

Longitudinal tooth fractures: findings that contribute to complex endodontic diagnoses

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The purpose of this review is to describe and discuss the diagnostic and treatment challenges related to tooth fractures primarily in the vertical plane, that is, the long axis of the crown and/or root. This includes when and how to identify and determine the extent of the fracture, when a coronal restoration should be placed, when root canal treatment is needed, and when a tooth or root should be extracted based on the location and extent of the fracture. The term 'longitudinal fractures' is used because they usually represent vertical extensions of fractures over distance *and* time. These fractures often present problems with diagnosis and treatment, but should be considered as findings only. They are not to be considered as pulpal or periapical diagnoses, but as pathways for bacteria that may induce pulpal and/or periapical inflammation or disease. Longitudinal fractures are divided into five definitive classifications, generally from least to most severe: (1) *craze lines*; (2) *fractured cusp*; (3) *cracked tooth*; (4) *split tooth*; and (5) *vertical root fracture*. These differ but have frequently been confused or combined in clinical articles, creating misunderstanding and resulting in incorrect diagnosis and inappropriate treatment. These classifications have been devised to provide global definitions that researchers and clinicians can use to eliminate this confusion. This review is subdivided into these five classifications as to incidence, pathogenesis, clinical features, etiologies, diagnosis, treatment, prognosis, and prevention.

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Introduction

This review considers tooth fractures that occur primarily in the vertical plane, that is, the long axis of the crown and/or root. The term longitudinal tooth fracture is appropriate because it implies a vertical direction and a time component (1), i.e. linear fractures that tend to grow and change over time. These longitudinal fractures are common (2) and challenging. Some are not difficult to manage, whereas others are so devastating that the tooth must be extracted. Relatively little clinical outcomes research is available related to longitudinal tooth fractures. Most treatment modalities have been based on opinion and anecdotal information. Notwithstanding, many cases present problems with diagnosis and treatment and should be considered for referral.

Longitudinal (vertical) fractures occur in all tooth groups and are caused by occlusal forces and/or dental procedures. Of significant note, this review is not in-

tended to discuss fractures resulting from impact trauma, which may occur in the vertical, as well as horizontal or oblique direction. Impact trauma results in an immediate fracture in the tooth as opposed to a longitudinal fracture which propagates (grows) over a period of time.

Classification

There are five separate classifications (Table 1); they are, from least to most severe: (1) *craze lines*; (2) *fractured cusp*; (3) *cracked tooth*; (4) *split tooth*; and (5) *vertical root fracture* (3–7). These differ but have frequently been confused or combined in clinical articles (8–18). Bader et al. (2) have stated that no attempts to characterize the severity of tooth fractures in terms of the proportion of fractures that expose dentin or pulp have been reported. Lack of knowledge concerning the type, characterization, and variety of fractures may lead to misunderstanding with incorrect

Table 1. Classification of longitudinal tooth fractures

	Craze line	Fractured cusp	Cracked tooth	Split tooth	Vertical root fracture
Location	Enamel only Common on marginal ridges	Crown and cervical margin of root	Crown only or crown to root extension (depth varies)	Crown and root; extension to proximal surfaces	Root only
Direction	Occluso-gingival	Mesio-distal and facio-lingual	Mesio-distal	Mesio-distal	Facio-lingual
Origin	Occlusal surface	Occlusal surface	Occlusal surface	Occlusal surface	Root (any level)
Etiologies	Occlusal forces, thermocycling	Undermined cusp, damaging habits	Damaging habits, weakened tooth structure	Damaging habits, weakened tooth structure	Wedging posts, obturation forces, excessive root-dentin removal
Symptoms	Asymptomatic	Sharp pain with mastication and with cold	Highly variable	Pain with mastication	None to slight
Signs	None	None of significance	Variable	Separable segments, periodontal abscess	Variable
Identification	Direct visualization, transillumination	Visualize, remove restoration	Biting, remove restoration	Remove restoration	Reflect flap and transilluminate
Diagnostic tests	None	Visible fractures of cusps, biting test, transillumination	Transillumination, staining, wedge segments (unseparable), isolated/narrow perio-probing, biting test, magnification	Wedge segments (separable)	Reflect flap and transilluminate
Treatment	No treatment needed, esthetic	Remove cusp and/or restore	Root canal treatment depends on pulpal and periapical diagnosis, restore with full cuspal coverage	Variable, must remove one segment, restore, or extract	Remove tooth or fractured root, consider fixed and/or removable bridge, or implant
Prognosis	Very good	Very good	Always questionable to poor	Maintain intact (hopeless) Remove segment (variable)	Hopeless for fractured root
Prevention	None needed	Place conservative Class II restorations, coronal protection (onlay undermined cusps)	Eliminate damaging habits (ice chewing, etc.), coronal protection (onlay undermined cusps)	Eliminate damaging habits, coronal protection (onlay cusps)	Minimize root dentin removal, avoid wedging posts, reduce condensation forces, use of carbon fiber posts

diagnosis and inappropriate treatment. These five categories of longitudinal fractures have been devised to provide global definitions that researchers and clinicians can use to decrease this confusion (3–7). Only after these fractures have been defined and characterized can there be a better understanding of their epidemiology; this review will show how each longitudinal fracture classification is different, espe-

cially related to prognosis and treatment modalities. A chronological history of terms used to describe cracks in teeth indicates trends over time (16). Classification schemes that only consider whether a fracture is complete vs. incomplete (16, 19, 20) will not readily illuminate these differences.

Each of the cracks and fractures discussed in this review could be called ‘vertical fractures.’ Also, each

fracture that involves the tooth root, whether originating from the coronal (enamel) or apical (root) portion of the tooth, can be termed ‘vertical root fractures.’ Therefore, a crack that extends from crown to root in a mesio-distal direction, a split tooth, and a ‘true’ vertical root fracture which involves only the root have all been termed ‘vertical root fractures.’ The use of this term in these manners is not appropriate and has caused significant confusion clinically and in the dental literature; hence this use should be minimized.

Table 1 separates these five entities as to their incidence, pathogenesis, clinical features, etiologies, diagnosis, treatment, prognosis, and prevention. Figure 1 further illustrates how to clinically differentiate and categorize cracks and fractures in teeth according to location, separable segments (i.e. complete vs. incomplete), and treatment.

Incidence

The incidence of longitudinal fractures has been increasing for several reasons. Patients are aging, with

a decrease in tooth extraction. Therefore, more teeth undergo complex procedures and are present longer. These procedures include restorative and endodontic treatments that remove dentin, thereby compromising internal strength (21). In addition, the teeth absorb external forces that exceed dentin strength and gradually alter tooth structure (21). Once a destructive force exceeds the elastic limit of dentin or enamel, a fracture occurs (22, 23). Importantly, however, such fractures are neither confined to the elderly nor occur only in restored teeth (24–27). Another reason for the increased incidence is improved diagnosis. Awareness combined with procedures such as transillumination, biting devices, staining, magnification, and tomography help identify these fractures.

Clinical considerations

Patients must be informed of six important considerations:

- (1) Fractures occur from excessive forces, usually (but not always) long term.

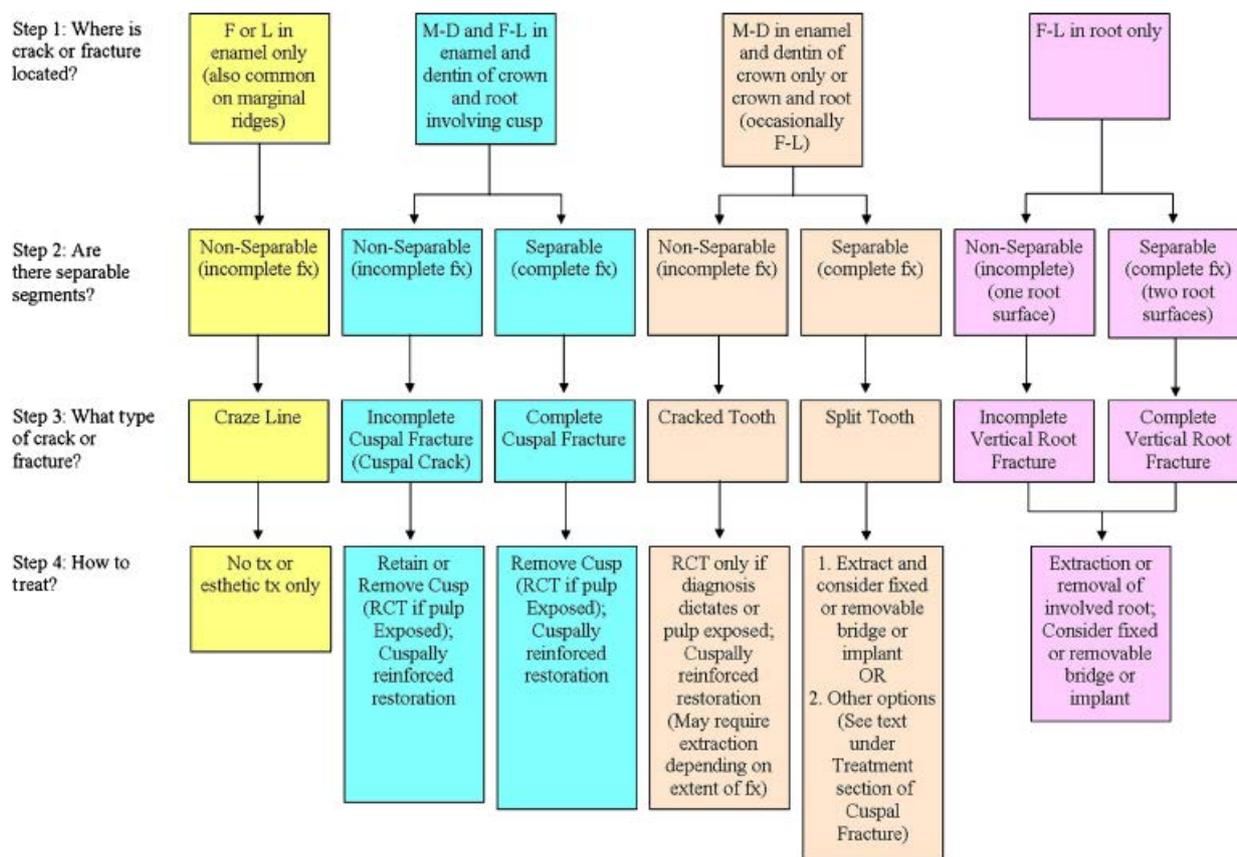


Fig. 1. Clinical determination of longitudinal cracks and fractures based on location and separable segments, including treatment.

- (2) They may be difficult or impossible to visualize, and not demonstrable until growth and/or expansion. Also, they may be under bone and gingiva and difficult to see, even after flap reflection.
- (3) Fracture spaces tend to acquire stains, making them more visible with time.
- (4) A small fracture tends to grow (maybe very slowly) with time. An analogy is a small crack in a windshield which often lengthens over months or years.
- (5) Clinical signs and symptoms often are not present early, but may manifest after months, years, or decades after fracture initiation.
- (6) Longitudinal fractures are not diagnoses, they are findings. Pulpal and periapical tissues are usually not affected by longitudinal fractures that do not communicate with the pulp. However, longitudinal fractures with pulpal communication allow bacterial contamination of the pulp.

