Vertical Root Fractures in Dentistry

Aviad Tamse
Igor Tsesis
Eyal Rosen
Editors

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Introduction

1

Aviad Tamse, Igor Tsesis, and Eyal Rosen

Abstract

Vertical root fractures (VRFs) are root-originated fractures in endodontically treated teeth and are considered as the third most common cause for tooth extraction after dental caries and periodontal diseases [1–3] (Fig. 1.1). They often present diagnostic problems that challenge the expertise of even skilled and most experienced clinicians [1, 2]. This clinical entity may be difficult to diagnose because often the clinical signs, symptoms, and radiographic features can mimic signs and symptoms of failed endodontic treatment or a periodontal disease [1, 4, 5]. In addition, there are many aspects and a variety of issues regarding the root fracture etiology and risk factors, and VRFs may develop also in teeth with good-quality endodontic treatment and well-prepared coronal restoration [1, 4, 5]. Therefore, prevention of these fractures is all together difficult and frustrating.

VRF is regarded as a clinical condition, in which several predisposing factors, such as the root anatomical structure, together with operative procedures, such as root canal treatment and dowel placement, contribute to the development of a fracture in the root [1, 4–12]. However, only after an unknown period of time, when the root canal and the fracture area becomes infected, an associated pathology may develop [1, 4–12].

Therefore, a VRF without infection, defined as a "*histological VRF*", is not clinically evident, until infection of the fracture occurs with ensuing emergence of clinical signs and symptoms [1, 4, 12]. At that stage, the VRF may be defined as a "*clinical VRF*". The prevalence of "clinical VRFs" as evaluated in extracted endodontically treated teeth was reported to range from 11 to 20 % [6, 7]. However, the prevalence of

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Fig. 1.1 A typical vertical root fracture in an endodontically treated, restored maxillary premolar

"histological VRFs" in endodontically treated teeth is yet unknown and is probably significantly larger than the prevalence of the clinically evident "clinical VRFs".

Imaging techniques, which are an essential landmark in the dental daily practice, may only be helpful sometimes for the definitive VRF diagnosis and are still incapable to demonstrate the incipient fracture [1, 4, 5].

It became acceptable and common to use cone beam computed tomography (CBCT) for the diagnosis of VRF [5], assuming that CBCT is clinically effective for this purpose and that it possesses superior efficacy over conventional periapical (PA) radiography. Nevertheless, recent published data raises a concern regarding the efficacy of CBCT and its alleged superiority over conventional PA radiography for the detection of VRF [13–15].

New reports suggest that actually there is no difference between the diagnostic accuracy of either imaging modalities and that both modalities have significant limitations [13, 15]. In addition, the presence of intracanal radiopaque materials adversely affects the diagnostic efficacy of CBCT; thus, CBCT is not beneficial for the diagnosis of VRF when metal dowels are present [14]. Therefore, there is a great concern regarding CBCT potential benefit to the patient compared to its potential radiation risks [16–23] and regarding its clinical effectiveness for the diagnosis of VRFs [13–15, 24, 25].

Adding to the clinical complexity of this root-originated fracture is the fact that when a VRF is finally diagnosed, often years after the fracture was initiated and after the root and the tooth are fully treated and restored, it not only requires in some cases invasive diagnostic procedures such as exploratory flap procedure but is already late in most cases to save the tooth or root [1, 4, 5]. However, over the years, there had been attempts to save some of these teeth by either extracting the fractured root in a multirooted teeth or by attempts to treat the fractured root itself [26–32]. Although extraction of the fractured tooth or root is still usually the treatment of choice, modern endodontic techniques combined with an appropriate case selection seems to be able to allow the preservation of some VRF teeth [26–32].

When extraction of the root or the tooth following VRF diagnosis becomes inevitable, the dentist faces many times an additional dilemma, since the bony socket of the extracted tooth or root is infected and much of the tooth supporting bone was resorbed due to the infection facing the infected fracture [5, 31, 33–35]. This clinical challenge is especially evident when the buccal bony plate which is originally very thin is resorbed, and if not diagnosed and treated earlier, the interproximal bone resorbs as well [5, 31, 33–35]. The clinician is now facing a challenge of when and how to treat the infected socket, an issue that nowadays the profession has some new treatment modalities to treat [5, 31, 33–35].

VRFs are sometimes diagnosed years after endodontic and prosthetic procedures have been completed [36, 37], and many times, extraction of the VRF tooth or root becomes inevitable [37]. This late diagnosis may also contribute to significant supporting alveolar bone loss, thus complicating the postextraction socket management and the future restoration [37]. Endodontic medicolegal claims are common among malpractice claims in dentistry [38, 39], and this combined diagnostic and treatment challenge of VRFs may expose the practitioner also to potential medicolegal risks [37].

It is for the first time that a book is dedicated to this complex clinical condition, presenting the wasn't updated scientific information on VRF'S in dentistry. Many figures and illustrations accordingly this text to enables an efficient reading and learning of the various issues of VRFs. In this way the book will be beneficial to all dental beneficial to all dental professionals who want to learn more on the topic students, practicing dentist specialists and researches.

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Categorization of Dental Fractures

2

Leif K. Bakland and Aviad Tamse

Abstract

Categorization of dental fractures should take into account the origin, the location, and the direction of fracture progression. Identifying the fracture category will influence the selection of treatment options. The type of fracture category to be covered in this book will be that primarily occurring in endodontically treated teeth; the fracture is of a *chronic* nature and characterized as having a vertical direction over time and identified as vertical root fracture (VRF). The other two fracture types—crown-originating fractures (COFs) and trauma-related fractures—will be briefly described in this chapter to differentiate them from VRFs.

Introduction

Fractures of bones and teeth can be described as discontinuity in the integrity of these anatomic entities and usually result from either acute or chronic injury [1, 2]. In this chapter, we will categorize dental fractures for the purpose of identifying the various fracture entities involving teeth. To reduce confusion, the term *fracture* will be used when describing these clinical situations rather than the many other terms that have been used such as *cracks* and *infractions*. The term *crack* will be used as the initial minute fracture originating in the dentin and doesn't have clinical relevance (See Chap. 3).

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One of the reasons why dental fractures can be very confusing in their clinical presentation is that teeth consist of several tissues—enamel, dentin, cementum, pulp, and periodontal ligament. Adding to the anatomic complexity is the observation that symptoms alone cannot always be relied on to arrive at a definitive diagnosis and in addition clinical signs may often be difficult to interpret. It is generally recognized that for some dental fractures, pathognomonic signs and symptoms are few and frequently difficult to identify. These complexities have contributed to the difficulty in developing a universally acceptable classification. Efforts that have been made toward classification of dental fractures—such as that by the American Association of Endodontists [3], have not been adopted universally. Treatment of teeth with any type of fracture must be preceded by a accurate diagnosis. As mentioned above, the more complex the fracture situation is, the more difficult it may be to make the accurate diagnosis; such a situation can often be frustrating for both the patient and the dentist. Add to that the fact that treatment options vary considerably depending on the diagnosis, thus it is easy to understand why dental fractures can present some of the more difficult dental problems in the scope of dental practice. Since making an accurate and timely diagnosis is so important in terms of treatment planning and establishing a prognosis, we suggest that developing a practical categorization or classification of the various dental fractures may contribute to more predictable outcomes.

Supporting the value of a generally acceptable classification system is the observation by Andreasen [4] that "because of the increased incidence of medical and dental litigation (See Chap. 8) a necessary aspect of any classification system is the provision of an accurate description of the injury that can be easily understood by individuals with differing educational backgrounds."

Categorization of dental fractures should take into account the origin, the location, and the direction of fracture propagation. Identifying the category will influence the selection of treatment options. The focus in this book will be on the dental fractures that are of a *chronic* nature and characterized as generally having a vertical direction, corresponding to the long axis of the tooth, and having a time component that relates to the fracture line propagating over various time periods [5].

The clinical terms *craze lines*, *fractured cusp*, cracked tooth, and split tooth [3] describe fractures that are all longitudinal or variations thereof and can be categorized into one category. We suggest that category be referred to as *crown-originating fractures* (COFs). They are different from those resulting from *acute* traumatic injuries (trauma-related fractures) and those that are the focus of this book—vertical root fractures (VRFs) (See Table 2.1). The terms *crack* or *root crack* will be used to describe the initial minute fractures originating in dentin as explained previously.

Dental Fractures

The following is a scheme of categorization based on what can be observed with respect to the various dental fracture situations.

Table 2.1 Dental fractures

Categories	Characteristics
Crown-originating fracture (COF)	Spontaneous fracture originating in the crown and may progress into the root in an apical direction
Vertical root fracture (VRF)	A root-originating fracture that may originate anywhere in the root and occur primarily in endodontically treated teeth
Trauma-related fractures	Tooth fractures of acute nature may involve the crown or the root or both

Crown-Originating Fractures (COFs)

These types of fractures typically originate in the tooth crown and are not related to root canal treatment. The fractures progress toward the root; after reaching the coronal area of the root, the fracture lines continue in an apical direction. If not treated, teeth with such fractures will eventually split vertically, or if the fracture line progresses diagonally below a cusp, that cusp may fracture off the tooth. If the cusp fracture does not create a serious periodontal problem, usually this entity can be treated with good prognosis.

Craze lines are fractures limited to the enamel only and may extend over the marginal ridges (Fig. 2.1) in molars and occur in the anterior segments as well (Fig. 2.2) [3]. They are considered benign and require no treatment except occasionally for esthetic reasons.

Some crown-originating fractures (COFs) have been identified as *cracked teeth* [1]; they are found in maxillary and mandibular molars and maxillary premolars. These fractures occur mostly in teeth with vital pulps and have a mesiodistal pattern. They can be observed in intact crowns or may be seen next to a carious lesion or adjacent to a small restoration. The fracture in the crown can at times extend apically to eventually separate the tooth into two parts (*split tooth*) [3] (Figs. 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, and 2.9).

Crown-originating fractures typically extend to either or both of the marginal ridges through to the proximal surfaces [3]. Very few of these crown fractures have a bucolingual direction. The fractures progress from the marginal ridges through the pulp chambers and eventually may result in a split tooth.

Fractures may be visualized in the tooth crown with transillumination or with the use of dyes absorbed into the fracture lines. The patient's history and symptomatology may include pain in the tooth or pain referred to other oral regions increasing the diagnostic difficulty [6]. Many patients experience a vague discomfort during mastication, often with elevated sensitivity to cold.

Contributing to the diagnostic difficulty may be lack of notable caries or other reasons for pulpal disease. The patient's symptoms may also resemble those in patients with ear aches, TMJ dysfunction, sinusitis and neurological problems [7]. The longer the symptoms are present, the more diffuse they become, and the more difficult the diagnosis becomes [6]. It may be prudent to consider the presence of COF whenever the usual suspects (caries, etc.) are absent. Correct diagnosis and identification of the actual type of fracture involved will help in developing treatment options.

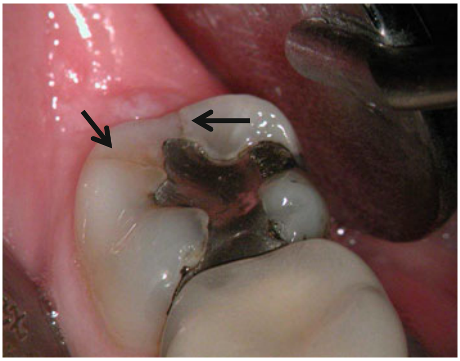

Fig. 2.1 Two craze lines in a mandibular molar. The *two black arrows* point at the craze lines extending from the amalgam filling to the external distal surface of the crown (Courtesy Dr R. Paul)

Fig. 2.2 A *black arrow* pointing at a craze line in a maxillary incisor

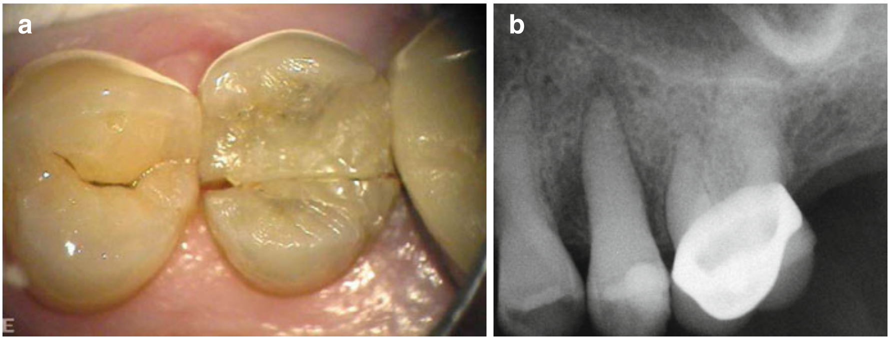

Fig. 2.3 (**a**, **b**) A mesiodistal fracture in a maxillary premolar crown. The crown was previously treated with an esthetic white restoration. The patient's chief complaint was of "problems in brushing the teeth in this area." (**a**) The pulp was diagnosed as necrotic with asymptomatic apical periodontitis. The fracture extends apically creating pockets of 6 mm in the proximal areas. Bone resorption due to the periodontal destruction can be seen mesially and distally (**b**) (Courtesy Dr N. Chivian)

Some patients do present with existing pulp necrosis with or without periapical disease as a result of long-term COF. The term *fracture necrosis* has been suggested for such an entity [8] (Figs. 2.10 and 2.11).

Fig. 2.4 A diagnosis of symptomatic irreversible pulpitis was done in a patient with a class I amalgam restoration in a maxillary premolar. With the use of magnification and illumination, two fractures can be seen extending mesially and distally from the amalgam restoration

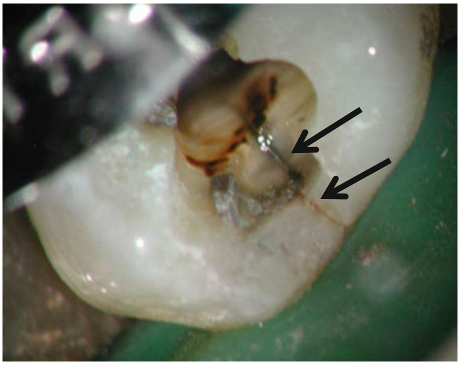

Fig. 2.5 Following local anesthetics and tooth isolation, the fracture is seen clearly (*two black arrows*) after removal of the restoration extending beyond the marginal ridge to the external surface (Courtesy Dr R. Paul)

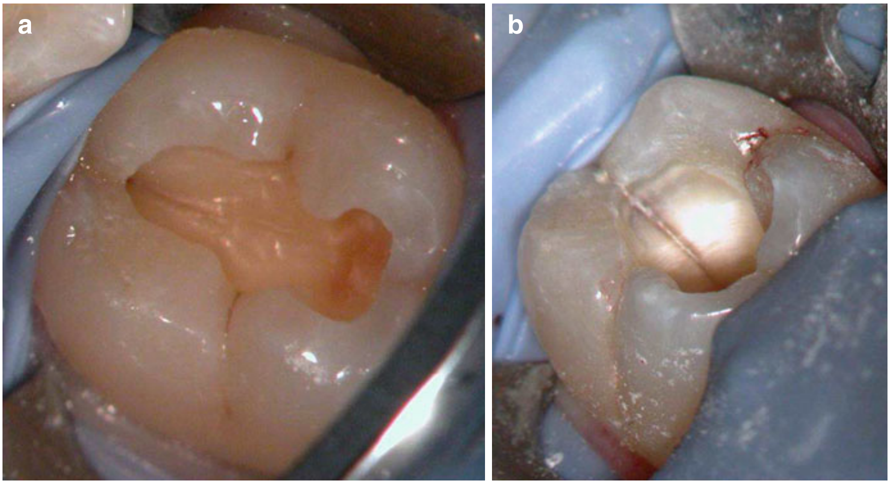

Fig. 2.6 (**a**, **b**) Mesiodistal fracture in a mandibular crown seen in the roof of the pulp chamber after removal of the coronal restoration (**a**). At the pulp chamber level, the fracture can be seen extending to the orifices of the root canal (**b**) (Courtesy Dr R. Paul)

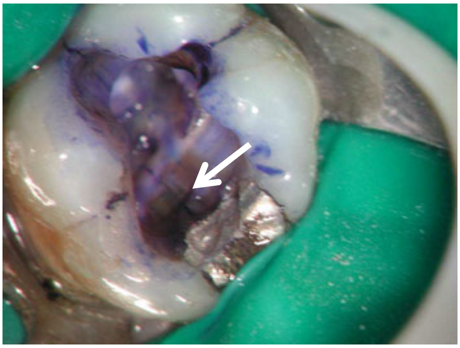

Fig. 2.7 Mesiodistal fracture can be seen at the floor of the chamber (*white arrow*) in mesial distal direction in a mandibular molar using methylene blue dye (Courtesy Dr R. Paul)

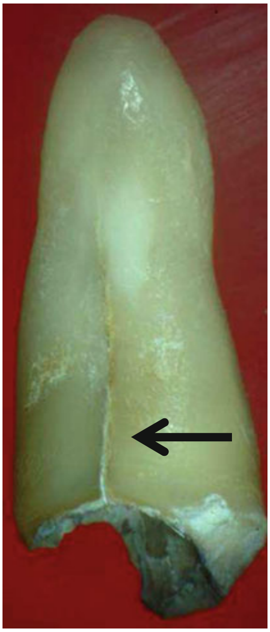

Fig. 2.8 An extracted maxillary premolar showing a VRF that originated in the crown and propagated apically (*Black arrow*)

Fig. 2.9 A fracture in the crown that extended apically to bifurcation area to separate a mandibular molar into two parts (Courtesy Dr. R. Paul)

Fig. 2.10 This radiograph was taken during routine patient examination. The tooth was asymptomatic. A shallow cl I intact amalgam restoration was noted in the crown. A small fracture was seen in the occlusal surface of the crown. The pulp tested nonvital. It caused necrosis of the pulp and as a result damage to the hard tissues. External apical resorption can be seen in the mesial root and bifurcation radiolucency (Fracture Necrosis) (Courtesy Dr R. Paul)

Vertical Root Fractures (VRFs)

Vertical root fracture (VRF) is a frustrating complication associated with root canal treatment in teeth and leads to their extraction [9, 10]. With a few exceptions of VRF in vital teeth [11], they primarily involve endodontically treated and restored teeth [12]; they are longitudinally oriented, thus having an apicocoronal direction. There is an overall prevalence of up to 11 % in endodontically treated teeth [13, 14]. In an incidence study done in a hospital clinic over 1 year [15], a total of 87 new cases of teeth had various types of crown and root fractures with 13 % of them VRFs in endodontically treated teeth.

A VRF can originate at any level in the root [3] although it appears that they commonly begin in the apical part. If they originate away from the apex, such as in the middle of the root, they can propagate in either direction, either apical or coronal. From the horizontal aspect, the fractures originate in the root canal wall and extend to the root surface over time and may involve either one side—buccal or lingual (incomplete)—or both sides (complete fracture) (Figs. 2.12, 2.13, and 2.14).

Fig. 2.11 A patient presented to the dental office with a complaint of "suppuration of pus from the gum." Clinical examination presented with a deep cl 1 amalgam restoration. The pulp tested nonvital, and a sinus tract was presented at the level of the apical part of the attached gingivae. A gutta-percha tracing can be seen in the radiograph all the way to the tip of the mesial root. Radiolucency between the roots can also be noted (Fracture Necrosis)

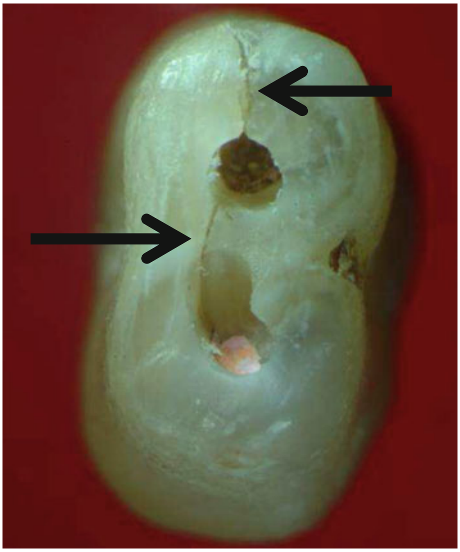

Fig. 2.12 *Two black arrows* are pointing at an incomplete VRF in double-canal single-rooted maxillary premolar. The fracture is not extending to the other root surface

Both in the incomplete and complete fractures, for the most part the fractures have a buccolingual pattern. Very rarely does a VRF have a mesiodistal orientation (Fig. 2.15).

In multirooted teeth, the fracture occurs mostly in one root, but fractured two roots of the mandibular molar (Fig. 2.16) or the two buccal roots of the maxillary molars

Fig. 2.13 A complete VRF in a buccal root of a bifurcated maxillary premolar

Fig. 2.14 An apical view in a complete VRF in a maxillary premolar. Note the typical "hourglass"morphology of these teeth in cross section and the typical mesial concavity in the trunk of the root

Fig. 2.15 A rare mesiodistal oriented VRF from the tip of the root extending to the crown of a maxillary premolar. The coronal restoration was removed for better visualization

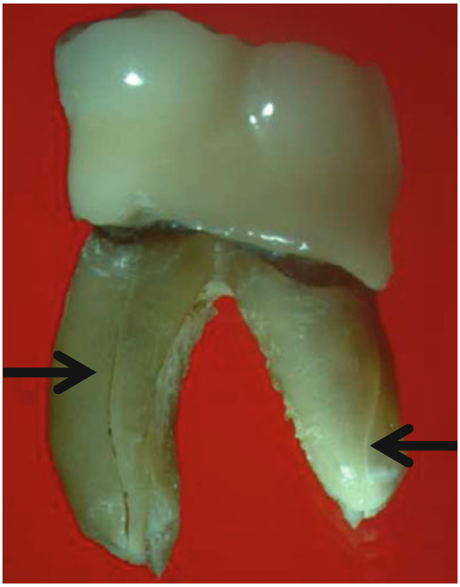

Fig. 2.16 VRFs in mesial and distal roots of a mandibular second molar. Note that the fracture in the distal root does not follow the long axis of the root (*Black arrow*)

(Fig. 2.17) can also be seen. Although VRFs for the most part are longitudinal, they do not always follow the root axis but may progress differently based on the bulkiness of the root and the influence of occlusal forces (Figs. 2.16, 2.18 and 2.19).

Fig. 2.17 VRFs in the two buccal roots of a maxillary first molar

Fig. 2.18 VRF in the mesial root is extending from the external lateral aspect of the root 5 mm coronally to the root tip to the coronal part of the root

In cases 2.16, 2.18 and 2.19 that where the teeth were extracted with their crowns, it is difficult to determine the origin of the fractures. It is possible that the fractures originated in the crowns and progressed apically (crown originating fracture—category 1) or originated in the roots and progressed to the cementoenamel junction.

The signs and symptoms of VRFs in endodontically treated teeth are similar to those of periodontal disease or failing endodontic treatment (see Chap. 4). In addition, they are usually diagnosed years after the endodontic and prosthodontic procedures have been completed [12, 16, 17]. These findings lead to frustration both for the patient and the dentist.

The teeth and roots most susceptible to VRF are those in which their mesiodistal diameter in cross section is narrow compared to the buccolingual dimension (oval, hourglass shaped, kidney shaped, ribbon shaped). Such teeth and roots are the maxillary and mandibular premolars (Figs. 2.12, 2.13, 2.14, and 2.15), the mesiobuccal root of mandibular molars (Figs. 2.16, 2.17, 2.18, and 2.19), the mandibular anterior teeth (Figs. 2.20 and 2.21a, b), and mesiobuccal roots of the maxillary molars (Fig. 2.17) (See also Chap. 3) [18].

From the apical–coronal aspect, the fracture can be limited to the apical area only (Fig. 2.22a, b), limited to the coronal part (Fig. 2.23a, b), both coronal and middle parts (Fig. 2.24a–g), limited only to the middle part of the root (Fig. 2.25a–c), or involving both the middle and apical parts (Fig. 2.26a, b). Often when a VRF diagnosis of an endodontically treated root is made, all the three thirds of the root are involved, i.e., from the tip of the root to the cervical part of the crown, and the fracture is complete from the buccal to the lingual sides. Examples are shown in the premolar teeth (Fig. 2.27a–d) and the mandibular molars (Figs. 2.28a–e and 2.29a, b).

Occasionally, a VRF is confined to the middle part of the root only and not involving the coronal or apical parts (Fig. 2.25). When a tooth with VRF is extracted and a full-length fracture is present, i.e., from the apex to the cementodentinal junction (Figs. 2.19, 2.27, 2.28 and 2.29), it is not possible to determine if the VRF originated in the coronal part of the root or even from the crown itself and progressed

Fig. 2.19 Two VRFs in a mandibular molar. Note that in both roots the fractures in the apical parts are located few millimeters coronally to the root tip

Fig. 2.20 Vertical root fracture can be seen clearly as a radiolucent line parallel to the gutta-percha in an endodontically treated central incisor

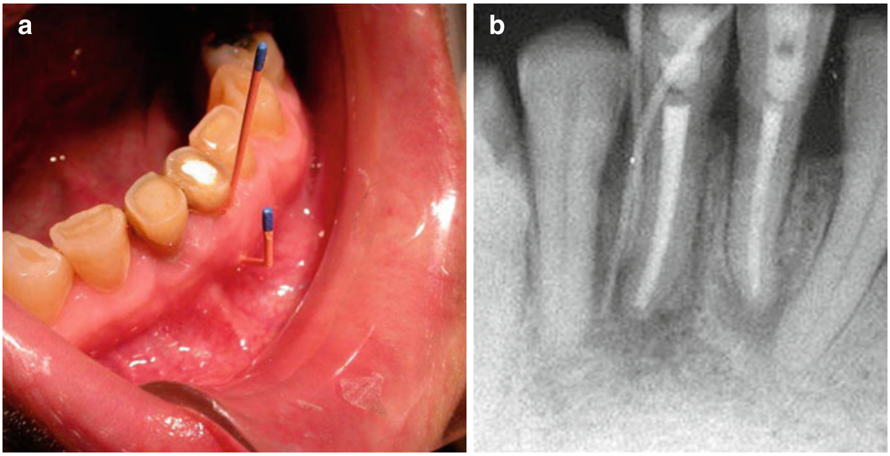

Fig. 2.21 Patient presented to the dental office with a request to restore the two mandibular central incisors. From the patient history, it was revealed that 7 years earlier, two root canal treatments were performed as a result of pulp exposure due to severe bruxism. Clinical examination revealed temporary restoration in the lower left incisor, 8 mm probing defect in the buccal aspect, and a sinus tract in the attached gingivae (**a**). The periapical radiograph (**b**) reveals two large areas of radiolucencies around the tip of the two roots and the two tracings of gutta-percha shown in **a**

apically or was initiated in the apical part and progressed coronally to the cementoenamel junction [17, 18].

The susceptibility of endodontically treated, restored teeth and roots to vertical fractures has been discussed in several publications [13, 15–17, 19]. Current

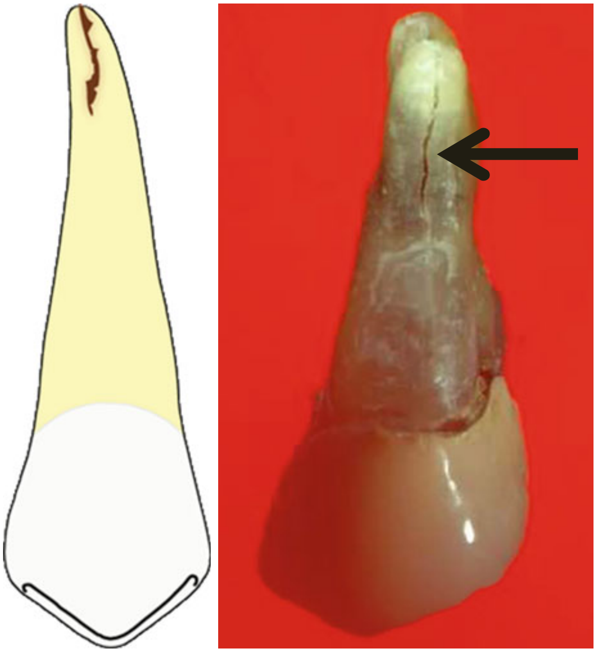

Fig. 2.22 Graphic illustration showing VRF limited to the apical part of a maxillary premolar root. (**a**) Middle and coronal parts of the root are not involved. (**b**) In an extracted maxillary premolar (*black arrow*)

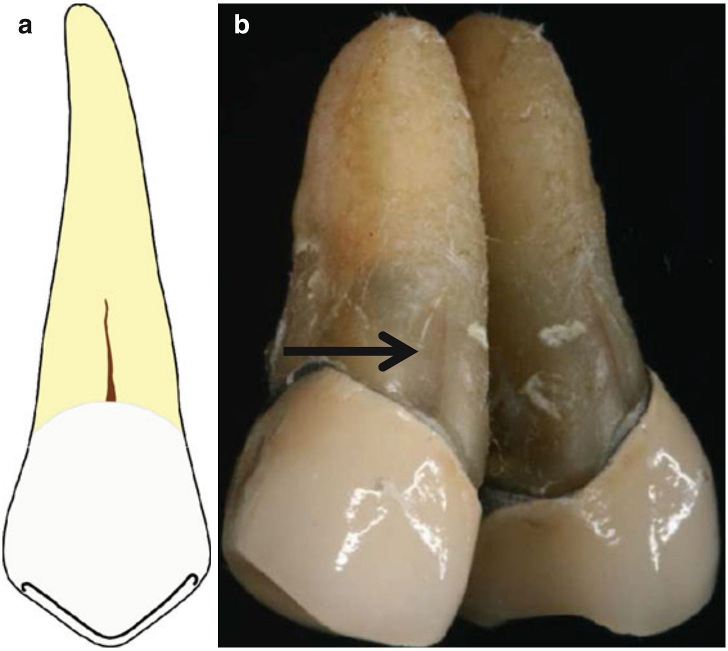

Fig. 2.23 Graphic view of a VRF in the coronal third of a maxillary premolar (**a**). In this case, the fracture originated either in the crown itself or in the coronal third of the root. (**b**) In an extracted single rooted maxillary premolar (*Black arrow*) (Courtesy Dr E. Venezia)

endodontic procedures, such as root canal treatment and retreatment, necessitate the removal of tooth structure to accomplish the procedure. Such loss of tooth structure probably reduces a tooth's resistance to fracture from even normal functional

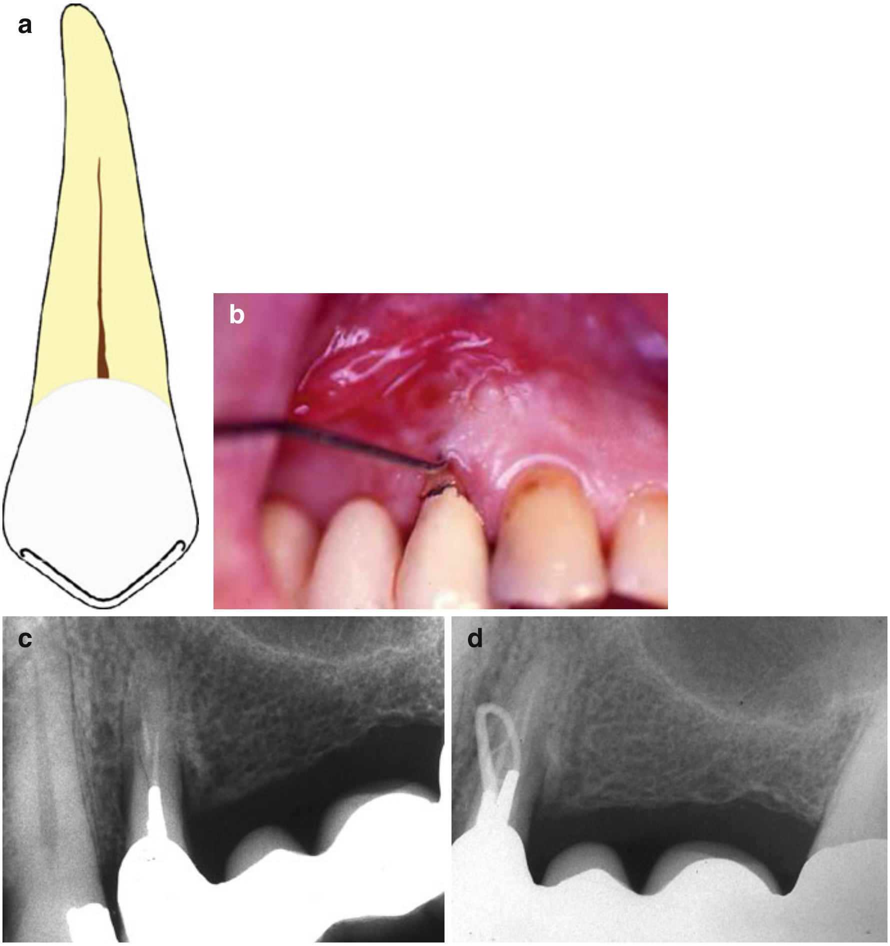

Fig. 2.24 Graphic illustration of a crown-initiated fracture which involves only the coronal and middle parts of the root (**a**). Highly located sinus tract can be seen in the attached gingivae of a maxillary premolar that was used as a mesial abutment for a four-unit bridge. A 7 mm probing defect was measured in midbuccal area (**b**). A periapical radiograph is showing a fracture line from the tip of the dowel diagonally to the mesial aspect. Two isolated radiolucent areas can be seen in the bone in the middle part of the root in the mesial and distal aspects (**c**). Another radiograph taken (**d**) with a gutta-percha tracing. Following a VRF diagnosis, the tooth was extracted (**e**). It can be noted that most likely, the fracture was initiated in the crown and propagated apically and diagonally causing fracture of the root in its coronal and middle parts. Two cross sections of a VRF in a single-rooted maxillary premolar with one canal (**f**, **g**) are showing that a VRF that was initiated in the crown can possibly due to the occlusal forces propagate apically in a diagonal way thus leaving the root canal and terminating at the root surface much more coronal to the apical end

