# Chapter 1

# Anatomy of Multi-rooted Teeth and Aetiopathogenesis of the Furcation Defect

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## 1.1 Introduction: Why Focus on Molars?

Dentists generally agree on three statements about molars:

- They play an important role in the dentition.
- They are difficult to reach for self-performed as well as professional cleaning due to their posterior position in the mouth.
- They pose some challenges due to their unique anatomy.

The important role of molar teeth in the dentition mainly consists in their contribution to mastication, because they carry a considerable part of the occlusal load. Hiiemäe (1967) focused on the masticatory function in mammals and molars grinding the food, and in 1975 Bates et al. reviewed the literature on the masticatory cycle in natural and artificial dentitions of men, attributing a fundamental role to our posterior teeth regarding the intake and preparation of nutrition. Thus, a focus on molars and the endeavour to retain our posterior teeth in a healthy functional state seems justified.

This chapter will reveal how the posterior position of molars makes them less accessible for cleaning, whether it may be self-performed or carried out by a dental professional. This fact, combined with the unique anatomy of molars, poses a challenge for all dentists focusing on molar retention.

## 1.2 The 'Special' Anatomy of Molar Teeth

The essential knowledge of molar root anatomy for every periodontist is stressed in a review by Al-Shammari et al. (2001). Due to the higher mortality and compromised diagnoses of furcation-involved molars, and likewise to the reduced efficacy of periodontal therapy in multi-rooted teeth, the authors suggest a thorough engagement with possibly decisive tooth factors such as furcation entrance area, (bi)furcation ridges, root surface area, root separation, and root trunk length, because they may critically affect the diagnosis and therapy of multi-rooted teeth (Leknes 1997; Al-Shammari et al. 2001).

For centuries, scientists have concerned themselves with the human teeth, their anatomy, evolution, function, histology, and histogenesis. Almost 3000 years ago, the Etruscans populating the northern and central part of what is now Italy from 900 to 100 BC recognized the importance of teeth and fabricated quite delicate dental prostheses, which Loevy and Kowitz (1997) compared to prostheses from the mid-twentieth century.

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The formation and genesis of teeth have been studied in more detail during the last three and a half centuries, starting with the works of the so-called father of microscopic anatomy and histology, Marcello Malpighi (1628–1694) from Italy (Rifkin and Ackerman 2011), who referred to an 'involucrum externum' describing the outer part of the tooth, which is today known as enamel. More than a century later the formation of cementum (1798–1801) and dentine (1835–1839) was described (e.g. Blake 1801; Bell 1835). Written in 1935, *Meyer's Normal Histology and Histogenesis of the Human Teeth and Associated Parts* (Churchill 1935) builds the foundation of our understanding regarding the anatomy of teeth. Orban and Mueller (1929), who studied the development of furcations in multi-rooted teeth, set a focus on molars using graphic reconstructions as early as 1929. Their three-dimensional illustrations allow a detailed impression of the root area comparable to those documented by Svärdström and Wennström (1988). In later years, scientists focused more and more on micro-anatomical and histological research.

Based on the knowledge thus created, the sequence of molar development can be divided into three phases analogous to the development of all teeth (Thesleff and Hurmerinta 1981): initiation, morphogenesis, and cell differentiation. The evolution of more than one root sets molars apart from the rest of the dentition: in multi-rooted teeth the enamel organ expands with projections of Hertwig's root sheath (an epithelial diaphragm). These expansions were described as lobular growing inwards between the lobes. Depending on the number of lobes, two to three (in rarer cases four) roots develop as soon as the projections have fused (Bhussry 1980). In an investigation by Bower (1983) of furcation development, evolving mandibular molars from 13 foetuses between 17 and 38 weeks of gestation were fixed, sectioned, and stained, giving a unique and detailed impression of furcation development. The author measured the base of the dental papilla as well as the buccal and lingual epithelial elements and described the development as follows: The first epithelial elements, which later evolve into the bifurcation, appear at the 24-week stage of gestational age. At that time, the crown formation of the molar is not complete and Hertwig's root sheath has not developed yet (Bhussry 1980; Bower 1983). Thus, the author suggests that the epithelial elements form extensions of the epithelium of the developing crown rather than the root (Bower 1983). Additionally, he detected stellate reticulum (which is essential for the formation of ameloblasts) in the furcation area. The author speculated about a possible mechanism of enamel formation due to the presence of stellate reticulum in the region of the furcation, which develops into ameloblasts, for example resulting in cervical projections of enamel.