Crack vs. fracture

Either the crown or the root is the site of initiation as well as the region of principle damage. In the crown (and in most situations, extension to the root) are the *cuspal fracture*, *cracked tooth*, and *split tooth* (Figs. 2 and 3); fractures confined to the root show the *vertical root fracture* (Fig. 4). The term ‘crack’ implies an incom-

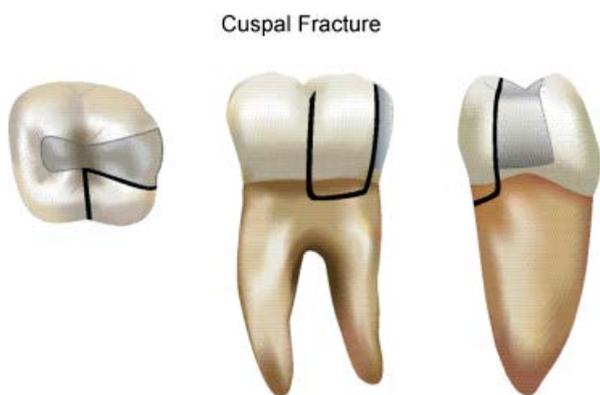


Fig. 2. Fractured cusp. The direction of the fracture is both mesio-distal and facio-lingual on the crown (crossing the marginal ridge and also extending down a facial or lingual groove), usually associated with teeth that have large restorations. The location is on the crown and can extend onto the cervical margin of the root; when viewed from the proximal, the fracture is usually not centered and follows the lateral surface of an existing restoration. Note that the tooth segments may be separable (complete fracture) or non-separable (incomplete fracture).

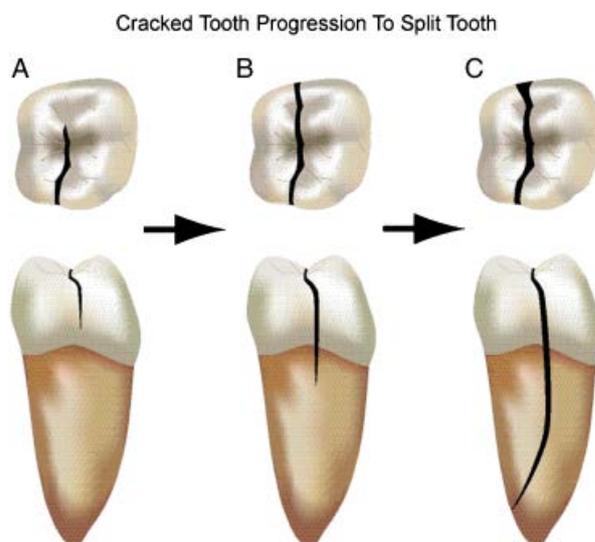


Fig. 3. Cracked tooth progression to split tooth. (A) Cracked tooth – The direction of the fracture is usually mesio-distal on the crown and normally associated with teeth that have no or minimal restorations; the location is on the crown and can extend onto the root. (B) When viewed from the proximal, the fracture is centered and the depth on the root varies; the tooth segments are not separable. (C) Split tooth – The direction of the fracture is mesio-distal on the crown and is the result of propagation/progression of a cracked tooth; the location is on the crown and extends onto the root. When viewed from the proximal, the fracture is centered and extends deeply toward the facial or lingual root surface; typically the tooth segments are separable.

plete break in a substance (such as a tea cup, tooth, etc.). The term ‘fracture’ implies a complete or incomplete break in a substance (such as a tea cup, tooth, bone, etc.). Healthline.com (28) states that if more pressure is put on a bone than it can stand, it will split or break. A break of any size is called a fracture; a stress fracture is a hairline crack in the bone that develops due to repeated or prolonged forces against the bone (28). Therefore, the terms ‘cuspal fracture’ and ‘vertical root fracture’ imply a complete or incomplete break of the tooth; ‘craze lines’ and ‘cracked teeth’ are only incomplete breaks in teeth (no separable segments); ‘split teeth’ are only complete breaks in teeth (separable segments) (Fig. 1).

Craze lines

The first (and non-serious) longitudinal fracture is craze lines. These are common in adults. They extend

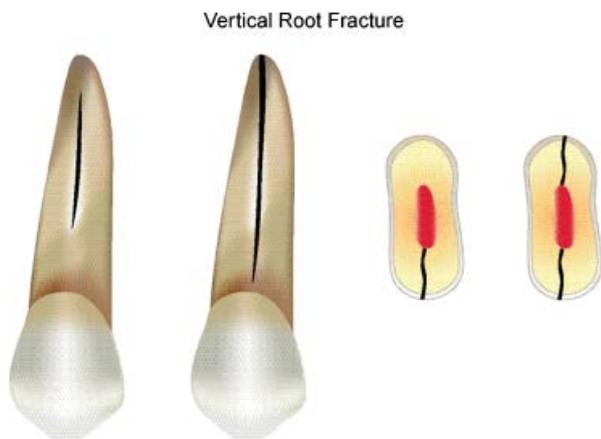


Fig. 4. Vertical root fracture. The direction of the fracture is usually facio-lingual on the root and is usually associated with teeth that have had condensation forces during root canal filling procedures or forces from placement of posts. The location is on the root only at any level. When viewed from the facial or lingual, the fracture may originate anywhere on or within the root and may extend coronally toward the cervical margin. The tooth segments may be separable (complete fracture involving two root surfaces) or non-separable (incomplete fracture involving one root surface).

over marginal ridges, buccal, and lingual surfaces in posterior teeth, and as long vertical defects in anteriors (Fig. 5). The crazing is confined to enamel and is a natural occurrence (4, 8). It is unlikely that these lines are a precursor to dentin fractures. Craze lines are unimportant other than as a frequent source of misidentification and confusion with cracked teeth when they occur on marginal ridges of posterior teeth (8) or because of esthetics. They are summarized in Table 1 and Fig. 1, and will not be discussed further.

Fractured cusp

The term ‘fractured cusp’ is defined as a complete or incomplete fracture initiated from the crown of the tooth and extending subgingivally, usually directed both mesio-distally and facio-lingually; the fracture usually involves at least two aspects of the cusp by crossing the marginal ridge and also extending down a facial or lingual groove. The fracture will extend to the cervical third of the crown or root. Fractured cusps are relatively easy to diagnose and treat and usually have a good prognosis (Table 1, Fig. 2).

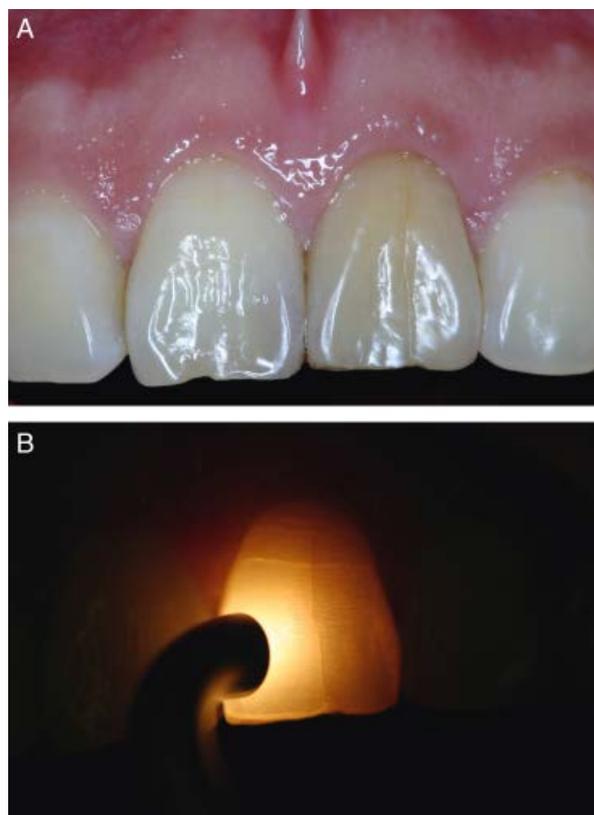


Fig. 5. (A) Craze lines evident. (B) Transillumination provides further details as to how the light penetrates through the craze line.

Incidence

Fractured cusps are more common than the other longitudinal fractures that involve dentin. This is fortunate because these are the least devastating and easiest to manage (4, 6). This fracture occurs more often in teeth with extensive caries or large restorations which do not protect undermined cusps (29).

Pathogenesis

A frequent cause of fractured cusps is inadequate dentin support of cusps from extensive caries or large restorations (30). A confusing entity is the type of cusp fracture that occurs infrequently as a result of traumatic injury; a traumatic upward blow to the mandible resulting in a sharp impact of teeth in occlusion that fractures several cusps. These fractures occur immediately (i.e. not over time) and so are technically not classified as longitudinal fractures, even though the end result is the loss of one or more cusps.

Clinical features

Cusp fractures are usually associated with wide and/or deep Class II restorations, or caries that have weakened a marginal ridge. These have compromised dentin support for the cusp, which is primarily from the marginal ridge (31). Often a single cusp is involved and will include both a mesial-distal and a facial-lingual component (Figs. 1 and 6–9). Therefore, the oblique, shearing fracture (Fig. 2) crosses the marginal ridge and extends down a facial or lingual groove, often into the cervical region at or below the gingival margin and epithelial attachment, usually not extending beyond the cervical third of the root (32, 33). If two cusps are involved, the fracture lines will be mesial and distal, without a facial or lingual component. Usually there is no pulp exposure, particularly in older teeth with smaller pulp chambers.



Fig. 6. Fractured cusp with exposure of the pulp. Note the presence of a large composite restoration.



Fig. 7. Fractured cusp evident as a change in opacity on the facial surface of the mesio-buccal cusp. Note the presence of a large amalgam restoration.

Unlike the cracked tooth (to be discussed later), the cuspal fracture is usually not centered in the tooth from either the occlusal view or the proximal view (Fig. 2). The restoration itself may tend to ‘hide’ the cuspal fracture (Fig. 9). In this scenario, an explorer is used to examine the interface of the restoration and tooth structure to determine if a separable segment exists.

Etiologies

Cuspal fractures may be iatrogenic if unsupported and undermined tooth structure is excessively removed. However, there is usually a history of extensive deep interproximal caries or a subsequent large Class II restoration. Occasionally these cusp fractures occur in non-restored teeth with extensive undermining caries.

Diagnosis

Cracks that are present in teeth are findings; they are not to be considered a pulpal or periapical diagnosis. The relationship between cracks in teeth and endodontic diagnosis depends upon the extent of the fracture. Usually, the fracture is not in close approximation to the pulp and bacterial by-products are neutralized in the dentinal tubules. Therefore, no significant pulpal inflammation or degeneration should be expected.

Subjective findings

Frequently there is brief, sharp pain on mastication or with temperature, particularly cold. Often the pain is more distinct upon masticatory release (not on closure but separation of teeth after biting). Pain is neither severe nor spontaneous, only occurring upon stimulus. Interestingly, symptoms may be relieved when the cusp fractures off, likely due to no further proprioceptive stimulation.