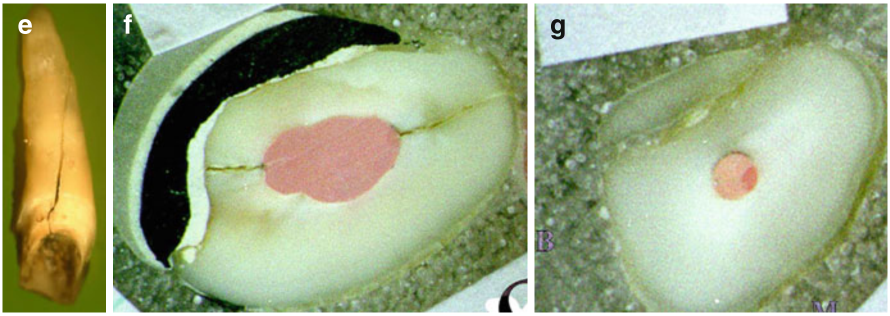

Fig. 2.24 (continued)

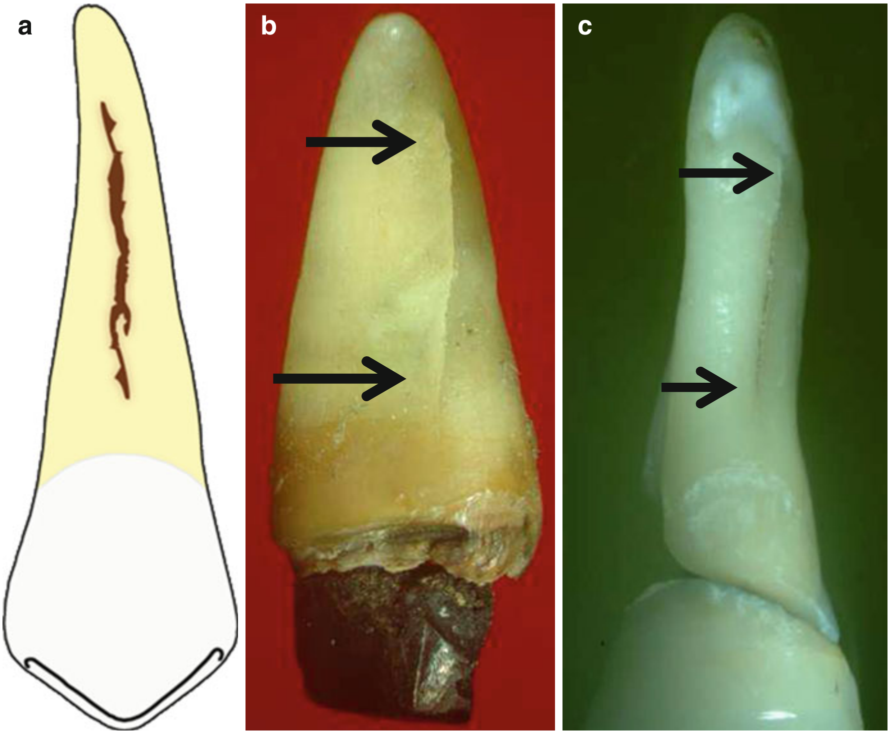

Fig. 2.25 (**a**–**c**) VRF in the middle part of the root of maxillary premolars which is not involving the coronal or apical parts (**a**) Graphic illustration, (**b**, **c**) examples in extracted maxillary premolars with VRFs (*arrows*)

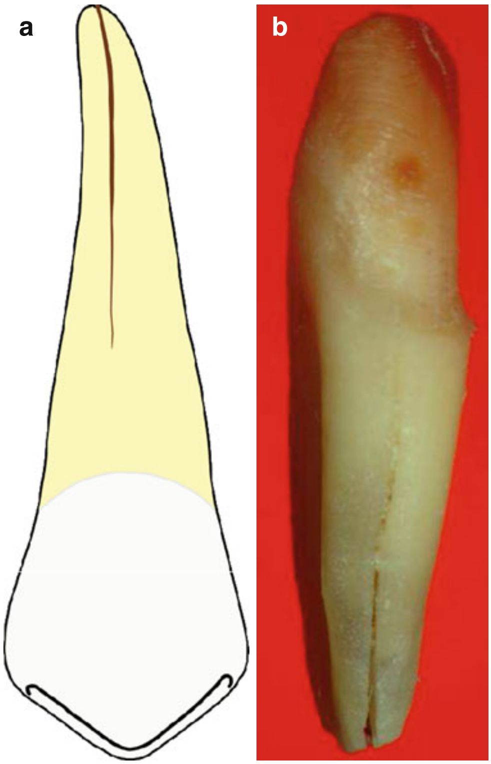

Fig. 2.26 (**a, b**) Graphic illustration of a VRF limited to the apical and middle parts of the root not involving the coronal one. (**a**) Extracted bifurcated maxillary premolar in which the apical and middle parts are fractured leaving the coronal part intact (**b**)

pressure during occlusion. Indeed, many of the VRFs occur in root canal treated teeth [20] where extensive amounts of dentin are removed from the root canal wall. These contributing factors will be discussed in detail in Chap. 3 on VRF Etiology. An example of a crown-originated fracture that progressed to the roots to create vertical fractures in the roots as well is demonstrated in Fig. 2.29.

Trauma-Related Tooth Fractures

Fractures that result from acute-impact trauma that occur mostly in intact as well as endodontically treated teeth are identified as (a) enamel craze lines, (b) enamel fractures (chipped enamel), (c) uncomplicated crown fractures (enamel and dentin, but no pulp exposure), (d) complicated crown fractures (enamel and dentin with exposure of the tooth pulp), (e) crown-root fractures (enamel, dentin, and cementum and may or may not expose tooth pulp), (f) horizontal root fractures (frequently these fractures are diagonally positioned across the root), and (g) cementum chips (cementum that has sequestrated from the root surface) [21] (Fig. 2.30a, b).

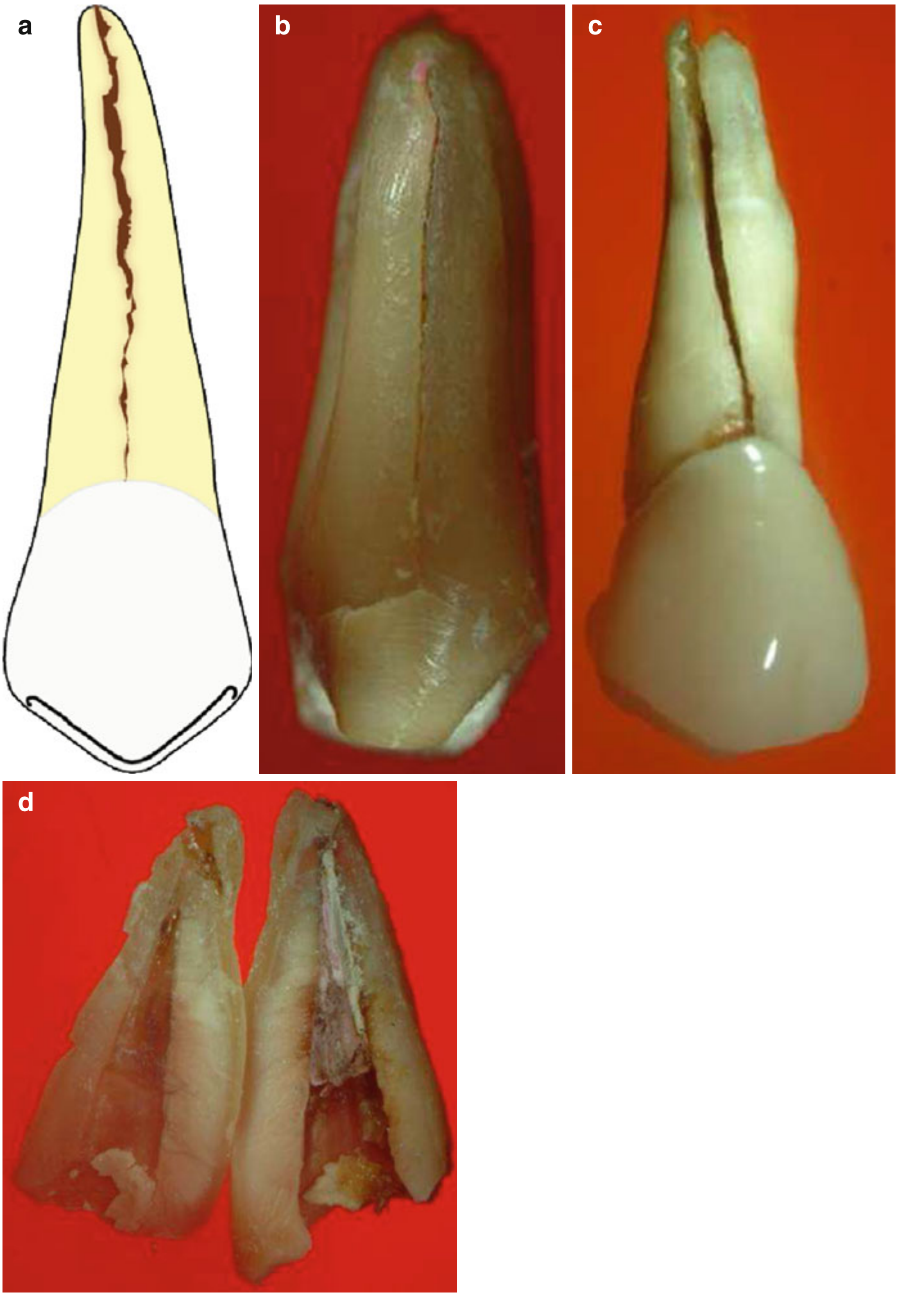

Fig. 2.27 (**a**–**d**) Graphic illustration of VRF that involves the three parts of the root (**a**) VRF in all the three parts of an extracted maxillary premolar tooth (**b**) The two parts of the fracture were not separated when extracted. Another extracted maxillary premolar where the parts are separated (**c**) showing the very typical buccal–lingual fracture of the root (**d**)

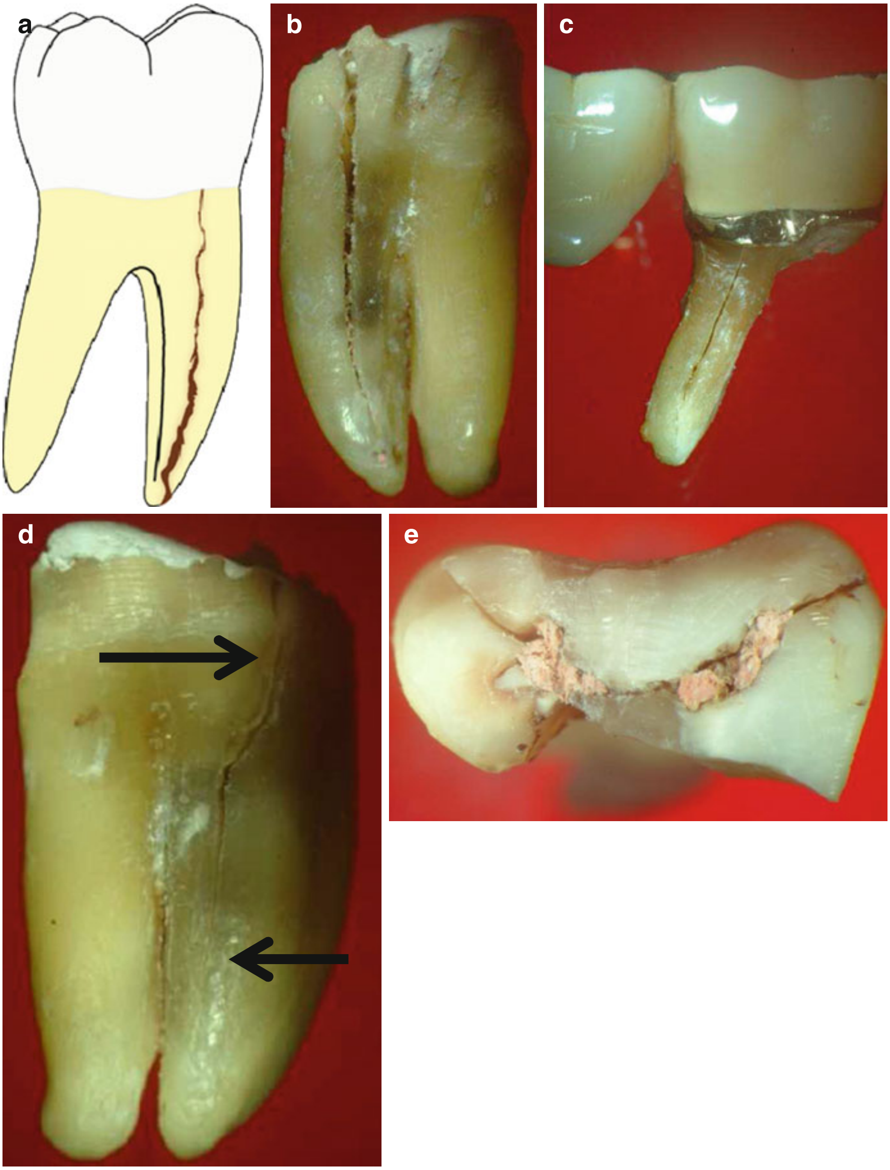

Fig. 2.28 (**a**–**d**) Graphic illustration of a typical VRF involving the three thirds of an endodontically treated mesial root of a mandibular molar (**a**). A complete fracture in the mesial root of a mandibular molar that follows a straight axis from the tip of the root to the crown (**b**). A straight line VRF that involves the three parts of the root (**c**). Note that in figure (**d**) of another VRF case in a mandibular molar, most likely the fracture was initiated in the crown mesiodistally (crown-originated fracture—*top black arrow*) and propagated from the mesial aspect of the crown, turning diagonally and apically to form a buccal–lingual fracture which is typical for a VRF (*Bottom Black arrow*). A complete VRF in a cross section (**e**) of endodontically treated mesial root of a mandibular molar. The complete fracture involved the two root canals in the root and most likely through the isthmus between the canals

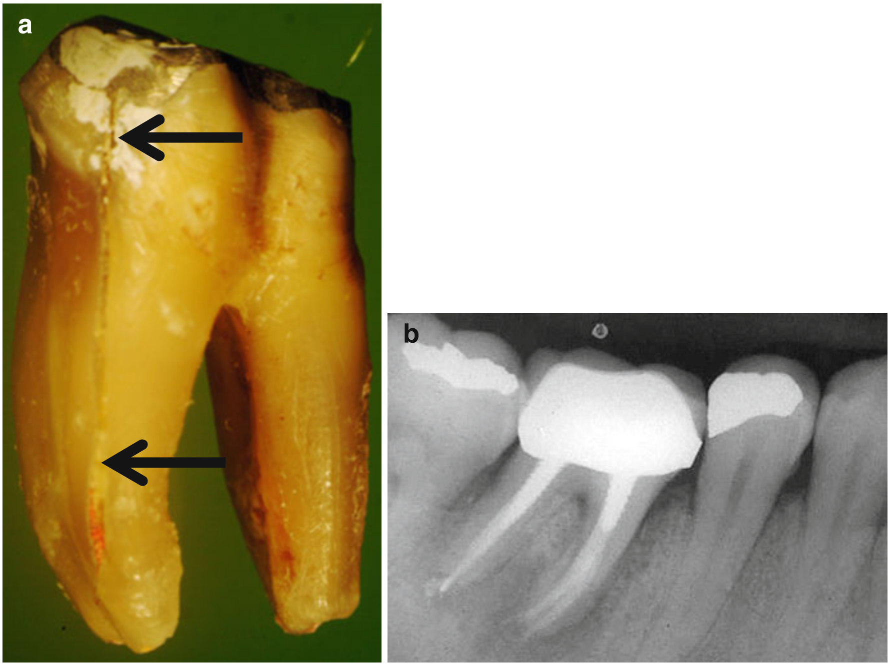

Fig. 2.29 (**a, b**) The patient presented to the dental office with a history of acute exacerbation in the right side of the mandible. Three years earlier, the root canal treatment was retreated and a new PFM crown placed. On clinical examination, there was redness at the attached mucosa adjacent to the mandibular first molar, sensitivity to percussion, and 8 mm probing defect at the MB site. The periapical radiograph (**b**) revealed well-obturated root canals and two dowels in the mesial and distal roots. Large "halo"-type radiolucency combined with a lateral one on the mesial aspect of the mesial root can be seen in the radiograph. Although the radiographic appearance and the probing hinted that there may be a VRF in this case, the diagnosis that was done was symptomatic apical periodontitis. The tooth was extracted because the prognosis for a new retreatment was poor. The extracted tooth (**a**) shows a VRF in the mesial root (*arrows*) that extends from the coronal area to the apical third of the root and a vertical root fracture in the bifurcation aspect (mesial) in the distal root as well. Most likely, this is a case of crown-originated fracture that progressed to the two roots as well

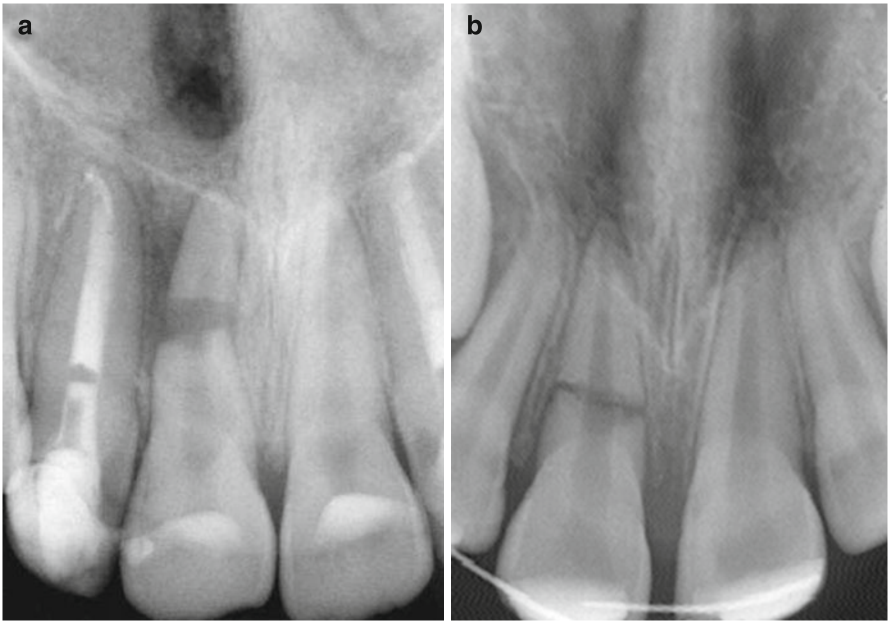

Fig. 2.30 Two examples (**a**, **b**) of acute-impact trauma to the maxillary central incisors causing fractures of the roots

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Etiology of Vertical Root Fractures

3

Aviad Tamse and Herzl Chai

Abstract

The etiology of vertical root fractures (VRFs) in endodontically treated teeth is complex because of its multifactorial nature. Since there is no single specific etiology that is pathognomonic for this complication that can be identified, prevention of vertical root fractures in endodontically treated teeth is quite difficult. There are predisposing factors as well as contributing ones. The predisposing factors are practically noncontrollable. These include the specific anatomy of the susceptible roots, biochemical changes in the root dentin in the endodontically treated tooth, and loss of healthy tooth substance as a result of caries and trauma before beginning endodontic procedures. The contributing factors are attributed to the iatrogenic risk factors associated with various dental procedures performed on the tooth. These clinical etiologies will be discussed in the first section, and a fracture mechanics perspective will be presented in the second section. This will incorporate geometry, material, and loading issues when a dentinal crack is initiated in the canal wall, which is a precursor for a future complete and incomplete fracture in the root at a later stage.

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Etiology of VRFs: Clinical Aspects

Etiology is the branch of medical science concerned with the causes and origins of diseases. The etiology of vertical root fractures (VRFs) in the endodontically treated tooth is complex and multifactorial. Although the fractures that originate in the root occur mostly in endodontically treated teeth, in rare occasions they can occur in nonendodontically treated molars [1]. The combination of a variety of predisposing and contributing factors for these fractures makes their prevention quite difficult [2]. In reducing the potential for fractures, especially in teeth susceptible to fracture, it may help the clinician to understand the etiological and risk factors that are involved.

Predisposing Etiological Factors

Although the predisposing factors for VRFs are beyond the control of the clinician, they should be considered carefully as part of the endodontic and restorative treatment planning [3]. These are the biochemical changes of root dentin of the endodontically treated tooth, preexisting cracks in the untreated tooth, and the specific anatomy of susceptible teeth with VRFs [3–5]. The amount of sound tooth structure in the crown and root as a result of caries and trauma is also a factor that increases the risk of crack formation in the dentin that could progress into a fracture (Fig. 3.1) [6].

Fig. 3.1 Root caries and external apical root resorption in a mandibular anterior tooth

The most susceptible roots to fracture are those in which the mesiodistal diameter is narrow compared to the buccolingual dimension (oval, triangular, kidney-shaped, ribbon-shaped) [2, 7]. These include the maxillary and mandibular premolars, mesial roots of mandibular molars, mandibular incisors, and the mesiobuccal root of the maxillary molars. In a retrospective prevalence study of fractured roots among this group, Tamse et al. [8] found that the most frequently fractured roots and teeth were those with this specific anatomy (79 %). To minimize the risk of VRF, familiarity with the root anatomy and morphology is essential for appropriate instrumentation, obturation, and restoration of these teeth [7].

Root depression in the interproximal aspect of the mesial root of the mandibular molars and in the buccal root of the bifurcated maxillary premolar is an anatomical entity that can predispose the likelihood for fractures and root perforations when excessive removal of dentin occurs. Thus, these areas should be considered as "danger zones" (Figs. 3.2 and 3.3) [9–11]. The prevalence of the furcation groove in the buccal root of the bifurcated maxillary premolar is high (62–100 %) (Figs. 3.4, 3.5 and 3.6) [9–11]. The initial dentin thickness can be as small as 1 mm [9, 11] in these areas. In an in vitro study that evaluated the amount of remaining dentin thickness after root canal preparation and post space preparation in both roots of the bifurcated maxillary premolar, the remaining dental thickness was less than 1 mm in 77 % in the buccal roots in the bifurcation aspect [12]. Therefore, the clinician should express extra caution with the endodontic and prosthetic procedures in this area.

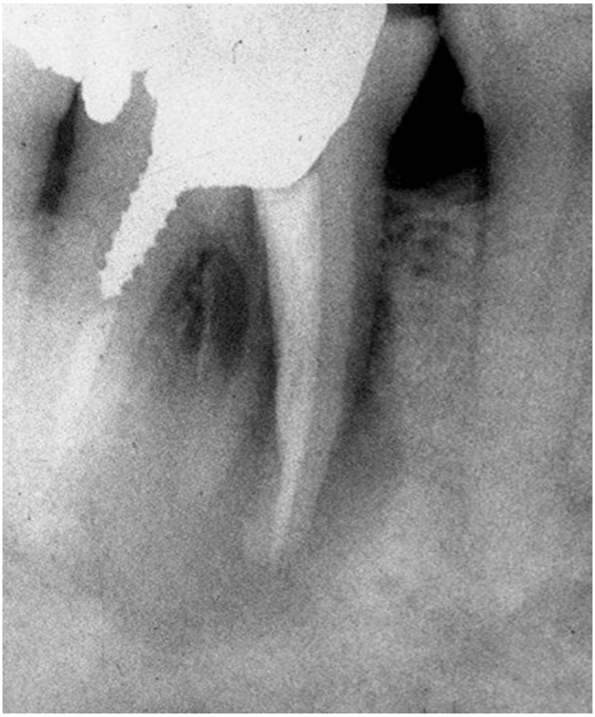

Fig. 3.2 Excessive removal of root dentin during root canal preparation in the mesial root of a mandibular molar caused a vertical root fracture. Separation of the root segments and large bone resorption can be seen in the radiograph

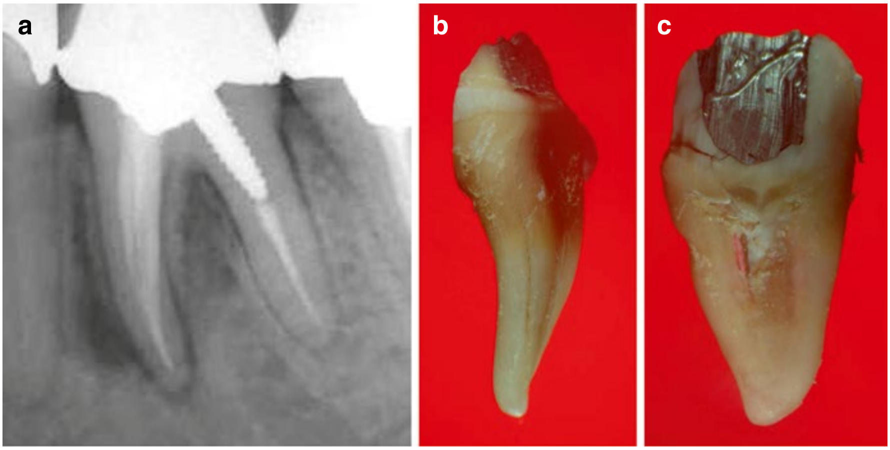

Fig. 3.3 A periapical radiograph of endodontically treated mandibular molar. (**a**) Due to excessive removal of the root dentin, both a VRF (**b**) and strip perforation (**c**) had occurred

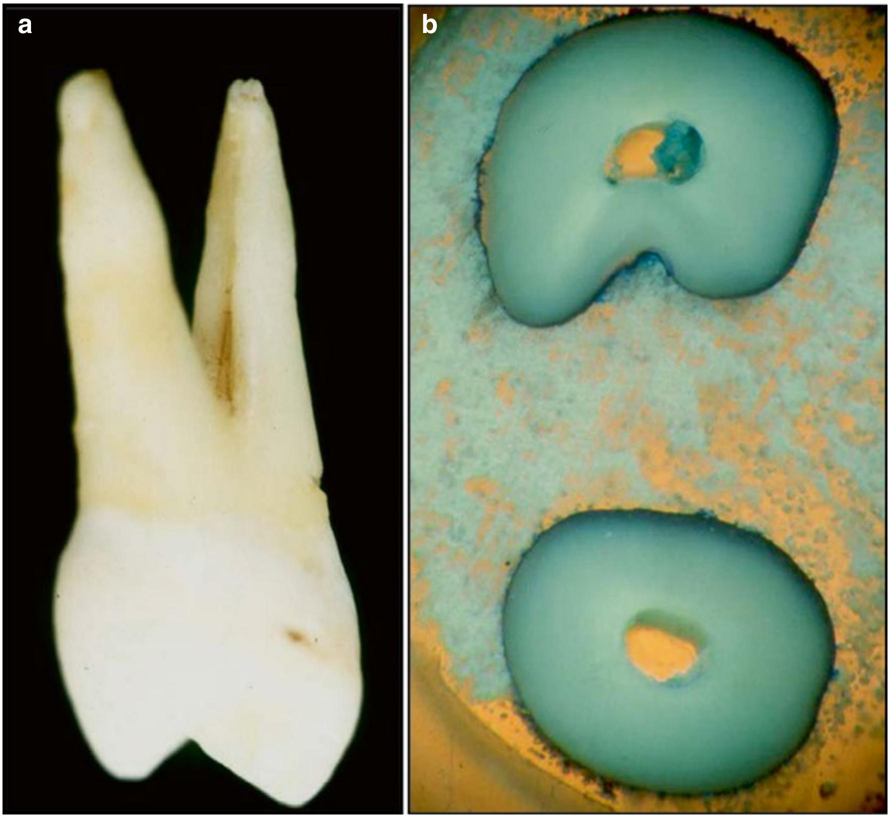

Fig. 3.4 The typical depression on the bifurcation aspect of the buccal root of the bifurcated maxillary premolar can be seen in an extracted tooth. (**a**) Cross section of the tooth (**b**) is showing the typical kidney-shaped buccal root of the maxillary bifurcated premolar and the depression facing the bifurcation aspect

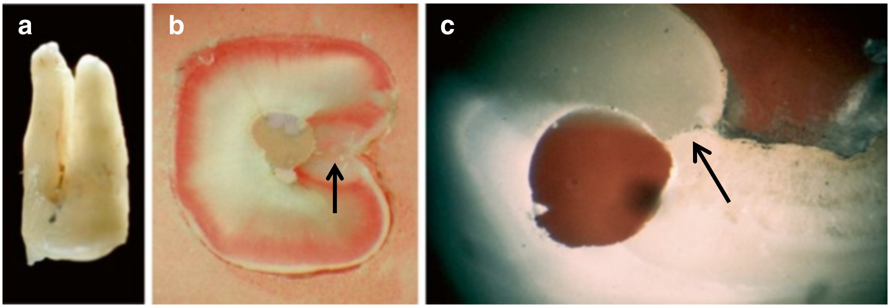

Fig. 3.5 Another extracted, bifurcated, endodontically treated maxillary premolar is showing the depression in the buccal root. (**a**) A cross section in the middle of the buccal root (**b**) is showing the irregular preparation of the root canal sealed with laterally condensed gutta-percha. The *black arrow* is pointing to the VRF. A different buccal root of the maxillary premolar is showing a round preparation for a dowel, leaving minimal residual dentin between the canal wall and the depression. The *black arrow* is pointing at the VRF (**c**)

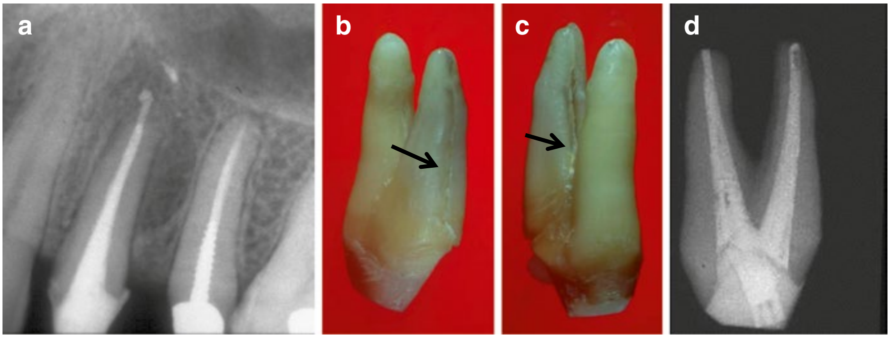

Fig. 3.6 A periapical radiograph of an endodontically treated maxillary premolar. (**a**) A large lateral radiolucency can be seen in the mesial aspect. Few exacerbations occured in recent years, and a deep buccal probing was noted in midbuccal area. The extracted tooth is showing the complete VRF in the buccal root. (**b**, **c**) The *black arrows* are pointing at the VRF. The bench periapical radiograph of the extracted tooth (**d**) is showing the large amount of dentin removed in the buccal root

The canal and root shape combined with dentin thickness affect tensile stress distribution during root canal procedures [13]. The root canal shape is the most important factor of the two since the area of reduced curvature radius (the buccal and lingual root aspects) is strongly influenced by stress concentrations. More than likely, this is the reason why these roots fracture in a buccolingual direction and not mesiodistally. This is the case although more dentin is usually removed from the mesial and distal aspects at the stage of canal instrumentation and post space preparation.