## 1.3 Anatomical Factors in Molar Teeth

In 1988, Svärdström and Wennström plotted three-dimensional contour maps in order to describe the topography of the furcation area and compared drawings of maxillary and mandibular molars. These show a complex area with small ridges, peaks, and pits, and the authors summarize that the complexity of the furcation topography evidently increases the difficulties with respect to proper debridement once the periodontal pocket reaches the furcation entrance and runs into the furcation area. Thus, in addition to the aforementioned potentially decisive factors – furcation entrance area, bifurcation ridges, root surface area, and root trunk length – it has to be kept in mind that the complexity of the furcation area itself poses a challenge to the dental practitioner (Svärdström and Wennström 1988). Figure 1.1 shows a diagram of a mandibular molar, highlighting the main anatomical features.

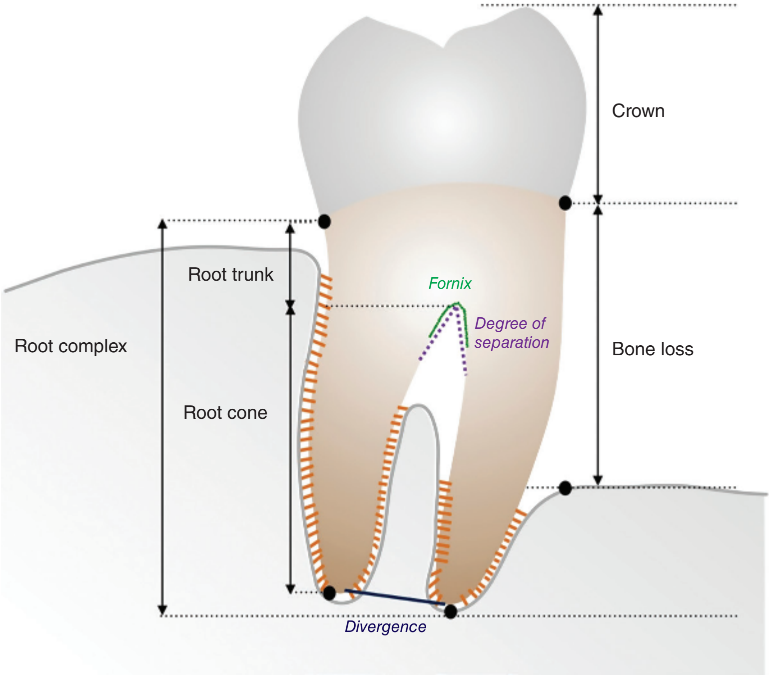

**Figure 1.1** Drawing of mandibular molar with furcation involvement, showing the main anatomical features, including root trunk (part of the root from the cemento-enamel junction [CEJ] to the furcation entrance) and root cones, and pointing at root divergence and degree of separation between roots. The 'bone loss' is schematically indicated as the distance between the CEJ and the most apical part of the bone. *Source*: Courtesy of Dr Aliye Akcali.

### 1.3.1 Furcation Entrance Area

The furcation entrance area was measured by Bower (1979a) in 114 maxillary and 103 mandibular first molars. The diameter of the entrance area was smaller than a curette blade in more than 50% of the examined furcations, with the smallest average diameter in buccal (b) sites of maxillary as well as mandibular first molars. No correlation between the size of the tooth and its furcation entrance area could be detected (Bower 1979a). Hou et al. (1994) studied 89 extracted maxillary and 93 extracted mandibular first and second molars microscopically. In their Chinese population sample, they concurred with the results presented by Bower (1979a) in the maxilla and found a larger diameter in mesio- (mp) and disto-palatal (dp) furcation entrances for first and second molars (mp: 1.04 mm and 0.90 mm; dp: 0.99 mm and 0.67 mm; b: 0.74 mm and 0.63 mm, respectively), which was confirmed by Svärdström and Wennström (1988) and dos Santos et al. (2009).

In mandibular molars the results differed, with wider entrance areas in buccal furcations of first and second molars (b: 0.88 mm and 0.73 mm; l: 0.81 mm and 0.71 mm, respectively). Nonetheless, the furcation entrance area was < 1 mm in the majority of molars and < 0.75 mm in 58%, 49%, and 52% of molars, respectively (Bower 1979a; Chiu et al. 1991; Hou et al. 1994). Thus, the standard width of curettes (0.75–1.0 mm) is mostly too large to access, let alone properly clean, a furcation entrance. Hou et al. (1994) concluded that in order to achieve complete debridement of root surfaces within furcations, an appropriate selection and combination of ultrasonic tips (diameter 0.56 mm) and periodontal curettes should be considered. A recent study by dos Santos et al.