Objective tests

Most indicative is the biting test, such as closing onto a cotton applicator, rubber polishing (burlew) wheel or specially designed bite testing instrument (‘Fracfinder’ or ‘Tooth Slooth’); an occlusal, gnashing force on the involved cusp will elicit sharp pain. Usually, pulp tests indicate vitality.

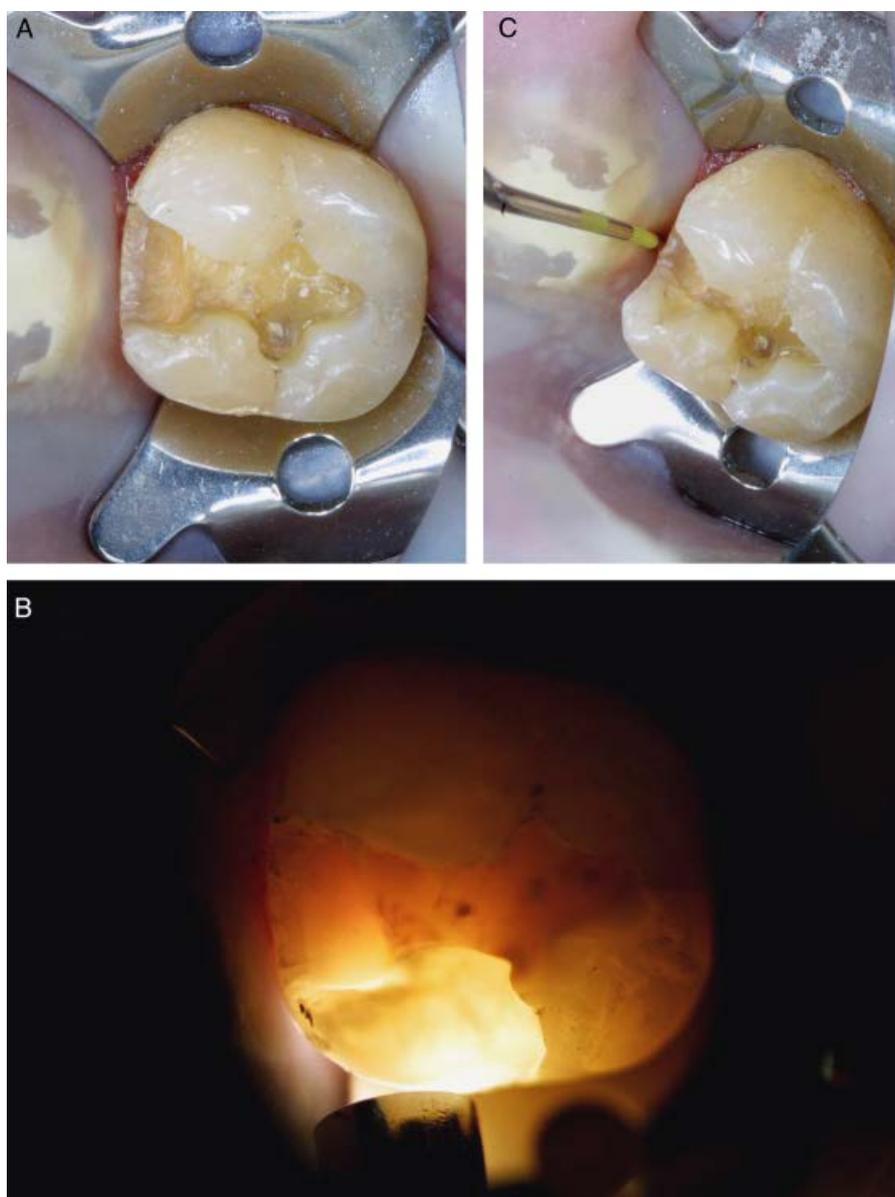


Fig. 8. Fractured cusp involving the mesio-lingual cusp. (A) The cusp fracture line originates near the cavity floor at the mesio-lingual line angle. (B) It was more evident with transillumination. (C) After removal of the restoration, periodontal probing was performed in the proximal portion(s) of the tooth.

Radiographic findings

These are not often useful; cusp fractures are not usually visible radiographically. If the entire cusp is missing, there may be a ‘ghost’ appearance on the radiograph.

Other findings

The restoration often must be removed. The fracture may then be visible or is disclosed by staining and/or

transillumination. Older fractures may have already acquired stain. The cusp fracture line usually originates at the cavity floor at a line angle (Figs. 8 and 9).

Treatment

Retaining the fractured cusp that is mobile and separable with wedging forces is usually not indicated (Fig. 1). The cusp is removed and the tooth restored as appropriate. Usually this is a 3/4 or full crown (or onlay) extending below or to the fracture margin. Root

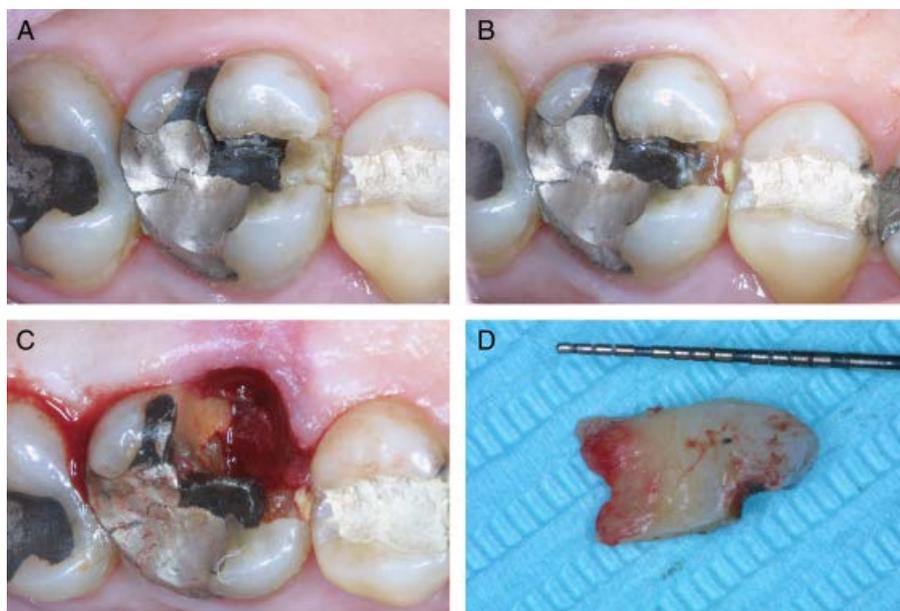


Fig. 9. Fractured cusp involving the mesio-lingual cusp. (A) The restoration tends to hide the cuspal fracture line. (B) Removal of the separable tooth segment on the mesial reveals extensive decay. (C) Removal of the fractured mesio-lingual cusp shows the fracture to be below the gingival margin and epithelial attachment. (D) The portion of the tooth removed is extensive and complicates treatment.

canal treatment is not usually necessary. Removing the segment using wedging and extraction forces usually allows the segment to continue its vertical unfavorable path. Therefore, when removing the cusp, it is helpful to use a bur to resect the cusp at or near the apical extent of the fracture horizontally to conserve tooth structure.

If the fractured cusp is not mobile or separable, the fracture line probably does not extend to a root surface subgingivally (Figs. 1 and 7). In this scenario, the cusp need not be removed, but a cusally reinforced restoration (crown or onlay) is placed to hold the segments and prevent bacterial contamination.

Prognosis

Long-term prognosis and success is favorable for cuspal fractures that are shallow, do not involve the pulp, and are generally restorable. Cusp fractures occasionally extend deeper, below the gingival attachment; these are more challenging to restore (33), but the prognosis usually remains favorable. An approach to restore cuspal fractures that extend onto tooth surfaces well below the gingival attachment is described later in the section on split teeth; the prognosis in these cases is questionable (guarded), but provides an alternative for patients who do not want to lose their natural tooth.

Prevention

Removal of dentin support should be avoided by minimizing width, and particularly depth, of cavity preparations (34). Wedging restorations without adequate dentin support, such as inlays, should be avoided. Cusps should be reduced and onlaid if undermined; both amalgam and gold onlays provide significant fracture resistance (35). Improperly placed bonded resins may shrink excessively upon polymerization; this contraction may displace and further weaken cusps, rendering them susceptible to occlusal forces and fracture.

In terms of bonding, adhesive resins, if placed with special techniques, may reinforce weakened cusps (36–40). However, resin-based composites are equivalent to amalgams with respect to cusp fracture occurrence in patients (41–44). Therefore, bonded restorations may provide only temporary reinforcement (45).

Cracked tooth

The term ‘cracked tooth’ is defined as an incomplete fracture initiated from the crown and extending subgingivally, usually directed mesio-distally (27, 46, 47). The fracture may extend through either or both of the marginal ridges and through the proximal surfaces. The fracture is located in the crown portion of the

tooth only, or may extend from the crown to the proximal root (Table 1, Fig. 3). Cracked teeth are also described as incomplete (greenstick) fractures, which describes their form (8, 19). The cracked tooth is a variation of the cusp fracture except that the associated fracture is centered more occlusally (Figs. 3 and 10–12). The effects of cracked teeth tend to be more devastating because their extent and direction are more centered and more apical (Table 1, Fig. 3).

Incidence

The actual frequency is unknown but apparently is increasing (8, 25, 48–50). Krell and Rivera (50) found that almost 10% of patients referred for endodontic evaluation and treatment over a 6-year period had a cracked tooth; the percentage is likely higher in general dentistry practices. Older patients predominate, although cracked teeth occur at any age (24, 27, 51). The longevity and complexity of restorations are related factors, but cracked teeth often are minimally restored or not restored at all (8, 27, 51). Mastication for many years, particularly of hard objects, is also a factor. Continued and repeated forces finally cause fatigue of tooth structure, resulting in a small fracture followed by continued growth of that fracture. Patients may give a dental history of other cracked teeth (47).

The teeth usually involved are mandibular second molars (both restored and non-restored), followed closely by mandibular first molars and then by either maxillary second molars or maxillary premolars depending on the study (27, 47, 50, 52). A recent Korean study (51) found that cracks were present in higher amounts in maxillary molars, and hypothesized that anatomical differences in races may play a role, especially because the more tilted lower molars of Koreans could reverse occlusal forces and act as plunger cusps to the maxillary molars. Also, smaller amounts of dentin and the surface area of the root could possibly absorb less occlusal stress and transfer less occlusal forces to the alveolar bone (51).

Anterior teeth occasionally develop true cracks, usually as a result of weakened tooth structure from a traumatic impact or from restorations. Cracks are rarely seen on mandibular premolars. Furthermore, Class I restored teeth fracture as often as Class II restored teeth, particularly molars. Therefore the phenomenon is not always dependent on violation of tooth structure by access preparations, caries, or restorations. There



Fig. 10. Cracked tooth involving the mesial marginal ridge, internal mesial proximal wall, and extending partially on the floor of the cavity preparation. The crack appears to not involve the floor of the pulp.

