor of apical surgery. **This recognition represents the most drastic departure from previous approaches to case selection and indications for apical surgery**.

Table 1. Patient considerations governing case selection in the management of existing disease after root canal treatment (adapted from 63)

Consideration	No	Yes
Motivation to retain tooth in question	extraction	retreatment or surgery
Motivation to pursue the best long-term outcome	surgery	retreatment
Critical time concerns	retreatment	surgery
Critical financial concerns	retreatment	surgery

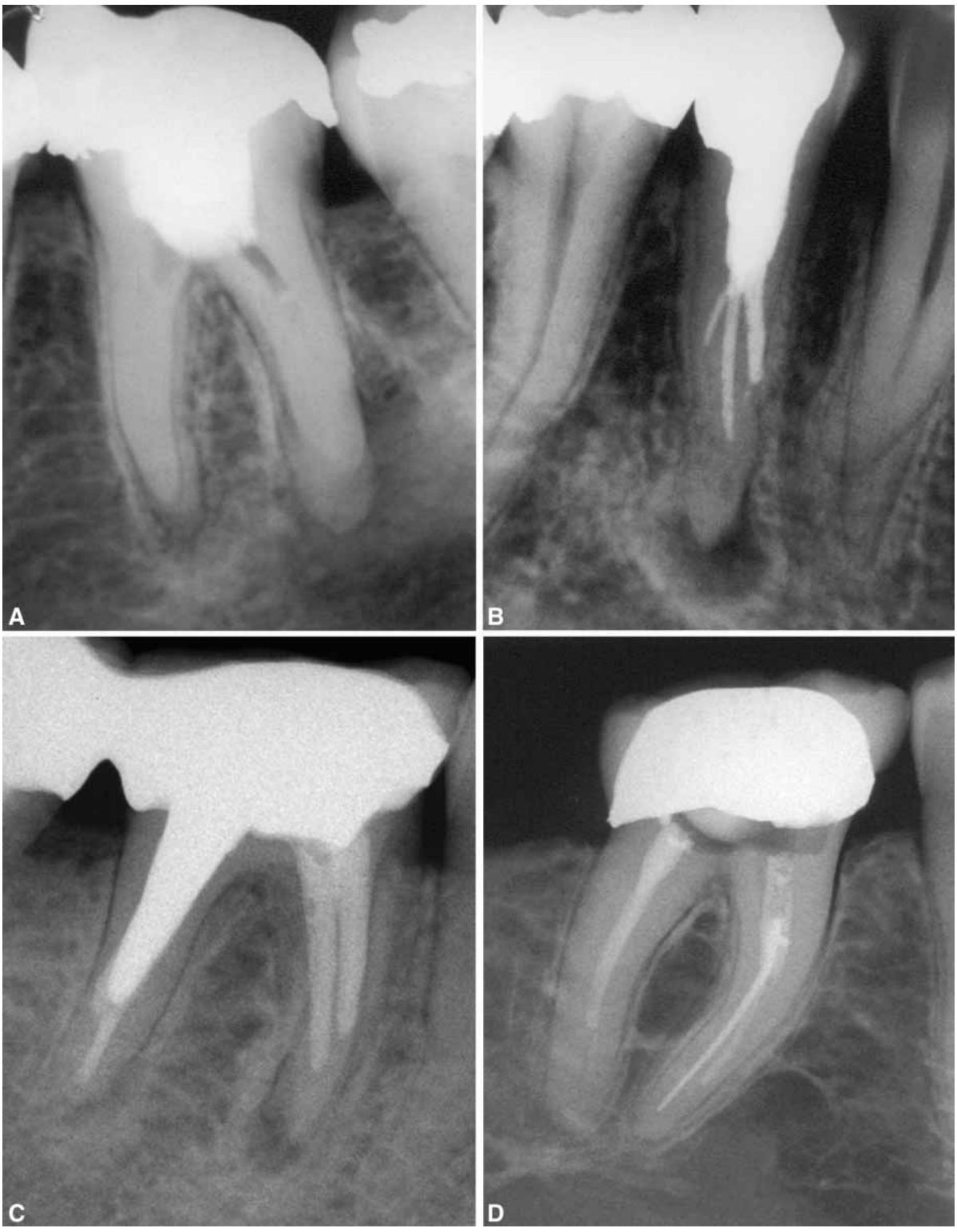

Fig. 6. Root canal obstacles considered to assess feasibility of retreatment. A. Calcific metamorphosis. B. Complex morphology. C. Suspected ledge. D. Broken instrument. These obstacles restrict the clinican's ability to renegotiate the canal and increases the risk of canal perforation. (Reprinted with permission from (63)).