(2009) analysed 50 maxillary and 50 mandibular molars and confirmed the aforementioned findings, concluding that some molar furcation entrances could not be adequately instrumented with curettes and suggesting the use of alternative hand instruments. In a review, Matthews and Tabesh (2004) stressed the importance of the diameter of the furcation entrance in order to judge the effect of professional cleaning, and thus the probable success of periodontal therapy. The challenges of furcation cleaning are discussed by Fu and Wang in Chapter 3.

### 1.3.2 (Bi)furcation Ridges

In early morphological studies of extracted first molar teeth, cementum was found in the furcation area in a ridge, building the furcation region in mandibular molars, and was called an intermediate bifurcation ridge (IBR), with a high presence of cementum adjacent to the furcation entrance (Everett et al. 1958; Bower 1979a, b; see Figure 1.2). In a study on developing first mandibular molars sectioned at different gestational ages, the lingual element was found to be wider in a mesio-distal dimension comparable to studies in extracted molars (Bower 1983, 1979b). Secondly, the exclusion of ectomesenchyme between the lobes described by Bhussry (1980) may explain the large quantities of cementum in the furcation area of the mature tooth corresponding to bifurcation ridges (Bower 1983). In general, two types of bifurcation ridge are known: one in the bucco-lingual direction, the other in the mesio-distal direction (intermediate = IBR). Everett et al. (1958) detected buccal and lingual ridges, mainly constituting of dentine, in 63% of mandibular first molars and IBRs, mainly composed of cementum, in 73%. The findings of Burch and Hulen (1974), Dunlap and Gher (1985), and Hou and Tsai (1997a) concur, with a prevalence of 76.3%, 70%, and 67.9%, respectively, in mandibular first molars.

Gher and Vernino (1980) suggest a connection between the presence of an IBR and the progression of the furcation defect due to the morphology and location of IBRs. Hou and Tsai (1997a) confirmed this correlation. Additionally, they stated that an even higher significant correlation exists between the simultaneous presence of IBRs combined with cemento-enamel projections and furcation involvement (FI).

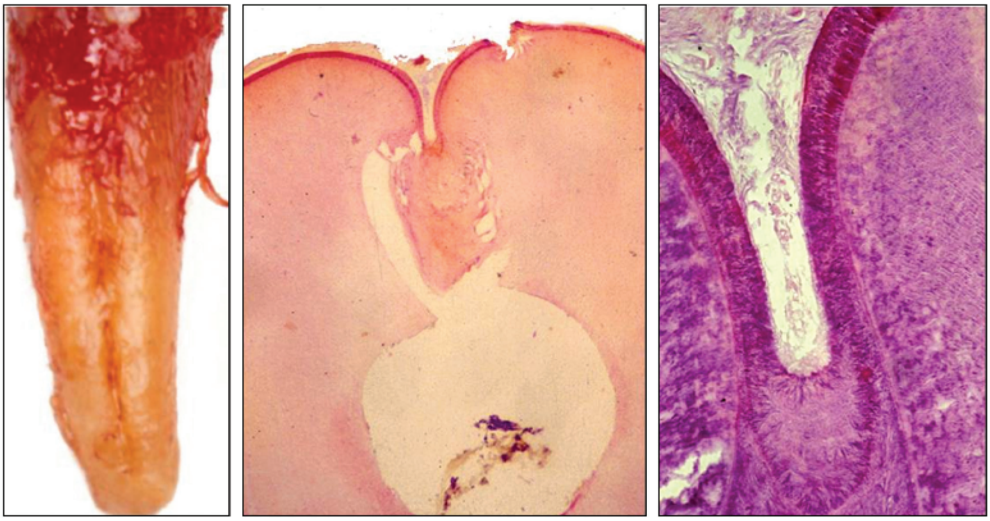

**Figure 1.2** Furcation ridge. *Source*: Courtesy of Dr Nicola Perrini.

### 1.3.3 Root Surface Area

A team of researchers (Hermann et al. 1983; Dunlap and Gher 1985; Gher and Dunlap 1985) focused on the topic of root surface area (RSA) in maxillary and mandibular first molars. In a meta-analysis derived of data from 22 original articles, Hujoel (1994) computed a total RSA (corresponding to the periodontal surface area) for the complete dentition of 65–86 cm$^2$, excluding third molars. In maxillary first molars a mean of 4.5 cm$^2$ (second: 4.0 cm$^2$) and in mandibular first molars a mean of 4.2 cm$^2$ (second: 3.4 cm$^2$) were calculated. In molars, it is often difficult to judge the extent of FI clinically (Bower 1979b) and thus to determine the RSA exactly.