In many cross sections of single-rooted teeth, the mesial and distal aspects are more calcified and harder than the buccolingual one showing a “butterfly effect.” This may also explain the high prevalence of vertical root fractures that are directed buccolingually [14].

Another important predisposing etiology is the amount of sound tooth structure pretreatment in the crown and root as a result of caries or trauma. Combined with the reduced amount of radicular dentin as a result of the various intracanal procedures (initial root canal therapy, retreatment, postspace preparation), sound tooth structure is directly correlated to the ability of the endodontically treated tooth to resist fractures [6, 7, 15–18].

A common clinical speculation is that an endodontically treated tooth is more brittle compared to one with a vital pulp [19] and that the dentin undergoes changes in collagen cross-linking after root canal treatment [20]. However, these studies have not been validated [21]. In endodontically treated teeth, moisture loss compared with teeth with vital pulps is not a major etiological factor but rather a predisposing one for root fracture [22].

Small cracks have been reported to be present in the dentin parallel or perpendicular to the root canal space in intact teeth [23–25]. During intracanal procedures when dentin is removed, especially in the mesiodistal areas, such cracks may turn into incomplete fractures and then later during the life of the tooth may progress in buccal and/or lingual directions to form a complete fracture [25].

The specific biochemical properties of dentin are also predisposing factors in VRFs. In a study on the stress–strain response in human dentin, Kishen et al. [5] found that the dentin adaptation to functional strain–stress distribution results in greater mineralization in the buccolingual areas. This may increase the likelihood for a fracture to propagate in this direction compared with less mineralization and more collagen in the mesiodistal areas.

By evaluating radiographs, it was found that a correlation exists between the height of the alveolar crest and the stress in the apical part of a post [26]. It may be assumed that loss of bone support due to periodontal disease and pre-endodontic and prosthetic treatment can result in reduced tooth ability to withstand functional stresses.

Contributing Etiological Factors

The iatrogenic factors are etiological factors that contribute to the susceptibility of a root to fracture. These include removal of large amounts of sound dentin during the endodontic and restorative procedures in the root canal (Figs. 3.7, 3.8 and 3.9), reduction of tooth stiffness as a result of the endodontic and restorative procedures and the stress they generate [27], and lateral condensation of gutta-percha followed by dowel selection and placement. These are all examples for such stress-generating procedures in the root canal [28–31].

The design of the NiTi instruments is an important factor when evaluating the ability of roots to resist fractures [18, 32]. These studies address the correlation of canal preparation to fracture susceptibility. Roots may be significantly weakened with larger instrument tapers which tend to remove more dentin, but by the same token, the greater taper may cause less stress during obturation with gutta-percha [18]. Recently, an additional flaw of the NiTi instruments, which is gaining more

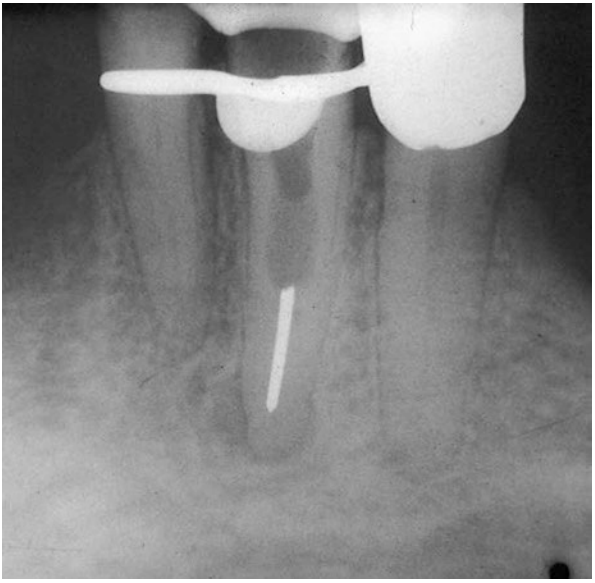

Fig. 3.7 An attempt to retract a previously endodontically treated mandibular premolar sealed with a silver cone, resulting in minimal remaining dentin and poor endodontic and restorative prognosis for the tooth

Fig. 3.8 Excessive removal of root dentin is shown in the two periapical radiographs (**a**, **b**). A bench periapical radiograph (**c**) is showing the large amount of dentin removed which was a major contributing etiology for the VRF in this tooth. (**d**) A *black arrow* is pointing at the fracture

attention, is the ability of various root canal instruments to induce dentinal microcracks due to their design (Fig. 3.10) [33–35]. The small cracks in the canal wall or at the root surface seen in in vitro studies following instrumentation with various NiTi instruments together with previous studies regarding the existence of cracks in the dentin even in the untreated tooth [23–25] are considered precursors to the development of incomplete and complete fractures at a later stage [36]. Dentinal cracks also occur after root end preparation with ultrasonic retrotips [37]. These cracks can be an etiological factor in the future success of endodontic surgical treatment.

Changes in the quality of the root canal wall dentin when using various medicaments and irrigation solutions in vitro suggest that these may have an effect on the future resistance of the root to fracture [38]. Erosion of the dentinal wall has been shown with different irrigation solutions and long-term exposure to the root canal dentin to calcium hydroxide and various other chemical agents [39].

Fig. 3.9 An extremely large amount of dentin removed from the root canal of a single-rooted maxillary premolar during the endodontic post preparation. Gutta-percha, sealer, and a metal post can be seen in this cross section. The preparation's left irregular canal walls and the VRF to the mesial aspect is shown with the *white arrow*

Fig. 3.10 A polished cross section of endodontically treated mesial root of a mandibular molar. Incomplete VRF is shown from the root canal to the lingual aspect, while a crack from the root canal is shown in the buccal part. Given enough time, this crack, shown by an *arrow*, will progress to the buccal aspect forming in this root a complete VRF from one aspect to the other

Tooth restorative procedures following root canal therapy such as postspace preparation, selection of dowels, and traumatic sitting of the dowels, especially in susceptible teeth and roots, are additional iatrogenic contributing etiologies for VRFs in endodontically treated teeth [40, 41]. In the AAE Colleagues for Excellence [42], it was emphasized that "The use of a post carries with it a certain attendant risk of root fracture, particularly if sound dentin is removed during preparation. Premolars require clinical judgment because of their transitional morphology."

Recently, the use of fiber posts in the endodontically treated tooth is increasing because their modulus of elasticity is similar to dentin, which allows them to flex with the root when under stress [42]. Cagidiaco et al. [43] have shown that the placement of the fiber post did improve the survival rate of endodontically treated premolars. Other studies show a preference of fiber posts with different coronal coverage [44, 45]. Ferrari et al. [46] have pointed out that the preservation of at least one coronal wall during the restoration of the endodontically treated tooth is also a significant factor in the reduction of fractures in maxillary premolars.

Factors that affect fracture resistance of post-restored teeth are post length, diameter, design, material and fitting, the core material, the ferruling effect, the luting cement, coronal coverage, remaining coronal tooth structure, the loading conditions, and the alveolar bone support [47].

Conclusions

The potential vertical root fracture in the endodontically treated restored tooth can be reduced by the clinician by being aware of the various etiological factors, especially in VRF-susceptible teeth. These are the minimal removal of sound crown and root dentin, controlling the force when sealing the root canals with lateral condensation of gutta-percha, using dowels only when necessary to retain core buildup, using the more recommended fiber-reinforced resin dowels if needed and incorporating them, and adequate ferrule when restoring the tooth with a crown.

Etiology of VRFs: A Fracture Mechanics Perspective

Vertical Root Fractures (VRF) is a leading failure mode in teeth which has been studied extensively. VRF may be caused by wedging forces or pressure transmitted to the root canal surface during root canal obturation or from cyclic occlusal forces. In this section, we explore VRF from a mechanistic viewpoint as a fracture mechanics problem incorporating unique geometry, material, and loading. Examination of horizontal sections of roots extracted due to VRF reveals interesting morphological features which are helpful in any analytic modeling. A previously developed two-dimensional fracture mechanics model of VRF for single-canal roots subjected to apical condensation of gutta-percha is reviewed. The model is used to determine the full crack path due to the application of uniform pressure on the canal surface. A simple relationship is then used to connect this pressure to the apical condensation force, yielding an analytic expression for the critical load needed to cause VRF in terms of the system's geometric and material variables, e.g., canal shape and taper, root wall thickness, and dentin's failure stress σ_F and toughness K_C.

VRF is a term associated with a fracture extending over part or all of the root length, see Fig. 3.11. Such failure, often necessitating tooth extraction, is conclusively associated with endodontic treatment involving root canal cleaning and shaping followed by condensation of gutta-percha (gp), a rubbery material used for canal filling. VRF may occur during the treatment itself from excessive apical forces or more commonly later in time from cyclic occlusal forces [4, 48]. The growth history of a crack in the dentin leading to VRF involves complex geometry, material, and loading aspects. Analytic studies of VRF commonly employ 3D finite element analysis (FEA) and are generally limited to elucidating the stress distribution in the root due to some loading applied to the canal surface, e.g., localized or distributed (pressure), or occlusal surface [18, 31, 49–56]. Lertchirakarn et al. [31, 53] and Sathorn et al. [54, 55] presented tensile stress contour plots for circular and elliptical

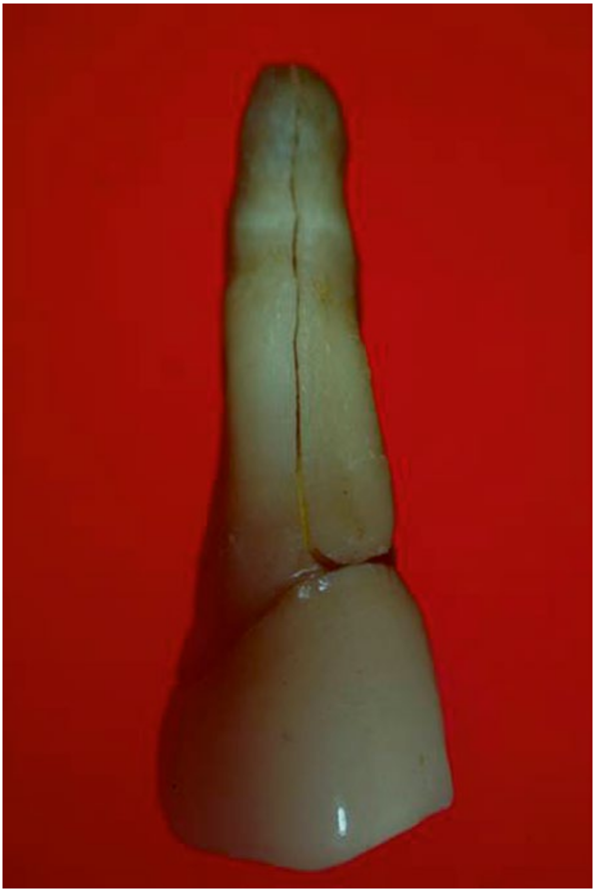

Fig. 3.11 Buccal view of endodontically treated mandibular premolar tooth extracted from a patient due to VRF in our laboratory

canal sections subjected to wedging forces or uniform pressure on the canal surface. The results show that the tensile stress responsible for crack initiation is maximized at the inner canal surface where the radius of curvature is the smallest, which is consistent with clinical observations. However, there appears to be no full-fledged FEA addressing the issue of crack growth in the dentin or relating canal pressure to apical or occlusal force.

Recently, a simple 2D fracture mechanics analysis for determining crack growth behavior due to uniform canal pressure was presented [57]. The analysis shows that dentinal cracks tend to grow continuously with pressure and that the apical condensation force needed to cause VRF derived from the canal pressure using a simple formula correlates quite well with values obtained from in vitro tests on extracted teeth. In this chapter, we will discuss such tests as well as analytic concepts aimed at understanding and preventing VRF.

In Vitro VRF Testing

Several studies have conducted in vitro tests on extracted single-canal human roots [30, 31, 54, 58–60]. Such tests provide a useful database for analytic studies. After supporting the roots by a soft medium they were instrumented, filled by laterally condensed gp to a certain height L above the root apex, and continuously loaded to fracture by a spreader. Fracture or VRF was generally taken to occur when a noticeable load drop in the load vs. displacement output was recorded. Figure 3.2 in Chai and Tamse [57] depicts the mean (F_{max}) and standard deviation load values vs. L. No distinction between the different instrumentation procedures used was made because such detail did not seem to be significant. The effect of loading distance L was moderate. The mean VRF load ranged from 80 to 170 N (1 KG = 9.8 N) with F_{max} for oval canals somewhat smaller than for round ones. Pitts et al. [61], Holcomb et al. [29], and Soros et al. [62] conducted similar tests on maxillary and mandibular human incisors and mandibular goat teeth in that order except that gp condensation took place in repeating ramp cycles at increasing load levels. The fact that the resulting mean VRF loads (i.e., 149, 70, and 133 N in that order) are similar to the values obtained under continuous loading indicates the clinical relevance of the single-cycle loading tests.

Root Sectioning

During our experimental studies, we accumulated numerous teeth extracted due to VRF. Figure 3.12 shows three sequences of horizontal cross sections of premolar teeth, all previously subjected to root canal treatment with gp, which embed some essential characteristics of the fracture morphology. The sequences in (a) and (b) are for single-canal roots while that in (c) is for a double-canal root. Note that each of the two canals in (c) contains a post which extends to the middle part of the root. As shown, the canal sections are generally irregular, tending to change size and

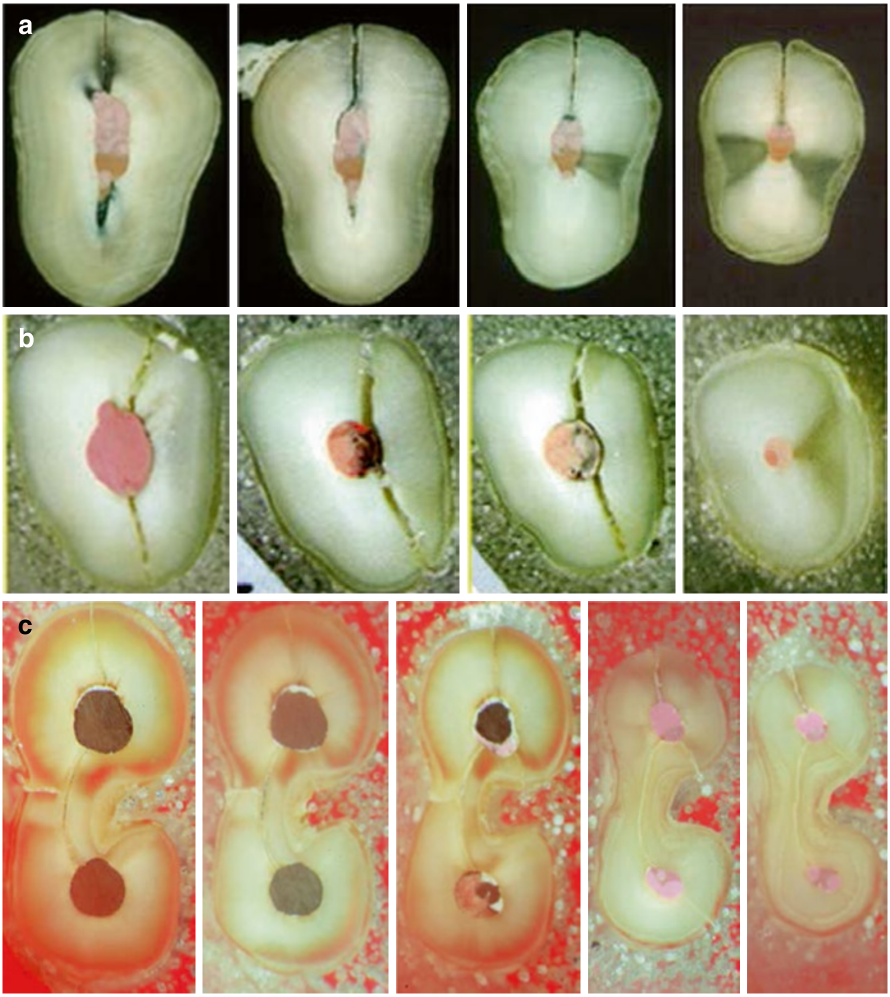

Fig. 3.12 Three micrograph sequences of horizontal cross sections for maxillary premolars extracted due to VRF in our laboratory: (**a**) Single-canal root showing incomplete VRF, (**b**) single-canal root showing complete VRF, (**c**) double-canal root with posts extending to the middle part of the root; a complete VRF occurs only in the apical part of the root. The fracture conclusively initiates at the root canal surface where the radius of curvature is the smallest (Courtesy Dr A. Raizman)

orientation along the root axis whether naturally or due to endodontic treatment. The sequence in (a) shows an incomplete VRF and that in (b) a complete one except in the apical section. In the case of (c), a complete VRF occurs only in the apical part of the root. In addition to major fractures leading to VRF, Fig. 3.12 shows some dentinal cracks of a limited extent, e.g., the first image in (b) and first two images in (c) from left to right. This indicates a competition for crack growth on the canal surface. A dominant feature in all micrographs in Fig. 3.12 is that cracks tend to initiate on the canal surface where the radius of curvature is the smallest irrespective of the outer root surface curvature.

Several less apparent morphological features can also be seen from Fig. 3.12. The relatively large gap between the fractured parts in the two middle images in Fig. 3.12b suggests that fracture may have initiated from this region. Observing the lingual canal in Fig. 3.12c, one notes the fracture in the lingual part of the root where the canal is filled with gp while no fracture can be seen in the region of the post. It may be speculated that VRF in this case has initiated from the apical part and propagated coronally and that the presence of post did not add additional damage to the root.

VRF Analysis

Basic fracture mechanics considerations suggest that the driving force responsible for VRF is the tensile hoop stress in the dentin wall (i.e., the stresses that tend to open up cracks propagating from the inner to outer dentin wall). Accordingly, the dependence of these stresses on the applied load is of central importance. The effect of canal pressure can be readily seen from available results pertaining to a large disk containing an elliptical cavity, major axis b and minor axis a, under uniform surface pressure q [63], i.e., Fig. 3.13 with $b_0 >> b$, $a_0 >> a$. The maximum tensile stress on the canal surface in this case occurs at the edge of major cavity axis where the radius of curvature is the smallest: $\sigma_{max} = (2b/a - 1)q$. With $\sigma_{max} = \sigma_F$, where σ_F is the failure stress of dentin, the pressure q_i needed to initiate cracking on the canal surface becomes

$$q_i = \sigma_F / (2b/a - 1) \tag{3.1}$$

Hence, the crack initiation pressure depends on the ratio b/a, i.e., it reduces with increasing b/a. As an example, for $b/a = 2$, the crack initiation pressure is only a third of that for a round cavity. According to Eq. 3.1, it is the inner rather than outer root curvature that controls the crack initiation site. These trends are consistent with well-documented clinical observations, e.g., Fig. 3.12, as well as with FEA [53, 54].

To understand VRF, the process of crack growth from inner to outer root surfaces need be established. Figure 3.13 is a fracture mechanics model developed for this purpose in an earlier study [57]. The model consists of a horizontal root slice containing elliptical cavity under uniform surface pressure q. The root is attached to a square block of bone, $D = 12$ mm, via a 0.2 mm thick periodontal ligament (PDL). The inner and outer edges of the root are assumed elliptical with minor axes a and a_o and major axes b and b_o. A small initial defect c emanates from the cavity boundary along the major axis. The pressure q leads to circumferential tensile stress σ on the cavity surface which may enlarge the defect. The pressure needed to advance the defect across the dentin wall is found with the aid of a FEM code (Ansys, Inc.) where crack length c is incremented in small steps and pressure q adjusted such that the stress intensity factor K equals the fracture toughness K_C during the growth history [57] (Fig. 3.13).

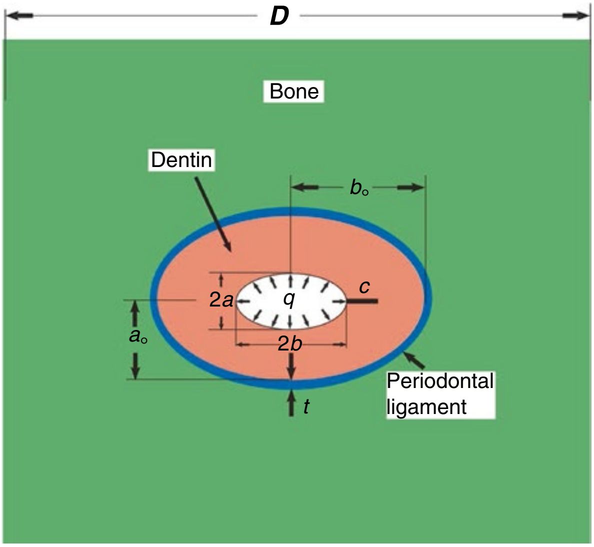

Fig. 3.13 Two-dimensional fracture mechanics model for VRF in single-canal roots. The specimen consists of a thin horizontal root slice containing an elliptical cavity subjected to uniform pressure q. The outer surface of the root is supported by a rectangular block of bone via a 0.2 mm PDL. The pressure drives an initial crack c to the root surface. The orientations of cavity and initial crack length may vary

Figure 3.14 plots contours of first principal (maximum) tensile stress for three configurations, all with no initial crack. The results confirm that the largest stress occurs at the smallest radius of curvature of the canal surface irrespective of the curvature of the outer root surface. It is also found that Eq. 3.1 pertaining to an infinitely large outer root dimension works quite well for the present case. Figure 3.15 shows qualitatively the variation of pressure needed to propagate a crack with crack length. For a given flaw size c_F in the dentin, the pressure initially declines with crack length, indicating a phase of rapid crack growth. However, after the crack is arrested, the equilibrium pressure increases continuously with crack length up to q_{max}. Thereafter, q declines, implying a rapid crack growth leading to VRF.

The next stage in the analysis is to connect between pressure q and apical force F. Assuming that the pressure in the gp right under the spreader is uniformly distributed over the canal cross section, the apical load F applied to the gp is readily found from

$$F = qA \tag{3.2}$$

where $A = \pi ab$ is the cross-sectional area of the elliptical canal. Introducing this in Eq. 3.1, the load needed to initiate crack growth F_i is found as

$$F_i = \pi a^2 \sigma_F / (2 - a/b) \tag{3.3}$$

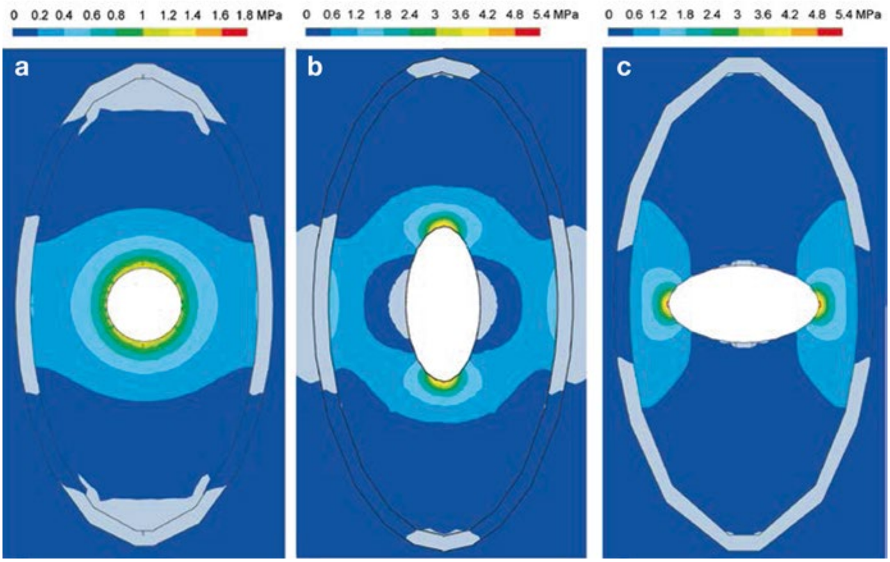

Fig. 3.14 FEM results showing contours of first principal (maximum) tensile stress for three canal cross sections corresponding to Fig. 3.13 with $c=0$, $q=1$ MPa, PDL thickness=0.2 mm, and major and minor axes of inner and outer root boundary equal 3 and 1.5 and 1 and 0.5 mm, in that order; (**a**) round canal, (**b**) major axis of inner and outer root boundaries coincide, (**c**) major axis of inner and outer root boundaries are perpendicular. Young's modulus for (dentin, PDL, bone) is (18, 0.05, 1.4) GPa while Poisson's ratio for this triplet is (0.31, 0.45, 0.3). Note the prints cover only part of the specimen

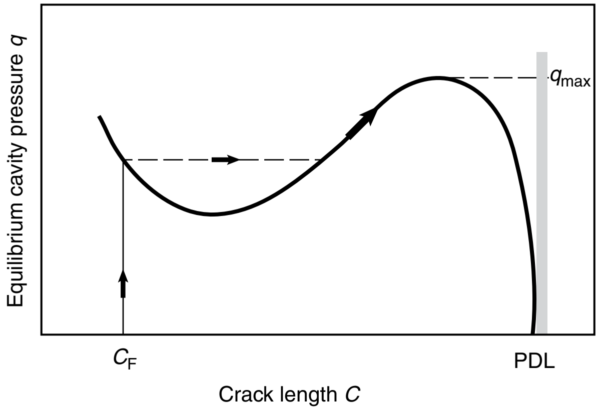

Fig. 3.15 Qualitative representation of the pressure on the canal surface needed to propagate a crack vs. crack length obtained from the FEA for the specimen in Fig. 3.13; c_F is the effective flaw size of dentin

Thus, F_i is proportional to canal size a^2 and inversely proportional to $1/(2-a/b)$. To get the VRF load $F_{max,}$ we substitute q_{max} (the pressure at which VRF occurs) in Eq. 3.2:

$$F_{max} = \pi abq_{max} \quad (3.4)$$

Some relationships for q_{max} as a function of cavity dimensions a and b are given in Ref. [57]. It is shown that q_{max} is proportional to the fracture toughness of dentin K_C.

Conclusions and Observations

It is generally accepted that root canal therapy is a precursor to VRF. Gutta-percha condensation is typically limited to apical forces ranging from of 15–30 N [64]. Studies have shown that the damage induced during endodontic treatment is generally insufficient to cause VRF [25, 65, 66]. Noting that the in vitro condensation studies discussed earlier yielded VRF load levels on the order of 100 N, one concludes that the propagation of dentinal cracks in single-canal roots produced during root canal therapy into VRF mostly occur under repeating occlusal forces. For a crack to propagate across the dentin wall, tensile stresses must operate perpendicular to the crack direction. How such stresses formed during occlusal loading to cause VRF is a subject not well understood, however.

The fracture mechanics approach to VRF provides several useful characteristics:

(a) The crack initiation site is controlled by the inner root curvature. The outer root curvature may affect the crack path only as the crack becomes sufficiently long.
(b) As seen from Eq. 3.3, a crack may initiate more easily in oval as compared to round canals.
(c) The VRF load is proportional to dentin fracture toughness K_C. Hence, VRF should be more common in older patients, for which K_C is known to reduce with age [67, 68], consistent with clinical trends [8, 69, 70]. Bacteria-accommodating dentinal cracks [71] is another important cause for reducing K_C (see also Chap. 6).
(d) The fracture mechanics analysis in Ref. [57] reveals little or moderate effects of root canal mean radius or root taper on VRF load. These observations agree with Ref. [61], which stated that “no significant correlation existed between fracture load and size of the root, size of the prepared canal, width of canal walls after instrumentation, and taper of the root or of the canal.”

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Diagnosis of Vertical Root Fractures

4

Richard E. Walton and Aviad Tamse

Abstract

Vertical root fracture in an endodontically treated tooth originates from the root at any level and is considered a frustrating and vexing complication in endodontic therapy. Many times, it is difficult to achieve an accurate diagnosis and to differentiate the fracture from other clinical entities. However, usually combination of cervicaly located sinus tract combined with a narrow deep periodontal defect present is highly suggestive of a vertical root fracture. When the diagnosis of a vertical root fracture is made, usually years after all endodontic and restorative procedures have been completed, extraction of the tooth or root should be done in a timely manner to minimize the bone loss in the surrounding bone. This bone loss may compromise subsequent implant placement in the area. This chapter will emphasize the importance of achieving an accurate and timely vertical root fracture diagnosis and will describe the more typical signs, symptoms, and radiographic features that are suggestive for vertical root fracture diagnosis in the susceptible teeth and roots.

Introduction

The vertical root fracture (VRF) is not uncommon [1]. This is a frustrating complication of endodontically treated teeth and is often difficult to identify [2]. The treatment plan is straightforward, that is, extraction of a single-rooted tooth or at least

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root removal in a molar. So the definitive and accurate diagnosis is important; the clinician does not wish to remove a nonfractured root. A further complication is that the VRF is frequently problematic to diagnose; these root fractures usually mimic other conditions. Signs and symptoms, for example, dull pain or pain on mastication, mobility, presence of a sinus tract, deep probing defects, a periodontal-type abscess, and periapical radiolucencies, are often similar to those found in failing root canal treatment or in periodontal disease [3–7]. A mistake in identification would lead to other inappropriate management. An example would be periodontal treatment or root canal retreatment; the VRF has damaged the periodontium to the point that it is mistaken for another entity. Complications in diagnosis of teeth scheduled for endodontic surgery may occur because of other causes such as a periodontal condition, VRF, and misdiagnosis of nonendodontic pathosis mimicking inflammatory periapical lesions [8]. An error in diagnosis is devastating and may have serious consequences. Therefore the need for a cautious and rigorous approach to identification of a suspected VRF.

How can the clinician make a definitive diagnosis and identification of a VRF? Are there any absolute signs, symptoms, tests, radiographic characteristics, or combinations that are “classic” for VRF? It is commonly believed that certain findings, for example, two narrow probing defects or two sinus tracts (one on the buccal and one on the lingual), indicate a VRF. If that is the finding, is this tooth to be extracted? The answer is *probably* yes, but this alone is not pathognomonic. In fact, with the evidence available, there are no noninvasive tests that are definitive for VRF.

A problem in recounting available information is always to locate and report on sound, evidence-based research. This is largely lacking on this topic. An article [9] systematically reviewed the subject of diagnosis of VRF in endodontically treated teeth. The conclusion was that there are not substantive evidence-based data concerning the diagnostic accuracy as to the effectiveness of clinical and radiographic evaluation. However, it is difficult to design randomized trials with controls (high levels of evidence of 1 and 2) on this type of complication because treatment is required. To date, most published information is lower levels of evidence [3–5] represented by case reports, case series, or case report studies.

Therefore, much of what is included in this chapter is based on the information that is currently available. Careful application, in fact, will usually result in accurate identification and diagnosis and ultimately the proper treatment.

Pathogenesis

This is reviewed in more detail in “Pathogenesis” (Chap. 6). The pathogenesis is an important consideration in designing a diagnostic approach because of the nature of the injury and the outcome. The histology of the VRF on extracted, fractured roots was examined by Walton et al. [10]. The findings were that the irritants from the fracture line generate an inflammatory lesion that results in irreversible linear devastation to the soft tissues and bone of the periodontium. This mimics other entities such as a periodontal-like defect or failed root canal treatment. The fracture may be complete apical to coronal/facial to lingual or incomplete. This further confuses the diagnosis [1]. Thus, the objective is differential diagnosis.

Diagnosis

A diagnostic process is based on the combination of the patient's subjective complaints and objective clinical and radiographic evaluation. In the case of VRF diagnosis, there is no known single pathognomonic sign, symptom, or radiographic feature to make the diagnosis definitive [11].

Importantly, most means of examination at the clinician's disposal must be employed when trying to achieve accurate and timely diagnosis of VRF. Omission of a step may result in an error. The sequence is the following: (1) Subjective evaluation, (2) Objective tests, (3) Radiographic findings, (4) History of the tooth, (5) Flap reflection when indicated. Usually, there are no specific combinations of non-invasive, classic tests or signs and symptoms that would predictable identify a VRF. There are findings—clinical and radiographic ones [12]—that strongly suggested a VRF, but usually flap reflection is necessary. The factors that point in the direction of fracture are reviewed below.

Subjective Evaluation

Interestingly (and importantly), symptoms tend to be minimal, that is, none to mild pain [7, 12]. Seldom are the pain levels moderate or severe. So the VRF does not elicit symptoms that bring the patient to the dentist. Often, the patient detects some mobility, but usually the tooth is stable. Symptoms from the periapical region, that is, pain on mastication, is common but mild. Many of these vertical root fractures may resemble periodontal lesions; the patient may report some localized swelling or a bad taste from drainage of a periodontal-type abscess. They may also report a "gum boil" (draining sinus tract) [1, 3, 4].