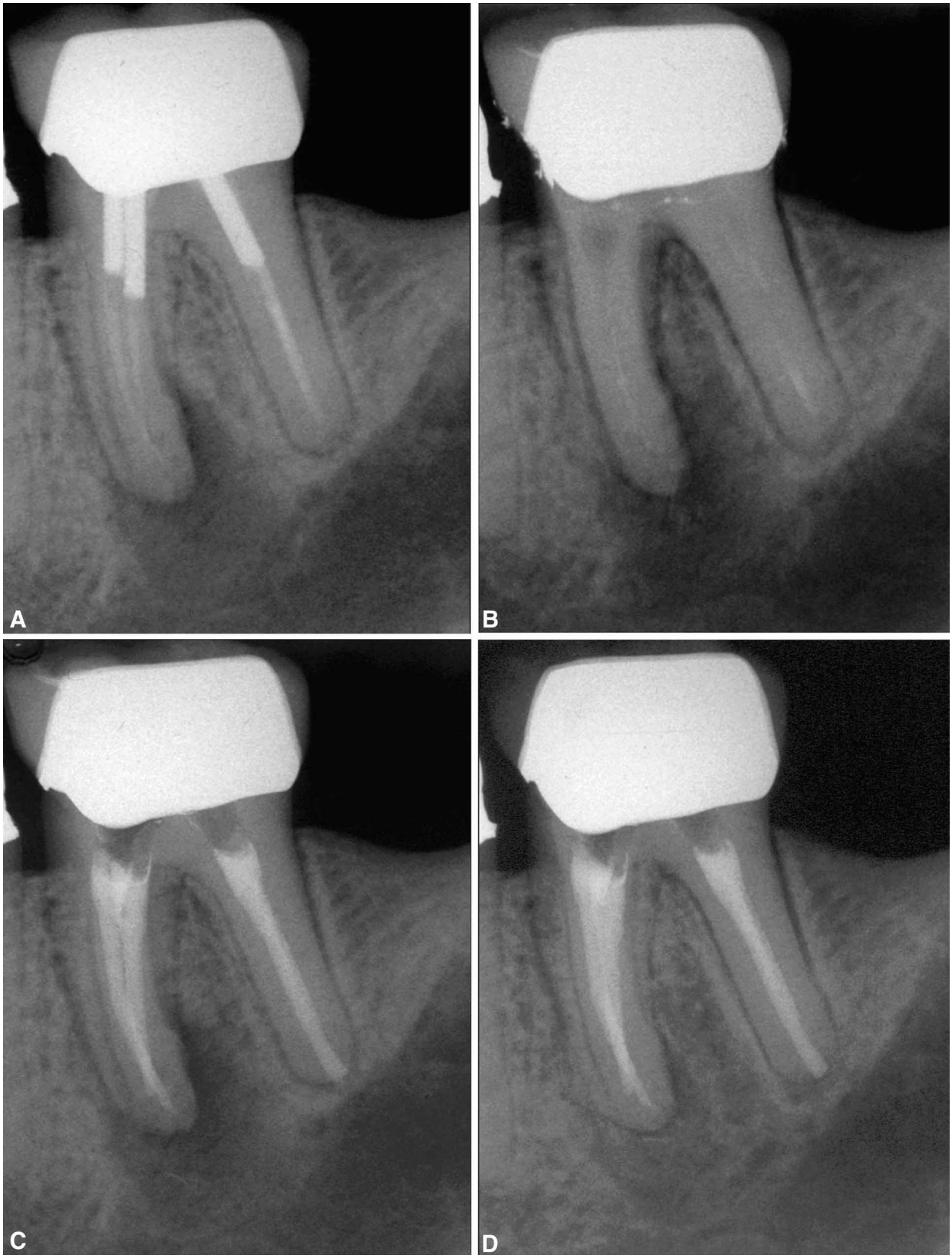

Fig. 7. Retreatment and post removal through the crown. A. Three prefabricated posts in mandibular molar with post-treatment disease. B. Access was prepared through the crown and posts were removed; the canals are dressed with calcium hydroxide. C. Completed retreatment. D. Progressive healing at 6 months. (Reprinted with permission from (63)).

Perforation

In the past, the presence of a perforation was considered an indication for surgical intervention aimed at external repair (5, 71, 90), because of a doubtful prognosis of internal repair (93, 94). Currently, however, it is recognized that a perforation of the pulp chamber or root impairs the prognosis only when it has become a pathway of infection (95). Therefore, retreatment in conjunction with internal repair of the perforation is usually warranted in an attempt to curtail the infection, and surgery is not the primary treatment of choice (Fig. 8) (64, 95, 96). Nevertheless, when healing is unlikely or does not occur, surgery may be required as an adjunct. The surgical procedure may include external repair of the perforation and an attempt at guided tissue regeneration (Fig. 9).

Restorative, periodontal and aesthetic factors

Teeth considered to have a hopeless restorative or periodontal prognosis should be extracted (70). With compromised periodontal support, apical surgery may result in an unfavorable crown–root ratio; therefore, retreatment is recommended. In teeth presenting with an oro-facial sinus tract, surgery may have to be performed as an adjunct to retreatment to minimize scarring associated with the healing of the sinus.

Clinician considerations

Clinicians vary with regards to capability, availability of armamentarium and latitude regarding the time they can (or are willing to) spend on an elaborate treatment of one tooth. All of the above determine a clinician's 'comfort zone', or confidence regarding specific treatment procedures. In the past, this comfort zone played a major role in the selection between retreatment and apical surgery (71). Currently, however, when the clinician does not feel comfortable performing the treatment procedure selected by the patient, it is considered appropriate to refer the patient to another clinician who can perform the selected procedure. It is appropriate for the clinician's 'comfort zone' to influence the selection only in the rare situations when *referral is unfeasible* (remote areas); in these situations, the selected treatment is that with which the clinician is most confident.

Capability

Capability is a combination of training, skill and experience. Specialist endodontists usually are more capable of treating post-treatment disease than the non-specialist dentists. Occasionally, however, even a specialist may not be equally adept at retreatment and apical surgery. When there is not an option of referral, the procedure that can be performed best by the attending clinician (specialist or not) is recommended.

Armamentarium

Use of special instruments can optimize the benefit–risk balance of both retreatment and apical surgery. Without a referral option, if only the instruments required to perform one of the procedures are available to the attending clinician, that procedure is recommended.

Time availability

In specific circumstances (remote areas, community clinics), an excessive practice load may prevent the clinician from undertaking an elaborate retreatment of one complex case. In these circumstances only, and without a referral option, surgery is recommended rather than the complex retreatment.

Previous treatment attempts

If a previous orthograde retreatment or apical surgery procedure did not result in healing, the quality of that procedure should be evaluated. If the initial case selection is considered to have been appropriate but the quality improvable, the same procedure is recommended again (Fig. 10). Otherwise, the alternative procedure is recommended, as it may better address the site of the infection and capacitate healing (Fig.s 11 and 12).

Prevention of potential disease

Endodontically treated teeth may appear to be free of any signs of disease and yet harbor microorganisms in