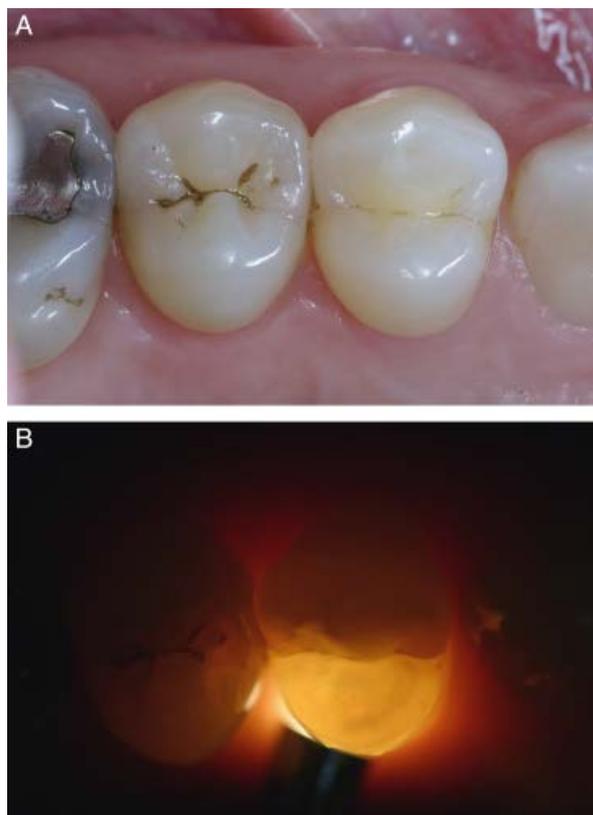


Fig. 11. (A) Cracks are present on the mesial marginal ridge of the maxillary first molar and on the mesial and distal marginal ridges of the maxillary first premolar. No cracks are evident on the maxillary second premolar. (B) Transillumination of the maxillary first premolar from the lingual reveals that the light is not allowed to penetrate through the fracture line, giving what is clinically described as the ‘night’ vs. ‘day’ appearance of the cracked tooth.

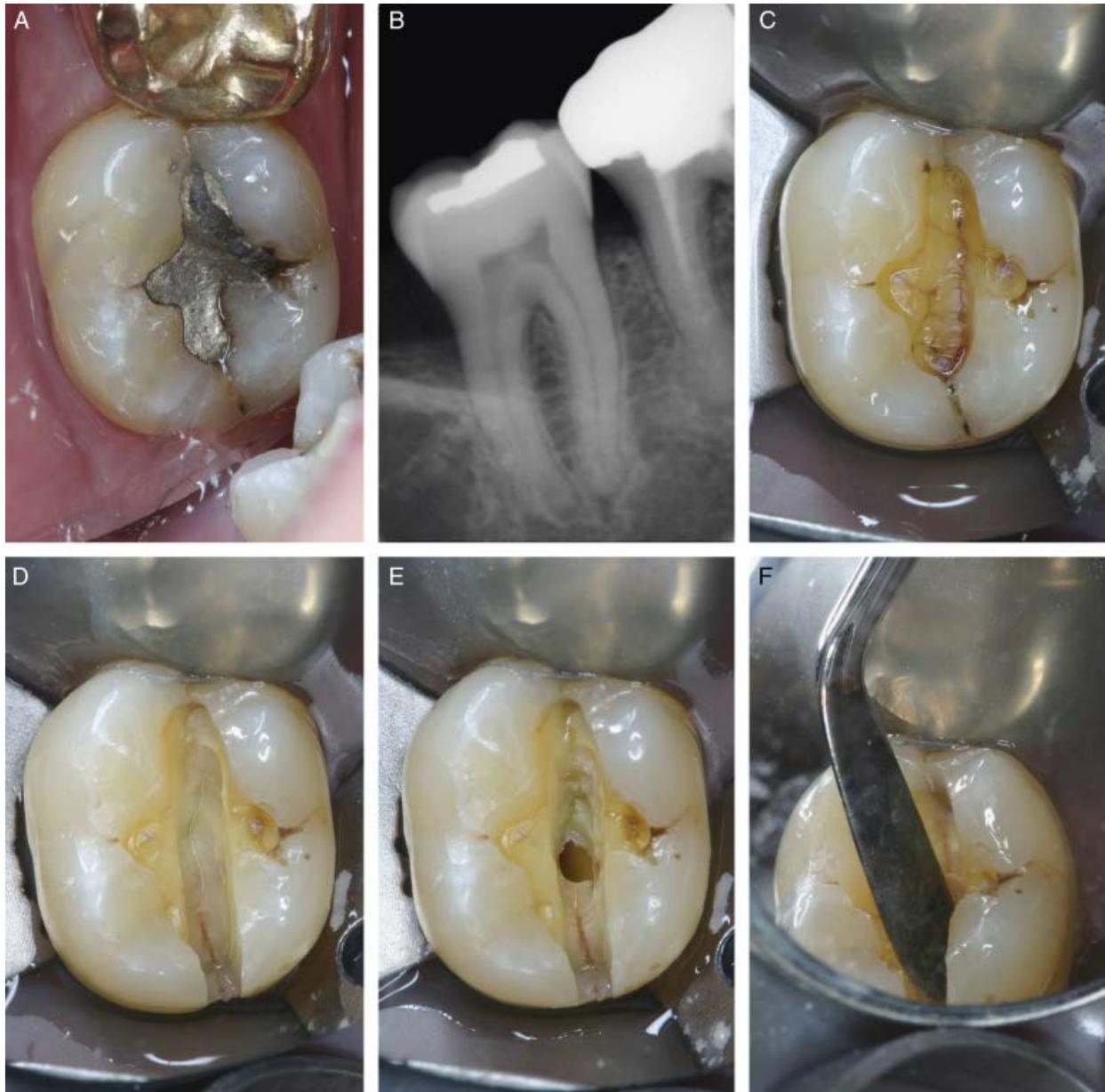


Fig. 12. (A) Cracked tooth involving the mesial and distal marginal ridges of a mandibular second molar. (B) Radiograph confirms a small restoration, but no evidence of the crack because this is a two-dimensional representation of a three-dimensional object. (C) After removal of the amalgam restoration, the crack is visualized on the floor of the cavity preparation. (D) Removal of dentin along the crack is continued. (E) This results in exposure of the pulp. (F) Wedging forces resulted in no movement of the tooth segments indicating an incomplete fracture.

has been speculation that teeth treated by root canals are more brittle and weakened and are therefore more susceptible to fracture. Evidence does not support this assumption (21, 31, 53–57).

Pathogenesis

Cracks in teeth tend to depend on time and patient habits. Forces in excess of dentin strength are

responsible; these forces are greater in the posterior region, i.e. close to the fulcrum of the mandible, invoking the ‘nutcracker’ effect (27, 47). Although occlusal anatomy (deep fissures or prominent or functional cusps) and occlusal dysfunction might render a tooth more susceptible to cracking, these factors are only speculative. Kishen (21) reviewed the relationships between anatomy and function in cracked teeth, the biomaterial considerations of dentin sub-

strate, and biomechanical considerations in intact and restored teeth.

Clinical features

Cracks in teeth are almost invariably mesio-distal fractures (27) (Figs. 1, 3 and 10–12), although mandibular molars occasionally fracture toward the facial-lingual surface. The diagnosis of a facial-lingual cracked molar is a common misinterpretation due to visualization of facial and lingual fractures. These are actually craze lines which follow the buccal and lingual grooves.

Cracks cross one or both marginal ridges. They generally shear toward the facial or lingual side toward a root surface, usually lingual. Because the fracture begins on the occlusal surface, it grows from this surface toward the cervical surface and down the root. Importantly, the more centered the fracture (initiated on the mid-occlusal surface), the more it has a tendency to extend deeper before it shears toward the root surface. The fracture is considered ‘greenstick’ because it is incomplete (either to the mesial or distal surface) or does not extend to the facial or lingual root surface (8). Wedging forces produce no separable segments that would indicate a complete fracture as with split teeth (refer to the section on ‘Split tooth’). The direct mid-occlusal fracture may be very deep; on maxillary molars it may extend toward the furcation (Fig. 10) or occasionally toward the apex on mandibular molars (Fig. 12).

The fracture may or may not include the pulp. The more centered the fracture, the greater the chance of current or future pulp exposure. Occasionally, fractures oriented toward the facial-lingual surface shear away from the pulp, although this is not likely and is difficult to determine clinically. Therefore many cracked teeth require root canal treatment, preferably before restoration for coronal protection. Wedging forces must be minimized during both root canal treatment and restoration to avoid aggravating the fracture.

Etiologies

Cracked teeth are often found in patients who chew hard, brittle substances (ice, unpopped popcorn kernels, hard candy, and so on). These patients may have prominent masticatory muscles (47) and show excessive occlusal wear as a result of heavy occlusal

forces. Importantly, however, cracked teeth may occur in patients without these damaging parafunctional habits and who do not display heavy musculature. If these teeth are restored, the restorations may be Class I or a deep Class II. Interestingly, cracks associated with wide Class II restorations are more likely to be cusp fractures and their effects are not as devastating (58).

Thermal stresses are also thought to be a cause of fractures, although the evidence of this is inconclusive. Supposedly, differences in expansion and contraction of restorations vs. tooth structure may weaken and crack dentin (59). Also speculated as a cause of dentin fractures are thermal stresses and pin placement. Differences in expansion and contraction of restorations and tooth structure may weaken and crack dentin (59, 60). Retentive pin placement with twist drills can produce high installation stresses which result in cracking or crazing of dentin (61).

Diagnosis

Remember that cracks which are present in teeth are findings; they are not to be considered a pulpal or periapical diagnosis. The objective is to detect the crack first and then to determine the extent of the crack.

Cracked teeth manifest a variety of test results, radiographical findings, and signs and symptoms depending upon many factors (13). This variety and unpredictability makes the cracked tooth a perplexing diagnostic and treatment entity because of differing pulp, periapical, and periodontal findings.

The relationship between cracks in teeth and endodontic diagnoses depends upon the extent of the fracture. If the fracture is into or in close approximation to the pulp and allows bacterial by-products or frank bacteria to communicate with the pulp, then inflammation and pulpal degeneration occurs. If the fracture is not in close approximation to the pulp and bacterial by-products are neutralized in the dentinal tubules, then no pulpal inflammation or degeneration should be expected. However, our inability to discern the extent of a fracture line is one aspect that leads to the misconception and complexity of determining an endodontic diagnosis. Another confusing aspect is that there has been no direct relationship established in the literature between a patient’s symptoms and the presence of a crack. This rationale is used by dental practitioners who do not provide any treatment for a patient with a cracked tooth that is asymptomatic.

Other practitioners adopt the extreme opposite philosophy of extracting any tooth that contains a crack.

Subjective findings

Often cracked teeth manifest as the so-called ‘cracked tooth syndrome’ (13, 46, 47, 49). This syndrome is characterized by acute pain on mastication (pressure or release) of grainy, tough foods and sharp, brief pain with cold (58). These findings are also related to cusp fracture. However, cracked teeth may present with a variety of symptoms ranging from slight to very severe spontaneous pain consistent with irreversible pulpitis, pulp necrosis, or apical periodontitis (62). Even an acute apical abscess, with or without swelling or a draining sinus tract, may be present if the pulp has undergone necrosis. In other words, once the fracture has extended to and exposed the pulp, severe pulp and/or periapical pathosis will likely be present. This explains the variation in signs and symptoms and therefore the term ‘syndrome’ should not be used.