#### 1.3.3.1 RSA in the Maxilla

Hermann et al. (1983) as well as Gher and Dunlap (1985) dissected 20 extracted first maxillary molars and cross-sectioned them in 1 mm increments. Molars with fused roots were excluded. They observed that the disto-buccal root had a significantly smaller RSA than either the mesio-buccal or palatal root, confirming the results of Bower (1979b). The root trunk surface area was significantly larger than any surface of the three individual roots, and averaged 32% of the total RSA of the maxillary first molar (Hermann et al. 1983). Gher and Dunlap (1985) measured a mean root length of 13.6 mm (ranging from 10.5 to 16 mm) and a total RSA of 4.77 cm$^2$ (ranging from 3.36 to 5.84 cm$^2$). Additionally, a 'ballooning' of the RSA percentage in the furcation area of maxillary molars was described, which could not be detected in other teeth. Accordingly, the importance of periodontal support in the furcation area of maxillary molars was stressed, concluding that a relatively small attachment gain or loss may have a significant impact on the stability of the maxillary first molar (Gher and Dunlap 1985).

#### 1.3.3.2 RSA in the Mandible

For a study on mandibular first molars, 10 teeth were hemisected and measured by Anderson et al. (1983). They concluded that the mesial root showed a statistically significant greater RSA than the distal root, which should be taken into consideration when planning treatment, especially regarding resective approaches. Dunlap and Gher (1985) dissected 20 extracted mandibulary first molars and cross-sectioned them in 1 mm increments. They too observed that the distal root had a significantly smaller RSA than the mesial one, but stressed that the shapes of the roots (conical for the distal one; hour-glass shaped for the mesial one) should be taken into consideration as well. In contrast to their findings in the maxilla, the root trunk surface area was not larger than the surface of the individual roots, and averaged 30.5% of the total RSA of the mandibulary first molar. They found a mean root length of 14.4 ± 1.1 mm and a total RSA of 4.37 ± 0.64 cm$^2$. In other studies (Jepsen 1963; Anderson et al. 1983), the total RSA varied from 4.31 to 4.7 cm$^2$.

### 1.3.4 Root Trunk Length

The portion of multi-rooted teeth located apical to the cemento-enamel junction (CEJ) is called the 'root complex' and is divided into root trunk and root cones. The root trunk is generally defined as the area of the tooth from the CEJ to the furcation fornix. In a study by Gher and Dunlap (1985), the distance between the CEJ and the furcation entrance in maxillary molars differed considerably between the mesial (3.6 ± 0.8 mm) and the distal entrance (4.8 ± 0.8 mm), whereas the buccal entrance was detected 4.2 ± 1.0 mm apical to the CEJ. These findings led to the conclusion that the clinician should suspect a through-and-through furcation (degree III according to Hamp et al. 1975) in maxillary molars once a loss of 6 mm in vertical attachment occurred. In more than 50% of the dissected maxillary molars, the furcation roof was found coronal of the root separations and formed a concave dome between the three roots.

It should be emphasized that the dome-like anatomy further complicates therapy and maintenance of maxillary first molars (Gher and Dunlap 1985). Hou and Tsai (1997b) measured the root trunk in 166 extracted first and second maxillary and 200 extracted first and second mandibular molars of a Taiwanese tooth sample. In the maxilla, short root trunks were more commonly found buccally, whereas long root trunks were more commonly found mesially (Hou and Tsai 1997b). The authors found generally longer root trunks in second molars than in first molars in both jaws, and additionally stated that long root trunks are associated with short root cone length (Hou and Tsai 1997b).

In 134 extracted first and second mandibular molars, Mandelaris et al. (1998) detected longer root trunks in lingual molar surfaces when compared to buccal surfaces (mean: 4.17 mm and 3.14 mm, respectively), confirming the results of Hou and Tsai (1997b). The mean distance between the CEJ and the furcation entrance was 4.0 ± 0.7 mm in mandibular molars (4.6 ± 0.6 mm in maxillary first molars; Dunlap and Gher 1985; Gher and Dunlap 1985), whereas no root trunk of > 6 mm could be found (Dunlap and Gher 1985; Mandelaris et al. 1998). Like in maxillary molars, it can be concluded that a through-and-through furcation (Hamp et al. 1975) should be expected in the mandible once a loss of 6 mm in vertical attachment was reached on both sides (buccal and lingual). On the other hand, it has to be kept in mind that a furcation defect has a horizontal component as well. Santana et al. (2004) measured 100 extracted first and second mandibular molars and their findings suggest that a horizontal attachment loss of 4.3–6.9 mm is essential in order to allow communication between the buccal and lingual furcation entrance. Complete or partial fusion of roots is also not unusual in multi-rooted teeth. Some 40% of maxillary premolars are two-rooted and the entrance to the furcation is located an average 8 mm from the CEJ, well into the middle third of the root complex (Bower 1979a).