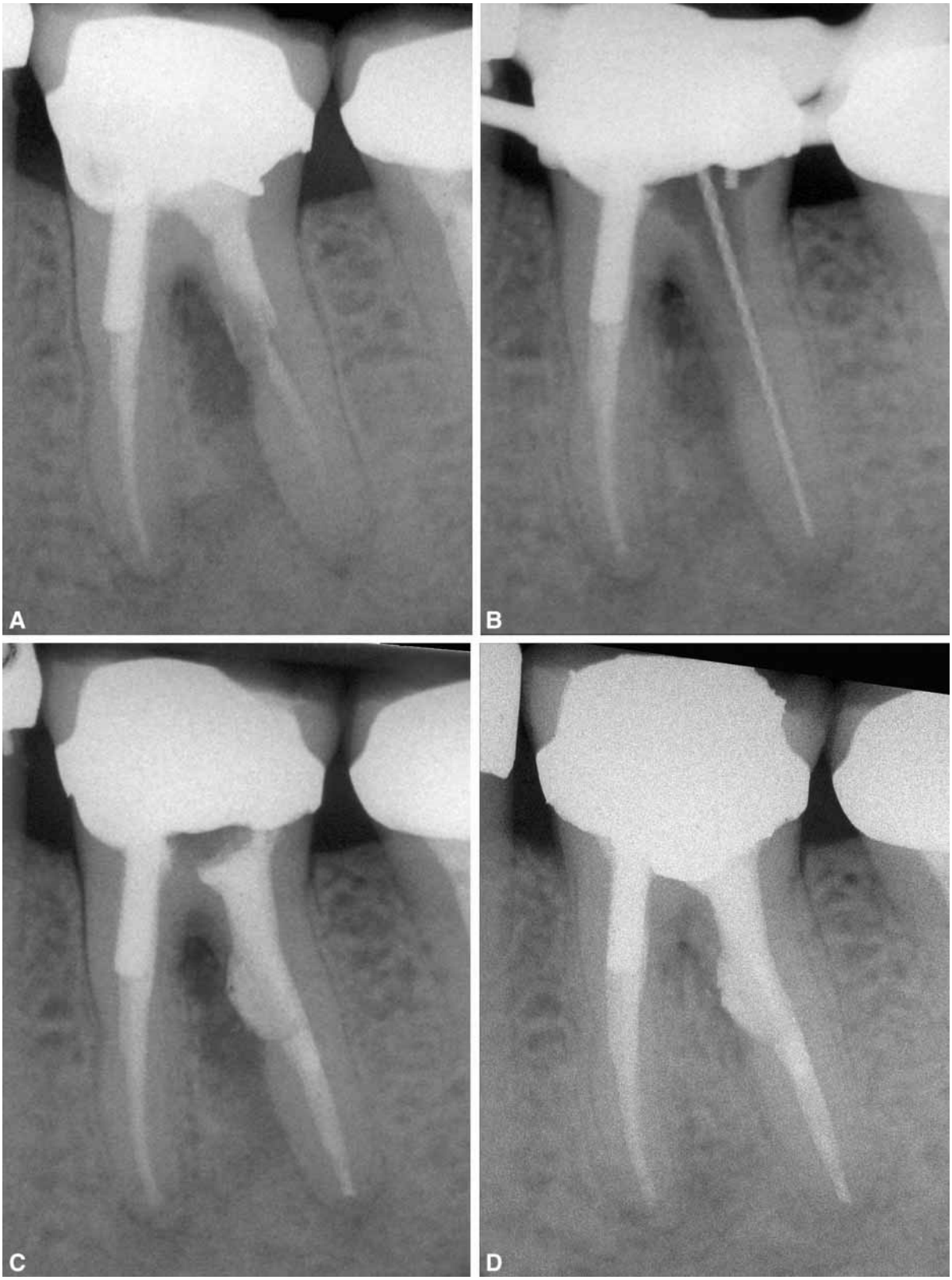

Fig. 8. Retreatment in conjunction with an internal perforation repair. A. Distal root perforation into a furcation in a mandibular molar with post-treatment disease. B. Access to the distal canal was established through the crown without disturbing the mesial root, and retreatment is in process. C. Completed retreatment and perforation seal with MTA. D. Complete healing at 1 year. (A, B and C reprinted with permission from (63)).

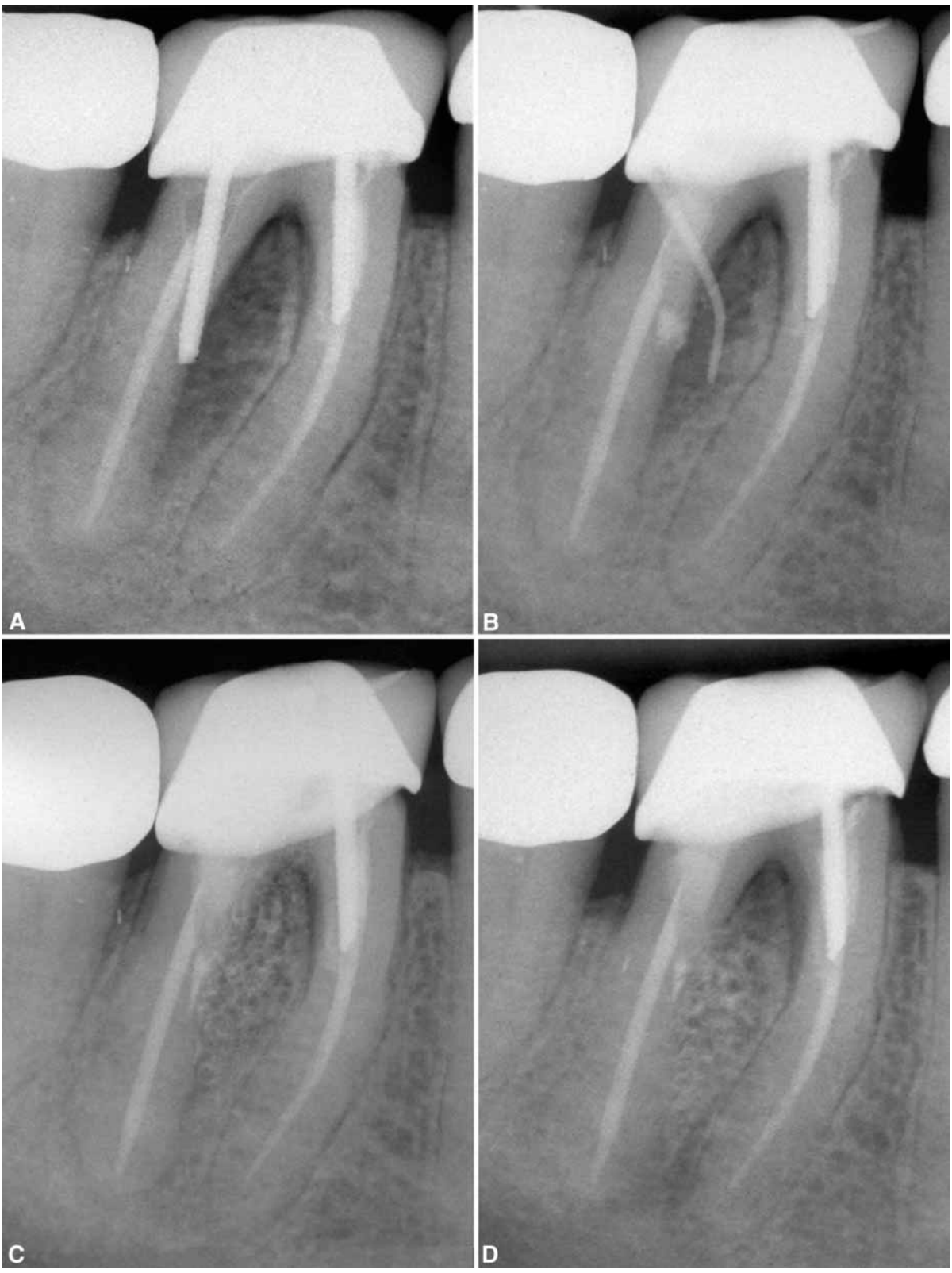

Fig. 9. Retreatment followed by an external perforation repair. A. Distal root perforation into the furcation of a mandibular molar with post-treatment disease. B. Access to the distal canal was established through the crown, the post extracted and the perforation sealed with MTA. However, a sinus tract persists at 3 months. C. The bone defect was accessed surgically, the perforation repaired externally with MTA, a bovine-derived bone substitute was placed, and a resorbable membrane inserted. D. Complete healing of the perforation site at 2 years, accompanied by loss of the marginal bone in the furcation.