Objective Pulpal and Periapical Tests

Pulpal: Because the tooth has had root canal treatment, these are not useful.

Periapical: These are not particularly useful either. Percussion and palpation usually generate a mild response, which is not diagnostic for VRF.

Clinical Examination Findings

A common finding is a sinus tract or a gingival swelling (Fig. 4.1a). Again, these may mimic either a periodontal or an endodontic lesion.

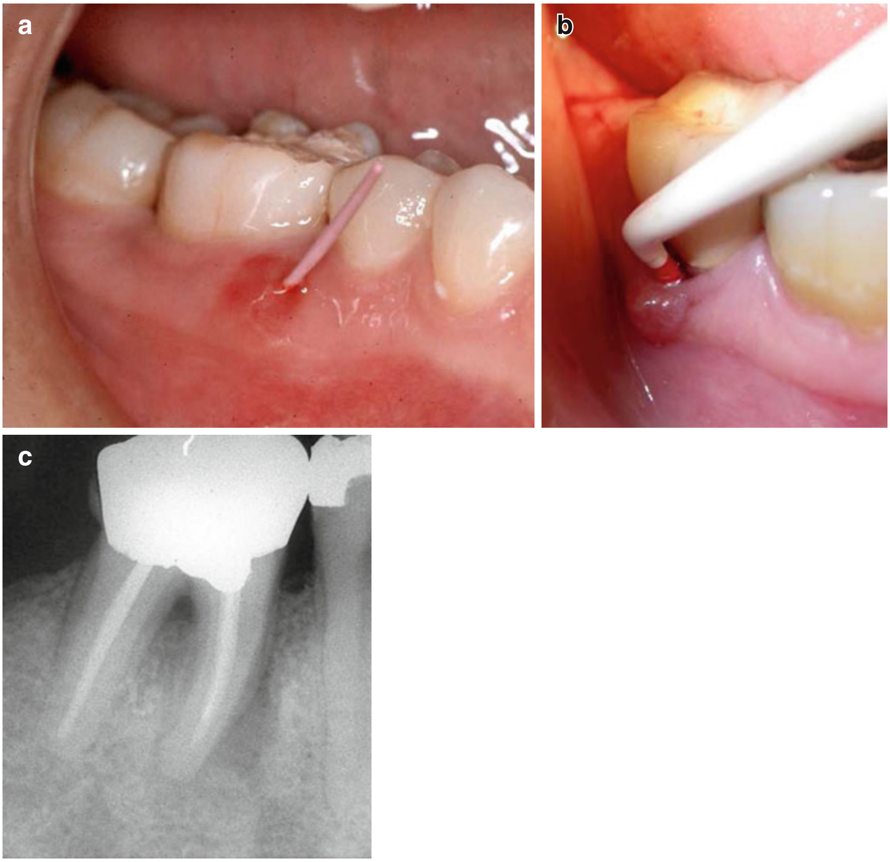

Fig. 4.1 Common findings: (**a**) A highly located sinus tract in a mandibular molar. (**b**) A highly located sinus tract and deep probing in midbuccal area of another mandibular molar. The periapical radiograph (**c**) shows a combined bony lesion in the bifurcation area and along the lateral aspect of the mesial root which is typical for VRF in mandibular molars. The combination of the clinical signs in the endodonyically treated tooth is considered pathognomonic for VRFs

Probing Patterns

These are more diagnostic although not absolute. There is a common assumption that VRFs produce narrow and deep defects on the facial and/or lingual surfaces representing the periodontal breakdown and inflammatory process facing the fracture [10, 13, 14]. Although this may occur, patterns are not predictable. *Significantly, some teeth with vertical root fractures have normal probing depths*. In a recent clinical prevalence study [15], in less than 24 % of the VRF cases was a deep probing defect found. However, most do show significant deep defects with narrow or rectangular patterns (Figs. 4.1b, c and 4.2). These also are often indicative of endodontic-type lesions. When present, these deep defects are not necessarily on both the facial and lingual aspects. When they are deep on the facial and lingual, VRF is strongly suspected, but if this is the only clinical sign, it is not pathognomonic. In summary, probing patterns are

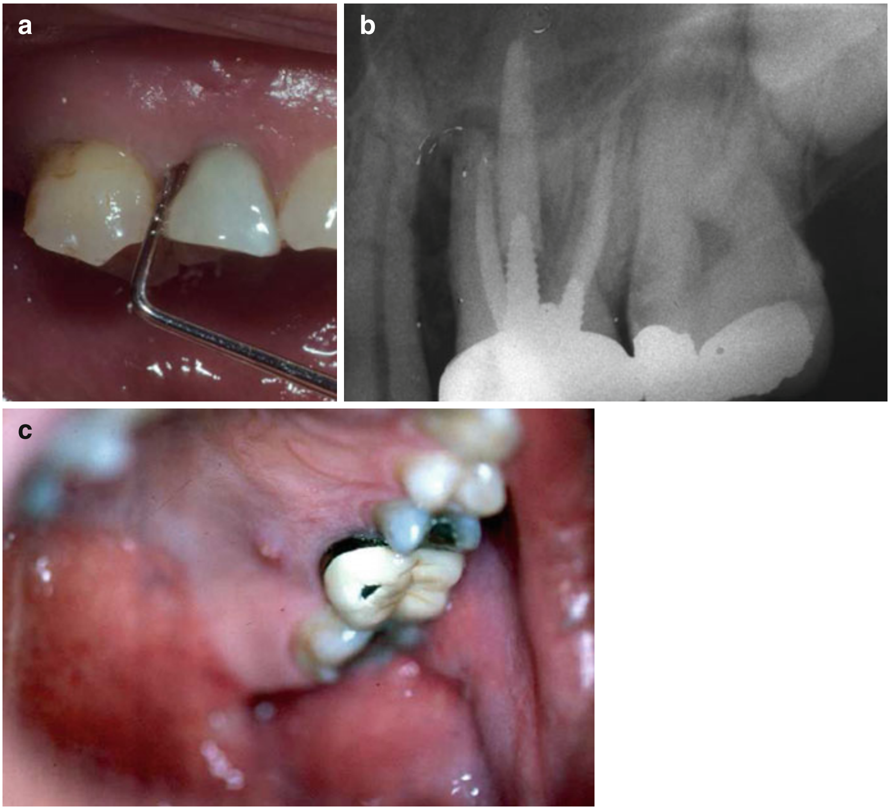

Fig. 4.2 Deep probing defects may occur on different surfaces but mostly in the buccal aspect as the buccal cortical plate is much thinner than the lingual and the palatal ones. (**a**) Mesiobuccal probing defect in a maxillary lateral incisor. (**b**) Periapical radiograph of a maxillary molar, showing the large bone loss along the MB root causing deep probing defects in the buccal as well as in the palatal. (**c**) A sinus tract can be seen as well on the attached gingivae at the palatal aspect

not in themselves totally diagnostic. However, these deep defects in association with other findings strongly suggest the presence of a fracture. In 2008 [16], the Guidelines of the American Association of Endodontists stated that when there is a combination of a probing defect coupled with a sinus tract in an endodontically treated tooth (with or without a post), this is often pathognomonic for a VRF (Figs.4.1b, c and 4.3).

Often, this "pathognomonic combination" does not exist, resulting in a high percentage of misdiagnoses [4].

Radiographic Findings

Radiographs show a very wide variation of patterns of bone resorption [7, 12]. These resorptive lesions are adjacent rather than within the tooth itself. Very rarely can a tiny hair-like radiolucent fracture line be demonstrated in a root.

There are no specific radiographic pathognomonic findings because there is an assortment of patterns that often resemble other entities such as periodontal or endodontic inflammatory resorptive lesions [16]. Importantly, a vertical root fracture may demonstrate no radiographic changes [4, 10]. In a recent publication [15], it was shown that many of the VRF cases did not show any pathological bony changes (Fig. 4.4). The clinician must rely on other suggestive findings to help make a correct and timely diagnosis.

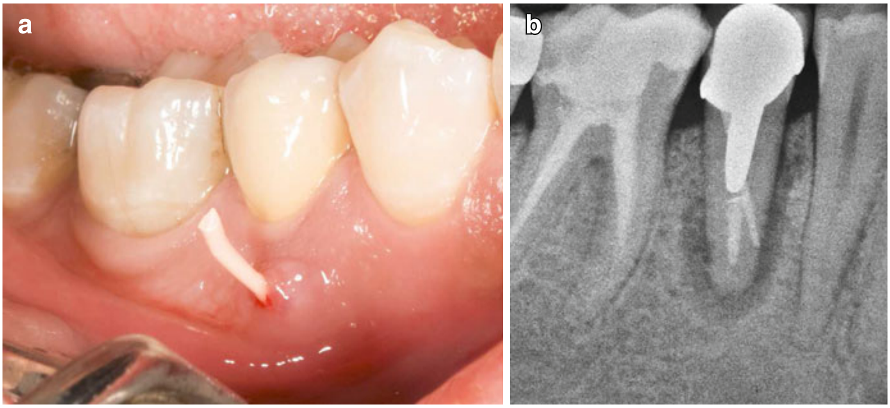

Fig. 4.3 A "pathognomonic combination" for VRF. A deep probing defect on the mesiobuccal aspect of the tooth and gutta-percha tracing cone through a highly located sinus tract (**a**) is directing to a "halo" radiolucency surrounding endodontically treated and restored mandibular premolar (**b**) (Courtesy Dr. S. Taschieri)

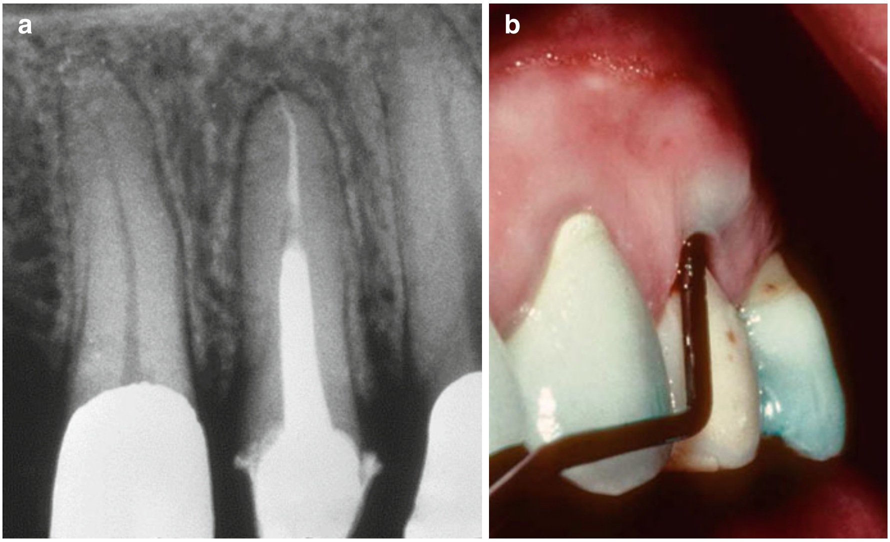

Fig 4.4 A common finding: (**a**) there are no significant radiographic changes. (**b**) A deep probing defect suggests a VRF

A most frequent radiographic feature of VRF is the “halo” (“J shaped”) (Figs. 4.5 and 4.6) appearance. This is a combined periapical and lateral radiolucency along the side of the root or a lateral radiolucency on one or both sides of the root. It may also present as an angular radiolucency from the crestal bone terminating on the side of the root (Fig. 4.7).

In mandibular molars, a furcal radiolucency is frequently found (Fig. 4.8) and is often coupled with other periapical/lateral changes [4, 12, 14]. The radiolucency may have other more familiar configurations such as the periapical “hanging-drop” shape (Fig. 4.9), thus resembling a lesion of failed root canal treatment [3].

Fig. 4.5 A very large “halo”-shaped lesion in a mandibular premolar

Fig. 4.6 A smaller-size “halo” radiolucent lesion in a mandibular premolar

Fig. 4.7 Angular bony defect along the mesial root of a mandibular molar extending from the crestal bone to the apical part

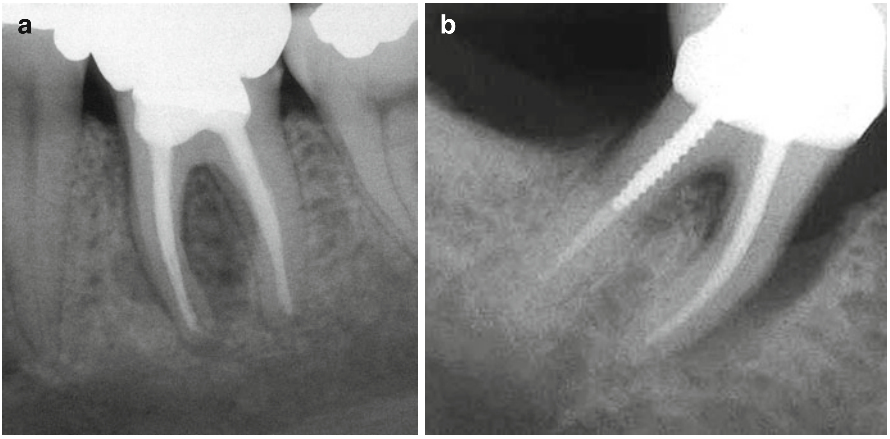

Fig. 4.8 Furcal resorptive lesions coupled with other radiolucencies around vertically fractured mesial roots may be seen often in mandibular molars (**a**, **b**)

Separated root segments are seldom visible on radiographs. If there is obvious separation, this is usually accompanied by a large radiolucency including and between the roots; this is inflammatory tissue separating the segments [17]. Obviously, when visible, these are absolutely diagnostic (Fig. 4.10). Segment separation with the large resorptive lesion indicates a long-standing event probably unnoticed by the patient. Lustig et al. [11] found that in most patients with other signs and symptoms (sinus tract, large osseous defect, mobility), or with acute exacerbations, greater interproximal bone loss was recorded than in patients in whom the VRF diagnosis was made at an early stage.

Computed tomography has been examined as a means of identifying vertical fractures of the root [18, 19]. Most studies have been in vitro with artificially

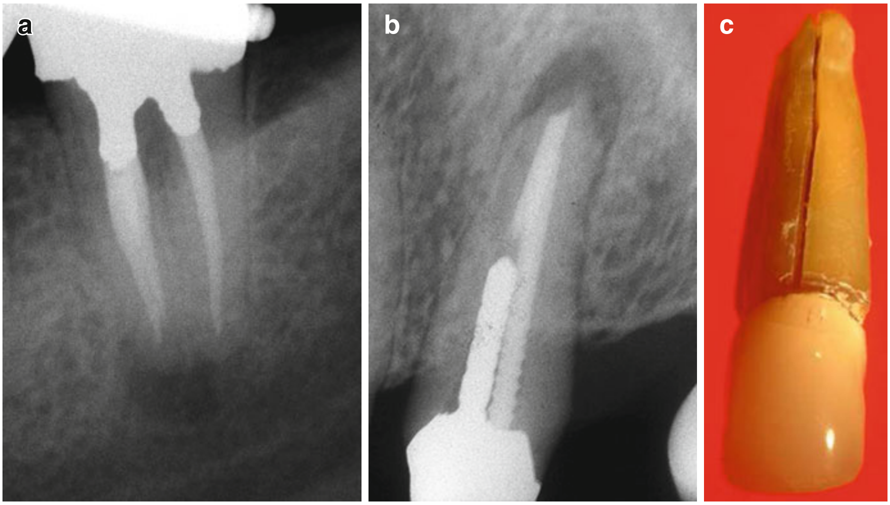

Fig. 4.9 (**a**–**c**) Radiolucent lesions may resemble those of failed root canal treatment with persistent disease. In a mandibular molar (**a**) and a maxillary premolar (**b**). The vertical root fracture in the premolar tooth is seen very clearly (**c**)

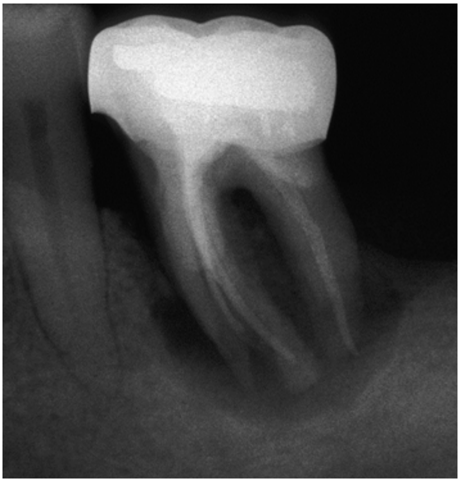

Fig. 4.10 Separated root fracture segments are an unusual finding and occur in long-standing inflammatory process in the area

generated fractures that really cannot be compared to in vivo situations. These are quite different than the actual fracture in situ; the data from these studies may not be useful in clinical situations. Also, the obturating materials that are always present and posts that are often in place may interfere with the beam and cause scattering. This would mask the presence of the fracture anyway. However, an advantage in cone beam computed tomography may be the ability to identify and study more subtle patterns of bone resorption that are not visible on standard digital or analogue radiographs; this has not been thoroughly examined in clinical trials. There have been publications in recent years claiming to demonstrate the superiority of CBCT scans over periapical radiographs to diagnose VRFs [19–21]. However, there is considerable heterogeneity in the experimental design of these studies resulting in a wide variability in the outcomes. At this point of time, there is insufficient evidence to suggest the superiority of CBCT over conventional radiographs to detect VRFs [22]. In fact, the American Association of Endodontists Colleagues for Excellence - Cone Beam Computed Tomography in Endodontics stated [23], "What may be observed is the resultant vertical bone loss in one or more scans" rather than the fracture itself (Fig. 4.11).

There is the common error of noting a radiolucent line separating the obturating material from the canal wall [7]. This is likely a radiolucent artifact. This artifact is common and is adjacent to gutta-percha or a post or is an incomplete root canal

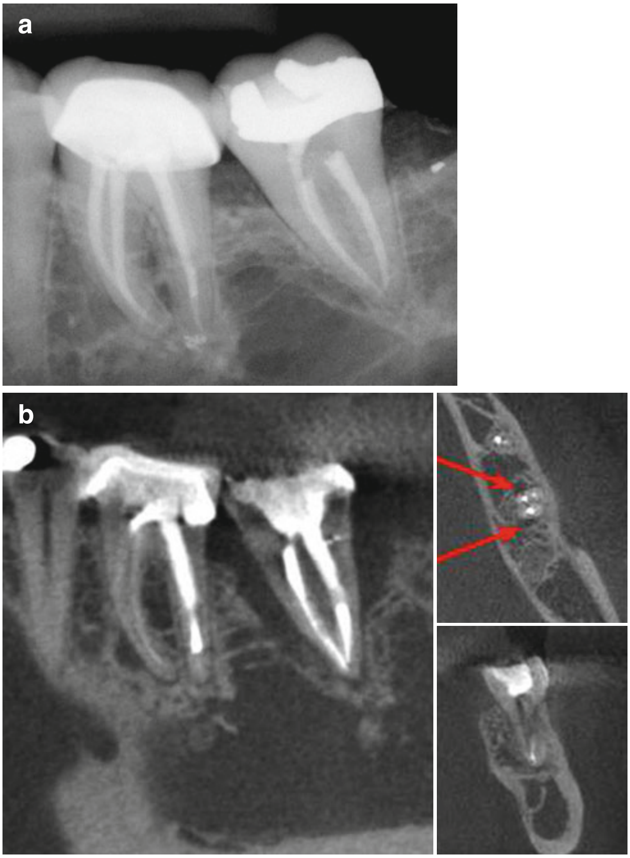

Fig 4.11 Digital radiography versus cone beam computed tomography. (**a**) Bony resorptive lesions are not evident. (**b**) CBCT scans on different planes clearly show the bony defects (Courtesy Dr M. Feldman)

filling. This thin radiolucent line may also represent an overlying bony pattern or another radiographic structure that is easily confused with a fracture.

Therefore, radiographs (including CBCT) can be helpful in identifying a suspected vertical root fracture but are seldom solely diagnostic except in those few instances when the fracture segment separation is readily visible.

Dental History

Identifying and considering past procedures that impact the root is very helpful in diagnosis. Vertical root fractures do not occur spontaneously. There is a defined history of certain treatment modalities. These procedures have generated lateral wedging forces. All fractured roots have experienced root canal treatment and/or root end surgery as well [15]. Many will demonstrate post placement. Different types of obturations are associated although those that generate more destructive forces such as lateral or vertical condensation tend to be major culprits [24, 25]. Certain post designs, particularly custom tapered posts, also generate more wedging forces [26–28]. Canal preparation techniques that remove more tooth structure have more potential to result in fractures [29–31]. These may be as part of root canal treatment or post preparation (See also Chap. 3).

Endodontic and restorative procedures may have been completed years before the fracture manifests itself clinically. Forces that stress the dentin are established early, but the actual fracture may begin and grow later taking considerable time to reach a root surface. It is seldom a sudden catastrophic event.

Root Anatomy

The shape of the root and size of canal in cross section are considered to be predisposing factors. This shape should be determined as it is indicative of what may be a VRF. Those with narrow mesial–distal and deep facial–lingual shapes are the most susceptible [32, 33]. These susceptible teeth and roots are the maxillary and mandibular premolars, mesial roots of mandibular molars, and mandibular anteriors. Therefore, more bulky roots such as maxillary central incisors and lingual roots of maxillary molars seldom fracture (Fig. 4.12) (See also Chap. 3).

Flap Reflection

To summarize the above information, seldom do any combinations of signs, symptoms, tests, or findings predictably identify the vertical root fracture. If this were true, the clinician could confidently extract the tooth or remove the fractured root from a molar. In studies on diagnosis [11, 12], all suspected teeth were subjected to

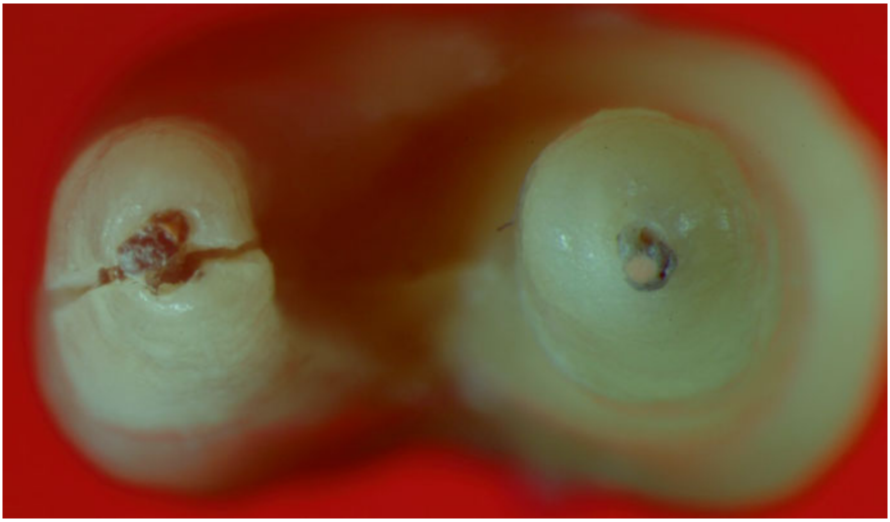

Fig. 4.12 Vertical root fracture in a buccal root of a maxillary bifurcated premolar. The buccal lingual direction of the complete VRF is shown extending to the bifurcation as well

flap reflection to examine bone and root patterns. It was determined that this exposure was the best and most reliable diagnostic approach for fracture confirmation. Vertical root fractures have consistent pathological patterns because of the potency of the irritants and the longitudinal nature of the fracture and accompanying inflammation. The inflammation stimulates bony resorption that is oblong and overlies the root surface. There is a visible "punched-out" bony defect taking the form of a dehiscence or fenestration at various root levels (Figs. 4.13, 4.14 and 4.15). Usually, the defect is cervical to apical but may be more limited. The defect is filled with granulomatous tissue.

After the granulomatous tissue is removed, the fracture is usually but not always visible on the root (Figs. 4.14 and 4.15). The operating microscope and application of a dye such as methylene blue are useful. If not readily obvious, the fracture may be very small or on a line angle of the root and tucked behind a bony ledge. Transillumination may be helpful as well. If the fracture line is still not visible, it is possible that this represents failed root treatment requiring surgical correction. An aggressive root end resection is then performed and the resected root end carefully examined. If a fracture line is still not identified, the root end surgery may be completed. The prognosis is questionable as the fracture may not extend as far as the level of resection and therefore not visible. If the fracture is an incomplete one on the lingual aspect of a maxillary premolar, it can be missed during endodontic surgery and will cause eventually unsuccessful results [34].

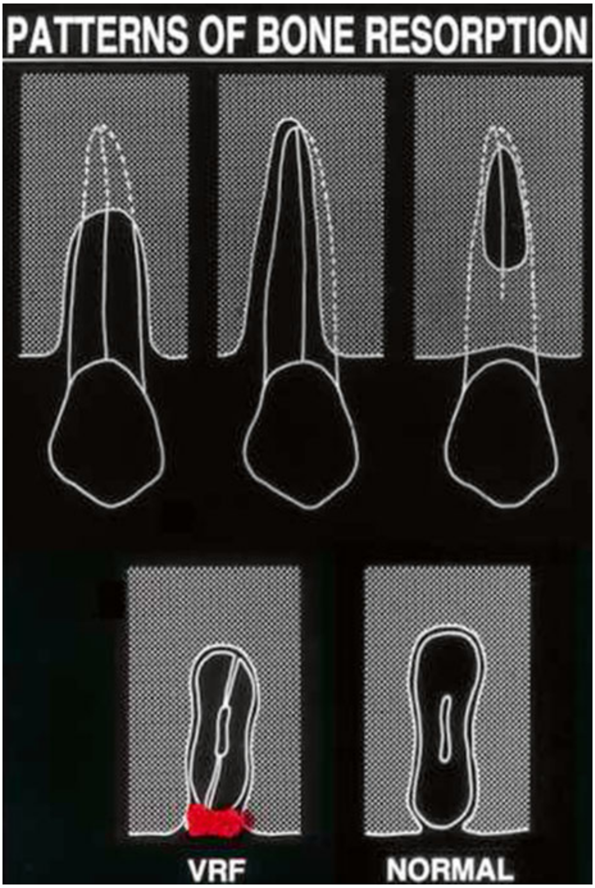

Fig. 4.13 The patterns of "punched-out" bony defects. *Lower left*: the red is the granulomatous inflammatory tissue within the defect. *Lower right*: a normal anatomic root exposure has thin bony margins and does not contain inflammatory tissue

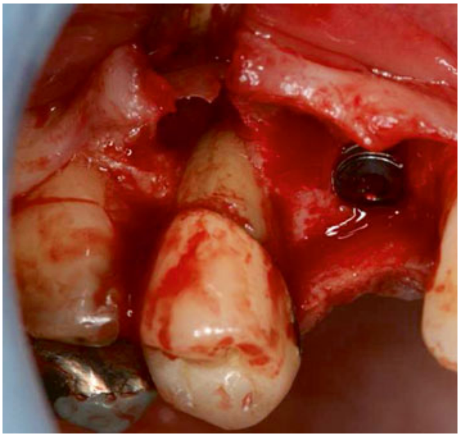

Fig. 4.14 Dehiscence. Flap reflection in a maxillary premolar demonstrates the bony dehiscence and the fracture line in the root after removal of granulomatous tissue (Courtesy Dr.E.Venezia)

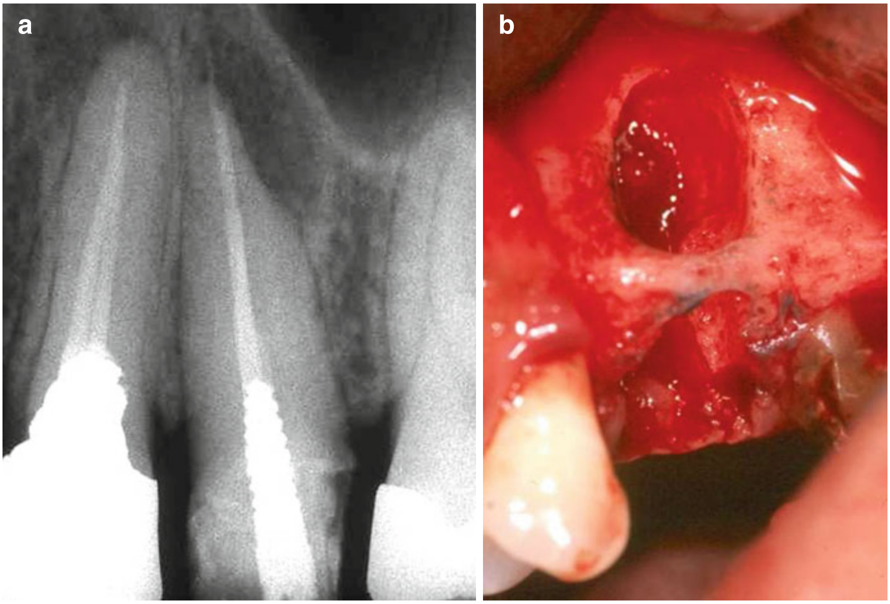

Fig. 4.15 Fenestration. (**a**) A second maxillary premolar with a typical “halo” radiolucency. There was no probing in this tooth, and upon surgical flap procedure and removal of the granulation tissue, a VRF was revealed. The tooth was extracted and the fenestration can be clearly seen (**b**)

Treatment Choices

The patient is informed prior to flap reflection that there are two alternatives if the fracture is identified. One is that the tooth or the root on a molar (root amputation) [35] (Fig. 4.16) is removed at that time (see also Chap. 6). The other approach is to delay extraction until a future appointment. Biologically, the best approach is immediate extraction as there will be further bone resorption if the fractured root is not removed. The future rehabilitation of the area of extraction will then be much more difficult (see also Chap. 7).

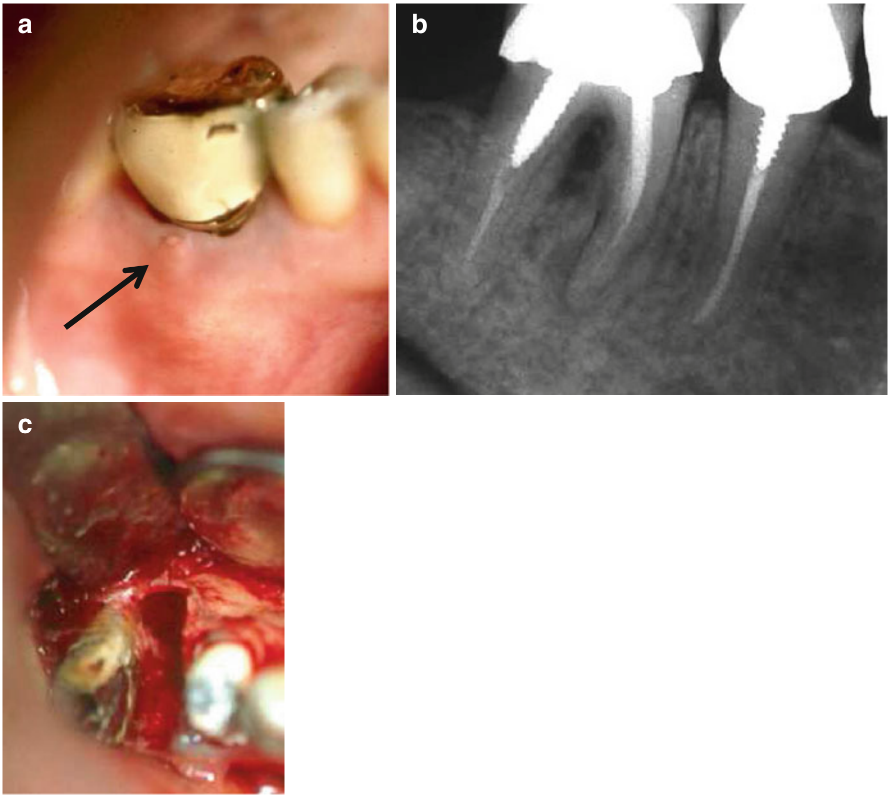

Fig. 4.16 Treatment option on a mandibular molar. (**a**) "pathognomonic combination" in a mandibular first molar. 9 mm probing in midbuccal area, and a cervicaly located sinus tract (*arrow*). (**b**) Periapical radiograph reveals combined bifurcation and "halo" radiolucency around the mesial root. (**c**) Following crown removal, the mesial root was amputated

Conclusions

Treatment of the vertical root fracture is straightforward most of the times but diagnosis is often challenging and has to be done accurately and in a timely manner. A series of findings is suggestive of a fracture. However, there are no noninvasive findings including subjective, objective, probing, radiographic, or clinical observations that are definitive. Certain combinations are indicative: deep probing defects, localized swelling, a sinus tract, and radiographic changes are very suggestive. Flap reflection has been shown to be the final and most reliable approach. The findings of dehiscences and fenestration bony defects filled with inflammatory tissue as well as the visualized fracture line are pathognomonic. The treatment is then extraction of the tooth if single rooted. As an alternative, if the tooth is multirooted, the fractured root may be removed, thus retaining the remainder of the tooth.