A clinically evident FI correlates with the vertical length and type of the root trunk (Carnevale 1995; Hou and Tsai 1997b, Al-Shammari et al. 2001). Thus, Al-Shammari et al. (2001) summarized that the root trunk length significantly relates to the prognosis and treatment of molars. A short root trunk worsens the prognosis with regard to a more likely FI, but once periodontal destruction has occurred, it improves the chances of a successful treatment (Horwitz et al. 2004).

## 1.4 Anatomical Aetiological Factors

### 1.4.1 Cervical Enamel Projections

Enamel surfaces do not allow for the attachment of connective tissue and represent an anatomical abnormality in the root area. Thus, cervical enamel projections (CEP) may contribute to the development of a furcation defect (Al-Shammari et al. 2001). The first to report a possible connection between CEPs and periodontal destruction in molars was Atkinson in 1949. According to Masters and Hoskins (1964), CEPs can be classified in three grades (Table 1.1).

Different prevalences of CEPs have been documented so far. Masters and Hoskins (1964) found CEPs in 29% of mandibular and 17% of maxillary molars. In Egyptian skulls, Bissada and Abdelmalek (1973) detected a CEP prevalence of 8.6%. In the 1138 molars studied, a higher incidence of CEPs in the

**Table 1.1** Classification of cervical enamel projections.

| | |
|---|---|
| Grade I | The enamel projection extends from the cemento-enamel junction of the tooth towards the furcation entrance (<1/3 of the root trunk). |
| Grade II | The enamel projection approaches the furcation entrance but does not enter it. No horizontal component is present (>1/3 of the root trunk). See Figure 1.3a. |
| Grade III | The enamel projection extends horizontally into the furcation. Compare Figures 1.3b and 1.3c. |

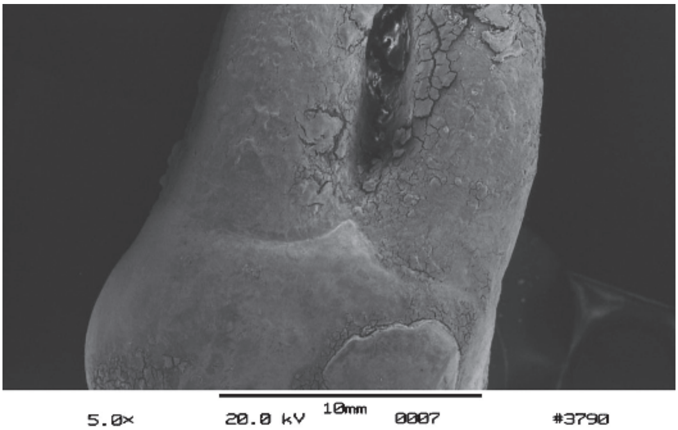

**Figure 1.3a** Cervical enamel projection grade II (>1/3 of root trunk; Masters and Hoskins 1964) on upper right first molar (REM microscope). *Source*: Eickholz and Hausmann 1998.

mandible could be confirmed. A study in 200 East Indian skulls with 2000 molars reported a 32.6% incidence rate of CEPs (Swan and Hurt 1976). They were most often reported in mandibular second molars (51.0%), followed by maxillary second molars (45.6%), mandibular first and maxillary first molars (13.6%). Grade I enamel projections (Masters and Hoskins 1964) were detected most frequently. These could not be significantly related to furcation involvement, as could grade II and III CEPs (Swan and Hurt 1976). An observation in 78 Taiwanese individuals reported detection of CEPs in 49.3% of second and 62.3% of first maxillary and 51.2% of second and 73.9% of first mandibular molars (Hou and Tsai 1987). A study by the same authors in furcation-involved mandibular molars reported even higher CEP percentages: 71% of second and 92.9% of first mandibular molars showed enamel projections (Hou and Tsai 1997b). Mandelaris et al. (1998) documented CEPs in 66.4% of mandibular molars (61.9% of buccal and 50.8% of lingual surfaces) ranging from 0.98 to 1.33 mm in diameter. Current research on CEPs was published in 2013 and 2016. Bhusari et al. (2013) investigated their incidence on the buccal surface of 944 upper and lower first, second and third permanent molars from 89 Indian dry human skulls, and additionally measured FI. Again, it could be confirmed that CEPs are found more frequently in the mandible and are significantly associated with the occurrence of FI. The incidence ranged from 14.7% in mandibular second molars to 5.5% in wisdom teeth. The most recent study was performed using cone-beam computed tomography data in a Korean population analysing 982 mandibular molars (Lim et al. 2016) and reported an overall prevalence rate of CEP of 76%. Grade I CEPs were the most common, followed by CEPs of grades II and III (Lim et al. 2016).