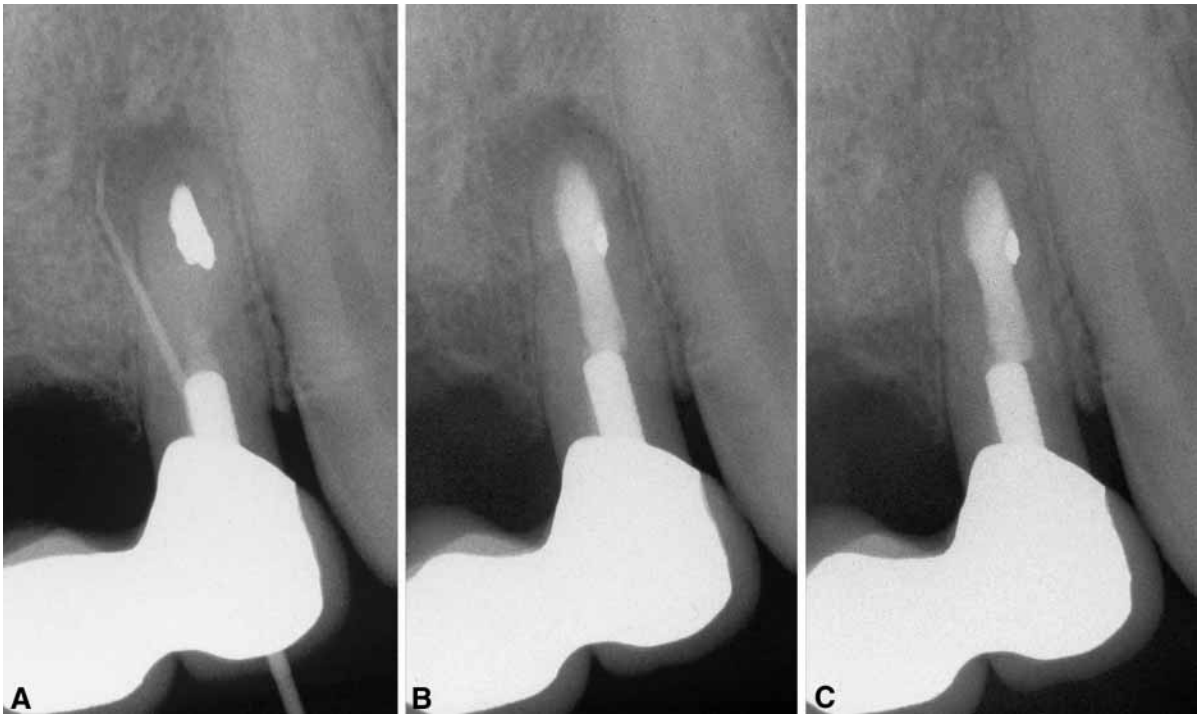

Fig. 10. Persistent disease after apical surgery. A. Post-treatment disease persists 2 years after apical surgery in the maxillary lateral incisor. Note the gutta-percha cone tracing the sinus tract. The patient selected to have apical surgery performed again. B. Repeated apical surgery, with an attempt to improve upon the quality of the previous procedure - the canal was retreated through the apex all the way to the post, and filled with MTA. C. Complete healing at 3 years.

the canal (28). The apparent absence of disease suggests that a balance exists between the root canal microorganisms, their specific environment and the host; if this balance is altered by changes in oxygen tension, supply of substrate or decreased host resistance, this can result in infection and disease (1).

Another distinct risk that has to be considered is coronal leakage. If microorganisms are allowed to invade and colonize the pulp chamber space, they can propagate to invade the filled canal and establish infection and disease within weeks or months, even if the root canal appears to be well filled (33).

The factors that may affect emergence of post-treatment endodontic disease are listed below:

Coronal restoration

When the endodontic system (pulp chamber, canals) has been exposed to coronal leakage or secondary caries, closure of this system by change of the restoration, even a simple filling, can modify the canal environment (availability of oxygen and substrate) to favor pathogenic microbial strains that may establish infection and disease.

Post restoration

In addition to the above, there is a risk of root canal contamination during the post space preparation, temporary restoration, and final post cementation.

Compromised host resistance

Theoretically, weakened host resistance can modify the balance and prompt infection. This factor, however, has not been thoroughly investigated.

To summarize, the considerations governing prevention of potential post-treatment disease include:

- the adequacy of the root filling;
- the adequacy of the coronal seal;
- the need for a new restoration.

Post-retained crown or bridge restorations represent a particular concern, because they will restrict the option of orthograde retreatment should disease emerge in the future. The likelihood of emerging post-treatment disease appears to be highest when both the root filling and the coronal seal are suspect, and a new restoration is needed. In these cases *retreatment is indicated,* as it offers the benefit of preventing post-