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5 Case Presentations of Vertical Root Fractures

Aviad Tamse

Abstract

A variety of clinical cases of vertical root fractures (VRFs) in endodontically treated teeth will be presented in this chapter. The importance in achieving accurate VRF diagnosis will be emphasized with figures and legends, and the clinical difficulties will be highlighted. The more typical cases will be presented, together with those in which the accurate VRF diagnosis was difficult to achieve. The importance of accumulating the most relevant information from the history of the involved tooth with meticulous clinical examination is shown in these clinical VRF cases.

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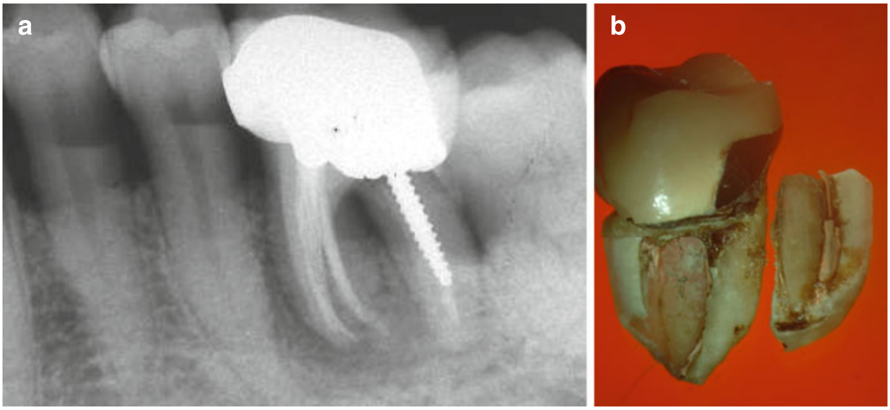

Fig. 5.1 (**a, b**) The patient arrived at the dental office with a chief complaint of recurrent abscesses in the past year. The left mandibular molar was tender to percussion and palpation, and cl II mobility was also noted. An 8 mm probing defect was recorded in the mesiobuccal area and 5 mm in the midbuccal. The periapical radiograph (**a**) showed a previously treated mandibular molar, gutta-percha–filled root canals, a Dentatus dowel in the distal root, an amalgam dowel in the mesial, and full coverage with a crown. There was bone loss in the bifurcation and at the coronal half of the distal root. The mesial root was surrounded by a radiolucent lesion. A VRF was suspected and the tooth extracted. The typical buccolingual fracture can be seen in Fig. 5.1b

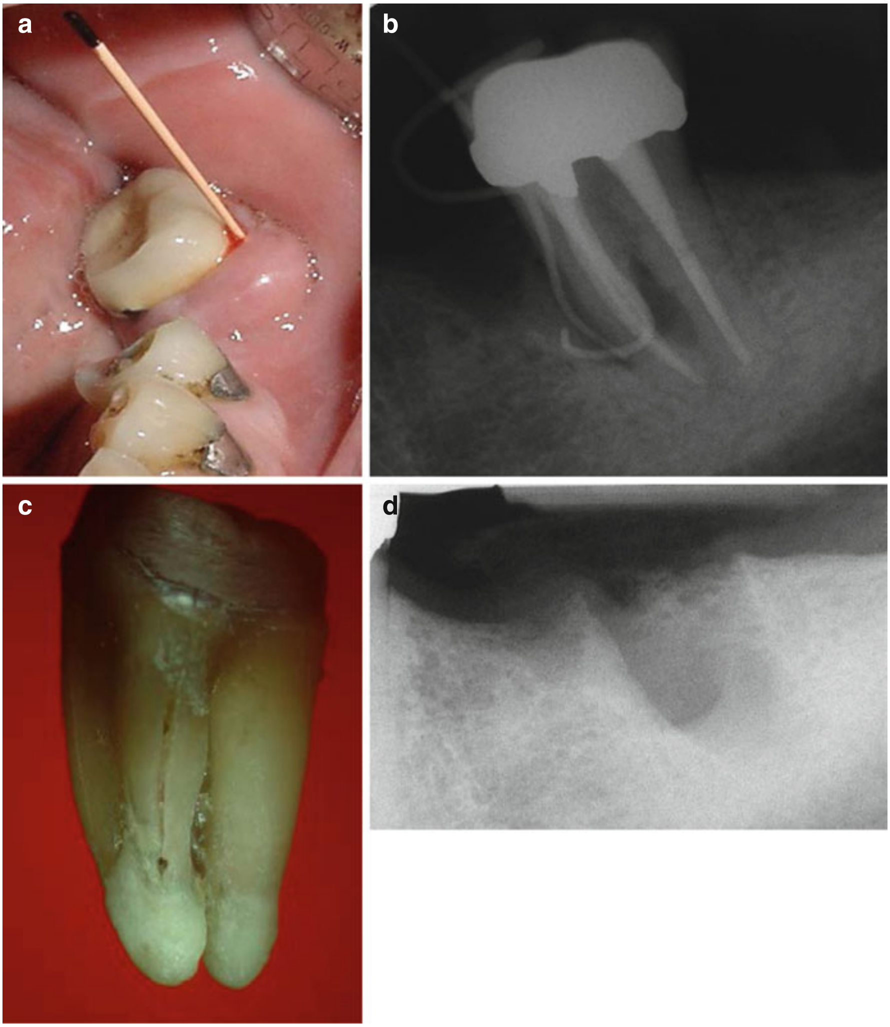

Fig. 5.2 (**a**–**d**) The patient arrived at the dental office with "soreness on biting for the last couple of months and a swelling in the area about a year ago." The first mandibular molar was extracted 5 years earlier but only the second molar endodontically treated, restored with amalgam dowels in the coronal 3 mm of the two roots and a crown (**a**). Clinical examination revealed sensitivity to percussion and two 8 mm probing defects both in the buccal and lingual aspects. The periapical radiograph (**b**) shows two gutta-percha tracing cones at the bone resorption area in the coronal two-thirds of the mesial root. A VRF diagnosis was made and the tooth extracted. In the extracted tooth (**c**), the fracture in the coronal two-thirds of the mesial root can be seen. A periapical radiograph of the extracted site (**d**) shows the amount of bone loss in the bone as a result of the continuous inflammatory process in the area (Courtesy Prof. J. Nissan)

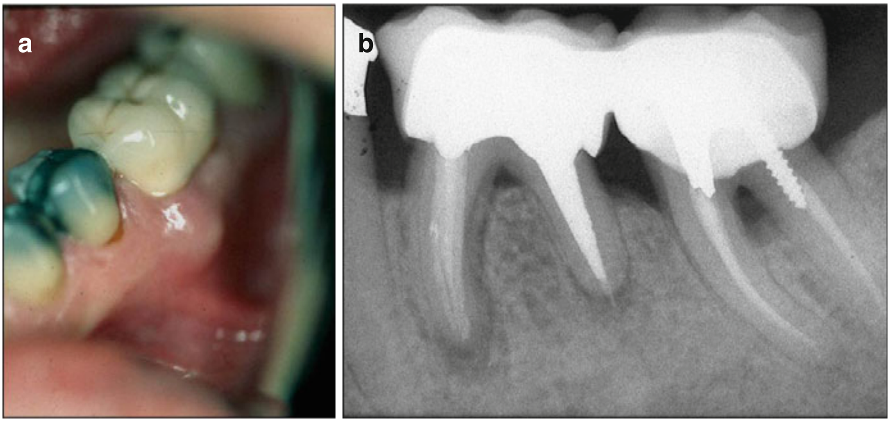

Fig. 5.3 (**a, b**) A patient with severe periodontal problems who was evaluated for periodontal surgery arrived at the office with a small swelling adjacent to the mesial root area (**a**). The mandibular left first molar was endodotically treated 7 years previously and restored afterward. Probing depth around the tooth was 5 mm in the midbuccal and 4 mm in the mesiobuccal area. The radiographic appearance of the radiolucency around the mesial root which most likely was of an endodontic origin (**b**) and swelling in the gingivae adjacent to the mesial root pointed to a VRF. However, in this periodontally involved patient, the final diagnosis was an acute apical abscess (Courtesy Dr. J Halpern)

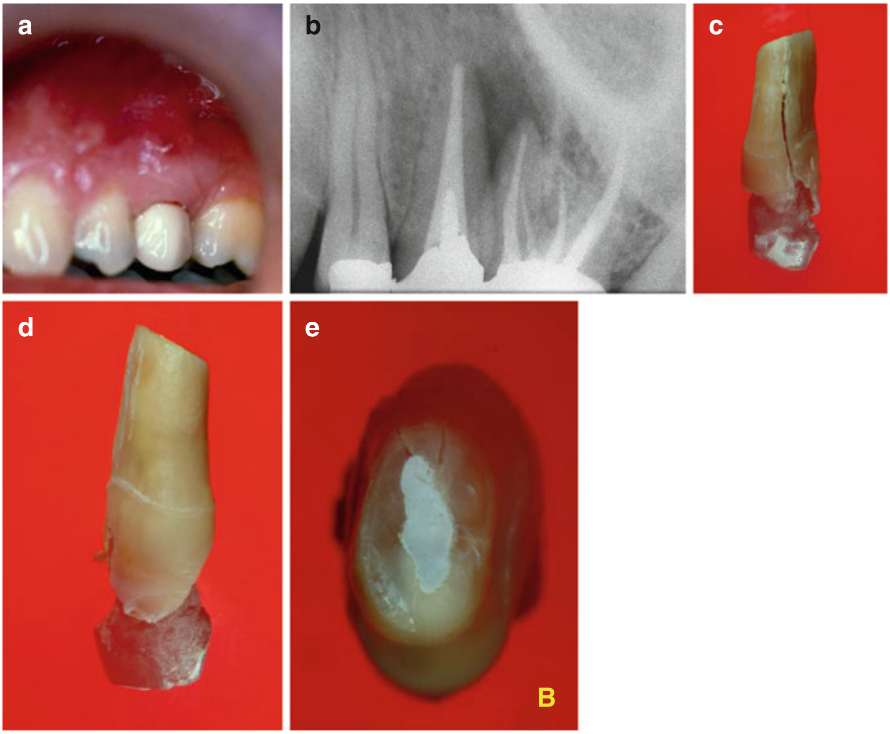

Fig. 5.4 (**a**–**e**) A patient arrived at the dental office with a complaint of “draining pus from the gum” in the upper jaw. Clinical examination revealed a veneer crown in the second premolar that was endodontically treated and restored at the same time with the maxillary molar adjacent to it (**a**). A highly located sinus tract was noted, but the probing numbers were between normal limits. Endodontic treatment appeared adequate in the radiograph (**b**), but a large radiolucent area can be seen laterally in the distal aspect of the premolar tooth involving the mesiobuccal root of the maxillary molar. Poor outcome of the endodontic treatment either in the maxillary premolar (chronic apical abscess) or the mesiobuccal root of the molar led to the treatment plan of endodontic surgery either in the premolar or the mesiobuccal root or both. Endodontic surgery was performed in the maxillary premolar with IRM as a retrograde filling material. At 12 months post-op, the patient returned with an acute abscess, and the premolar was extracted. A VRF was noted in the buccal aspect (**c**), but it was of the incomplete type since it was not seen in the buccal aspect (**d**). In the apical view (**e**), the incomplete VRF can be seen in the palatal aspect but not in the buccal one. Most likely, the incomplete VRF on the palatal aspect was not noticed during surgery

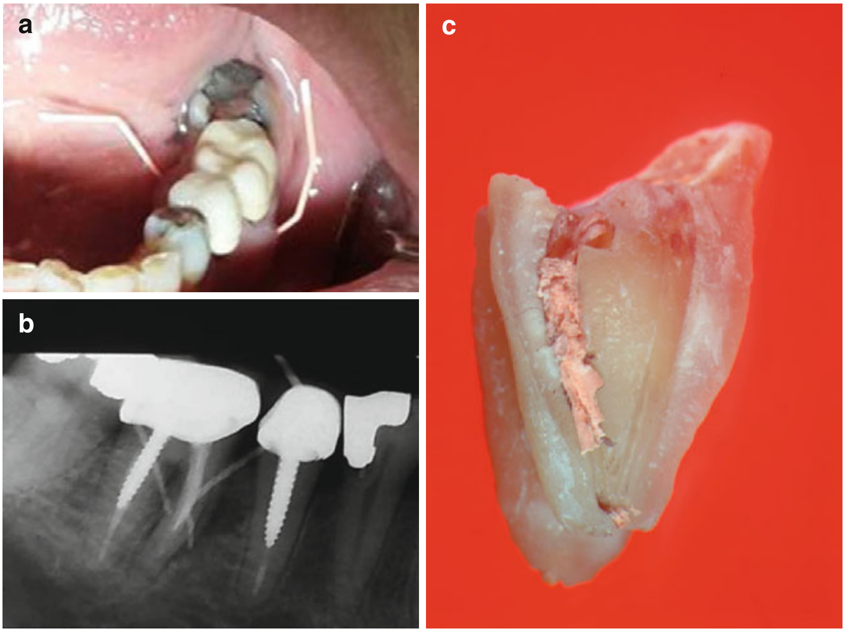

Fig. 5.5 (**a**–**c**) The mesial root of the mandibular molar showing two gutta-percha tracings from the buccal and lingual sinus tracts (**a**). Radiograph (**b**) shows the wide lateral radiolucency on the mesial root aspect. Also, there is radiolucency in the bifurcation. After VRF diagnosis and extraction, the crown was removed, and one part of the mesial root can be seen with some of the gutta-percha filling (**c**) (Courtesy Dr. A. Aronovich)

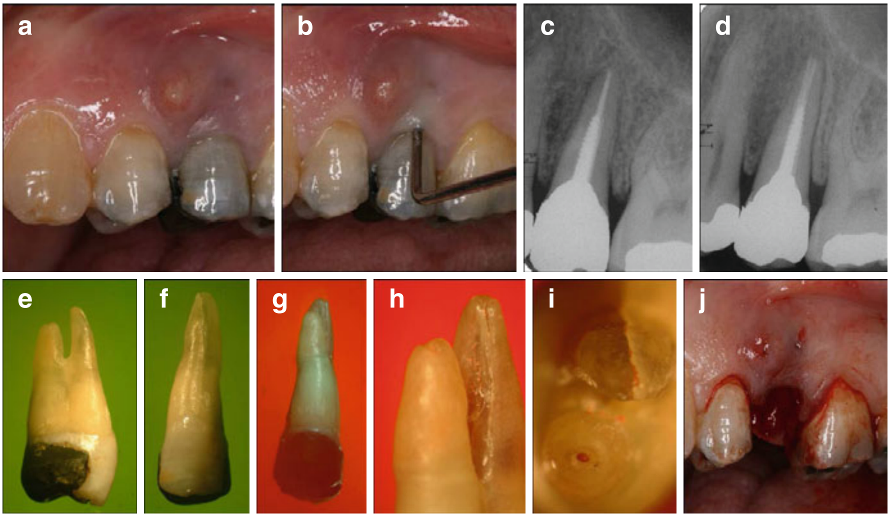

Fig. 5.6 (**a**–**j**) A patient arrived at the dental office with a complaint of a "lump in the gum" for several months (**a**). From the case history, it was revealed that the maxillary second premolar was endodontically treated 3 years earlier and Dentatus and a large amalgam restoration followed thereafter. Clinical evaluation revealed a highly located sinus tract (**a**, **b**), and a narrow midbuccal 7 mm probing defect was noted (**b**). A small isolated lateral radiolucency on the mesial aspect was noted along the root (**c**, **d**). A VRF diagnosis was made and the tooth extracted. It was a bifurcated maxillary premolar (**e**) of which only the buccal root was fractured (**f**) but not the lingual one (**g**). A closer examination of the two roots shows the typical depression on the bifurcation aspect of the buccal root (R) along with the apicocoronal VRF. A closer look at the two apices (**i**) the complete buccolingual VRF on the buccal root. After tooth extraction, the typical bony dehiscence, which faced the fracture in the buccal root, is reflected as triangular flabby attached gingivae (**j**) (Courtesy Dr. E. Venezia)

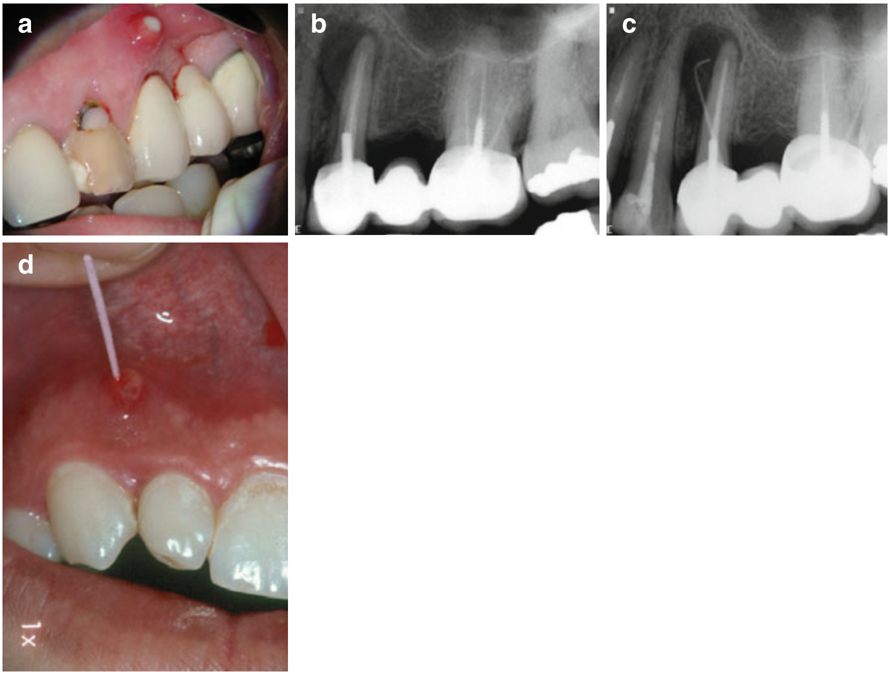

Fig. 5.7 (**a**–**d**) The patient arrived at the dental office with a chief complaint of "a lump in the gum that comes and goes." Upon examination, a highly located sinus tract was noticed in the second premolar attached gingivae (**a**) with some pus extruding on slight pressure. A narrow 9 mm probing defect was noted in the buccal aspect and no probing noted in the palatal side. The periapical radiograph revealed that the tooth was used as a mesial abutment for a three-unit bridge and that both the second premolar and first molar were endodontically treated (**b**). A large "halo"-type radiolucency can be seen in the mesial root aspect extending from the root tip of the root laterally to the coronal part. A gutta-percha tracing through the sinus tract extends to this area (**c**). In patients with chronic apical abscess in non-VRF cases, the sinus tract is located in the gingivae much closer to the apical area (**d**). The patient had clinical signs and symptoms that are pathognomonic for the diagnosis of VRF (**a**–**c**) (Courtesy Dr. R. Paul)

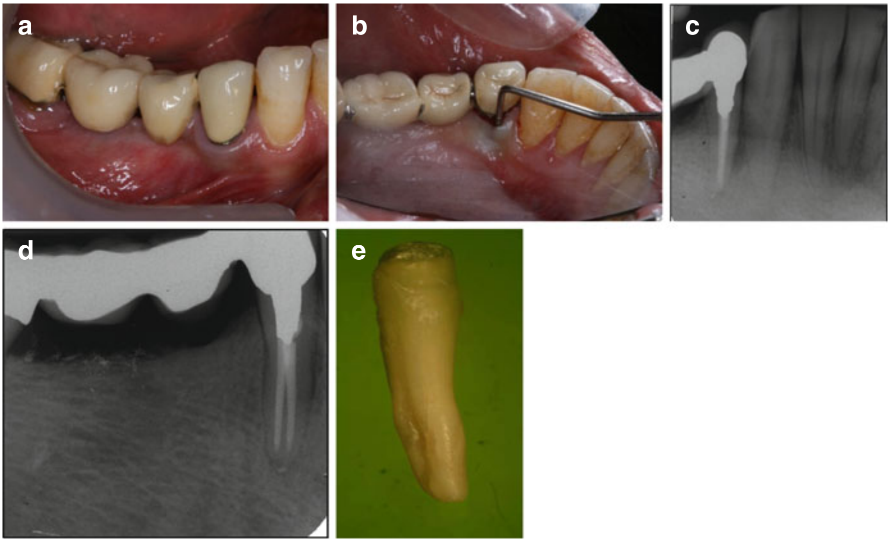

Fig. 5.8 (**a**–**e**) The mandibular first premolar was used as a mesial abutment for a four-unit bridge (**a**). The patient presented for a routine examination with no symptoms. Upon examination, a 7 mm probing defect was found on the lingual gingivae (**b**). There was no probing on the buccal aspect. The radiographs (**c**, **d**) revealed two well-condensed canals with gutta-percha and a wide metal post in the coronal part of the root. A lateral radiolucent area can be seen next to the middle third of the root in the mesial aspect. Since these signs were not present when the endodontic and restorative procedures were performed 6 years earlier, a diagnosis of asymptomatic apical periodontitis was made and the tooth extracted (**e**). A hairline fracture can be seen on the lingual aspect. As demonstrated in this case, the use of a mandibular or a maxillary sole abutment for a bridge is highly inadvisable due to the large horizontal and torquing forces during function (Courtesy Dr. E. Venezia)

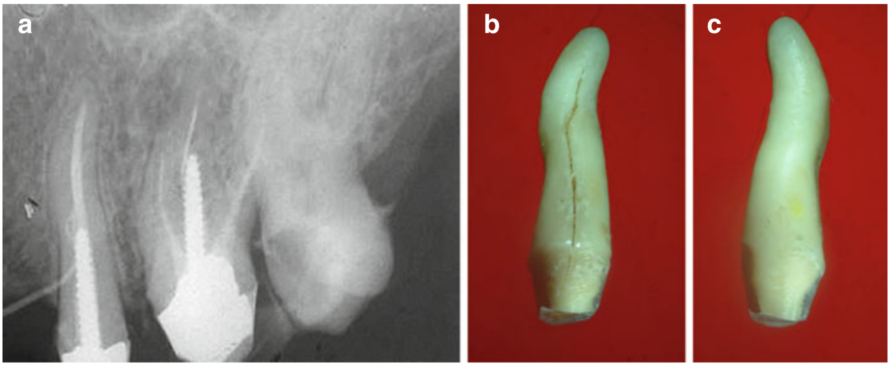

Fig. 5.9 (**a**–**c**) The patient arrived at the dental office for a re-examination to replace two temporary crowns with permanent ones. Root canal treatment was performed 16 months earlier in a maxillary premolar, restored with a dowel and a temporary crown as well as in the maxillary molar. No radiolucencies in the bone surrounding the tooth could be detected in the radiograph (**a**). The patient initially declined to return to continue the restorative procedures. However, when he did return, there was a 9 mm probing defect in the midbuccal root and a highly located sinus tract. The gutta-percha tracing cone can be seen in the radiograph. The tooth was extracted. The incomplete VRF was found in the buccal side (**b**) but not in the lingual side (**c**)

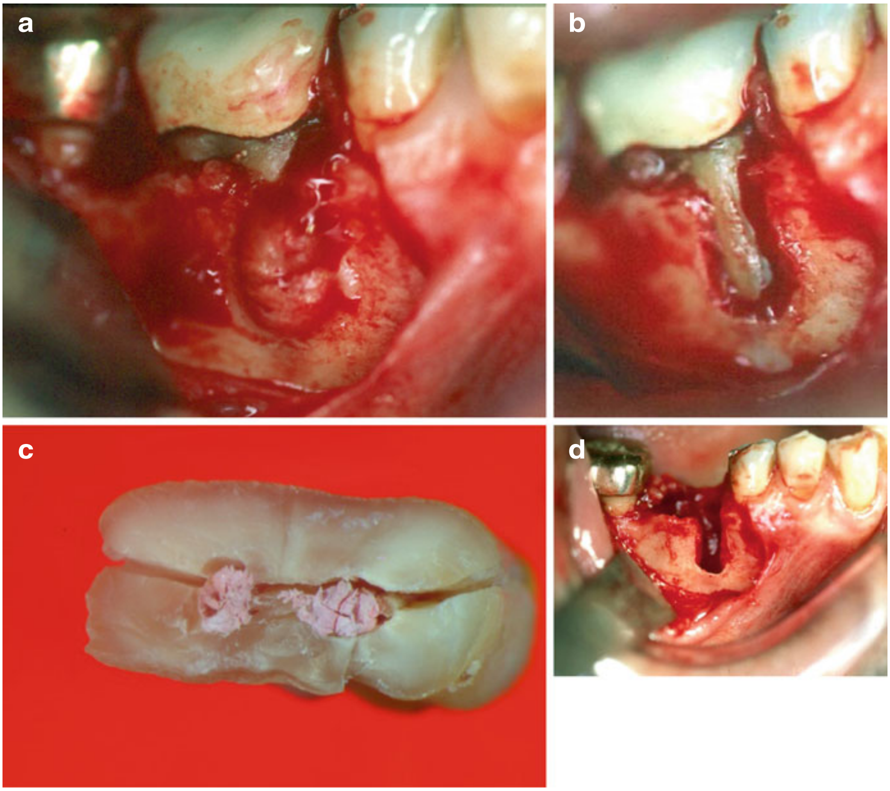

Fig. 5.10 (**a**–**d**) A large granulation tissue was seen when an exploratory flap procedure was performed to confirm a tentative diagnosis of a VRF in a mandibular first molar (**a**). After the granulation tissue was removed, a large dehiscence was seen in the buccal plate (**b**). Although the VRF was complete (all the way from buccal to lingual) (**c**), the large dehiscence was in the buccal plate as it was originally thinner than the lingual one (**d**)

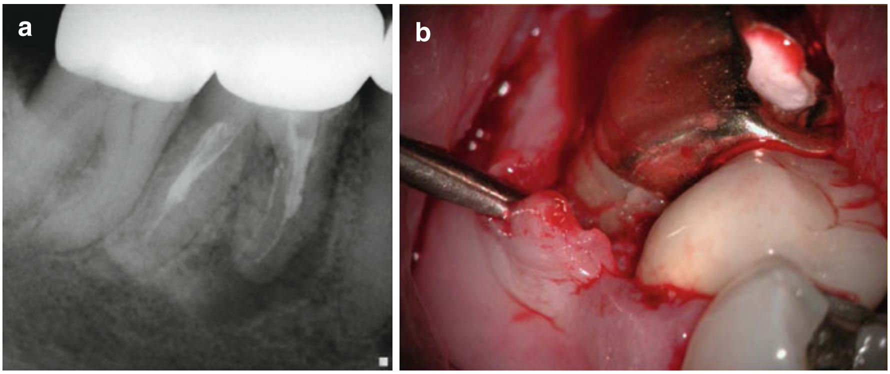

Fig. 5.11 (**a**, **b**) Mandibular first molar during retreatment. Following removal of the gutta-percha, calcium hydroxide was placed in the root canal. There was no probing; however, the" halo" radiolucency around the mesial root was suggestive for VRF (**a**). Upon probable flap reflection (**b**), the fracture can be seen in the mesial root (Courtesy Dr. R. Paul)

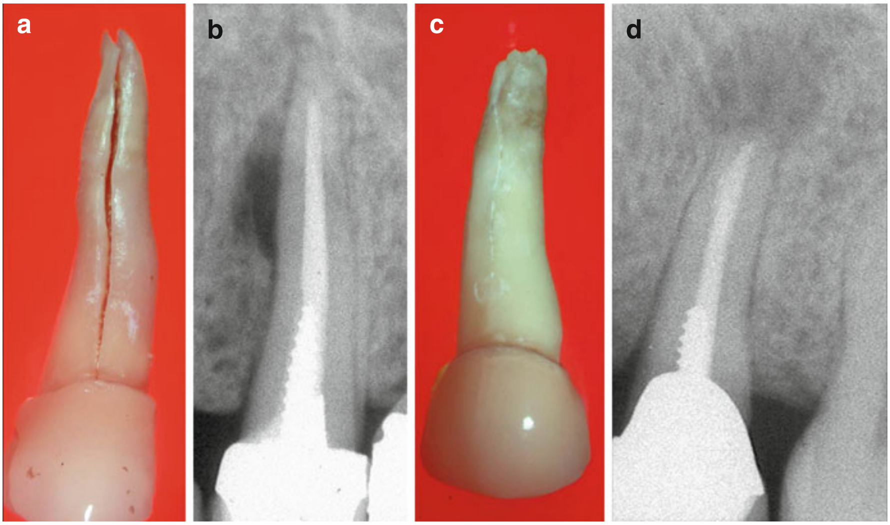

Fig. 5.12 (**a**–**d**) Two longitudinal VRFs are presented. The segments are separated as in Fig. 5.12a, and the parts are still attached to each other in the other extracted tooth as in Fig. 5.12c. Although both VRFs are to the full length of the root, the radiolucency in the bone in case (**a**) is limited to the lateral part of the middle third of the root (**b**), and in the tooth (**c**), the radiolucency is limited to the periapical area (**d**), which is not typical to a vertically fractured tooth but rather to the failure of root canal treatment

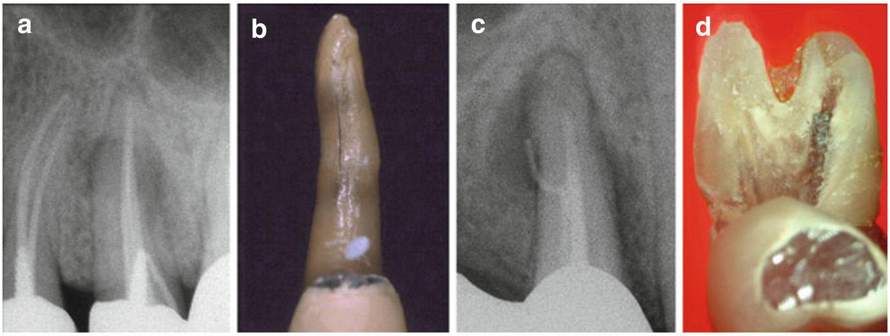

Fig. 5.13 (**a**–**d**) Bony radiolucencies are seen in the mesial and distal lateral aspects of the middle third of the roots in two maxillary premolars (**a**, **c**). However, the types of fractures are different. In Fig. 5.13b, the fracture is limited to the middle third of the root, whereas in (**d**), the fracture is completely buccolingual

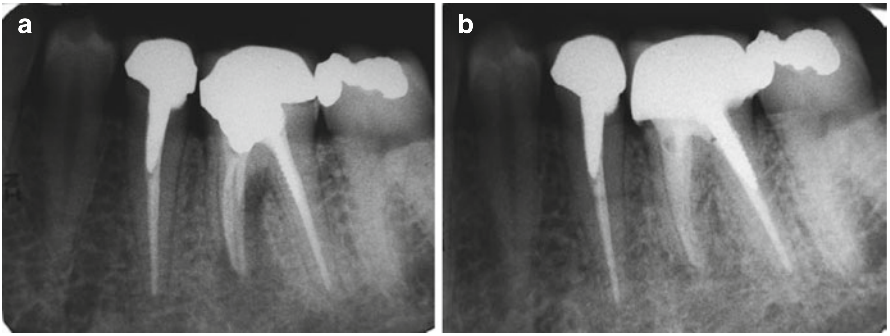

Fig. 5.14 (**a**, **b**) The need for meticulous clinical examination to achieve accurate VRF diagnosis is emphasized in Figs. 5.14, 5.15, and 5.16. A periapical radiograph shows well-condensed gutta-percha filling in the mesial root of a mandibular molar, an amalgam dowel, and typical “halo” radiolucency around the mesial root combined with radiolucency in the bifurcation. Since there were no other signs or symptoms to make a VRF diagnosis, a diagnosis of asymptomatic apical periodontitis was made and the patient scheduled for retreatment (**a**). Complete healing of the radiolucency can be seen 1 year after retreatment (**b**) and a new restoration (Courtesy Dr. Z. Elkes)