The huge variations can partly be explained by different study objects: in human skulls healthier periodontal conditions can be assumed, while extracted molars most probably show worse conditions, and Hou and Tsai (1987, 1997a) as well as Mandelaris et al. (1998) studied furcation-involved molars in periodontal patients. Additionally, a higher prevalence of CEPs in Oriental subjects than in Caucasians is suspected (Hou and Tsai 1987; Lim et al. 2016).

Nonetheless, it can be concluded that CEPs are a common problem which must be addressed by clinicians when treating molar teeth. They are more prevalent than enamel pearls and prevent connective tissue attachment, thus contributing to the aetiology of furcation defects, possibly resulting in localized chronic periodontitis and FI in molars (Leknes

**Figure 1.3b** Cervical enamel projection on lower left first molar; grade III (reaching furcation entrance area; Masters and Hoskins 1964). *Source*: Eickholz 2005.

**Figure 1.3c** Cervical enamel projection on extracted lower right first molar; grade III (reaching furcation entrance area; Masters and Hoskins 1964). *Source*: Eickholz and Hausmann 1998.

1997; Al-Shammari et al. 2001; Bhusari et al. 2013). Additionally, significantly higher plaque and gingivitis index values have been reported in the presence of CEPs (Carnevale et al. 1995).

## 1.4.2 Enamel Pearls

Enamel pearls (see Figure 1.4) were first described in an article in the *American Journal of Dental Science* in 1841 (Moskow

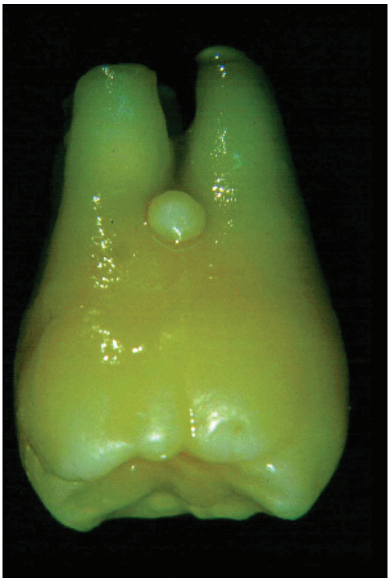

**Figure 1.4a** Macroscopic image of an enamel pearl on an extracted molar. *Source*: Courtesy of Prof. Dr. H.-K. Albers.