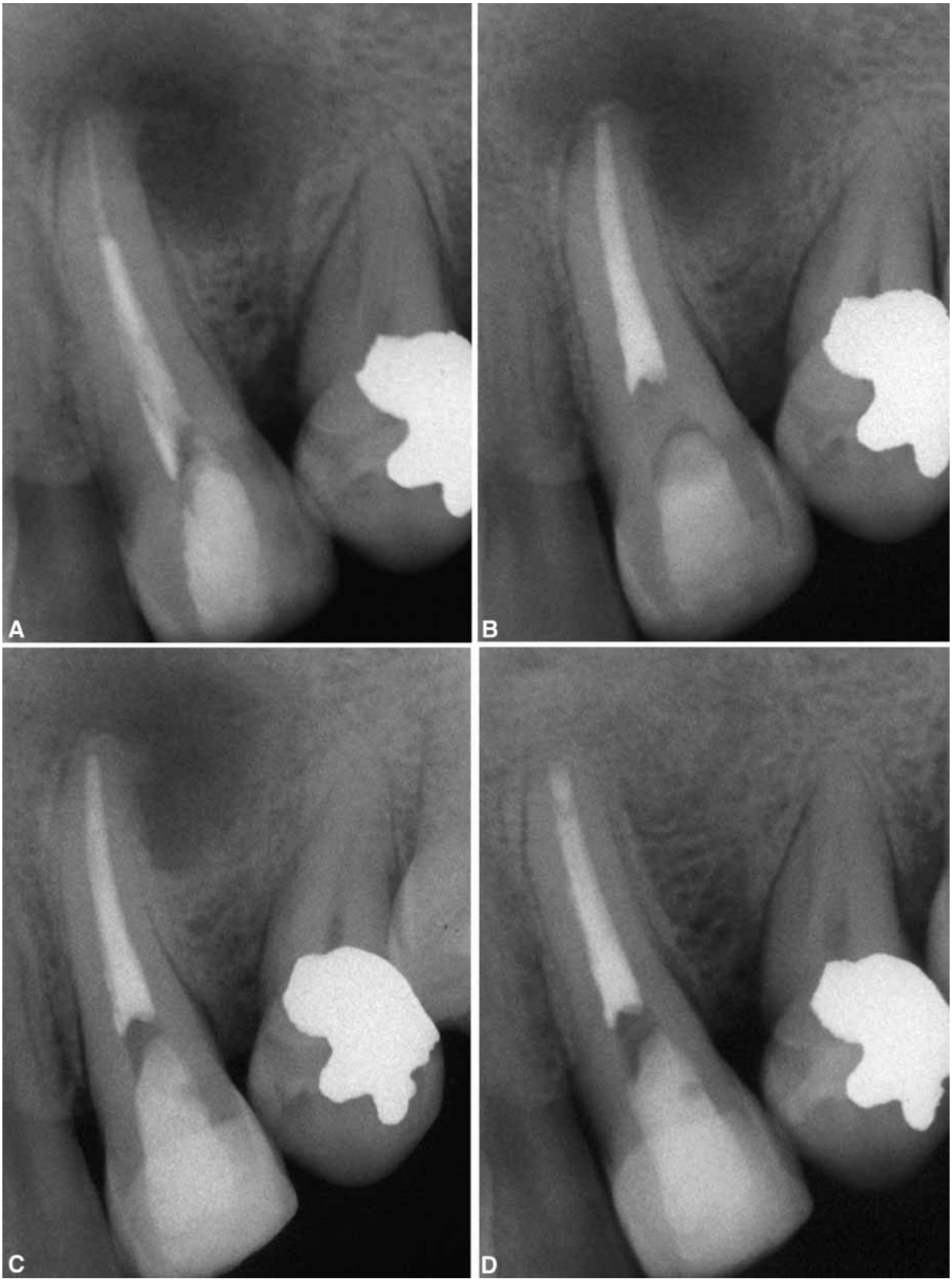

Fig. 11. Persistent disease after retreatment. A. Post-treatment disease in maxillary lateral incisor. B. Completed retreatment. Note apical patency and extensive apical enlargement. C. Disease persists at 1 year; because healing is unlikely following another retreatment, apical surgery is indicated. D. Complete healing at 6 months after apical surgery. (Reprinted with permission from (63)).

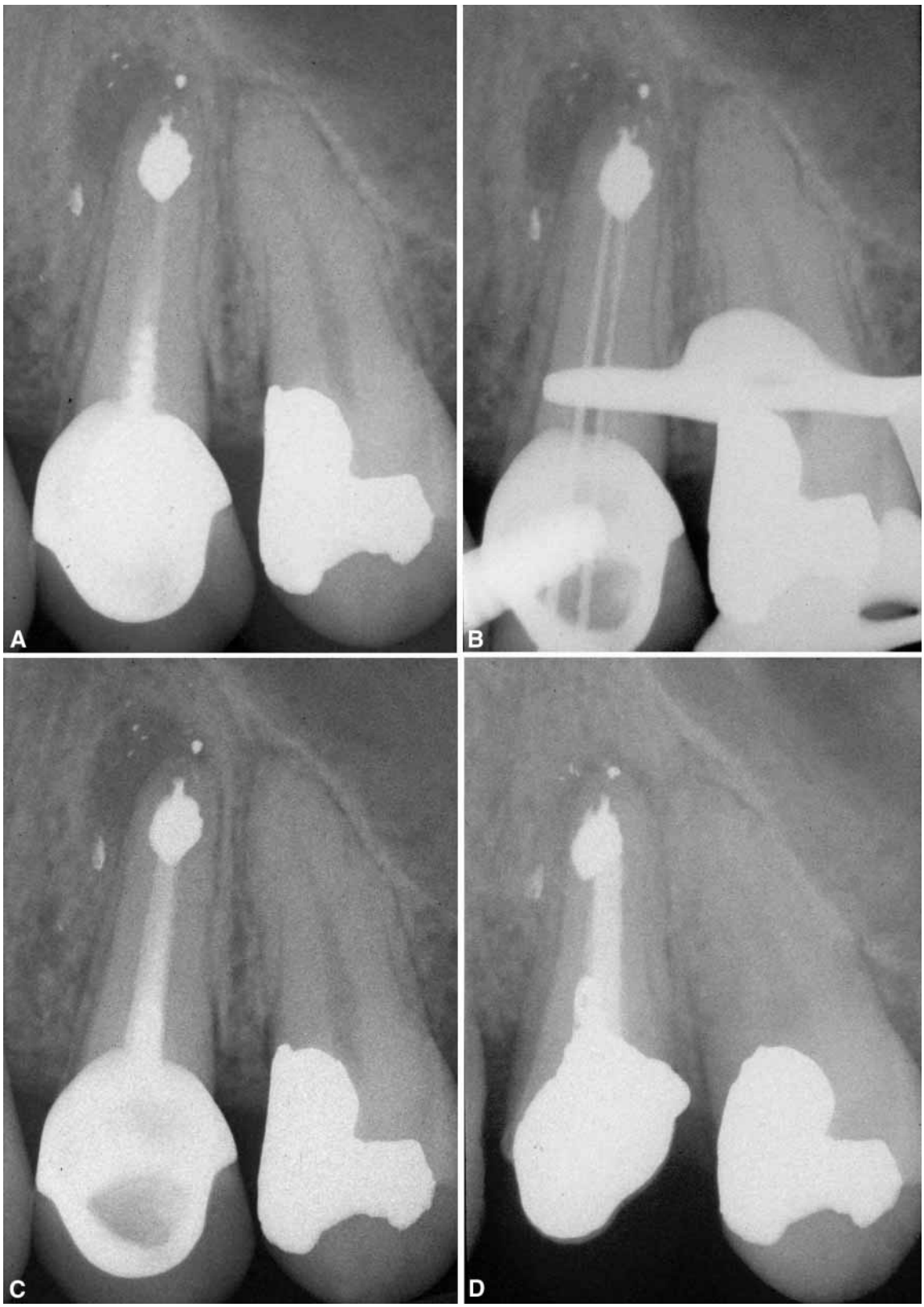

Fig. 12. Persistent disease after apical surgery. A. Post-treatment disease in maxillary first premolar. Because canals are assumed to be the site of infection, retreatment is indicated rather than repeated surgery. B. Access was prepared through the crown, the post was removed, and retreatment is underway. C. Completed retreatment. D. Progressive healing at 6 months. The crown is being replaced. (Courtesy Dr. David Campbell).

treatment disease. However, when a new restoration is not needed and only the root filling is suspect, emergence of post-treatment disease is less likely, and retreatment offers a lesser or no benefit. In these cases only *follow-up is indicated;* retreatment, and associated possible complications, can be avoided (5, 70).