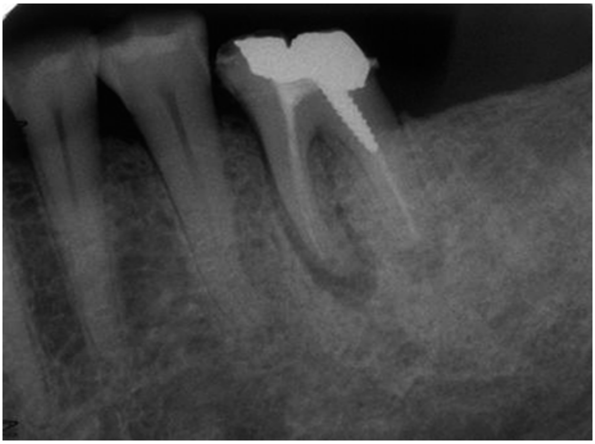

Fig. 5.15 Typical bony appearance of a “halo” radiolucency in a poorly filled mandibular molar, combined with radiolucency in the bifurcation. Other signs and symptoms typical to a VRF tooth led to the accurate diagnosis of VRF (Courtesy Dr. T. Blazer)

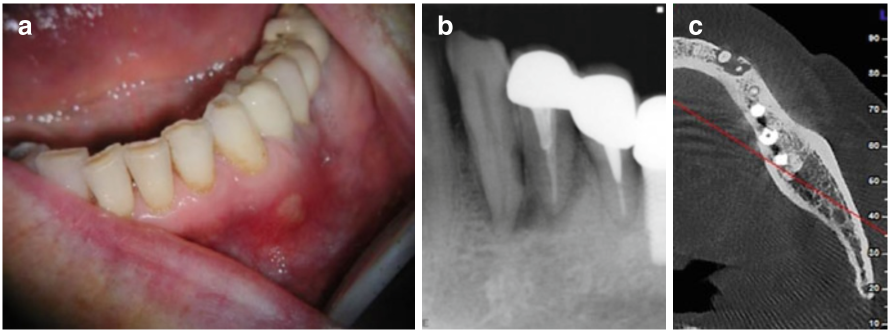

Fig. 5.16 (**a**–**c**) The patient arrived at the dental office for evaluation regarding tenderness on "touching the gum in the lower jaw." Clinical examination (**a**) revealed two connected crowns in the first and second premolars next to implants in the posterior region. A highly located sinus tract was seen in the attached gingivae adjacent to the first premolar. The area was sensitive to palpation but no probing defect noted. The periapical radiograph (**b**) revealed a diffuse radiolucent bony lesion on the mesial and distal aspect of the root that was suspicious to be more typical to a VRF than of failure of root canal treatment. The canine tested vital. The large bony defect seen in the axial slices of the CBCT Scan (**c**) (this slice in the apical 2 mm) resulted in a diagnosis of chronic apical abscess, and the tooth was extracted. The extracted tooth did not reveal any fracture (Courtesy Dr. R. Paul)

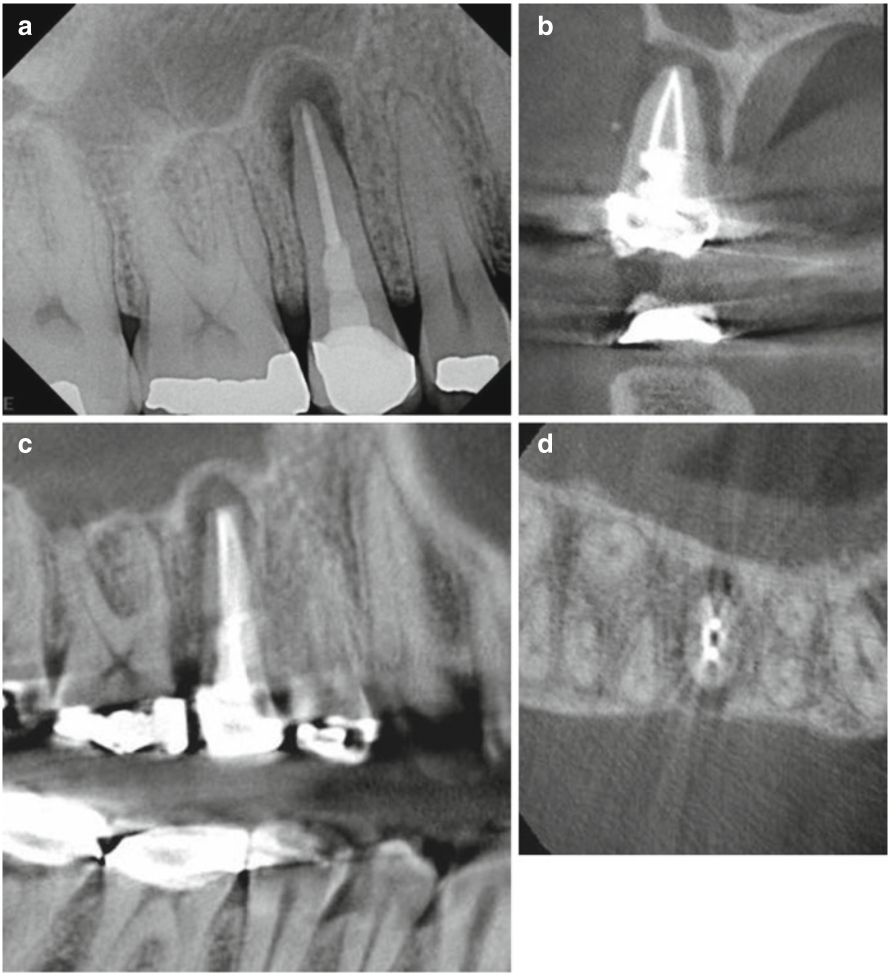

Fig. 5.17 (**a**–**d**) A periapical radiograph of a VRF tooth in a maxillary second premolar (**a**). Note the typical "halo" radiolucency around the root. With CBCT imaging, the radiolucency around the root can be seen in the coronal (**b**), sagittal (**c**), and axial (**d**) images. What can be observed is the bone loss around the root but not the fracture itself (Courtesy Dr. R. Ganik)

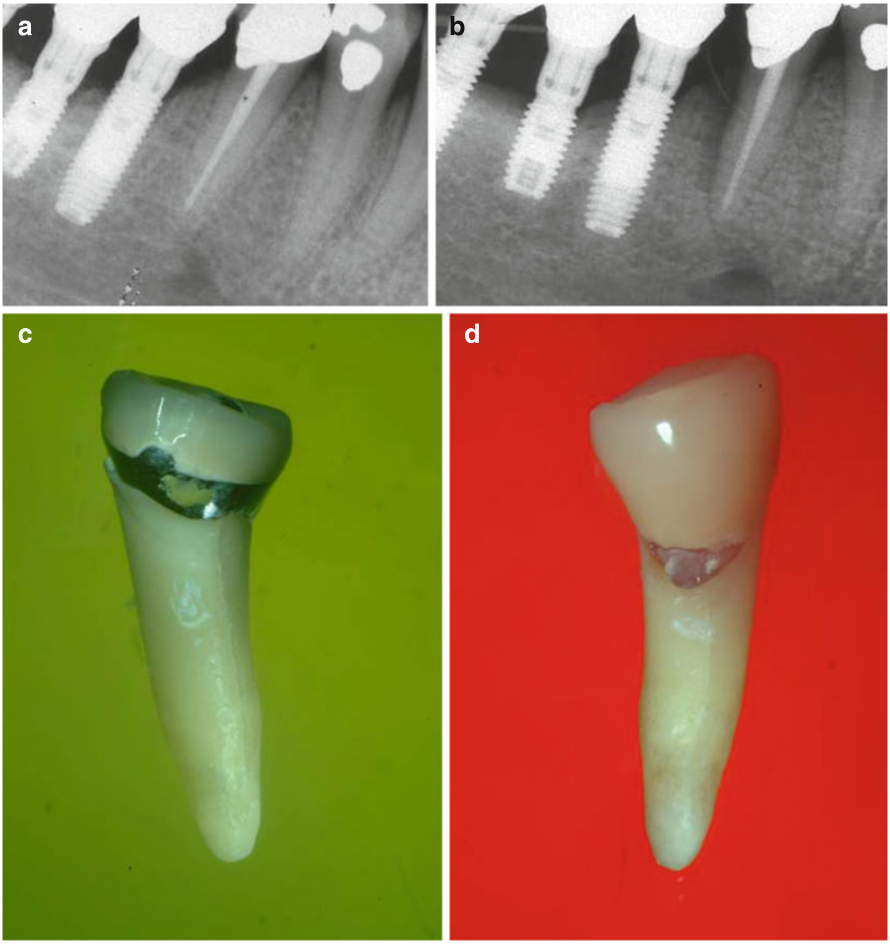

Fig. 5.18 (**a**–**d**) Five years following root canal treatment as a result of symptomatic irreversible pulpitis in a mandibular premolar (**a**), signs and symptoms of a VRF in this tooth were diagnosed (**b**). A lateral radiolucency along the distal aspect of the root can be seen, together with a No. 20 gutta-percha tracer via a highly located sinus tract. The utmost importance of urgent tooth extraction was explained to the patient to prevent bone loss adjacent to the tooth, especially in such proximity to the implants (**b**). The extracted tooth shows a complete narrow fracture both at the lingual (**c**) and buccal (**d**) aspects of the tooth

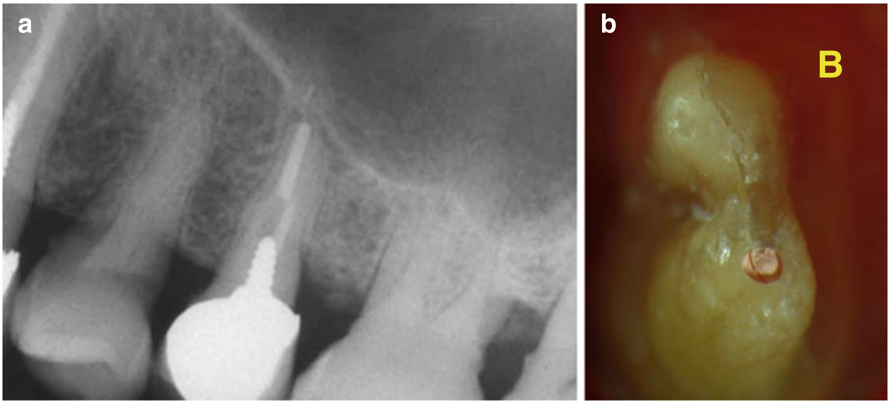

Fig. 5.19 (**a**, **b**) The patient arrived at the dental office with a complaint about discomfort in "touching the tooth and when biting" and pointed to the maxillary second premolar. The tooth had been endodontically treated 4 years previously with gutta-percha, passive cementing of a serrated dowel in the palatal canal, and full coverage to the crown. Examination of the tooth revealed sensitivity to percussion and a 6 mm probing depth in the midbuccal area. The radiograph revealed two obturated canals and the dowel most likely placed in the palatal canal (**a**). A diagnosis of acute apical periodontitis was made. Since the endodontic prognosis for retreatment was poor, endodontic surgery procedure was suggested. The patient declined any surgery, and the tooth was extracted. Examination of the extracted tooth from the apices (**b**) shows the deep mesial concavity in the root trunk and the incomplete VRF from the buccal aspect toward the palatal area of the root

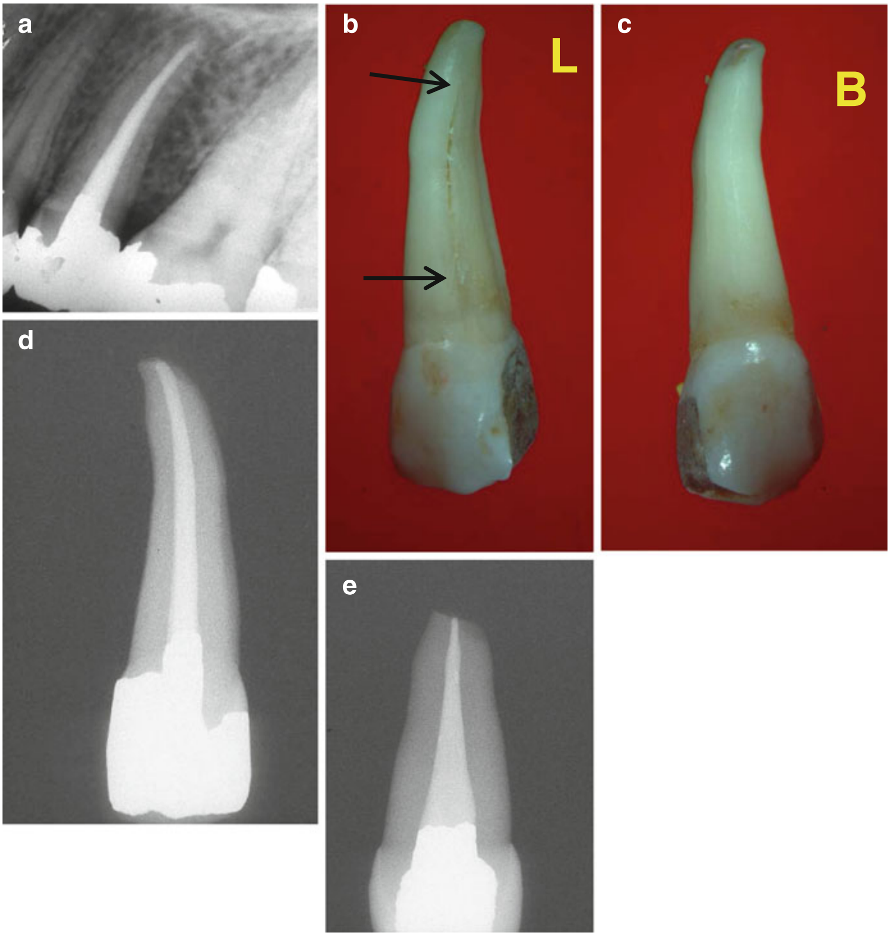

Fig. 5.20 (**a**–**e**) Root canal therapy was performed on a maxillary second premolar as a result of chronic irreversible pulpitis. The root canal was obturated with laterally condensed gutta-percha (**a**). Shortly afterward and for several months, the patient complained of tenderness on biting. On clinical examination, the only sign noted was sensitivity to percussion. No probing, mobility, or bony radiolucency was noted even when the patient was examined 4 months post-op. The patient declined any further treatment, such as endodontic surgery. The tooth was extracted and cleaned. A VRF was found in the middle third of the palatal aspect of the root (*Arrows*) (**b**) but not in the buccal aspect (**c**). The well-obturated premolar can be seen in the bench periapical radiographs (**d**, **e**). This partial midroot palatal VRF could not be clinically diagnosed. This expresses the difficulties clinicians encounter in making accurate and timely VRF diagnosis (Courtesy Dr. Z. Elkes)

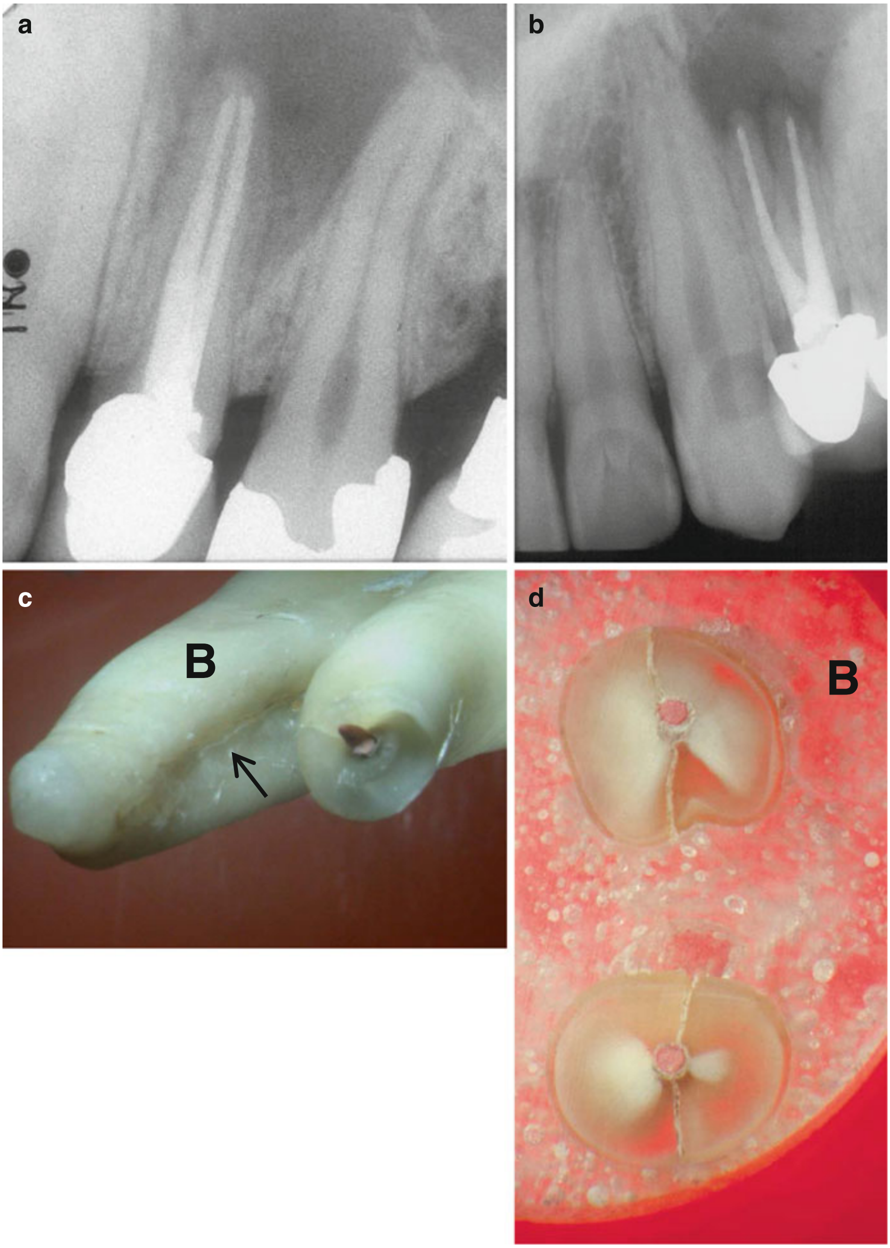
a
b
c
B
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Fig. 5.21 (**a**–**d**) Patient history revealed that 5 years prior to arriving at the dental office, root canal therapy was performed on the maxillary first premolar with an amalgam dowel and PFM crown. The patient's chief complaint was tenderness on biting and a "loose tooth." The patient also experienced two episodes of swelling in the area over the past 3 years. Clinical examination revealed slight mobility, sensitivity to percussion, and a 7 mm probing defect on the midbuccal area. The first periapical radiograph revealed a well-obturated root canal and large "halo" radiolucency (**a**). An additional radiograph with a slight change in angulation showed (**b**) this tooth to be a bifurcated maxillary premolar. When a VRF is suspected it is highly recommended to take two periapical radiographs from different angulations. There was no sinus tract in the attached gingivae, and a definitive diagnosis of a VRF tooth could not be done. The patient declined a surgical flap procedure for final diagnosis and treatment. The tooth was extracted (**c**). The typical depression on the bifurcation aspect of the buccal root with the longitudinal fracture along the depression can be seen in this image following some shaving of the palatal root (*black arrow*). In one of the cross sections done (**d**), complete VRF from one side of the root to the other can be seen in both roots. The typical depression in the buccal root can also be seen

Acknowledgments To Dr J. Lustig for his continuous inspiration and professional support and to

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Pathogenesis of the Vertical Root Fracture

6

Richard E. Walton and Eric Rivera

Abstract

When a vertical root fracture reaches the outer surface of the root, it communicates with the periodontal ligament, and an inflammatory process begins in this area. On communication with the oral cavity through the gingival sulcus, foreign material and bacteria obtain access to the fracture area. The inflammatory process increases with a slow separation of the fractured parts of the root and a breakdown in the periodontal ligament and the alveolar bone. Consequently, granulomatous tissue is formed, and bone subsequently resorbs with typical features such that most are clinically manifested. This chapter will describe the histopathological features of the hard and soft tissues associated with vertical root fractured teeth, including the various tissues and elements involved.

Introduction

A vertical root fracture (VRF) is not an uncommon complication in root canal–treated teeth [1, 2]. This results in major damage to the periodontium. There is substantial clinical evidence that this vertically aligned fracture also generates primarily a vertical destructive lesion of the supporting structures [3, 4]. This damage includes both the soft tissues and the adjacent alveolar bone [5]. Destruction may occur slowly but is often rapid and profound. The clinical signs, symptoms, and findings are such that a periodontal disease-type lesion is often a first impression

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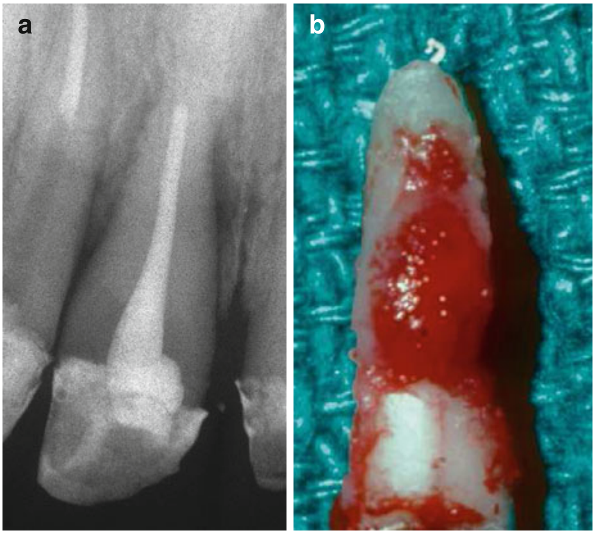

Fig. 6.1 A deep probing defect on the buccal aspect of the root in an endodontically treated maxillary central incisor. The radiograph (**a**) shows lateral radiolucencies in the mesial and distal aspect of the root. The extracted tooth (**b**) shows the inflammatory tissue attached to the root

[6]. When a VRF is diagnosed clinically, the clinical evidence is that the fractured root cannot predictably be repaired and salvaged [7, 8].

Observations following flap reflection and/or tooth or root removal as the result of VRF show an inflammatory lesion adherent to the root surface directly overlying the fracture (Figs. 6.1 and 6.2).

Why is the destruction so profound? Currently, there is one published study [9] that examined fractured roots and adherent tissues histologically. Specimens were studied to ascertain the pattern of the fractures and to clarify the nature and the location of irritants that were associated with the fracture. In addition, the inflammatory lesions were examined as to the nature and pattern of inflammation. These findings from this study [9] are the primary basis of information for this chapter. In this study [9], roots with clinically identified fractures were obtained following tooth extraction or during exploratory surgery (Figs. 6.3 and 6.4).

More about the surgery flap procedure as a clinical adjunct to help diagnose VRF is described in Chapter 4.

The specimens were fixed in formalin, decalcified, embedded in paraffin, and cross sectioned. Histological sections were stained with H&E to identify general characteristics; alternate sections were stained for bacteria. Regions studied with the light microscope were from the cervical, middle, and apical thirds.

The histology showed patterns of the fractures in the root. Also demonstrated was that the canal and fracture spaces contained combinations of irritants that were etiologies for the inflammatory lesions that overlaid the root surface.

The characteristics of the fractures were important and followed a general pattern but with variations. These types are demonstrated in Chap. 2 on categorization.

All were in a buccolingual plane. Most extended to both surfaces (complete fractures), but some were to one surface only (incomplete fractures) (Figs. 6.5a–c and 6.6a, b).

All the fractures communicated with a canal or canals. Most fractures were likely "old" because they contained an ingrowth of vital tissue. Another indicator that the

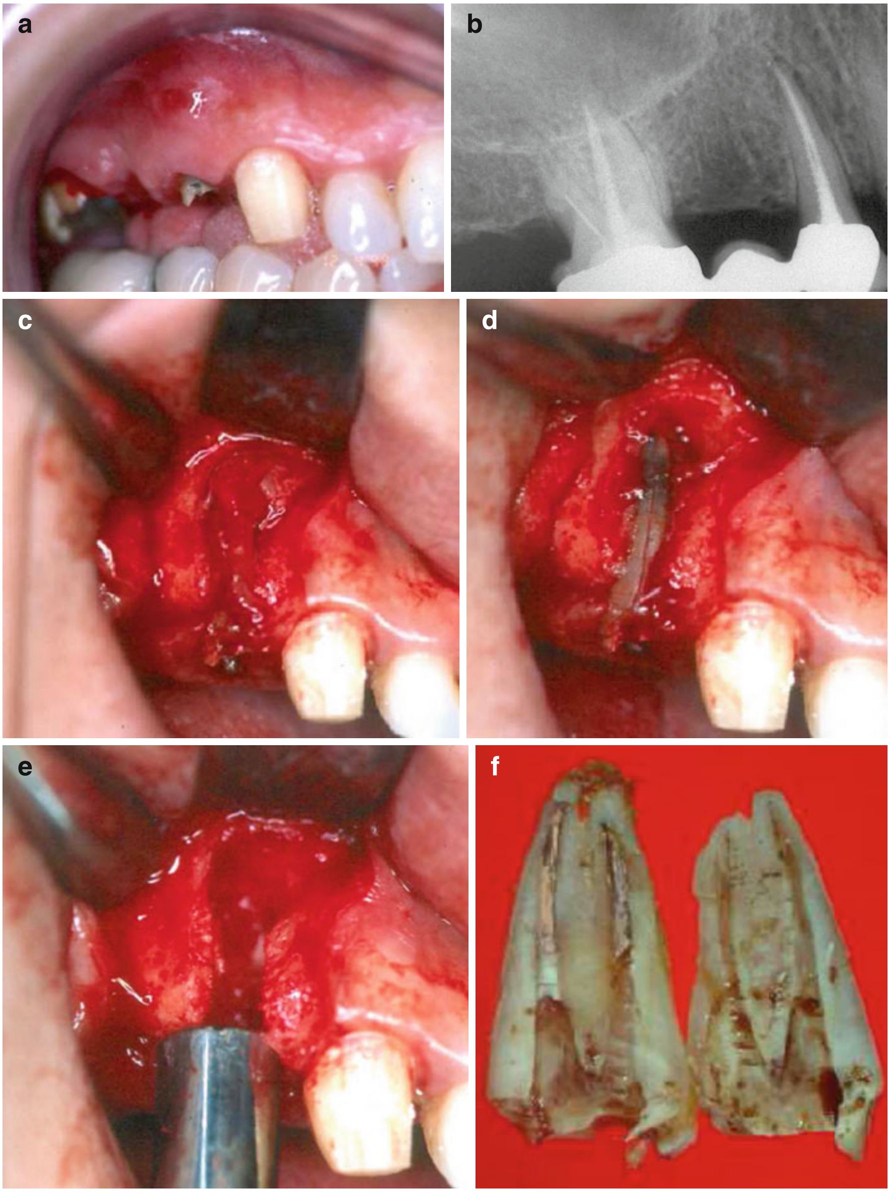

Fig. 6.2 (**a**–**f**) Patient presented to the dental office with a complaint of a "loose bridge" and "suppuration from the gingivae." The maxillary first premolar was used as an abutment together with the maxillary canine (**a**). The probing defect was not contributory. The periapical radiograph (**b**) revealed widening of the PDL on the mesial aspect of root. Since the diagnosis of VRF was not conclusive, it was decided to perform surgical flap procedure for diagnosis and treatment. When the flap was performed, a large bony dehiscence was seen (**c**) filled with granulation tissue. After removal of the inflammatory tissue, a VRF was seen from the coronal part to the apical (**d**). The dehiscence of the buccal bone which was facing the fracture can be seen very clearly (**e**). The fracture was a typical buccolingual fracture, and the root was extracted in two parts (**f**) (Courtesy Prof. A. Tamse)

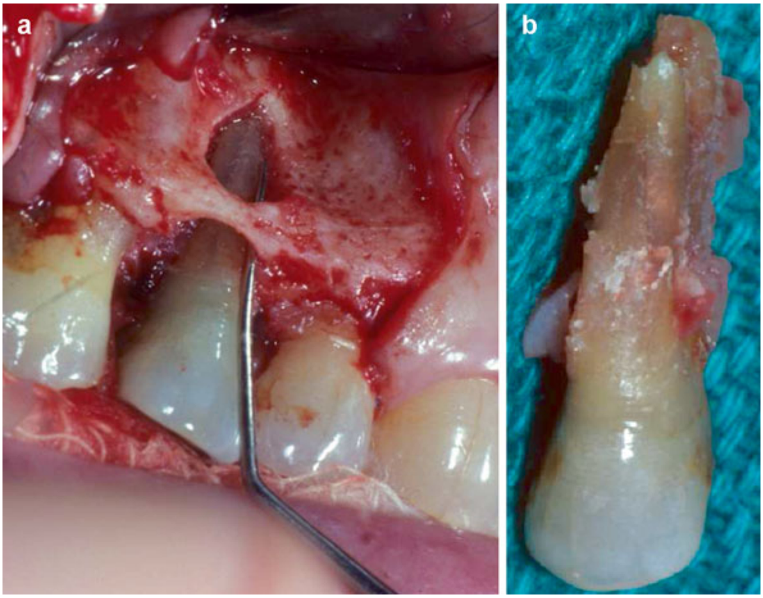

Fig. 6.3 (**a, b**) A large fenestration can be seen upon flap procedure performed on a maxillary lateral incisor (**a**). The inflammatory tissue can be seen attached to the fractured root (**b**)

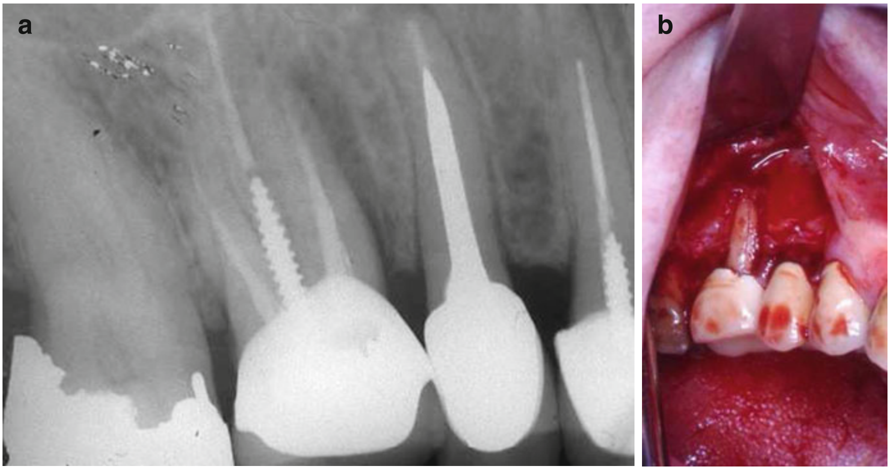

Fig. 6.4 (**a**, **b**) Patient's chief complaint in this case was "I have an abscess that comes and goes for nearly a year." The tooth was endodontically treated 4 years earlier and a crown placed. Upon examination, a 10 mm probing defect was measured in the mesiobuccal aspect. The radiograph (**a**) shows a previously treated maxillary first molar and a large lateral radiolucency along the mesiobuccal root. Since there was no sinus tract and VRF diagnosis was inconclusive, a surgical flap procedure was performed (**b**). A complete bony dehiscence can be seen which was the result of a long-standing inflammation in the area facing the fracture (Courtesy Prof. A. Tamse)

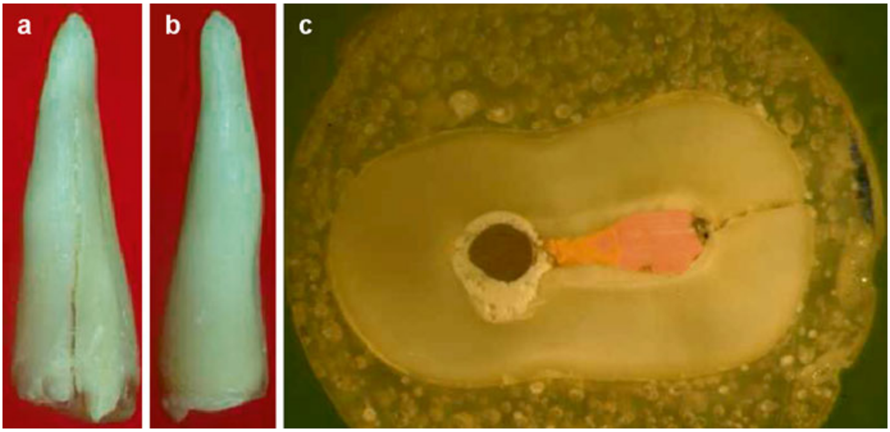

Fig. 6.5 An incomplete VRF in an extracted maxillary premolar due to a VRF. The fracture can be seen in the buccal aspect of the root (**a**) but not in the palatal one (**b**). Cross section of the root (**c**) demonstrates the incomplete fracture from the root canal to the external buccal surface (Courtesy Prof. A. Tamse)

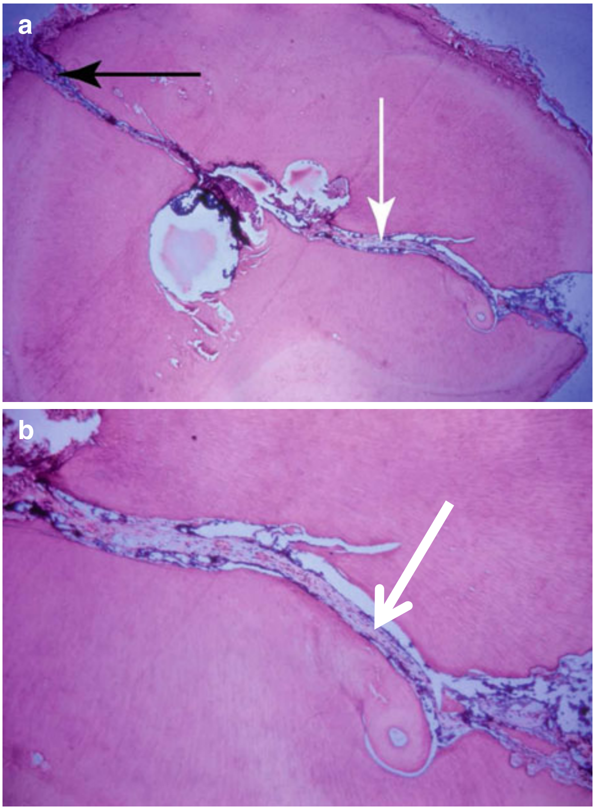

Fig. 6.6 (**a**, **b**) A histological section of a vertically fractured single-rooted maxillary premolar showing the complete buccal to palatal fracture. Areas of resorptions and appositions of bone can be seen along the fracture border with vital tissue penetrating between the fragments. See the *white* and *black arrows* (**a**, **b**), These are an indication that the fracture had occurred in the past

Fig. 6.7 VRF in mesial root of a mandibular molar. Although a very wide separation of the segments can be seen, it is due to an artifact. A complete buccolingual fracture is evident. Colonies of eosinophilic bacteria (red stained) are visible on the fracture surface (*box insert*). Sealer and gutta-percha are black because they block transmitted light and can be seen throughout the canal (Brown and Brenn. Mag ×60)

fracture had occurred in the past was resorptions and appositions of cementum-like tissue on the walls of the fracture (Fig. 6.6). The contents of the fractures were generally associated with potential and actual irritants. Bacteria were always present (Fig. 6.7).