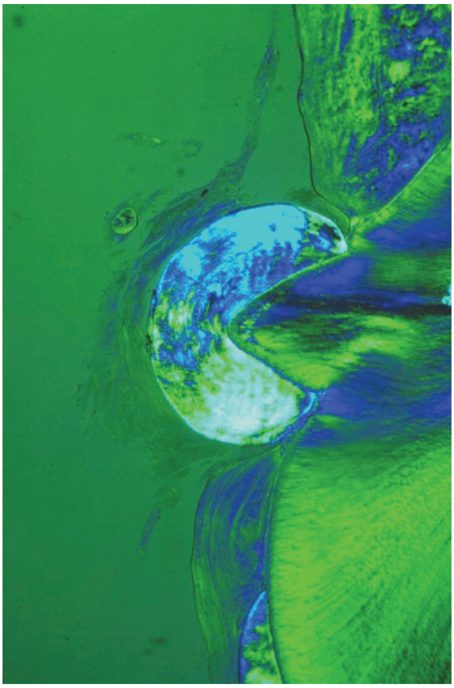

**Figure 1.4b** Microscopic image of an enamel pearl. *Source*: Courtesy of Prof. Dr. H.-K. Albers.

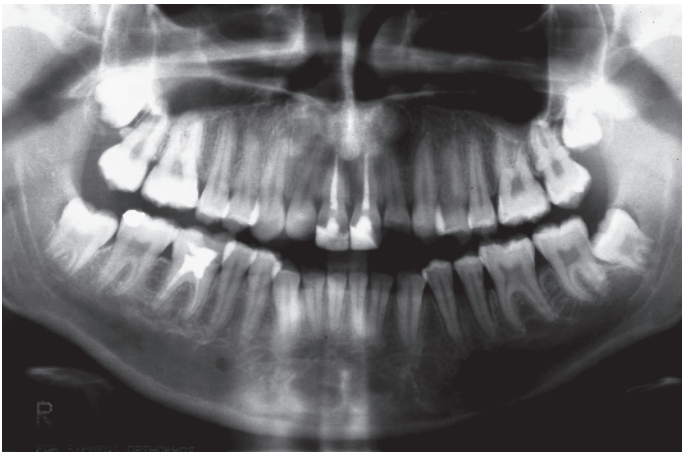

**Figure 1.4c** Orthopantomogram showing enamel pearls on upper right and left second molars. *Source*: Eickholz and Hausmann 1998.

and Canut 1990). They are ectopic globules consisting mostly of enamel, often containing a core of dentine, and they adhere to the tooth root surface, with a distinct predilection for the furcation areas of molar teeth, particularly maxillary third and second molars. In a review from 1990, an incidence of 2.6% (ranging from 1.1 to 9.7%) was reported, with differences among racial groups and a greater incidence in histological studies (Moskow and Canut 1990). Like CEPs, enamel projections prevent connective tissue attachment and thus contribute to the aetiology of periodontal destruction. They usually occur singularly, but up to four enamel pearls have been observed on the same tooth (Moskow and Canut 1990).

More recent research demonstrates an incidence within the range documented by Moskow and Canut (1990). Darwazeh and Hamasha (2000) evaluated the presence of enamel pearls in a Jordanian patient sample, studying 1032 periapical radiographs. An incidence of 1.6% of enamel pearls in molars and 4.76% per subject with no gender differences was reported. Chrcanovic et al. (2010) evaluated the prevalence of enamel pearls in 45 539 permanent teeth (20 218 molars) from a human tooth bank in Brazil. They confirmed the predominant presence in the maxilla and reported an incidence of 1.71% in molars. Akgül et al. (2012) evaluated the presence of enamel pearls using cone-beam computed tomography in 15 185 teeth (4334 molars). An incidence of enamel pearls of 0.83% in molars and 4.69% per subject with no gender differences was reported. Again, the incidence was significantly higher in the maxilla. Colak et al. (2014) studied the prevalence of enamel pearls in Turkish dental patients and detected them in 0.85% of teeth and 5.1% of subjects, with a contradictory higher incidence in the mandible and in male patients.

Although lower in incidence than enamel projections, it can be summarized that enamel pearls play an important role in the aetiology of furcation defects, and it is considered essential to diagnose enamel pearls early on to allow for an adequate prognosis of molar retention and probably alter the therapeutic approach.

## 1.5 Periodontal Aetiological Factors in Molar Teeth

Aetiological factors interact with the previously described anatomical factors and may lead to periodontal destruction and attachment loss in molars, and thus result in a furcation defect. According to Al-Shammari et al. (2001), plaque-associated inflammation, trauma from occlusion, pulpal pathology, vertical root fractures, and iatrogenic factors need to be taken into consideration.

### 1.5.1 Plaque-associated Inflammation

The reader of this book will surely be well accustomed to plaque formation and the inflammatory component of gingivitis and periodontitis. What is special about molars in this context? In general, it can be stated that furcations are more prone to plaque adhesion and less likely to stay plaque free. The anatomy of the furcation favours retention of bacterial deposits and renders hygiene procedures difficult (Matthews and Tabesh 2004). In 1987, Nordland et al. monitored 2472 sites in 19 periodontal patients for 24 months after periodontal therapy, and reported that furcation sites responded less favourably to therapy and were more likely to exhibit higher plaque and gingivitis scores. Apart from that, it is assumed that furcation areas are an extension of periodontal pockets, because unique histological features are lacking (Glickman 1950; Al-Shammari et al. 2001). Thus, plaque formation follows the same process in molars and their furcations as in the remaining dentition (Leknes 1997).