As for the treatment of existing disease, the decision regarding retreatment to prevent potential disease rests with the patient, after the dentist communicates the pertinent considerations and associated benefits and risks. In this context, the benefit of excellent treatment outcome with complete healing rates of 88–100% has been documented (2). When the patient excludes the option of retreatment, the pulp chamber and post space should be thoroughly irrigated with an antimicrobial solution, such as sodium hypochlorite or chlorhexidine, in an attempt to curtail any existing microorganisms.

Communication and referral

Orthograde retreatment and apical surgery are more frequently associated with procedural complications than is initial treatment. Effective communication is required *before treatment is started,* to avoid frustration, discontent, and possible litigation. Appropriate communication should include explanation of the benefits, risks, potential restrictive factors, and the long-term outcome. The patient can then be in a position to select and authorize either retreatment or apical surgery, as well as the subsequent restorative procedures (9).

Even when the patient is referred to a specialist, communication of these factors is still essential; it allows the patient to consider the option of referral and consultation with the specialist. Furthermore, the patient will approach the specialist having more realistic expectations.

The referral should be in writing, and include all pertinent information about the patient, case history, previous radiographs, and outline of the restorative and prosthetic treatment plan, particularly for the tooth in question. Emergency procedures performed by the referring clinician should also be outlined. Mid-treatment referrals, particularly aborted retreatment attempts, should be avoided, because they are frequently associated with complications (9). To avoid mid-treatment referrals, clinicians should carefully discriminate between cases they can undertake and those they should refer to colleagues who may be more experienced in performing the particular procedure selected by the patient.

References

1. Ørstavik D, Pitt Ford TR. Apical periodontitis. Microbial infection and host responses. In: Ørstavik D, Pitt Ford TR, eds. *Essential endodontology: prevention and treatment of apical periodontitis.* Oxford: Blackwell Science, 1998.
2. Friedman S. Treatment outcome and prognosis of endodontic therapy. In: Ørstavik D, Pitt Ford TR, eds. *Essential endodontology: prevention and treatment of apical periodontitis.* Oxford: Blackwell Science, 1998.
3. Smith DE, Zarb GA. Criteria for success of osseointegrated endosseous implants. *J Prosthet Dent* 1989: **62**: 567–572.
4. Creugers NHJ, Kreulen CM, Snoek PA, de Kanter RJAM. A systematic review of single-tooth restorations supported by implants. *J Dent* 2000: **28**: 209–217.
5. Taintor JF, Ingle JI, Fahid A. Retreatment versus further treatment. *Clin Prev Dent* 1983: **5**: 8–14.
6. Ørstavik D. Time-course and risk analyses of the development and healing of chronic apical periodontitis in man. *Int Endod J* 1996: **29**: 150–155.
7. Kvist T, Reit C, Esposito M, Mileman P, Bianchi S, Pettersson K et al. Prescribing endodontic retreatment: towards a theory of dentist behaviour. *Int Endod J* 1994: **27**: 285–290.
8. Kvist T. Endodontic retreatment. Aspects of decision making and clinical outcome. *Swed Dent J* 2001: **144** (Suppl) 1–5.
9. Selbst AG. Understanding informed consent and its relationship to the incidence of adverse treatment events in conventional endodontic therapy. *J Endod* 1990: **16**: 387–390.
10. Abitbol S. Outcome of non-surgical endodontic treatment. MSc Dissertation.. Toronto: University of Toronto, 2001.
11. Eriksen HM. Epidemiology of apical periodontitis. In: Ørstavik D, Pitt Ford TR, eds. *Essential endodontology: prevention and treatment of apical periodontitis.* Oxford: Blackwell Science, 1998.
12. De Moor RJG, Hommez GMG, De Boever JG, Delme KIM, Martens GEI. Periapical health related to the quality of root canal treatment in a Belgian population. *Int Endod J* 2000: **33**: 113–120.
13. Kirkevang L-L, Hörsted-Bindslev P, Ørstavik D, Wenzel A. Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population. *Int Endod J* 2001: **34**: 198–205.
14. Kirkevang L-L, Ørstavik D, Hörsted-Bindslev P, Wenzel A. Periapical status and quality of root fillings and coronal restorations in a Danish population. *Int Endod J* 2000: **33**: 509–515.
15. Marques MD, Moreira B, Eriksen HM. Prevalence of apical periodontitis and results of endodontic treatment in an adult Portuguese population. *Int Endod J* 1998: **31**: 161–165.