These bacteria were often in a biofilm form or within tubules. Necrotic tissue was evident, and foreign debris such as food remnants were an occasional finding. Sealer and/or gutta-percha were also often observed. The root canal contents were similar to the fractures. Bacteria were always present, often as a biofilm and within tubules. Many areas of the canal contained necrotic tissue and amorphous debris, sealer, and gutta-percha. Inflammation was always present on the root surface and overlying the fracture. The characteristics of the inflammation were similar to the periapical granuloma, that is, predominantly chronic inflammation. The lesions were bacteria free.

The interpretation of the histological findings is that the VRF is a dynamic entity with a unique microenvironment of tissue destruction. The fracture itself resembles a *long* apical foramen that communicates with a canal space that contains numerous potential and identifiable significant irritants. These irritants percolate through the fracture to the surface. There, these irritants contact connective supporting tissues and induce inflammation similar (or identical) to what occurs at the apex. The irritants are nonspecific and/or antigenic, thereby resulting in an immune response [10]. The outcome is both direct and indirect tissue damage and destruction of periodontium (both soft and hard tissues) in the region of the fracture.

The inflammation, as stated above, resembles the periapical granulomatous response. It is established [10] that the primary source of irritant that induces this response is necrotic tissue that contains bacteria. So it is not surprising that periapically and laterally, their histological appearance is similar. The lateral root surface lesion includes a predominance of chronic inflammatory cells (Fig. 6.8) and an absence of bacteria.

However, the bacterial colonization and biofilm formation within the canal is important in a pathogenesis of tissue destruction following VRF. Although specific bacterial species have not been conclusively identified in the fractured root, they are

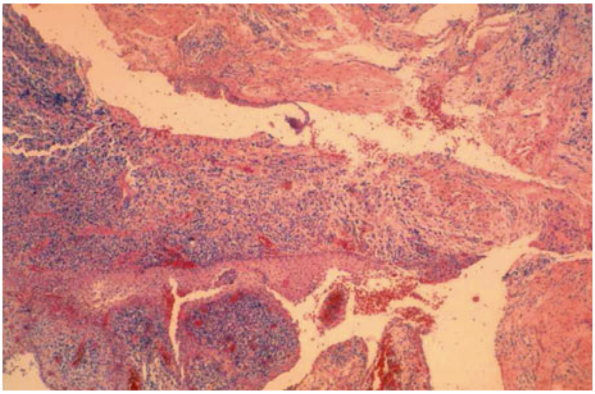

Fig. 6.8 Inflammatory tissue attached to the lateral surface of a vertically fractured root. There is a predominance of chronic inflammation and an absence of bacteria (Courtesy Prof. A. Tamse)

known to be present and important in both initial and in failed root canal treatments [11, 12]. The frequent appearance of a biofilm of bacteria (Fig. 6.7 box insert) is important. Biofilms are a particularly potent irritant [13]. Biofilms tend to persist and are composed of mixed flora that includes pathogenic bacteria [14]. Gram stain showed the presence of gram-positive microorganisms; these are a pathogen associated strongly with periapical pathosis.

Although the sources of these bacteria within the fracture have not been identified, they could arrive by different avenues [15]. These avenues would include from the oral cavity directly into the fracture [16] and via the periodontium or from the remnants of bacteria not removed during root canal treatment [17, 18].

In addition to bacteria, other potential and actual irritants likely are significant contributors. These include food debris, sealers, necrotic tissue, and other possible contaminants such as saliva or other chemicals present in the oral cavity. All these would have direct access to the periodontal tissues via the fracture. Similar to the necrotic pulp space, the defense mechanisms have no or limited access to the fracture space. The finding that the fractures demonstrated a variety of patterns is interesting as well as clinically significant. Different patterns were noted on the extracted teeth as well as histologically. These variations have been reported in other studies [19, 20]. Although not determined, those incomplete fractures likely demonstrate inflammatory lesions that reflect the fracture. Therefore, a probing defect may not be present when the fracture and associated inflammation is limited. If the fracture is only on the lingual, it would not be visible with flap reflection on the facial. If the fracture does not extend to the cervical margin, this may explain why many VRFs do not have associated probing defects (See additional information in Chap. 4 on diagnosis of VRF) (Fig. 6.9).

Importantly, the pathosis associated with the VRF is neither true periodontal disease nor is it a true “combined endo-perio” lesion. There was no histological evidence of a loss of attachment, which, in addition to bone resorption, is a feature of periodontal disease [21]. The inflammatory lesions were attached and adherent at all levels.They represent endodontic pathosis; a probe would pass easily into the inflammation.

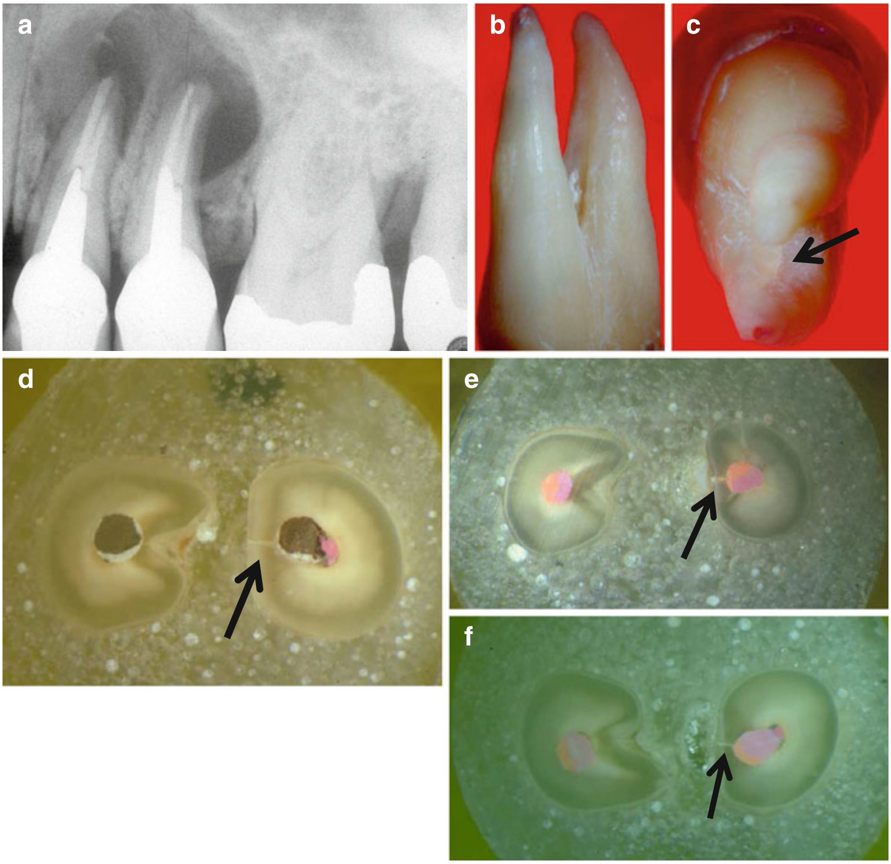

Fig. 6.9 (**a**–**f**) A patient presented to the dental office with a chief complaint of "loose teeth that were treated many years before and a strange discomfort upon touching the gum on the palate." The teeth were endodontically treated and restored with two cast dowels and PFM crowns 11 years previously. Dental examination revealed slight mobility of the two maxillary premolars (**a**). A 7 mm probing defect was recorded in the first premolar, but the probing was normal in all aspects of the second premolar. The attached gingiva in the palatal aspect of the second premolar was sensitive to palpation. The periapical radiograph shows a large radiolucent area in the bone surrounding the two roots and extending mesially to the lateral aspect of the canine and distally to the mesiobuccal root of the first molar. (**a**) The two teeth were suspected of having fractured roots. However, since retreatment prognosis in these teeth was poor, they were extracted. The extracted second premolar is shown in (**b**) In the mesial view of the extracted bifurcated premolar (**c**), a VRF can be seen in the bifurcation aspect of the palatal root (*Black arrow*). Three cross section slices of this root (**d**–**f**) are showing the incomplete VRF in the palatal root (*Black arrows*). No fracture is seen in the buccal root. Note the very minimal remaining dental thickness between the gutta-percha-filled palatal canal and the external surface of the root facing the bifurcation area (Courtesy Prof. A. Tamse)

Conclusions

The pathogenesis of the VRF has been demonstrated in the histological examination of cross sections of extracted roots. Both the fractures and the canals with which they communicated contained irritants capable of causing or contributing to the inflammatory lesion on the root surface. Fractures are not always complete buccal to lingual or coronal to apical but contained tissue, bacteria and root filling materials, necrotic debris, and other nonspecific irritants. Canals are similar in that the same irritants can be demonstrated. The interpretation is that the fracture is a long apical foramen communicating with spaces that contain profound irritants that generate an immune/inflammatory response that significantly damages the supporting periodontium.

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Treatment Alternatives for the Preservation of Vertically Root Fractured Teeth

7

Igor Tsesis, Ilan Beitlitum, and Eyal Rosen

Abstract

When a vertical root fracture (VRF) is diagnosed in an endodontically treated tooth, in most cases, extraction of the VRF tooth or root is still the treatment of choice. However, in certain cases, modern endodontics provides new treatment alternatives to treat and maintain some VRF teeth. The dilemma of whether to extract a VRF tooth and replace it with an implant or to adopt a more conservative treatment planning of an additional endodontic treatment aimed to preserve the natural tooth is complex and requires a multifactorial clinical decision-making process. This process should encapsulate endodontic, prosthetic, periodontal, and esthetic considerations as well as take into account patient values. Treatment options for VRF teeth vary from a simple root amputation in multirooted teeth to a complex surgical management in order to retain a fractured tooth.

Introduction

A vertical root fracture (VRF) has been defined by the American Association of Endodontists—Colleagues for Excellence as *"a complete or incomplete fracture initiated from the root at any level, usually directed buccolingually"* [1], mainly based on its descriptive anatomical characteristics.

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VRFs are relatively common, with a reported prevalence of 11–20 % of extracted endodontically treated teeth [2, 3]. VRF often expands laterally from the root canal wall to the root surface [4]. An incomplete fracture involves only one aspect of the root surface, while a complete fracture expands in opposite directions of the root canal and involves two root surface aspects [4–6], sometimes leading to a gradual separation of the tooth segments [4].

Many theories have been suggested regarding the possible etiologies of VRFs, but it is generally accepted that there is an association between root canal treatments, including endodontic and post placement related procedures, and the occurrence of VRFs [3, 7] and that virtually all VRFs have a history of root canal treatment (RCT) [3, 7].

Every medical procedure bears a risk of complications. Complications may be defined as "*any undesirable, unintended and direct results of the procedure affecting the patient, which would not have occurred had the procedure gone as well as could reasonably be hoped*" [8].

We therefore suggest that the definition of VRF should be extended to include the following: "*a complication of RCT, characterized by a complete or incomplete fracture initiated from the root at any level, usually directed buccolingually.*"

It should be noted that this revised definition of VRFs as a complication does not imply that the occurrence of VRFs is a direct result of a procedural error. A procedural error is defined as "*a failed process that is clearly linked to adverse outcome*" [9]. Although a practitioner's procedural error may lead to complications, not every complication is related to a procedural error [8, 9]. Since VRFs may occur in teeth with either good- or poor-quality RCTs, VRFs should be considered as a possible complication, not necessarily a direct result of a procedural error.

This novel definition of a VRF, which is based not only on descriptive anatomical characteristics, but is more comprehensive as a treatment complication, better describes both the clinical and the medicolegal aspects of VRFs [2, 3].

A timely mannered diagnosis and an appropriate management are prudent to avoid excessive alveolar bone loss, which may impair the future reconstructive procedures, should implant therapy be the treatment of choice [3–6]. In doubtful cases, a definitive diagnosis of VRF is best attained by invasive diagnostic procedures like a direct observation of the suspected site obtained by a flap elevation during a surgical endodontic treatment [3, 4, 10–12].

Traditionally, the prognosis of VRF root was considered as hopeless [3, 4, 13]. Attempts to treat VRF, for example, by a replantation procedure combined with bonding of the fractured segments, have been reported [3, 4, 13–16]. However, such treatment alternatives were found to be unpredictable and are not recommended as treatment of choice [3, 4, 13]. And therefore, extraction [4, 6], and an ensuing alternative treatment option consist of placement of a dental implant supporting a fixed restoration was usually indicated [4].

In recent years, several reports suggested novel treatment alternatives aimed to preserve VRF teeth [3, 4, 13] which were traditionally doomed to extraction [3, 4, 13, 17–19]. Although these novel treatment attempts are just in their primary stage of development and are based on case reports only [3, 4, 13], modern endodontics, including magnification and illumination devices that improve the diagnostic capability and increase the accuracy of the endodontic procedure [18, 20], and the use of modern materials such as mineral trioxide aggregate (MTA) [21] for the repair of VRF [3, 4, 13] seems to offer practical and promising treatment alternatives at least for some VRF teeth.

This chapter will review modern treatment alternatives for the preservation of VRF roots.

Case Selection

Modern endodontic modalities offer a wide variety of treatment alternatives that enable the preservation of severely compromised teeth [22]. However, VRF is still considered as a major problem in dentistry and a common cause of tooth loss [3, 23]. And with the wider scale of endodontic treatment options, new dilemmas emerged [22].

A common dilemma is the decision whether to preserve the compromised vertically fractured natural tooth or to extract the fractured root or tooth and replace it with a single dental implant [3, 22]. A quick decision to extract the tooth or root may be necessary since the inflammation in the supporting tissues would otherwise lead to periodontal breakdown followed by the development of a deep osseous defect [3, 5, 22] and bone resorption that may lead to complicated restoration of the area of extraction, should an implant be considered the treatment of choice [3, 6, 22].

Therefore, when a VRF is diagnosed, the case selection process requires a combination of endodontic, as well as prosthetic, periodontal, and esthetic considerations [3, 22]. The tooth type, presence of a predisposing periodontal disease, the type of the coronal restoration [24–29], the capabilities offered by the modern endodontic treatment, and the alternatives in case of treatment failure, post-treatment quality of life and patient's values should all be recognized and incorporated in the practitioner's decision-making. The integration of these considerations is crucial in order to achieve a rational treatment plan for the benefit of the patient [3, 22, 29].

For multirooted teeth with a diagnosis of VRF in one of the roots, there are potential alternatives to preserve the tooth, such as root amputation of the vertically fractured root [30], many times making the option to maintain the fractured root by additional treatments unnecessary (Fig. 7.1). However, for single-rooted teeth, the entire survival of the tooth relies on the ability to maintain the fractured root [4].

The periodontal status of the VRF tooth and especially the presence of a predisposing periodontal disease are important confounders for the ability to successfully treat and preserve the tooth [31]. The periodontium serves as the supporting apparatus for the teeth and is consisted from the alveolar mucosa, gingiva, cementum, periodontal ligament, and alveolar bone [32]. Periodontal diseases are infections and are caused by microorganisms that colonize the tooth surface at the gingival margin and may sometimes lead to a destruction of the periodontium [33].

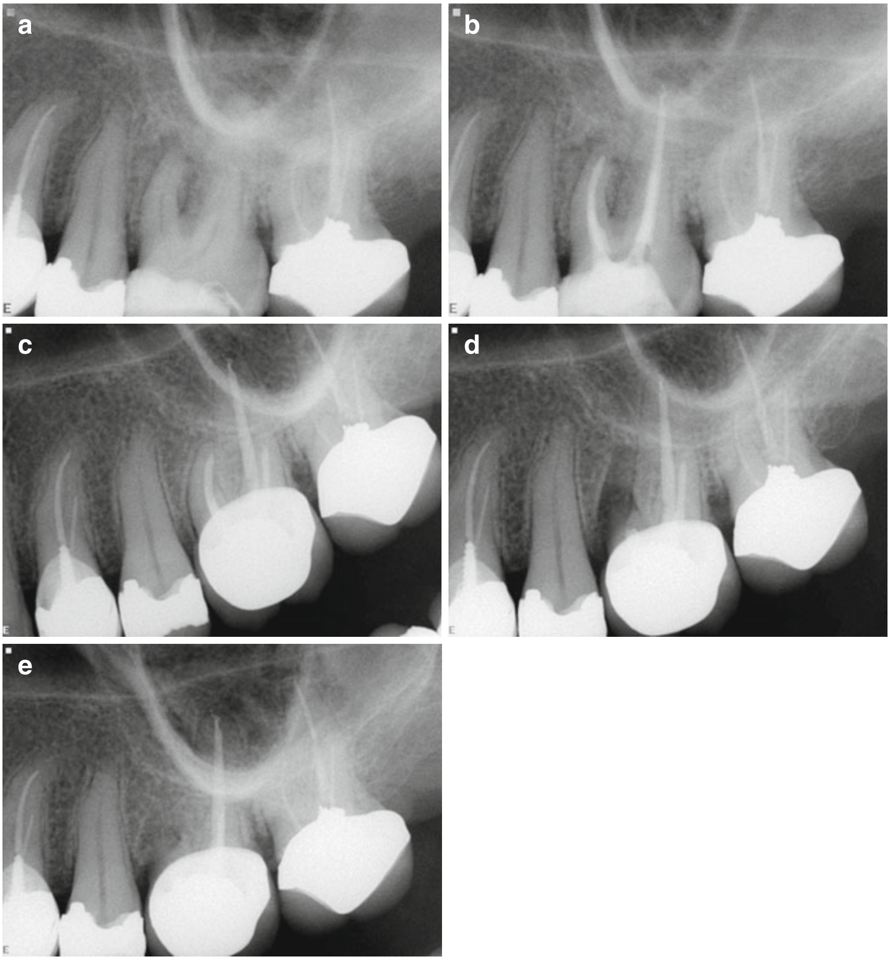

Fig. 7.1 Root amputation of a vertically fractured mesiobuccal root of an upper molar. (**a**) An upper molar was diagnosed with pulp necrosis and asymptomatic apical periodontitis. (**b**) A root canal treatment was performed. (**c**) One-year latter the patient presented with a sinus tract, and the tooth was diagnosed with chronic apical abscess. The patient was scheduled to endodontic surgery. (**d**) During endodontic surgery, a vertical root fracture was diagnosed in the mesiobuccal root. The root was amputated just apically to the epithelial attachment. (**e**) One-year postsurgery follow-up: the tooth was asymptomatic and was diagnosed with normal apical issues

A severe periodontal disease may compromise the ability to preserve the natural tooth, and interpretation of commonly used clinical parameters to determine the periodontal disease severity is therefore indicated [31]. In general, deep periodontal probing depth with an associated bleeding are indicators of periodontal disease activity as well as predictors of future attachment loss [31]. And severe periodontal disease with significant mobility, especially vertical mobility, significantly reduces the tooth prognosis [26].

Failure to maintain the natural tooth may lead to esthetic complications [34]. With modern dental practice, osseointegration of implants is readily attainable with high long-term survival rates [35–38]. However, dental implant success should be judged not only by osseointegration but also by esthetic results, and aesthetic predictability can often be difficult to attain. In addition, when esthetic implant failures occur, it may be impossible to be fully corrected [35–38].

On the other hand, periodontal defects such as gingival recession may be caused by surgical manipulations during attempts to preserve the VRF tooth [32, 39–44]. And periodontal bone loss with ensuing esthetic complications is more extensive in patients presented with thin periodontal biotype [34]. Therefore, a comprehensive periodontal and esthetic evaluation should be an integral part of the treatment planning of a VRF tooth [31, 35–38].

Although early diagnosis of VRF is important, the VRF may be diagnosed only after all endodontic and prosthetic procedures have been completed [8] due to lack of specific signs, symptoms, or radiographic features and because several etiologic factors may be involved [3, 11, 45–51]. Therefore, the timing of VRF diagnosis, either before or after the restorative procedures have been completed, and also the type of prosthetic restoration (e.g., a tooth that is a part of a bridge or a stand-alone restoration) may affect the decision whether to make additional efforts to preserve the vertically fractured tooth [31].

Many prosthetic and periodontal parameters affect the long-term prognosis of endodontically treated teeth, such as the amount of remaining tooth structure, the crown–root ratio, presence of tooth mobility, ferrule effect, and many more [28]. In addition, an appropriate postendodontic treatment restoration is extremely important for the long-term prognosis of the tooth [52].

Therefore, the decision to perform an additional treatment to preserve a VRF tooth should not be based only on the technical ability to endodontically treat the fracture line but on a broader spectrum of prosthetic, periodontal, and esthetic considerations that determine the long-term prognosis of the tooth and the risk of complications.

Treatment Options

In cases of strategically important teeth, an attempt can be made to preserve the tooth by treating the VRF. Several treatment options may be considered, including root amputation or root extraction, apical surgery with root shaving coronally to the fracture line, and sealing/cementation of the fracture following flap elevation approach or by extraction and replantation.

Various attempts to treat VRF teeth have been reported. While in most cases the treatments eventually resulted in tooth extraction, certain advances have been achieved in recent years, enabling the preservation of VRF teeth [7, 13, 14, 53–57]. The specific treatment alternative should be selected based on the tooth type, fracture type and location, prosthetic and esthetic considerations, and periodontal considerations.

Root Amputation and Root Extraction

When a VRF is diagnosed in single roots of a multirooted tooth, the most straightforward option is to surgically remove the fractured root only. More than 100 years ago, Farrar [58] described a surgical technique that included root resection with a filling of the remaining part with an ordinary filling material, such as amalgam. Farrar proposed resection at various levels, even leaving a short root stamp in the gingival tissue [58].

In some cases, a portion of the crown can be resected together with the involved root. In other cases, a tooth can be extruded orthodontically for easier management of the remaining tooth structure [7].

Root amputation may be recommended for maxillary molars with one fractured root (Fig. 7.1). Depending on the level of the fracture line and periodontal status of the patient, the resection can be performed at different levels of the root, and the most coronal part of the root can be retained following a root-end management and retrograde filling. A careful presurgical evaluation should be performed to exclude the possibility of fused roots rendering the amputation impossible. For fractured fused roots, a proper technique was described by Matusow [59] as "root stripping." He presented a case of a second mandibular moral that served as a bridge abutment with fused medial root with VRF. The fused root was surgically "stripped," leaving the distal root segment intact. This technique may be attempted for management of maxillary premolars with fractured buccal root where apically positioned furcation prevents a conventional root resection. For mandibular molars, while a root amputation is sometimes performed, hemisection and extraction of the fractured root or root resection is a more reliable option.

Techniques for the Preservation of a Fractured Root

The actual treatment for the VRF may be divided into two main categories: a treatment modality that includes extraction and replantation of the involved root or tooth following extraoral repair of the fracture; and repair of the fracture using flap elevation procedure while the tooth remains attached in the periodontium.

Tooth Extraction, Cementation of the Root Fracture, and Replantation

Extraction of the fractured tooth, cementation of the root fracture, and replantation as an attempt to preserve VRF teeth was reported in several case reports and in a case series [14–16].

Hayashi Kinomoto et al. [16] reported on treatments of 26 vertically fractured roots using replantation and reconstruction with dentin-bonded resin. They found that 18 cases were functional and retained, with 6 fully successful, after 4–76 months. They found that teeth with longitudinal fractures extending more than 2/3 from the cervical portion toward the apex and posterior teeth showed significantly lower success rates [16].

Arikan et al. [14] presented a successful treatment after 18 months follow-up of a central incisor with complete VRF that was extracted and root segment bonded and replanted. Kawai et al. [15] attempted a modification of this approach by replanting two VRF teeth with resin-bonded segments at 180° rotation into the original socket in order to bring the fracture line under healthy bony coverage and sound periodontal ligaments on the tooth surface face the destroyed boneless area. Hadrossek et al. [55] treated a central incisor by filling the fracture line and the retrograde preparation with a calcium silicate cement (Biodentine).

Another case of bonding the fracture line with adhesive resin cement was reported by Moradi Majd Akhtari et al. [60]: vertically fractured maxillary incisor was extracted, the fracture line was treated with adhesive resin cement, and the tooth was replanted. After 12 months, the tooth was asymptomatic [60].

In addition to doubtful prognosis of the fracture repair, the main disadvantage of this treatment modality is the risk of complications related to the extraction, such as inability to extract the tooth in one piece, lack of periodontal healing or bone resorption following replantation, and root resorption due to the damaged PDL. Therefore, the contraindications for tooth extraction and replantation are teeth which probably cannot be extracted and repositioned due to a complicated root anatomy, teeth with severe periodontitis, teeth without adjacent teeth, a noncompliant patient, and patients with critical general medical conditions [55].

Flap Elevation and Cementation of the Root Fracture

Several attempts to treat VRF by a flap procedure to gain access to the fracture line and enable its management were described. Selden [61] reported on a conservative treatment of six teeth with incomplete VRF using silver glass ionomer cement with bone graft, but all cases presented in that study failed in the long term [61].

Modern endodontics presents a possibility to treat fractured teeth by employing magnification and illumination devices that allow better visualization of the surgical field, thus increasing the accuracy of the treatment.

MTA was proposed as a sealing material to repair VRF [21], by preparing a groove along the entire vertical fracture, placing MTA in the groove and covering it with a absorbable membrane. Floratos et al. prepared the fracture line using a rotary or ultrasonic instrument with ensuing sealing of the defect with MTA and coverage with absorbable collagen membrane or calcium sulfate using microsurgical techniques and the microscope-assisted regenerative procedures [13].

Taschieri et al. [4] reported on 10 maxillary anterior teeth with incomplete VRF treated by a modern surgical endodontic technique (Fig. 7.2). Strict inclusion criteria were applied—teeth with probing depths of more than 4 mm or cases with halo-like periradicular radiolucency or interproximal angular radiolucency on one side of the root were excluded from that study. Following flap elevation, a groove following the fracture line was prepared using ultrasonic devices and sealed with MTA,

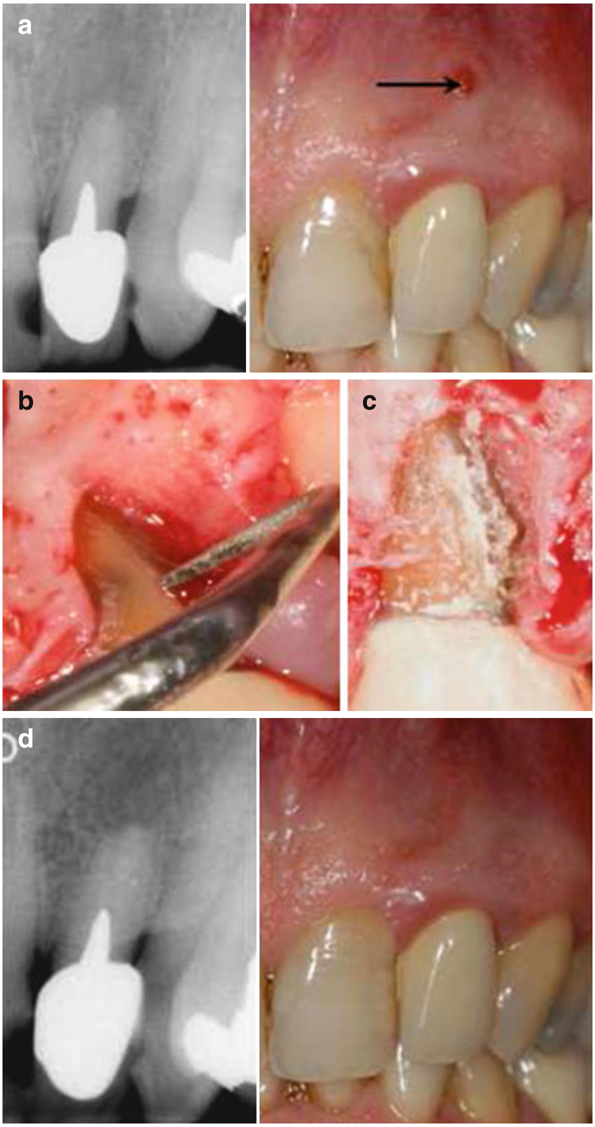

Fig. 7.2 Flap elevation procedure to repair incomplete vertical root fracture. Maxillary left lateral incisor. (**a**) Preoperative radiograph and clinical evidence of a sinus tract (*arrow*); (**b**) a groove was made on the root surface using a zirconium nitride retrotip along the fracture line; (**c**) the groove was filled with MTA as sealing material; (**d**) clinical and radiographic evidence of complete healing at 33 months follow-up (Reprinted from Taschieri et al. [4], Copyright (2010), with permission from Elsevier)

and then filling of the bone defect with calcium sulfate. At 12 months follow-up, all cases were successful. After 33 months from seven patients available for follow-up, five cases remained healed [4].

Dederich et al. [62] in a case report of a mandibular premolar sealed a hairline vertical fracture associated with a vertical bone defect using a CO_2 laser with subsequent placement of collagen matrix barrier over the defect. After 12 months, no evidence of inflammation was detected; however, gingival recession was present [62].

Floratos and Kratchman [13] treated four cases in which endodontically treated maxillary or mandibular molars had an incomplete VRF involving one of the roots. Unlike in the study by Taschieri et al. [4], in this study, a similar technique was used successfully in anterior teeth with vertical fracture lines deriving from the apical part of the root. The fracture line was eliminated by resecting the root in a beveled manner, after which root-end preparation and root-end filling were performed by using MTA. The osteotomy was covered with an absorbable collagen membrane. After 8–24 months, cases demonstrated clinical success [13].

The flap procedure may have several disadvantages: a possible scar may form in the esthetic area of the gingiva, an additional osteotomy may be needed which generates extra loss of healthy bone structure, and a gingival recession may be expected. Therefore, in some cases this procedure is not indicated because of esthetic considerations [55].

Conclusions

The dilemma of whether to extract a VRF tooth and replace it with an implant or to adopt a more conservative treatment planning of an additional endodontic treatment aimed to preserve the natural tooth is complex and requires a multifactorial clinical decision-making process. Extraction of the VRF tooth or root is still the treatment of choice. However, in certain cases, modern endodontics provides new treatment alternatives to treat and maintain certain VRF teeth. Additional clinical studies are indicated to shed light on the prognosis of these new treatments.