### 1.5.2 Occlusal Trauma

Trauma from occlusion is suspected to be another aetiological factor contributing to periodontal destruction in molars. Two groups of researchers, Glickman and co-workers as well as Lindhe and co-workers, focused on this topic in animal studies applying excessive occlusal forces on molars. In their classic studies on beagle dogs, Lindhe and Svanberg (1974) and Nyman et al. (1978) reported significant alterations in tooth mobility combined with angular bony defects and loss of periodontal support in artificially created, gingivally inflamed multi-rooted teeth carrying splints, compared to teeth with inflammation but carrying no additional occlusal load. Even before that, Glickman et al. (1961) compared the effect of occlusal force on splinted and non-splinted teeth in rhesus monkeys, and suggested that the fibre orientation in the furcation area makes multi-rooted teeth more susceptible to increased functional forces. More recently, Nakatsu et al. (2014) confirmed the aforementioned findings in an observation in rats. On the other hand, Waerhaug (1980) concluded from his observations of 46 human molars (extracted because of advanced periodontal destruction) that increased mobility and occlusal trauma are *not* involved in the aetiology of the FI and are instead a late symptom of periodontal disease. Thus, the impact of occlusal forces in the aetiology of periodontitis in general and FI in particular remains controversial (Al-Shammari et al. 2001; Reinhardt and Killeen 2015). In a review, Harrel (2003) suggest that occlusal interferences should be regarded as a potential risk factor comparable to smoking, rather than a causative or aetiological factor.

### 1.5.3 Vertical Root Fractures

It is generally agreed that vertical root fractures, which can occur in a longitudinal direction on any surface of the root, are difficult to diagnose because they share symptoms with other dental conditions (Matthews and Tabesh 2004). Additionally, in most cases mild pain or a dull discomfort is the only clinical symptom of a vertical root fracture (Meister at al. 1980). They result in rapid localized loss of attachment and bone (Walton et al. 1984) and can lead to FI depending on their position. Mostly, a poor prognosis is assigned to teeth exhibiting vertical root fractures (Al-Shammari et al. 2001; Matthews and Tabesh 2004).

### 1.5.4 Endodontic Origin and Pulpal Pathology

Accessory canals are quite common in molar teeth. A study of 46 extracted molars of both jaws found accessory canals in 59% of examined teeth (Lowman et al. 1973). Burch and Hulen (1974) reported 'openings' in 76% of the furcations of maxillary and mandibular molars. These canals allow for products of pulpal necrosis to enter the furcation area and cause an inflammatory lesion (Carnevale et al. 1995). Thus, a pulpal pathosis can result in FI. Carnevale et al. (1995) reported that proximal and inter-radicular bone destruction of endodontic origin is reversible after root canal treatment. Periodontal therapy only becomes necessary in the case of a persistent lesion after the endodontic treatment. A more detailed description of the associations between FI and endodontic pathology is provided in Chapter 4.

### 1.5.5 Iatrogenic Factors

Generally, overhanging dental restorations or discrepancies of the subgingival margin in any kind of restoration or even orthodontic bands allow for adhesion of plaque and show detrimental effects on adjacent gingival tissues; additionally, the fit of prosthetic restorations is mostly less than perfect (Leknes 1997) and builds a niche, where plaque formation is facilitated and cleansing difficult. According to a study by Lang et al. (1983) in dental students with healthy gingivae who received proximal inlays with 1 mm overhangs, the microbial composition of the subgingival biofilm shifted from healthy to a composition characteristically found in periodontitis. Thus, the authors concluded that the changes observed in the subgingival microflora document a potential mechanism for the initiation of periodontal disease associated with iatrogenic factors. Wang et al. (1993) focused on molars and assessed the correlation between FI and the presence of a crown or proximal restoration in 134 periodontal patients during maintenance therapy. Their results showed a significant association between FI as well as periodontal attachment loss and the presence of a crown or restoration.

Additionally, Matthews and Tabesh (2004) commented that overhangs not only build a plaque retention niche, but also impinge on the biological width (between the depth of a healthy sulcus and the alveolar crest) and thus cause damage. They report ranges of overhangs in restored teeth from 18 to 87% (Matthews and Tabesh 2004). In general, the placement of restorative margins subgingivally results in more plaque, more gingival inflammation and deeper periodontal pockets.

It can be concluded that special care needs to be taken when placing restorations, and overhangs need to be diagnosed and removed as early as possible. Should a restoration margin need to be placed subgingivally, the biological width has to be kept in mind and crown lengthening considered. Thus, a dento-gingival attachment may be achieved (Herrero et al. 1995).

## Summary of Evidence

- Numerous anatomical factors like furcation entrance area, bifurcation ridges, root surface area, and root trunk length need to be considered in the diagnosis and periodontal treatment of molars. The periodontist should be aware of these factors because they may have a significant impact on the prognosis and therapeutic outcome of multi-rooted teeth.
- Iatrogenic factors should be tackled early on (at the beginning of periodontal therapy), thus allowing for improvement of gingival and periodontal conditions.

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