16. Sidaravicius B, Aleksejuniene J, Eriksen HM. Endodontic treatment and prevalence of apical periodontitis in an adult population of Vilnius. *Lithuania Endod Dent Traumatol* 1999: **15**: 210–215.
17. Tronstad L, Asbjørnsen K, Døving L, Pedersen I, Eriksen HM. Influence of coronal restorations on the periapical health of endodontically treated teeth. *Endod Dent Traumatol* 2000: **16**: 218–221.
18. Weiger R, Hitzler S, Hermle G, Löst C. Periapical status, quality of root canal fillings and estimated endodontic treatment needs in an urban German population. *Endod Dent Traumatol* 1997: **13**: 69–74.
19. Ödesjö B, Helldén L, Salonen L, Langeland K. Prevalence of previous endodontic treatment, technical standard and occurrence of periapical lesions in a randomly selected adult general population. *Endod Dent Traumatol* 1990: **6**: 265–272.
20. Nair PNR, Sjögren U, Krey G, Kahnberg K-E, Sundqvist G. Intraradicular bacteria and fungi in root-filled, asymptomatic human teeth with therapy-resistant periapical lesions: a long-term light and electron microscopic follow-up study. *J Endod* 1990: **16**: 580–595.
21. Sjögren U, Hägglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. *J Endod* 1990: **16**: 498–504.
22. Siqueira JF. Aetiology of root canal treatment failure: why well-treated teeth can fail. *Int Endod J* 2001: **34**: 1–10.
23. Baumgartner JC, Falkler WA. Bacteria in the apical 5 mm of infected root canals. *J Endod* 1991: **17**: 380–383.
24. Fukushima H, Yamamoto K, Hirohata K, Sagawa H, Leung K-P, Walker CB. Localization and identification of root canal bacteria in clinically asymptomatic periapical pathosis. *J Endod* 1990: **16**: 534–538.
25. Hancock HH, Sigurdson A, Trope M, Moiseiwitsch J. Bacteria isolated after unsuccessful endodontic treatment in a North American population. *Oral Surg Oral Med Oral Pathol* 2001: **91**: 579–586.
26. Lin LM, Pascon EA, Skribner J, Gängler P, Langeland K. Clinical, radiographic, and histologic study of endodontic treatment failures. *Oral Surg Oral Med Oral Pathol* 1991: **71**: 603–611.
27. Lin LM, Skribner JE, Gängler P. Factors associated with endodontic treatment failures. *J Endod* 1992: **12**: 625–627.
28. Molander A, Reit C, Dahlén G, Kvist T. Microbiological status of root filled teeth with apical periodontitis. *Int Endod J* 1998: **31**: 1–7.
29. Peciuliene V, Balciuniene I, Eriksen HM, Haapasalo M. Isolation of *Enterococcus faecalis* in previously root-filled canals in a Lithuanian population. *J Endod* 2000: **26**: 593–595.
30. Peciuliene V, Reynaud AH, Balciuniene I, Haapasalo M. Isolation of yeasts and enteric bacteria in root-filled teeth with chronic apical periodontitis. *Int Endod J* 2001: **34**: 429–434.
31. Sundqvist G, Figdor D, Persson S, Sjögren U. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative retreatment. *Oral Surg Oral Med Oral Pathol* 1998: **85**: 86–93.
32. Sjögren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. *Int Endod J* 1997: **30**: 297–306.
33. Friedman S, Komorowski R, Maillet W, Klimaite R, Nguyen HQ, Torneck CD. Resistance of coronally induced bacterial ingress by an experimental glass ionomer cement root canal sealer *in vivo*. *J Endod* 2000: **26**: 1–5.
34. Gatti JJ, Dobeck JM, Smith C, White RR, Socransky SS, Skobe Z. Bacteria of asymptomatic periradicular endodontic lesions identified by DNA–DNA hybridization. *Endod Dent Traumatol* 2000: **16**: 197–204.
35. Sunde PT, Olsen I, Lind PO, Tronstad L. Extraradicular infection: a methodological study. *Endod Dent Traumatol* 2000: **16**: 84–90.
36. Sunde PT, Tronstad L, Eribe ER, Lind PO, Olsen I. Assessment of periradicular microbiota by DNA–DNA hybridization. *Endod Dent Traumatol* 2000: **16**: 191–196.
37. Sakellariou PL. Periapical actinomycosis: report of a case and review of the literature. *Endod Dent Traumatol* 1996: **12**: 151–154.
38. Tronstad L, Barnett F, Riso K, Slots J. Extraradicular endodontic infections. *Endod Dent Traumatol* 1987: **3**: 86–90.
39. Pitt Ford TR. The effects on the periapical tissues of bacterial contamination of the filled root canal. *Int Endod J* 1982: **15**: 16–22.
40. Nair PNR. Light and electron microscopic studies of root canal flora and periapical lesions. *J Endod* 1987: **13**: 29–39.
41. Siqueira JF, Lopes HP. Bacteria on the apical root surfaces of untreated teeth with periradicular lesions: a scanning electron microscopic study. *Int Endod J* 2001: **34**: 216–220.
42. Tronstad L, Barnett F, Cervone F. Periapical bacterial plaque in teeth refractory to endodontic treatment. *Endod Dent Traumatol* 1990: **6**: 73–77.
43. Tronstad L, Kreshtool D, Barnett F. Microbiological monitoring and results of treatment of extraradicular endodontic infection. *Endod Dent Traumatol* 1990: **6**: 129–136.
44. Yusuf H. The significance of the presence of foreign material periapically as a cause of failure of root treatment. *Oral Surg Oral Med Oral Pathol* 1982: **54**: 566–574.
45. Molven O, Halse A, Grung B. Surgical management of endodontic failures: indications and treatment results. *Int Dent J* 1991: **41**: 33–42.
46. Danin J, Strömberg T, Forsgren H, Linder LE, Ramsköld LO. Clinical management of nonhealing periradicular pathosis. Surgery versus endodontic retreatment. *Oral Surg Oral Med Oral Pathol* 1996: **82**: 213–217.
47. Kvist T, Reit C. Results of endodontic retreatment: a randomized clinical study comparing surgical and nonsurgical procedures. *J Endod* 1999: **25**: 814–817.
48. Abbott P. A retrospective analysis of the reasons for, and the outcome of, conservative endodontic re-treatment and periradicular surgery. *Aust Dent J* 1994: **44 (ADRF Spec** Suppl): 3–44.
49. Piatowska D, Pawlicka H, Laskiewicz J, Boltacz-Rzepkowska E, Brauman-Furmanek S. Evaluation of endodontic retreatment. *Czas Stomat* 1997: **L**: 451–458.
50. Cheung LK, Lam J. Apicectomy of posterior teeth – a clinical study. *Austr Dent J* 1993: **38**: 17–21.
51. Rahbaran S, Gilthorpe MS, Harrison SD, Gulabivala K. Comparison of clinical outcome of periapical surgery in endodontic and oral surgery units of a teaching dental hospital: a retrospective study. *Oral Surg Oral Med Oral Pathol* 2001: **91**: 700–709.
52. Rubinstein RA, Kim S. Short-term observation of the re-