Objective tests

Pulp and periapical tests also produce variable results. The pulp is usually responsive (vital) (47) but may be non-responsive (necrosis). Periapical tests also vary but usually pain is not elicited with percussion or palpation if the pulp is vital. Directional percussion is also advocated. Percussion that separates the crack may cause pain. Opposite-direction percussion usually is asymptomatic. This pain is probably related to stimulation of the periodontal ligament proprioceptors.

Radiographic findings

Because of the mesio-distal direction of the fracture, it is not visible radiographically. Radiographs are made to help determine the pulp-periapical status. Usually there are no significant findings, although occasionally different entities occur. At times, loss of proximal (horizontal, vertical, or furcal) bone is related to the fracture; bone loss increases as the severity of the crack increases. Newer methods of analysis, such as cone beam computerized tomography, are currently being studied in order to help identify longitudinal fractures in a non-destructive fashion (63–66).

Other findings

Craze lines in posterior teeth that cross marginal ridges or buccal and lingual surfaces must be differentiated with transillumination (8). With craze lines, transilluminated light from the facial or lingual surface is not blocked or reflected; the entire tooth is illuminated in a facial-lingual orientation.

When a crack is suspected, it is important to try to visualize the length and location of the fracture; direct inspection, combined with staining and transillumination, are usually effective (62). Occlusal and proximal restorations are first removed (67). Then transillumination, which often shows a characteristic abrupt blockage of transmitted light, is performed. With transillumination, the portion of the tooth where the light originates illuminates to the fracture. A fracture contains a thin air space which does not readily transmit light. Therefore, the crack (or fracture) blocks or reflects the light, causing the other portion to appear dark (Fig. 11).

Staining with methylene blue or iodine may also disclose the fracture, although not predictably. A cotton pledget soaked with methylene blue or some other dye is placed against the cavity floor; the dye may be washed away immediately to reveal the crack or may be held in place by a temporary sealing such as IRM. The temporary restoration and pledget are removed after a few days. The dye may have been in contact with the crack long enough to disclose it clearly. Patients should be advised that the tooth may temporarily turn blue; hence they may wish to forgo this test.

Viewing with a surgical microscope is particularly useful to identify both the presence and extent of the fracture.

Occasionally (particularly if the crack is centered), an access preparation is necessary to disclose the extent of the crack (Fig. 12). After the chamber roof and coronal pulp have been removed, the floor is transilluminated as for a fracture (not to be confused with anatomic grooves). Sealing in a disclosing dye for a few days may be helpful. Again, visualization with the microscope allows for more definitive identification.

Removal of the fracture line in the area of the cavity floor (which would include an ideal endodontic access opening) is helpful in removing and/or determining the apical extent of the crack and whether the pulp is involved (Fig. 12). However, the fracture is small and invisible at the furthest extent (even after staining).

Therefore the crack probably continues deeper into dentin than can be visualized. Removal of the fracture line in the proximal portion of the tooth may provide information on the extent, but also likely causes the tooth to become non-restorable. Both of these procedures, particularly removal of proximal marginal ridge and tooth structure, remove sound tooth structure, thereby decreasing tooth strength and resistance to fracture (68–72).

Wedging forces are used to determine if the tooth segments are separable (Figs. 1 and 12). If a fracture is detected, any restorations are removed and an instrument is placed in the cavity with moderate pressure exerted on opposing walls to try to separate the segments. If no movement is detected, the classification is a cracked tooth; when the segments separate, it is a split tooth (discussed later). It is important to notify the patient of possible sequelae before performing this test. Clinicians and patients may be hesitant to perform wedging of the segments for fear of splitting the tooth iatrogenically or causing pain. However, if controlled force exacerbates the crack, certainly the tooth is predisposed to a future split anyway; the patient is best served to know this expeditiously.

Periodontal probing is important and may disclose the approximate depth and severity of the fracture. Removal of interproximal restorations is helpful because it allows improved access for placement of the periodontal probe. However, subgingival fractures often do not create a probing defect. Therefore the absence of deep probing does not preclude a cracked tooth. The presence of deep probing is serious and indicates a more adverse prognosis (73).

Selective biting on objects such as the Tooth Slooth or Fracfinder (as described earlier under ‘Fractured cusp’) is helpful, particularly when pain is reported on mastication.

Multiple types of cracks and/or fractures may exist in the same tooth. Cuspal fractures and cracks found in the same tooth are findings that contribute to the complexity of determining endodontic diagnoses (Fig. 13).

Treatment

Remember that the diagnosis determines the treatment. When the pulpal and periapical and periodontal diagnoses have been established, and both clinician and

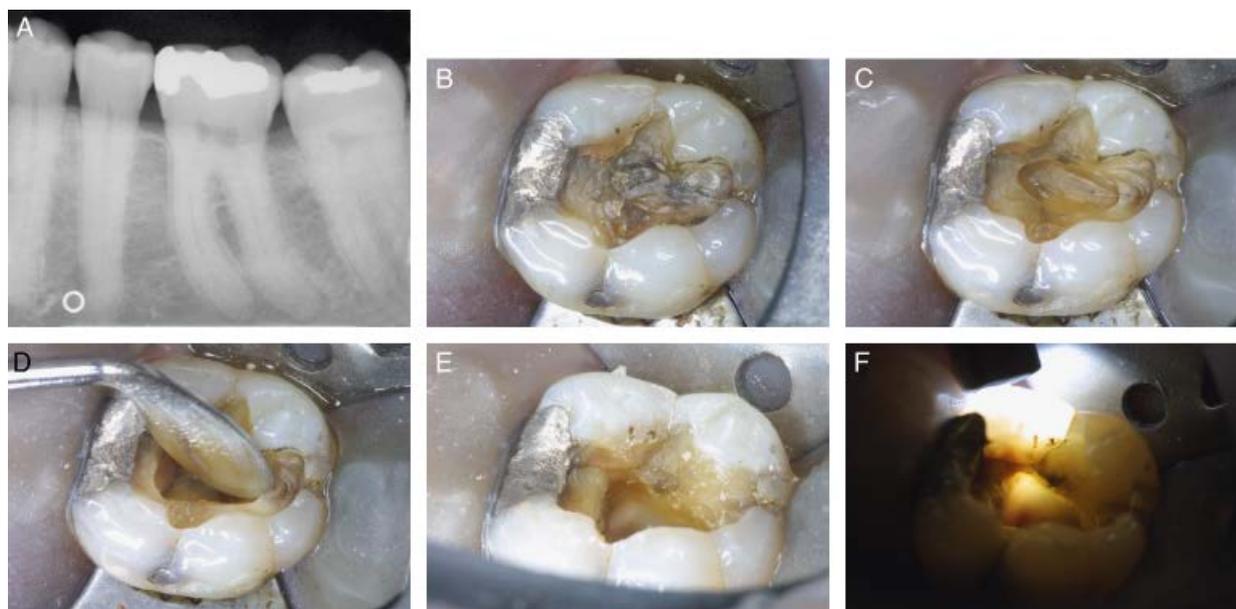


Fig. 13. Cracked tooth with a fractured cusp. (A) The radiograph shows a large amalgam, but does not provide an indication that a fracture is present. (B) After removal of a portion of the amalgam, a crack is visualized involving the distal marginal ridge, internal distal proximal wall, and extending on the floor of the cavity preparation. A crack is also visualized on the cavity floor adjacent to the mesio-buccal cusp extending across the facial groove. Also note the presence of a craze line in the area of the buccal groove, which is a common and confusing finding. (C) Removal of dentin in the area where an ideal endodontic access preparation would be initiated allows further visualization of the extension of the crack internally. (D) Wedging forces resulted in no movement of the tooth segments, indicating an incomplete fracture. (E) The mesio-buccal fractured cusp is more readily visualized from a different angle. (F) With transillumination.

patient are aware of the complications and questionable outcomes, treatment plans are formulated. Treatment alternatives are provided to the patient. The patient's questions are answered, and the patient elects which treatment will be performed. The six important 'Considerations for longitudinal fractures' mentioned earlier should be reviewed.

Extraction is a reasonable solution in many situations. Much depends on the nature (depth and location) of the fracture (Fig. 1). Again, the segments must not separate on wedging. If they do not separate, there are many treatment alternatives to retaining an intact tooth. If the occlusal-proximal fracture is centered in the facial-lingual aspect and involves the floor of the cavity preparation, there are treatment options. If there are no symptoms of irreversible pulpitis, a crown may be placed, although some of these teeth will eventually manifest irreversible pulpitis or pulp necrosis (50). They will then require root canal treatment through the crown.

After endodontic access, the pulp chamber floor is examined; transillumination is again helpful. If the fracture extends through the chamber floor, further treatment is usually hopeless and extraction is preferred (Fig. 14) (74). An exception is the maxillary molar, which may be hemisected along the fracture, saving half (or both halves) of the crown and supporting roots. Many of these treatments are complex, and the patient should be considered for referral to an endodontist. If a partial fracture of the chamber floor is detected, the crown may be bound with a stainless-steel or an orthodontic band, or temporary crown to protect the cusps until final restoration is performed (19, 75). This also helps to determine whether symptoms decrease during root canal treatment (76). The rationale (not well supported) is that if pain symptoms are not relieved, the prognosis is significantly poorer and extraction may be necessary.

If the fracture appears to be incomplete (not terminating on a root surface), the tooth is restored to bind the fractured segments (barrel-stave effect) and also to protect the cusps. For a permanent restoration, a full crown is preferred, although an onlay with bevels may suffice. Posts and internally wedging foundations are to be avoided. Acid-etch dentin bonding resins may help to provide a foundation for the crown to prevent crack propagation, although more research is necessary to support this concept (36, 76–82). Amalgam, which

tends to expand and which requires a wedging effect with condensation, is not a good choice.

Prognosis

The overall prognosis depends on the situation but is always questionable at best. The patient is informed about the possible outcomes and the unpredictability of the duration of treatment. The fracture may continue to grow and become a split tooth, with devastating consequences requiring tooth extraction or additional treatments (Fig. 14). Furthermore, the patient should be informed that cracks may be present in other teeth as well and could manifest in the future.

In general, the more centered the origin of the fracture is on the occlusal surface, the poorer the long-term prognosis; these fractures tend to remain centered and grow deeper. The result is major damage to the tooth and periodontium. In other words, the cracked tooth may ultimately evolve to a split tooth or develop severe periodontal defects.

Only recently have studies been published that outline the chances for a successful outcome of cracked teeth, but these studies are limited and only for specific conditions. Tan et al. (73) studied a small number ($n = 50$) of root-filled cracked teeth with a diagnosis of irreversible pulpitis and determined a 2-year survival rate of 85.5%. This study indicated that the only significant prognostic factors were teeth with multiple cracks, terminal teeth in the arch, and pre-root filling pocketing (73). Krell & Rivera (50) evaluated 127 patients with teeth diagnosed with reversible pulpitis that had a cracked tooth in which the treatment was placement of a crown restoration without performing root canal treatment. Twenty percent of these cases turned into irreversible pulpitis or necrosis within 6 months and required root canal treatment, but none of the other teeth required root canal treatment over the 6-year evaluation period (50).