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Management of the Infected Socket Following the Extraction of VRF Teeth

8

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Abstract

Following a vertically fractured tooth extraction, the fresh socket is usually infected. In such cases, the remaining bone characteristics should be carefully evaluated to allow an optimal implant placement treatment plan. The immediate postextraction implant may present certain advantages over implant placement in healed sites such as possibility for immediate restoration and reduction of overall treatment time and surgical sessions. This chapter deals with bone defects resulting following extraction of a vertically fractured tooth and reviews the literature concerning treatment options in such cases, including implant placement together with different bone regeneration procedures. Advantages and risks involved of implant placement in the infected socket immediately following the extraction of the vertically fractured root will be discussed.

Introduction

One of the most common dilemmas in clinical dental practice is the choice of whether to maintain or extract compromised teeth. The decision becomes even more complex when combinations of periodontal, endodontic, and reconstructive aspects must be considered.

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VRFs are one of the main causes of endodontic therapy failure, and the percentage of tooth extraction due to VRF ranges from 9 to 11 % [1–3]. All these studies had certain limitations such as the population characteristics, retrospective design, and in certain cases the operators skills.

VRF diagnosis may not always be clear due to lack of specific clinical and radiographic signs and/or symptoms [4]. These limitations to determine the presence of a VRF may, when absolutely necessary, command the use of invasive exploratory flap procedures [5, 6].

Lack of diagnosis and preservation of the fractured tooth represents a clear risk for short- or mid-term failure with the consequences of supporting bone damage that may compromise certain rehabilitation alternatives.

The prognosis of teeth with VRF is generally poor, and only in very few cases, it might be possible to obviate tooth extraction [7–10].

Implant-supported restoration seems to be the most widely accepted treatment alternative to replace missing teeth. However, the implant therapy success is related to a number of factors such as the timing of surgery and surgical approach following tooth extraction, the residual bone volume, and the presence of residual infection [11].

VRF, depending on the type, extent, and duration of the fracture, causes a communication between the root canal and the periodontal space which may lead to a relatively rapid bone loss [12–14].

Alveolar bone damage due to VRF results in different surgical scenarios with varying levels of difficulty in their surgical management. Several treatment alternatives are available, such as delaying implant placement to achieve soft tissue healing, ridge preservation, bone augmentation, and immediate postextraction implant placement. The immediate implant placement presents certain advantages, including patient satisfaction, early prosthetic loading with possibility for immediate restoration, and reduction of overall treatment time.

Immediate implants placed in fresh extraction sites of vertically fractured teeth have reported survival rates comparable to implants placed in healed sites [5, 15–17].

In this chapter, the postextraction socket management will be described. A classification of various types of bony defects related to the treatment of choice for implant placement to facilitate clinical decision-making in such cases will be presented.

Socket Healing

Postextraction socket healing involves important alterations in volume and shape as the result of concomitant mechanisms of bone resorption and apposition [18, 19]. The cascade of events, during healing of the alveolar socket following extraction, has been described in several histological studies [20, 21]. Briefly, immediately after tooth extraction, a blood clot fills most of the fresh socket. Histological analysis shows the beginning of the formation of a fibrin network. Already, during the first 48 h, neutrophilic granulocytes, monocytes, and fibroblasts begin to migrate within the fibrin network, enhancing tissue healing through an inflammatory response. After a couple of days, the clot starts to be replaced by granulation tissue. One week after extraction, the clot is partly replaced with a provisional matrix while most of the socket is filled with granulation tissue, young connective tissue, and osteoid in its apical area. In the beginning of the second week, the tissue of the socket is comprised of provisional matrix and woven bone, and on day 30, mineralized bone occupies 88 % of the socket volume. This tissue will decrease to 75 % on day 60, increasing to 85 % on day 180 [22]. Eight weeks after tooth extraction, signs of ongoing hard tissue resorption on the outside and on the top of the buccal and lingual bone wall can be appreciated there.

The presence of infection not completely removed after tooth extraction could cause a slower and incomplete healing [23].

Classification of VRF Alveolar Bone Defects

The following classification is intended to provide the clinician a helpful guide for the best treatment alternative for implant placement following tooth extraction.

Class I: Narrow and Wide Buccal Dehiscences

Class I defects present as bone dehiscence with loss of the cortical bony plate limited to the buccal (or lingual/palatal) wall. The defect could be V shaped (located at the buccal plate) or U shaped (at buccal or lingual plate) [14]. V-shaped defects are often narrow while U-shaped ones present as a wide dehiscence and shallow, rounded slope resorptions [14].

This type of defect has three subcategories:

- Class Ia: affecting only the most coronal third of the alveolar bone surrounding the fractured root (Fig. 8.1a–c).
- Class Ib: including bony dehiscence in which the defect involves the coronal and middle third of the root without affecting the apical third (Fig. 8.2a–c)
- Subclasses (a-c) represent the evolution from an incomplete fracture affecting only the coronal portion of the root (Class Ia) to a fracture extending to the middle portion (Class Ib) and finally encompassing the apical third of the root (Class Ic) (Fig. 8.3a–c).

Class II: Vertical Bone Defects

Class II defects include bony dehiscence (V- or U-shaped) involving both buccal and interdental bone.

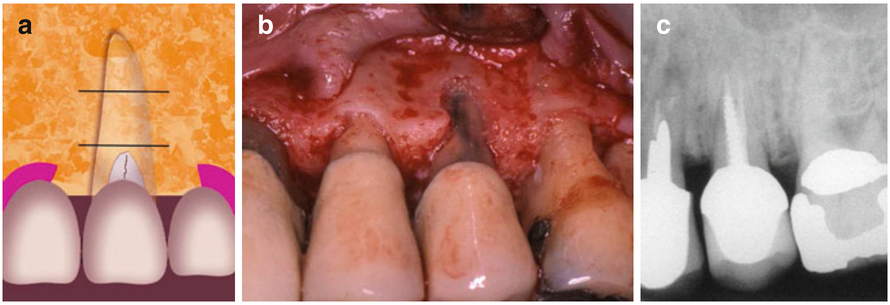

Fig. 8.1 (**a**–**c**) A patient was scheduled for periodontal surgery in the maxillary left quadrant. The periapical radiograph revealed endodontically treated bifurcated premolar with a dowel in the palatal root (**b**). A 5 mm probing defect was noted in midbuccal area and the probing was between normal limits in all the other aspects. Upon reflecting the periodontal flap (**c**), a typical dehiscence for a vertical root fracture in an endodontically treated tooth was seen. The dehiscence was limited to mainly the coronal area of the root which corresponds with the graphic illustration (**a**).The fracture and the dehiscence were noted early enough so there is still interproximal bone that will enhance the prognosis of the future implant

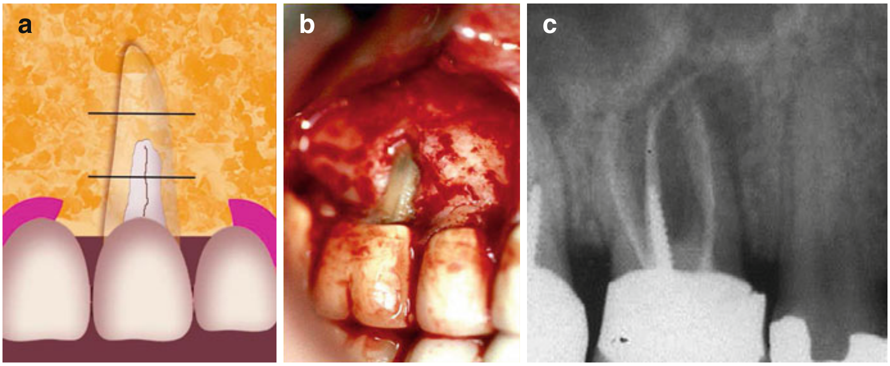

Fig. 8.2 (**a**–**c**) A graphic illustration of class 1b of which the defect involves the coronal and middle part of the root not involving the apical third (**a**). (**b**) Shows a dehiscence along a mesiobuccal root of a maxillary molar. The periapical radiograph (**c**) shows a large radiolucency around the palatal and the mesiobuccal root of the maxillary molar with a gutta-percha tracing cone in the area from a draining sinus tract

This type of defects has three subcategories depending on the vertical dimension: Class IIa involves the most coronal third of the bone socket, Class IIb involves also the middle third, and Class IIc extends to the apical portion.

Defects affecting interdental bone may cause the complete loss of one bone peak (mesial and/or distal) (Fig. 8.4a–c).

The absence of one of the bone peaks creates a defect in which only a single residual wall remains after tooth extraction.

The involvement of interdental bone could be an evolution of defects (Class II) over time. The complete loss of one interdental bone peak leads to a one-wall defect.

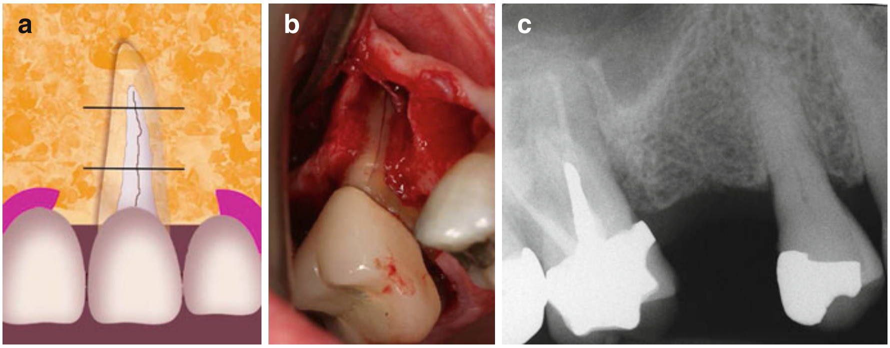

Fig. 8.3 (**a**–**c**) A large dehiscence of bone facing a vertical root fracture in a maxillary molar. The schematic illustration shows that the fracture line and the dehiscence include all three thirds of the root (**a**). A VRF extending to the full length of the mesiobuccal root of a maxillary molar (**b**). The radiographic image (**c**) shows bone loss adjacent to the MB root (Courtesy Dr. D. Greenfield)

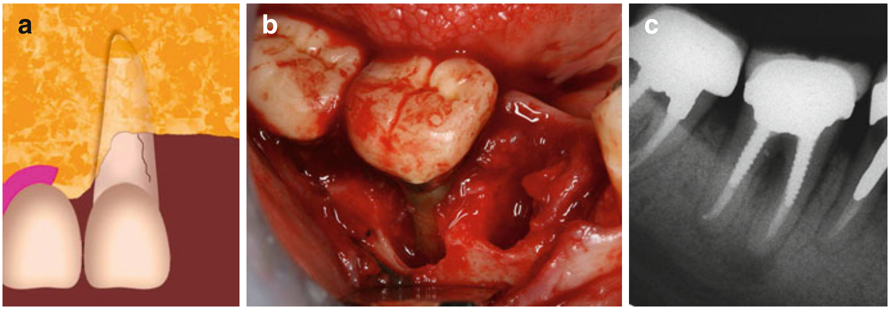

Fig. 8.4 (**a**–**c**) A graphic illustration of an interproximal defect causing bone loss of the crest on either mesial or distal aspects of a tooth or both (**a**). A typical angular–mesial and distal bone loss due to a root fracture in a mesial root of a mandibular molar (**b**). The periapical radiograph (**c**) show both mesial and interproximal radiolucencies around the mesial root (Courtesy Dr. E. Venezia)

Class III: Sites with Fenestrations

Class III defects are fenestrations, bone defects characterized by the presence of a bridge of intact bone coronal to the defect and usually located at the apical third of the postextraction socket (Fig. 8.5a–c).

These defects may be due to the presence of an inflammatory or infective focus due to an incomplete VRF at the apical portion of the root [14].

Class III could be caused by incomplete fractures developing from the apex in a coronal direction.

It has been suggested that vertical root fractures insidiously can evolve over a period of time, from a marginal crack to a complete fracture involving the whole length of the root [24].

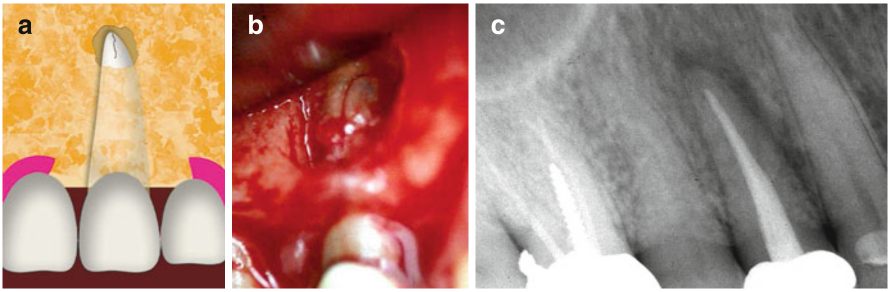

Fig. 8.5 (**a**–**c**) The graphic illustration (**a**) and the clinical VRF case in a maxillary premolar (**b**) are demonstrating a typical fenestration in the bone. The periapical radiograph (**c**) shows a typical "halo" ("J")-type radiolucency around the apical part of an endodontically treated maxillary premolar

Implant Treatment Choice After Extraction of VRF Tooth in Consideration to Classification of VRF Alveolar Bone Defects

VRF Class Discussion and Clinical Guidance

Class I: Narrow and Wide Buccal Dehiscences

The use of resorbable (mainly collagen) and nonresorbable (mainly ePTFE) membranes for treatment of bone dehiscence both with or without the use of bone grafting material has been widely reported [25–37].

A number of studies described the use of autogenous bone [26, 28–30, 32, 33, 36, 37], deproteinized bovine bone mineral [27, 32–34], allogeneic graft [31], or no graft [25] in association with nonresorbable membranes.

The 5-year survival rate of maxillary implants placed together with ePTFE membranes varied from 76.8 % [26] to 100 % [32, 36]. Percentage of defect fill with this technique ranged between 70 and 100 % [25, 28–30, 34, 35], while in one study the bone fill was higher than 70 % [28]. The most frequently described complication was membrane exposure (up to 41.2 % of cases [35]).

Resorbable membranes have also been successfully applied for the treatment of dehiscence-like defects associated with implant placement [27, 28, 32, 33, 35, 37–48].

Bioresorbable barriers may be used alone [28, 35, 38, 39] or in combination with deproteinized bovine bone mineral (DBBM) [25, 32, 33, 37, 41–44, 46, 47] or other grafting materials, such as allograft or autogenous bone [28, 32, 33, 36, 45, 48]. High implant survival rates have been described also with this type of membrane alone [28] or combined with DBBM [41–44, 46, 47] and autologous bone or other bone substitutes [28, 36, 45, 49]. The incidence of reported complications (mainly membrane exposures) reached up to 39 % [35]. In one single study, the use of titanium meshes and autogenous bone was described, reporting 93.5 % bone defect fill [50].

Our review of the literature indicates that in Class I defects, the dehiscence could be successfully resolved with either nonresorbable or resorbable barriers. Moreover, no differences could be evaluated in bone regeneration in relation to the height of the defect [36]. An important clinical consideration here is the ability to achieve an adequate primary stability of the implant and complete soft tissue closure during the healing phase [51, 52].

Class II: Vertical Bone Defects

A number of studies reported techniques for the regeneration of vertical bone defects simultaneously with implant placement [53–63].

No statistically significant differences in implant survival were reported between nonresorbable and resorbable barrier membranes among studies where this type of comparison was performed [58–60].

Implant survival rates were generally high [54–57]. Postsurgical complications were frequent ranging from 9 to 45.5 % [58, 59]. Membrane exposure was the most frequent but the only complication reported [59].

Studies describing the treatment of vertical defects, with loss of interdental bone only on one side, categorized here as Class II cases, are relatively scarce. A previous systematic review [64] suggested, based on clinical and histological data, the potential use of vertical bone regeneration techniques in such situations. High survival rates for implants placed simultaneously with vertical ridge augmentation have been reported [53–63]. The frequency of complications in such cases appears to be high and should be carefully considered in the overall treatment plan. In these cases, the stabilization of the barrier (both resorbable and nonresorbable) is often challenging due to the characteristics of the bone defect, while the experience of the operator is also a factor that determines success [59]. Due to these reasons, a two-stage rather than a single-visit surgical protocol appears to yield more success in Class II defects [64].

Class III: Sites with Fenestrations

Several studies have reported on the management of fenestrations by guided bone regeneration (GBR) with membranes at the time of implant placement [26–29, 38–40, 49, 50].

Reported survival rates are high [26]. Apparently, bioresorbable membranes lead to a higher implant survival rate than the nonresorbable ones. Membrane exposures were reported only in the use of nonresorbable membranes.

There are a relatively few studies related to the Class III classification with bony fenestrations [26–29, 38–40, 49, 50]. In two studies, the use of ePTFE membranes showed a relatively low percentage of complete bone defect filling (above 85 %) [25, 26], and this could be a reasonable basis to avoid their application [26].

Final Considerations

Immediate implant placement following the extraction of a vertically fractured tooth may be a challenging treatment alternative due to the presence of bone defects as well as infection and inflammation in the surgical area [65]. Accurate debridement of the extraction socket is mandatory as one of the fundamental prerequisites for obtaining long-term implant survival rates [66]. Following improper lesion debridement, bacteria could be isolated even from specimens taken from fully healed bone [67].

Spread of infection into subjacent niches from the fracture site may also be a serious concern when planning implant placement [12–14].

It has been proposed, in particular in anterior esthetic zones, that immediate and, even more, early postextraction implants may be helpful in maintaining the stability of the soft tissues to achieve better esthetic outcome [68–71]. Implants can be placed in infected sites without the occurrence of severe complications, when an adequate debridement of the socket is performed [17, 72, 73]. Primary soft tissue closure is mandatory for the success of any bone regenerative procedure, especially when barrier membranes are applied. Delaying implant placement and bone regeneration for a few weeks could present a viable treatment alternative to lower complication rate due to spontaneous membrane exposure [41].

The scientific literature has validated the use of guided bone regeneration to treat peri-implant bone defects at the time of implant placement [74, 75].

The fact that wider defects are more clinically challenging implies that careful diagnostic evaluations are needed to detect the fracture at an earlier stage. While only invasive procedures, as open flap, can confirm the exact extent of VRF [4], the use of advanced imaging techniques such as cone beam computed tomography can be of help for early diagnosis [76]. Finally, whenever cases of VRF are detected during explorative surgery [4, 77, 78], a sound knowledge of the bone defect anatomy can help in the decision concerning the best bone augmentation alternative.

Detailed studies documenting the dimensions and anatomy of bony defects connected to VRF are necessary to base the present classification on evidence .

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Medicolegal Aspects of Vertical Root Fractures

9

Lars Bjørndal and Henrik Nielsen

Abstract

The vertical root fracture may appear in conjunction with a physical or occlusal trauma or iatrogenic complications often encompassing endodontic and prosthodontic treatments involving the placement of a post. Under certain circumstances, this complex scenario may trigger a wish from the patient for economic compensation. The determination of a fractured root is complicated and challenging as it is often not distinctly objective and more a prediction rather than a definitive diagnosis. In case a vertical root fracture is suspected, a timely decision regarding the diagnosis is required to avoid unnecessary bone loss and ensuing legal claim. In many parts of the world, the patient would have to take the practitioner into a civil court to get compensation. However, in a number of countries, there is legislation which deals with injuries in relation to medical treatment or compensation. Medicolegal considerations are in a few countries particularly detailed. Within these countries, dental complaints and insurance cases are relatively frequently occurring. A subcategorization of endodontics-related complaints shows that the inadequate root filling represents a major risk for complaints. In combination with the occurrence of vertical root fractures, it represents a challenging complication clinically as well as medicolegally, because inadequate root filling may mask the presence of a vertical root fracture. Statistics about claims may indicate where risk management and educational

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efforts can be most effectively directed to improve the standard of dental care. A continuous improvement of preventive treatment concepts including the development of diagnostic tools seems warranted, as an accurate diagnosis may prevent or reduce the risk of complications in particular related to vertical root fractures.

Malpractice in a General Dental Practitioner Environment

The ability to raise concerns regarding the dental care quality as carried out by a practitioner [1] is a relatively modern concept [2]. Several recent reports provide information about the management of liability claims between patients and dental practitioners. The proportion of endodontic-related complaints is relatively high compared to other dental specialties and is comparable worldwide. In the context of vertical root fractures, in particular, whether a vertical root fracture has taken place before or after extensive dental treatment may be difficult to diagnose. Seldom, even the complete vertical root fracture appears as obvious as illustrated in Fig. 9.1. General recommendation about the medicolegal consequences may be a task, as the system differs within various countries. In this chapter, some general medicolegal considerations are presented, including an example of how a particular medicolegal system is organized with focus on the so-called Nordic model. Finally, emphasis is made to improve the diagnostic tools for detecting incomplete as well as complete vertical root fractures. An accurate diagnosis is crucial in order to avoid not only the loss of more bone as a result of the infection accompanying the fractured root but

Fig. 9.1 An upper premolar with a vertical root fracture. The apical part of the root filling is not apparent. A potential medicolegal case will be based on the evaluation of the clinical procedures carried out (Courtesy DDS Vibe Rud)

also to avoid additional hours in the dental chair (spending on clinical procedures that will not cure a vertical root fracture), including the extra cost for the patient. All these elements will increase the risk for medicolegal considerations.

The Global Medicolegal System

In several countries, having a general dental practitioner (GDP)–related insurance is an obligation. In other countries, the GDPs are encouraged to be associated with an insurance company [2].

In some countries, like Israel and Italy [3, 4], most of the dental practitioners are obligated to report any incidence or suspicion of a legal action against them, as part of their professional liability insurance terms. In the USA, the GDPs are encouraged by their insurance company to report dental incidents [5]. In the Nordic countries, there is a complaint management and insurance system described below as "The Nordic Model." This model is relatively unique and includes both complaint management and insurance systems.

The Nordic Model Complaint Management System

In Denmark and Sweden, where the Nordic model is applied, the medicolegal system is closely related to health legislation [2]. Complaints are managed by local committees or regional dental complaint boards (DCBs) consisting of members from the dental association and officials. The committee makes administrative decisions based on best clinical practice and legislation [6–8]. Patients' complaints are evaluated by the DCB, followed by a decision whether malpractice exists or not. If the DCB states that there is malpractice, the practitioner is obligated to return the fee for the treatment to the patient [2]. The DCB may also propose a settlement, where the practitioner accepts to cover the patients' expenses for retreatment provided by another practitioner. Both the practitioner and the patient may appeal the decision to a national board (NDCB) that includes a civil court judge. The NDCB may accept or change the regional DCB decision. The involved part's have the option to appeal the NDCB decision to a civil court [2].

The Nordic Model Insurance System

In Denmark, patient insurance system has been a part of health care legislation since 1992, covering both private and public treatments. The dental insurance system is founded by the government and dental practitioners which pay's a premium depending on their revenues [2].

The insurance system in Denmark is considered a "no-fault insurance" which means that the insurance is based on the clarification to which extent the patient suffers from an injury in relation to treatment. It is not a focus to esthablish malpractice. This would be handled in the complaint system. Diagnosing vertical root fracture in conjunction with a root filling may be very difficult due to whether the fracture was present before the start of the dental treatment or the root fracture occurred as a consequence of the treatment. Taking the concept of "no-fault insurance" into account, it is important to establish if the treatment *per se* leaves the patient in a situation where the status of the dentition has been deteriorated. Additionally, a retreatment would not possibly reestablish the patient's tooth/dentition integrity and functionality (Fig. 9.2). Finally, four principles are used to distinguish between well-known complications to a particular treatment and injuries [2]:

1. Would another specialist/dentist have done it differently?
2. Could another method have been used?
3. Is the injury caused by a technically inadequate procedure?
4. Must the patient tolerate more discomfort than the average patient?

To describe the content of the four principles, the following should be observed:

Ad 1. It is possible to think of a hypothetical GDP who would have chosen another treatment based on best evidence and by that avoided the injury.
Ad 2. It is possible to treat the patient with another method and achieve the same result but without the risk of injury.
Ad 3. For example, the injury is caused by an inadequate post space preparation (Fig. 9.2).

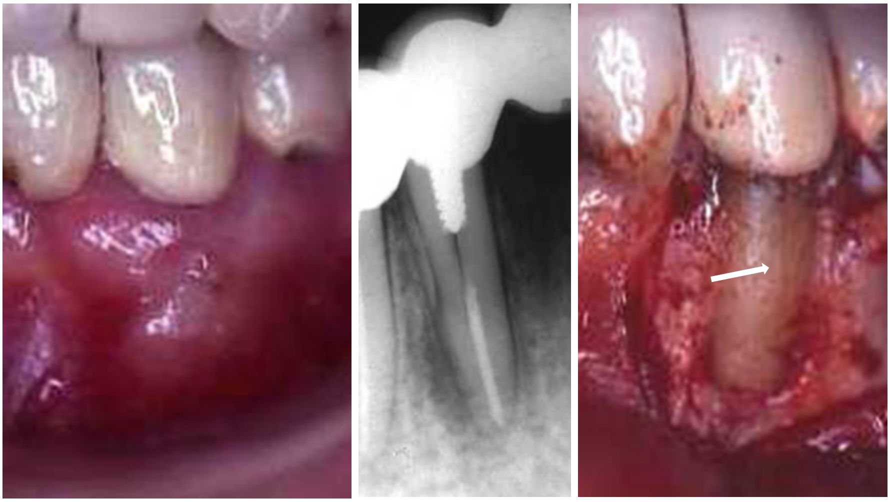

Fig. 9.2 An example of a VRF of a canine involved in a bridge construction. The pin of the post is too short and the post space preparation sub-optimal; consequently, this region has been deteriorated. It is not possible to reestablish the tooth by an endodontic retreatment. Along the buccal surface of the root, the VRF is apparent (*white arrow*). An injury as shown would in the Nordic model be categorized as a type 3 case. This is based on the expectation that another specialist would have prepared a sufficient post space in order to avoid a suboptimal load on the canine

Ad 4. It is a well-known fact that treatment often implies discomfort. However, a nerve injury in relation to conventional endodontics would be anticipated as more discomfort than the average patient would experience.

In Sweden, a "no–fault" compensation system was also introduced, aimed to provide the patient the right to be compensated in case of treatment-related injury, regardless of whether the injury is related to a practitioner's negligence or not [9]. However, the system can still pursue practitioners where they were responsible for medical negligence under tort law [2].

In cases where patients would like to appeal regarding the insurance system decision, they can do so by the Danish appeal board and later even bring that decision to a civil court [10].

Prevalence and Dental Areas of Malpractice Claims and Vertical Root Fractures

Should we expect vertical root fractures in conjunction with endodontic treatments? Facts are presented, indicating that the dentist needs to pay attention and awareness about this topic:

- The frequency of root canal treatment has increased over the last decades [11], therefore the number of endodontically related malpractice claims are still a matter of concern.
- Endodontically treated teeth are structurally more susceptible to root fractures [12].
- From prevalence studies, vertical root fractures range between 8.9 and 10.9 % of the reasons for endodontic retreatments and extractions [13, 14].
- From various observational studies world wide, root fillings are often of poor technical quality in a GDP environment [15–17] rarely performed with the use of rubber dam [18, 19], and a high frequency of persistent periapical inflammatory lesions is noted. This complicates the history and diagnosis of vertical root fractures.
- Nowadays, the molar is the most frequent tooth that receives endodontic treatment, and if only a few endodontic specialists are available to refer complicated cases to (as in countries without endodontic specialist training), malpractice claims are expected to reflect this situation and to a substantial part be associated with the results of defective root fillings and technical treatment complications.
- Malpractice claims in relation to vertical root fractures are complex, as the cause of fracture may be due to several different causes, and typically the vertical root fractured tooth has been extracted prior to onset of complaint.

Prevalence of Dental Malpractice Claims

The prevalence of dental treatment-related malpractice claims seems to increase over the years, depending on the specific country being evaluated:

In Sweden, malpractice cases occurred in less than 1 case per 1,000 dentists, over the period from 1977 to 1983 [7]. However, in the USA, the number of malpractice cases per 1,000 dentists seems to increase over the years, from 11 to 27 malpractice cases in the period from 1988 to 1992 [20], and more recent studies from 2007 show that dentists with at least one filled claim increased from 27 per 1,000 dentists to 40 per 1,000 dentists in the USA [21].

In Denmark, the number of malpractice cases increased from 4 to 5 per 1,000 dentists, between 1995 and 2004 [8]. Dental malpractice claims evaluated per patient has been relatively constant over a the period from 1995 to 2004. However, in urban areas, the prevalence of claims was greater than the overall mean of the country (24.7 versus 13.1, respectively) [8]. A similar difference between urban and rural areas was reported also in Sweden [2, 7].

It can be concluded that regarding the claims prevalence, the medicolegal system varies between countries, and therefore direct comparisons are difficult to make, but in general complaints from patients about dental treatments are internationally rising [2].

Dental Areas of Malpractice Claims

Endodontic treatment–related claims are among the top three frequent reported complaint areas [2], and among specific causes for these complaints, are vertical root fractures [4].

Several subcategories of endodontic claims have been reported. Inadequate root filling quality is a major contributor to endodontics-related claims [8], Specifically, short root fillings appear's to dominate. Iatrogenic root perforations represent another high-risk category followed by separated instruments. Also, the inappropriate use of outdated endodontic materials such as paraformaldehyde application was represented. In all reported cases in Denmark it led to a decision of malpractice [2, 8]. Altered nerve sensation following surgical and nonsurgical endodontic treatments is also associated with malpractice claims. A typical profile for a complaint of altered nerve sensation is a female patient having a second mandibular molar treatment associated with overfilling [22].

Vertical Root Fractures in Root Filled Teeth

Vertical root fracture in root filled teeth is a challenging complication clinically as well as medicolegally and seldom not as obvious as illustrated in Fig. 9.1. Analysis of vertical root fracture's in endodontically treated teeth has shown that premolar and mandibular molar teeth are more prone to medicolegal claims. Moreover, an inadequate root filling complicates and delays the correct diagnosis of vertical root fracture, thus extending the required time for obtaining an accurate diagnosis and hereby increasing the medicolegal risk [23]. Analysis of data from the dental insurance appeals board in Denmark from 2008 to 2012 [10] listing the number and the reasons of all the appeals revealed that the prevalence of endodontics-related appeals comprise 20.2 % ($n=163$) of all the cases ($n=806$) and of these root fractured roots in root filled teeth accounted for only a very small fraction of the cases [2].

The Fate of the "Complaint Tooth" in Relation to Vertical Root Fractures

The gender of the practitioner and the complainant are important factors for the emergence of a complaint. Several studies reported an over-representation of male practitioners and of female complainants [8, 22]. These data support the importance of the patient–practitioner communication in these potential malpractice cases and indicates that the professional communication may have a gender aspect [2, 24–27]. Patient-centerd communication, being more frequent among female practitioners [25], might decrease the risk of being involved in liability claims. A "frustrating patient visit" [28] may develop when a treatment decision regarding the "complaint tooth" has to be carried out, and in case of a crucial relationship deterioration between the practitioner and the patient, irrational treatment solutions, such as to extract the tooth, may be chosen [2]. For example, it had been reported that almost 50 % of teeth with a short root filling, almost 90 % of perforated teeth, and all teeth diagnosed with a separated instrument were extracted [4]. However, for the vertical root fracture, it may be the opposite way around—the tooth has typically been extracted because it is untreatable and then a medicolegal scenario may arise shortly after.

Advances of Diagnostic Tools Is Crucial from a Medicolegal Viewpoint

There is no high-level evidence for which diagnostic tools should be used for proper diagnosis for incomplete as well as complete vertical root fractures [29]. However, many recent papers have examined various radiographic and tomographic methods [30, 31]. In vitro data shows improvement by the use of CBCT for detecting vertical root fractures [32, 33]. However, within a clinical setting, the results are not that clear and convincing [34]. Several variables may influence the interpretation of these diagnostic tools: presence or not of root filling and postmaterial [30, 31, 35, 36], various parameters used for interpreting the digital images [32], as well as the voxel size used when evaluating the tomographic field of view [30].

Conclusion

Vertical root fracture is a very difficult topic with respect to medicolegal considerations. First and foremost, efforts for preventing the vertical root fracture should be highlighted and relate's to (1) proper root canal treatment and (2) analysis of the actual need for a post, including the dimension of the post preparations as well as the material of the post.

In particular, an inadequate root canal treatment may jeopardize an accurate diagnosis and hereby increase the medicolegal risk as time may be extended, before the vertical root fracture becomes obvious. Future improvements and the diagnostic efficacy of digital periapical radiography and Cone Beam computed tomography are therefore needed since their current limitations still confound the clinical diagnosis of VRF [34].

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