sults of endodontic surgery with the use of a surgical operation microscope and Super-EBA as root-end filling material. *J Endod* 1999: **25**: 43–48.
53. Rud J, Munksgaard EC, Andreasen JO, Rud V. Retrograde root filling with composite and a dentin-bonding agent. 2. *Endod Dent Traumatol* 1991: **7**: 126–131.
54. Rud J, Rud V, Munksgaard EC. Periapical healing of mandibular molars after root-end sealing with dentine-bonded composite. *Int Endod J* 2001: **34**: 285–292.
55. Rud J, Rud V, Munksgaard EC. Retrograde root filling with dentin-bonded modified resin composite. *J Endod* 1996: **22**: 477–480.
56. Testori T, Capelli M, Milani S, Weinstein RL. Success and failure in periradicular surgery. A longitudinal retrospective analysis. *Oral Surg Oral Med Oral Pathol* 1999: **87**: 493–498.
57. von Arx T, Gerber C, Hardt N. Periradicular surgery of molars: a prospective clinical study with a one-year follow-up. *Int Endod J* 2001: **34**: 520–525.
58. von Arx T, Kurt B. Root-end cavity preparation after apicoectomy using a new type of sonic and diamond-surfaced retrotip: a 1-year follow-up study. *J Oral Maxillofac Surg* 1999: **57**: 656–661.
59. Stabholz A, Friedman S. Endodontic retreatment – case selection and technique. Part 2: Treatment planning for retreatment. *J Endod* 1988: **14**: 607–614.
60. Smith BJ. Removal of fractured posts using ultrasonic vibration: an *in vivo* study. *J Endod* 2001: **27**: 632–634.
61. Gomes APM, Kubo CH, Santos RAB, Santos DR, Padilha RQ. The influence of ultrasound on the retention of cast posts cemented with different agents. *Int Endod J* 2001: **34**: 93–99.
62. Abbott PV. Incidence of root fractures and methods used for post removal. *Int Endod J* 2001: in press.
63. Friedman S. Orthograde retreatment. In: Walton RE, Torabinejad M, eds. *Principles and practice of endodontics.* 4th edn. Philadelphia: W. B. Saunders, 2001.
64. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. *J Endod* 1999: **25**: 197–205.
65. Ericson S, Finne K, Persson G. Results of apicoectomy of maxillary canines, premolars and molars with special reference to oroantral communication as a prognostic factor. *Int J Oral Surg* 1974: **3**: 386–393.
66. Rud J, V.Rud. Surgical endodontics of upper molars: relation to the maxillary sinus and operation in acute state of infection. *J Endod* 1998: **24**: 260–261.
67. Gutmann JL, Harrison JW. *Surgical endodontics.* St. Louis: Ishiyaku EuroAmerica, 1994: 175.
68. Kvist T, Reit C. Postoperative discomfort associated with surgical and nonsurgical endodontic retreatment. *Endod Dent Traumatol* 2000: **16**: 71–74.
69. Stamos DE, Gutmann JL. Survey of endodontic retreatment methods used to remove intraradicular posts. *J Endod* 1993: **19**: 366–369.
70. Friedman S, Stabholz A. Endodontic retreatment: case selection and technique. Part 1: Criteria for case selection. *J Endod* 1986: **12**: 28–33.
71. Lewis RD, Block RM. Management of endodontic failures. *Oral Surg Oral Med Oral Pathol* 1988: **66**: 711–721.
72. Friedman S, Lustmann J, Shaharabany V. Treatment results of apical surgery in premolar and molar teeth. *J Endod* 1991: **17**: 30–33.
73. Petersson K, Håkansson R, Håkansson J, Olsson B, Wennber A. Follow-up study of endodontic status in an adult Swedish population. *Endod Dent Traumatol* 1991: **7**: 221–225.
74. Petersson K, Lewin B, Håkansson J, Olsson B, Wennberg A. Endodontic status and suggested treatment in a population requiring substantial dental care. *Endod Dent Traumatol* 1989: **5**: 153–158.
75. Aryanpour S, Van Nieuwenhuysen J-P, D'Hoore W. Endodontic retreatment decisions: no consensus. *Int Endod J* 2000: **33**: 208–218.
76. Hülsmann M. Retreatment decision making by a group of general dental practitioners in Germany. *Int Endod J* 1994: **27**: 125–132.
77. Reit C, Gröndahl H-G, Engström B. Endodontic treatment decisions. A study of the clinical decision-making process. *Endod Dent Traumatol* 1985: **1**: 102–107.
78. Reit C, Gröndahl H-G. Application of statistical decision theory to radiographic diagnosis of endodontically treated teeth. *Scand J Dent Res* 1983: **91**: 213–218.
79. Reit C, Gröndahl H-G. Endodontic decision-making under uncertainty. A decision analytic approach to management of periapical lesions in endodontically treated teeth. *Endod Dent Traumatol* 1987: **3**: 15–20.
80. Reit C, Gröndahl H-G. Endodontic retreatment decision making among a group of general practitioners. *Scand J Dent Res* 1988: **96**: 112–117.
81. Reit C, Gröndahl H-G. Management of periapical lesions in endodontically treated teeth. A study on clinical decision making. *Swed Dent J* 1984: **8**: 1–7.
82. Reit C, Grondahl H–G. Endodontic retreatment decision making among a group of general practitioners. *Scand J Dent Res* 1988: **96**: 112–117.
83. Reit C, Kvist T. Endodontic retreatment behavior: the influence of disease concepts and personal values. *Int Endod J* 1998: **31**: 358–363.
84. Reit C. On decision making in endodontics. A study of diagnosis and management of periapical lesions in endodontically treated teeth. *Swed Dent J* 1986: **41** (Suppl).
85. Smith JW, Crisp JP, Torney DL. A survey: controversies in endodontic treatment and re-treatment. *J Endod* 1981: **7**: 477–483.
86. Appleton JLT. A note on the clinical value of bacteriologically controlling the treatment of periapical infection. *Dent Cosmos* 1932: **124**: 798–800.
87. Pekruhn RB. The incidence of failure following single-visit endodontic therapy. *J Endod* 1986: **12**: 68–72.
88. Crump M. Differential diagnosis in endodontic failure. *Dent Clin North Am* 1979: **23**: 617–635.
89. Abou-Rass M. Evaluation and clinical management of previous endodontic therapy. *J Prosthet Dent* 1982: **47**: 528–534.
90. Luebke RG, Glick DH, Ingle JI. Indications and contraindications for endodontic surgery. *Oral Surg Oral Med Oral Pathol* 1964: **18**: 97–113.
91. Reit C. Decision strategies in endodontics: on the design of a recall program. *Endod Dent Traumatol* 1987: **3**: 233–239.
92. Pitts DL, Natkin E. Diagnosis and treatment of vertical root fracture. *J Endod* 1983: **9**: 338–346.

93. Kvinnsland I, Oswald RJ, Halse AG, Grønningsæter AG. A clinical and roentgenological study of 55 cases of root perforation. *Int Endod J* 1989: **22**: 75–84.
94. Martin LR, Gilbert B, Dickerson AW. Management of endodontic perforations. *Oral Surg Oral Med Oral Pathol* 1982: **54**: 668–677.
95. Fuss Z, Trope M. Root perforations. classification and treatment choices based on prognostic factors. *Endod Dent Traumatol* 1996: **12**: 255–264.
96. Holland R, Otoboni Filho JA, de Souza V, Nery MJ, Bernabe PFE, Dezan Jr E. Mineral trioxide aggregate repair of lateral root perforations. *J Endod* 2001: **27**: 281–284.