Prognosis is more variable with cracks than with other longitudinal fractures. Determining the position and extent may be helpful in determining prognosis and when to recommend extraction. Techniques that provide more information related to the extent of cracks internally and on the proximal surfaces below the cemento-enamel junction are needed. It is hypothesized that the prognosis decreases from questionable to poor when cracks involve the following (in order):

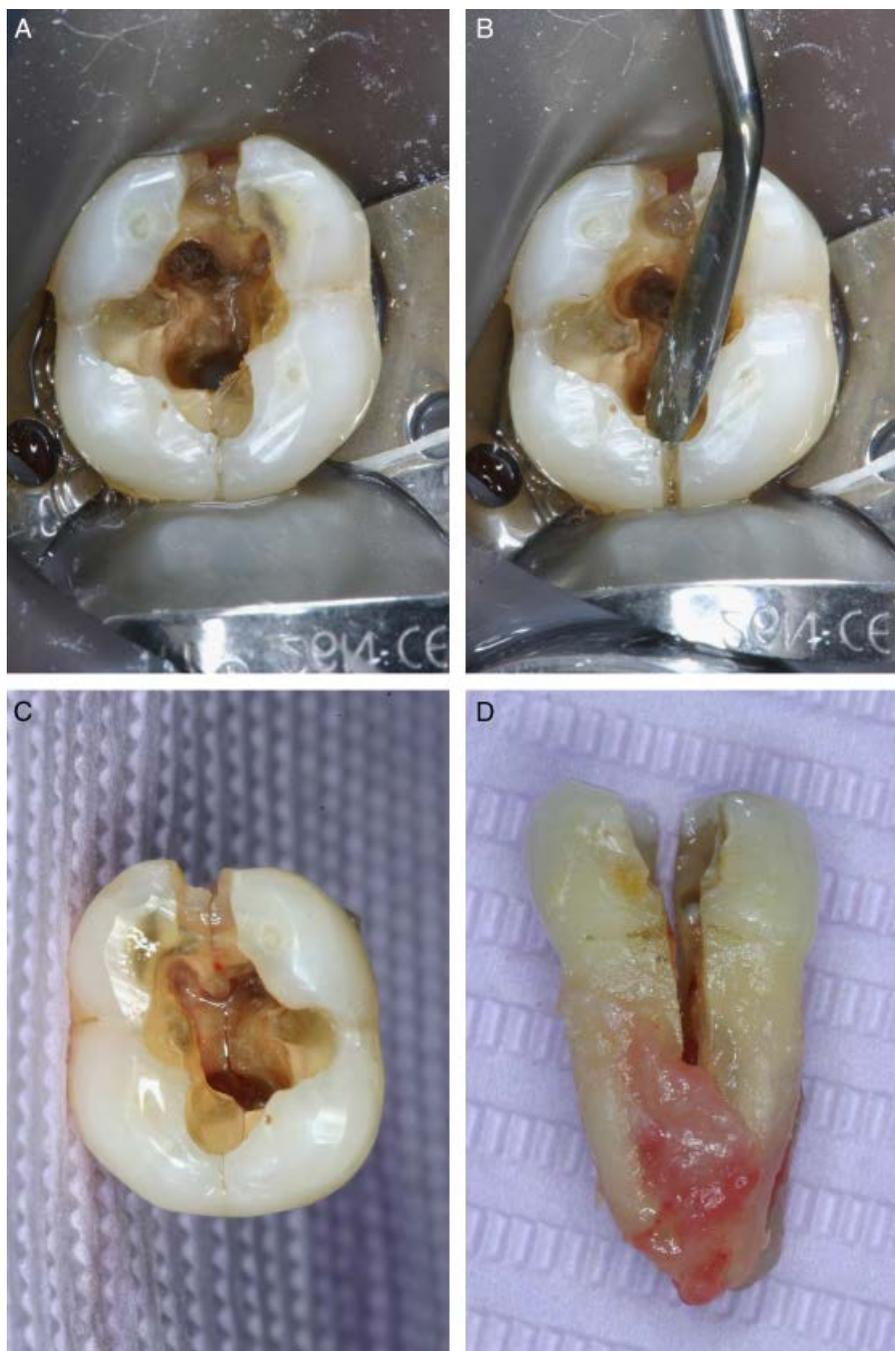


Fig. 14. (A) Split tooth is visualized. (B) Confirmed using wedging forces, which resulted in separation of the tooth segment. (C) The extracted tooth highlights the fracture line extending from the mesial marginal ridge, through the floor of the cavity preparation, and also involving the distal marginal ridge. (D) The proximal view of the extracted tooth shows a complete fracture that extends deeply to the root surface with infiltration of granulomatous tissue.

- one marginal ridge limited to the crown;
- two marginal ridges limited to the crown;
- marginal ridge(s) and internal proximal cavity wall only;
- marginal ridge(s) and floor of cavity preparation (may involve restoration removal);
- one marginal ridge extending from the crown to the root surface (difficult to visualize);
- two marginal ridges extending from the crown to the root surface (difficult to visualize);
- marginal ridge(s) and into canal orifice(s);
- marginal ridge(s) and pulpal floor;

- furcation involvement (only confirmed after exploratory surgery or extraction).

Prevention

Generally, patients are encouraged to forego destructive habits (ice chewing, etc.). In addition, most of the suggestions made earlier relative to preventing cusp fractures apply. The use of deep Class I or Class II restorations should be minimized, particularly on maxillary premolars (cusp protection may be helpful) (83). There is no indication for altering occlusal anatomy or occlusal relationships. Bader et al. (84) determined that 44% of North Carolina general practitioners placed crowns to prevent fracture, although there was little agreement about which teeth should be crowned due to the potential risk of fracture.

Split tooth

The term ‘split tooth’ is defined as a complete fracture initiated from the crown and extending subgingivally, usually directed mesio-distally through both of the marginal ridges and through the proximal surfaces. The fracture is located coronally and extends from the crown to the proximal root (Table 1, Fig. 3). A split tooth is the evolution (end result) of a cracked tooth. The fracture is now complete and extends to a surface in all areas (25). The root surface involved is in the middle or apical third. There are no dentin connections; tooth segments are now entirely separate (Figs. 3 and 14–16). The split may occur suddenly but it is more likely the result of long-term growth in an incomplete cracked tooth (Table 1).

Incidence

As with cracked teeth, the occurrence of split teeth is apparently increasing (85). Obviously, many factors related to cracked teeth are endemic to split teeth. An assumption is that root canal treatment weakens dentin and renders teeth more susceptible to severe fractures; this is unlikely (21, 31, 53–57).

Pathogenesis

Causative factors related to cracked teeth also apply to split teeth. Why some cracked tooth fractures continue to grow to a complete split is unknown. Two major

causes are probably persistent destructive wedging or displacing forces on existing restorations and new traumatic forces that exceed the elastic limits of the remaining intact dentin.

Clinical features

These are primarily mesio-distal fractures that cross both marginal ridges and extend deep to shear onto the root surfaces. The more centered the fracture is occlusally, the greater the tendency to extend apically. These fractures are more devastating. Mobility (or separation) of one or both segments is present (Figs. 1 and 14–16).

These fractures usually include the pulp. The more centered the fracture, the greater the probability of exposure.

Etiologies

Split teeth have the same causes as cracked teeth. Split teeth may be more common in root canal-treated teeth. However, this is not because the treatment *per se* weakens the tooth by dehydrating or altering dentin (86). Rather, the strength of these teeth has already been compromised by caries, restorations, or over-extended access preparations (24).

Diagnosis

Split teeth do not have the same variety of confusing signs, symptoms, and test results as cracked teeth. Generally, split teeth are easier to identify. Damage to periodontium is usually significant and is detected by both patient and dentist (87, 88). There is often a visual separation of segments.

Subjective findings

Commonly, the patient reports marked pain on mastication. These teeth tend to be less painful with occlusal centric contacts than with mastication. A periodontal abscess may be present, often resulting in mistaken diagnosis.

Objective tests

Objective findings are not particularly helpful but should include both pulp and periapical tests.

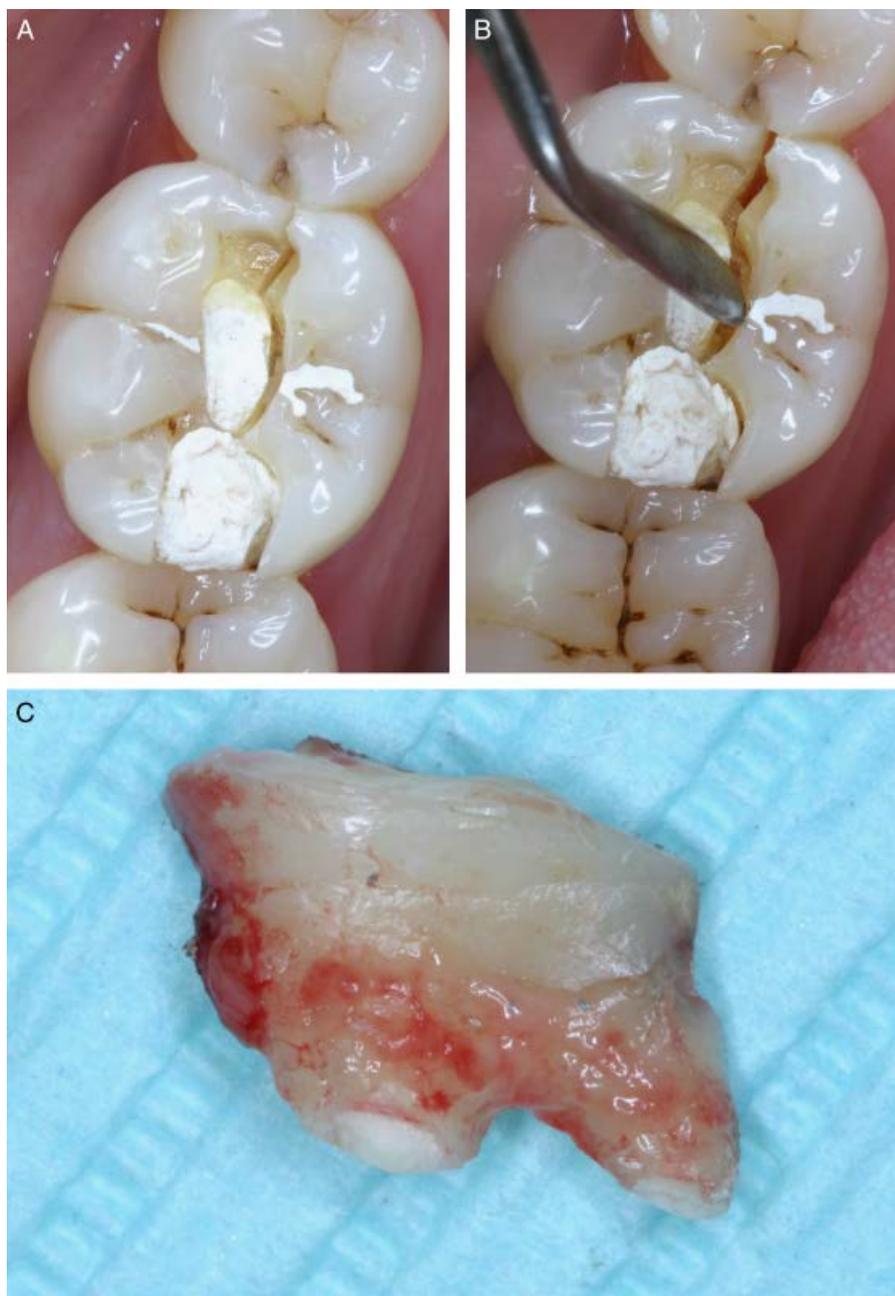


Fig. 15. (A) Split tooth involving a mandibular first molar is visualized. (B) Confirmed with wedging forces. (C) Extraction of the lingual segment shows the considerable depth of the fracture on the root well below the cemento-enamel junction and the attachment level.

Radiographic findings

Findings on radiographs depend partially on pulp status but are more likely to reflect damage to the periodontium. Often there is marked horizontal loss of interproximal or interradicular bone. The fracture line, which is usually mesial-distal, is not visible.

Other findings

The most important consideration is to identify the extent and severity of the fracture, which often requires removal of a restoration. With a split tooth, the fracture line is usually readily visible under or adjacent to the restoration; it includes the occlusal surface and both marginal ridges.



Fig. 16. (A) This split tooth may initially be confused with a fractured cusp. (B) Confusion still exists even after separation of the tooth segments is achieved with an endodontic explorer. (C) Removal of the restoration reveals a fracture centered in the tooth from the mesial across the floor of the cavity preparation and involving the distal proximal internal wall and distal marginal ridge. (D) Removal of decay allows better visualization and shows areas of complete separation and purulent exudate. (E) Initial endodontic access preparation reveals that the fracture also involves the floor of the pulp.

Wedging to determine whether segments are separable is also important (Fig. 1). As with a cracked tooth, an instrument is placed in the cavity. Wedging against the walls is done with moderate pressure; the walls are then visualized for separation (Figs. 14–16). The surgical microscope is a very useful aid. A separating movement indicates a through-and-through fracture.

Periodontal probing generally shows deep defects; probings tend to be adjacent to the fracture. Here again, removal of existing restorations is helpful in visualizing interproximal areas.

Treatment

Maintaining an intact tooth is impossible (Fig. 1). If the fracture is severe (that is, deep apically), the tooth

must be extracted. If the fracture shears to a root surface that is not too far apical (middle to cervical third of the root), the smaller segment will be very mobile. In this case, there is a good possibility that the small segment can be removed and the remainder of the tooth salvaged.

Different approaches to maintenance are used depending on the conditions. Some choices are as follows.

Remove the fractured segment

Then the type of treatment and restoration are determined. However, the following choice (retention of fractured segment temporarily) is preferred and is generally less complicated.

Retain the fractured segment temporarily

First, a rubber dam is applied with a strong rubber dam clamp to isolate and hold the segments together. Root canal treatment is completed (if not already performed), and restoration with a retentive amalcore (onlaying the undermined cusps) or bonded restoration is performed. Then the fractured segment is removed. Granulation tissue proliferates to occupy the space and reattach the periodontium to the root dentin surface. The final restoration usually is the amalcore but may be a full crown with a margin related to the new attachment.

Remove the fractured segment and perform crown lengthening or orthodontic extrusion

The mobile segment is removed first, root canal treatment is performed next, followed by crown lengthening or orthodontic extrusion and placement of an appropriate restoration. This is not feasible in most situations because the fracture is too deep on the root surface.

Remove the fractured segment and perform no further treatment

This choice is appropriate when root canal treatment has been completed previously and the tooth has already been restored. All pulp space areas *must* be filled to the margins with permanent restorative material (e.g. amalgam) with no root canal filling material (e.g. gutta-percha or Resilon) exposed. The defect usually granulates in, and reattachment to the fractured dentin surface occurs.

In summary, treatment may be complex or relatively simple depending on the situation. However, due to the complexity of their situations, these patients should be considered for referral to a specialist for diagnosis and treatment.

Prognosis

As expected, prognosis is variable. Some treatments of split teeth are successful whereas others are doomed to failure if attempted. When the fracture extends and surfaces in the middle to cervical third of the root, there is a reasonable chance of successful treatment and restoration. If the fracture surfaces in the middle to apical third, the prognosis is poor. With these deep

fractures, usually too much of the pulp space is exposed to the periodontium; root canal treatment with restoration of this space would result in deep periodontal defects.

Sometimes prediction of success or failure cannot be determined before treatment is completed if the more conservative approach is taken, that is, if the segment is temporarily held in place during root canal treatment and restoration. After root canal treatment has been completed and the segment has been removed, the dentist may discover that, unfortunately, the fracture is indeed very deep and the tooth is unsalvageable. The patient must be informed of all of these possibilities before treatment is commenced.

Prevention

Generally, preventive measures are similar to those recommended for cracked teeth; oral habits which damage tooth structure and impose wedging forces should be eliminated. Teeth requiring large, deep access preparations should be protected by an onlay or full crown restoration. Large access preparations also require appropriate cusp protection (31).

Vertical root fracture

The term 'true' vertical root fracture is defined as a complete or incomplete fracture initiated from the root at any level, usually directed facio-lingually. The fracture may involve one proximal surface (facial or lingual) or both facial and lingual proximal surfaces. The fracture is located in the root portion of the tooth only and may extend coronally toward the cervical periodontal attachment (Table 1, Fig. 4). A review of vertical root fractures has recently been published (89, 90).

Vertical root fracture differs from the entities described previously in this chapter because the treatment plan is easy, but diagnosis often is tricky and elusive because the vertical root fracture mimics other conditions (91). Because treatment invariably consists of either tooth extraction or removal of the fractured root, an error in diagnosis has serious consequences.

Incidence

The overall occurrence is unknown, but vertical root fracture is not uncommon (89, 92). These defects occur more often in teeth which have undergone complex restorative procedures, that is, root canal treatment and intraradicular post-retention.

Pathogenesis

Vertical root fracture results from wedging forces within the canal. These excessive forces exceed the binding strength of root dentin, causing fatigue and fracture. Irritants that induce severe inflammation in the adjacent periodontium result from the fracture (93). Generally, this periodontal destruction and the accompanying findings, signs, and symptoms bring the fracture to the attention of the patient or dentist.

Clinical features

These fractures occur primarily in the facial-lingual plane (Figs. 1, 4 and 17–21) (89, 91, 92, 94–98). They are longitudinal and may either be short or extend the length of the root, that is, from apical to cervical (Figs. 4 and 17). The fracture likely initiates internally (canal wall) and grows outward to the root surface. In addition, the fracture may begin at the apex or at mid-root (99). Therefore it may be incomplete (Fig. 4), extending neither to both facial and lingual root surfaces nor from apical to cervical root surfaces.

Although vertical root fractures usually show only mild clinical signs and symptoms, the effects on the periodontium are eventually devastating and irresolvable (by current therapeutic means).

Etiologies

There are two major causes (the only demonstrated ones) of vertical root fractures. These are post-placement (cementation) and condensation during root canal filling (91, 94, 100–105). Other etiologies have been mentioned (but not convincingly demonstrated) such as occlusal forces, wedging of restorations, corrosion, and expansion of metallic posts (106), and expansion of post-surgical retrograde restorations. The only reported cases of vertical root fracture occurring in non-endodontically treated teeth are in Chinese patients (107, 108). Other causes have been mentioned but not convincingly shown.

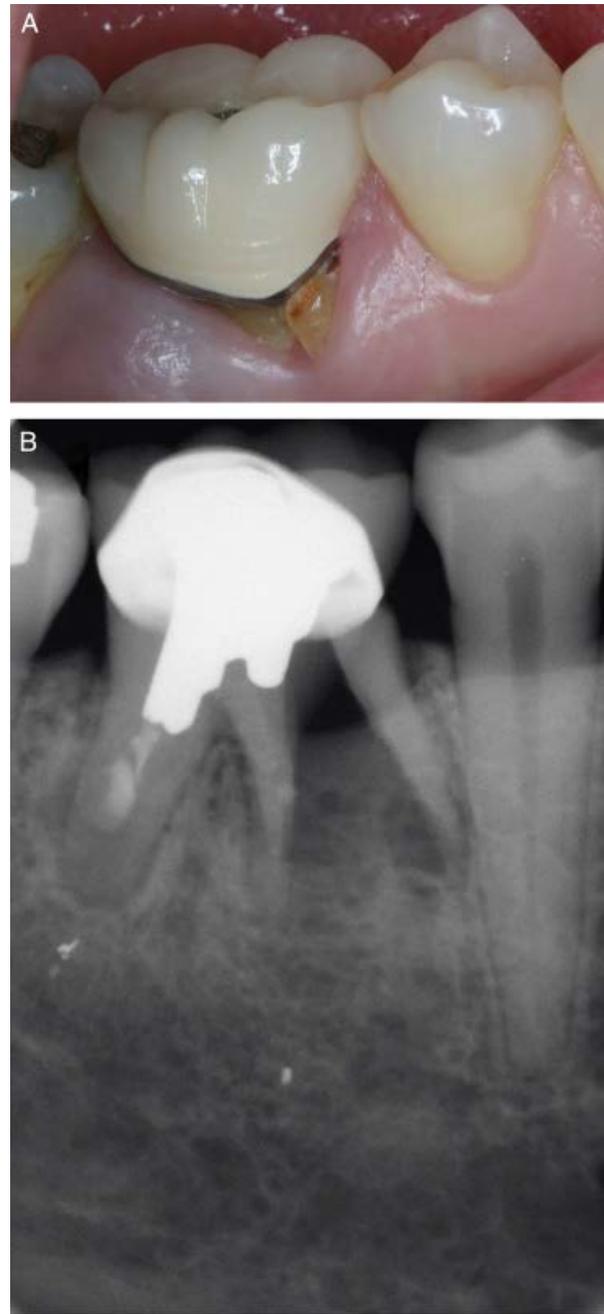


Fig. 17. This mandibular first molar has a history of prior root canal treatment, post-placement, and placement of a porcelain-fused-to-metal restoration. (A) A narrow, isolated periodontal probing defect is present in the mid-mesial root area, and a fracture can be visualized on the mesial root in the area of gingival recession. (B) Confirmation of a vertical root fracture is obtained radiographically. Please note that most vertical root fractures are not this exaggerated.

Condensation, both lateral and vertical, may cause excessive wedging forces, creating a vertical root fracture (89, 94, 95, 99, 102, 103, 109–113).



Fig. 18. The root of this maxillary pre-molar was exposed after removal of the coronal restoration following initiation of an endodontic re-treatment procedure in which a fracture was suspected. The vertical root fracture extends from the internal canal walls to both the facial and lingual root surfaces.

Intraradicular retentive posts have also been implicated (21, 100, 102, 114). Two aspects of posts cause wedging forces. Wedging occurs during cementation of posts and also during the seating of tapered posts or with posts that depend on frictional retention (100, 103). Occlusal forces exerted on the post after cementation and restoration may also be a factor, but probably a minor one. Post-placement has been shown to exert a greater wedging force than lateral condensation (103).

Certain root shapes and sizes are more susceptible to vertical root fracture. Roots that are curved and are deep facially and lingually but narrow mesially and distally are particularly prone to fracture (97, 99). Examples are mandibular incisors and premolars, maxillary second premolars, mesio-buccal roots of maxillary molars, and mesial and distal roots of mandibular molars. Round, oval, or bulky roots are

resistant to fracture; examples are maxillary central incisors, lingual roots of maxillary molars, and maxillary canines.

Susceptibility of any root to fracture is markedly increased by excessive dentin removal during canal instrumentation or post-preparation (21, 95, 115–117). An additional factor occurring during condensation is the placement of excessive numbers of accessory cones requiring multiple spreader insertions (99, 109). Also, the insertion of tapered, inflexible condensing instruments into curved canals creates root distortion and the potential for fracture (110). Different techniques used for condensing gutta-percha have shown various fracture potentials (95, 118); however, larger canal preparations can lead to higher stresses when these condensation forces are applied (95).

Diagnosis

Vertical root fractures become manifest by a variety of signs, symptoms, and other clinical findings. They may mimic other entities such as periodontal disease or failed root canal treatment. This variety of findings often makes vertical root fracture a perplexing diagnosis (92). Interestingly, because vertical root fractures are often mistaken for periodontal lesions or for failed root canal treatment, the dentist may refer these difficult diagnosis patients to the periodontist or endodontist, presumably for periodontal therapy or endodontic retreatment.

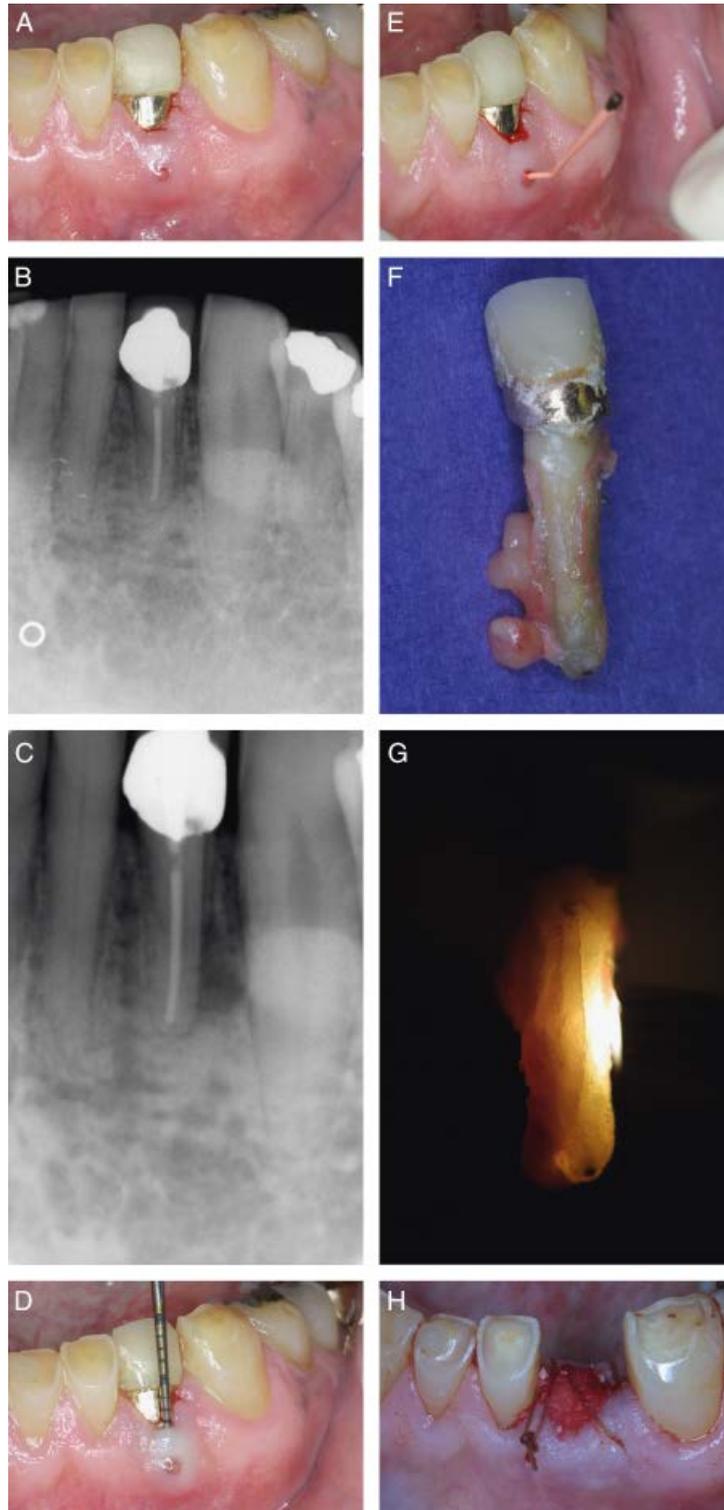
Diagnostic findings of vertical root fracture were reported in a series of 42 clinical cases in a study performed by R. J. Michelich et al. (personal communication). Much of the information that follows is derived from the findings in that study in conjunction with other reports.

Fig. 19. (A) This mandibular lateral incisor has a history of root canal treatment, placement of a porcelain-fused-to-metal restoration, placement of a gold foil restoration, and periodontal flap surgery. (B) A radiograph from 14 months ago reveals a healthy periodontium with an intact lamina dura. (C) A recent radiograph reveals the presence of a widened periodontal ligament space apically and a lateral radiolucency distally with loss of lamina dura. (D) A 7 mm narrow, isolated periodontal defect and Class II mobility is present. (E) A sinus tract on the attached gingiva threaded with a root-filling cone is present. The patient has mild symptoms that include a throbbing sensation. A vertical root fracture is suspected and the patient elected to have the tooth extracted. (F) Upon extraction and removal of granulomatous tissue from the root, a vertical root fracture was visualized. (G) Transillumination. (H) Site preservation was performed with BioOss covered with Colla Plug and the area sutured in preparation for eventual implant or bridge placement. Note that having a sinus tract on the attached gingival and a narrow, isolated periodontal probing defect in association with a tooth that has had root canal treatment, with or without a post-placement, is considered to be pathoneumonic for the presence of a vertical root fracture.

Subjective findings

Symptoms tend to be minimal. Seldom is the vertical root fracture painful, and it is often asymptomatic or shows mild, insignificant signs and symptoms. Often,

some mobility is detectable, but many teeth are stable. Periapical symptoms (pain on pressure or mastication) are common but mild. Because many vertical root fractures resemble periodontal lesions, a periodontal-type abscess (either as a presenting sign or in the



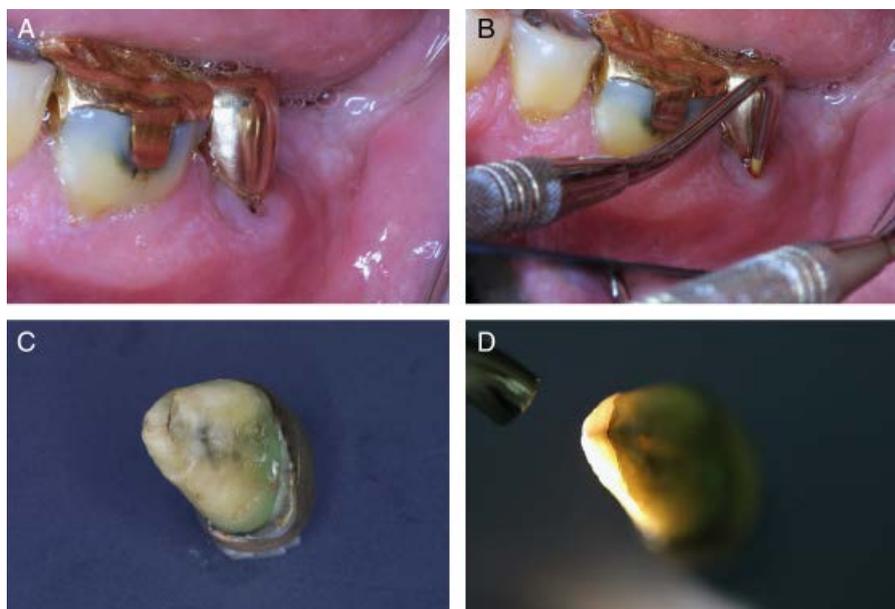


Fig. 20. (A) This mandibular second molar had a history of vertical root fracture of the distal root, which was hemisected and had a gold crown restoration placed. (B) This was asymptomatic for many years, but now a narrow, isolated periodontal probing is present mid-facial on the mesial root. (C) A suspicion of vertical root fracture was confirmed after extraction. (D) Transillumination reveals that the light is not allowed to penetrate through the fracture line.

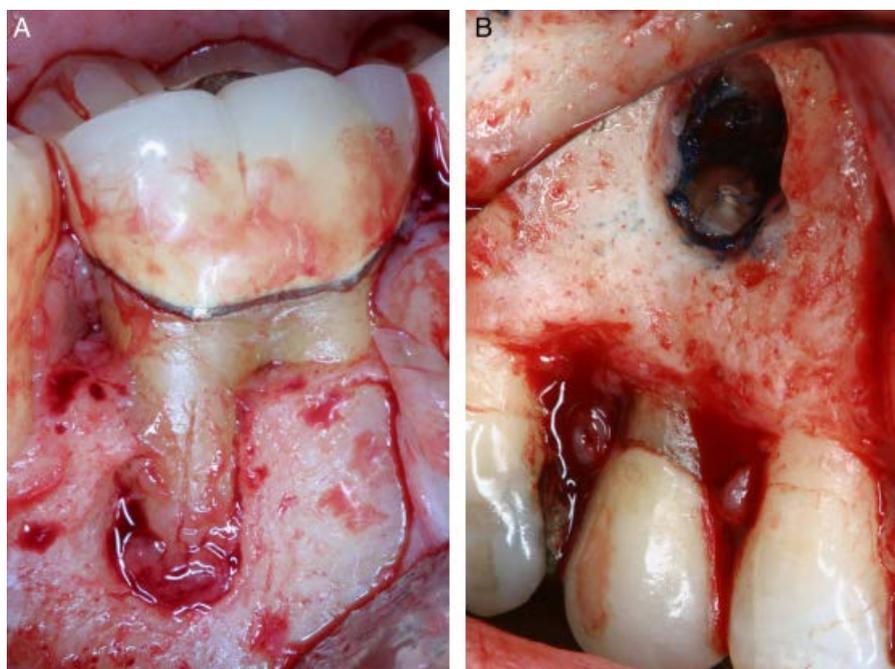


Fig. 21. Patterns of clinical bone loss exhibited with vertical root fractures. No granulomatous tissue may be present after flap reflection, but usually there is a characteristic punched-out, granulomatous tissue filled defect that is diagnostic of vertical root fracture. (A) This defect may have a classic V-shaped appearance with loss of marginal bone. (B) Or it may appear as a typical endodontic lesion defect with intact marginal bone as shown on this resected root. Transillumination and staining may be beneficial in locating fracture lines.

history) is a common occurrence (93, 102). In fact, this localized swelling is often what brings the patient to the dentist's office.

Objective tests

Periapical tests of palpation and percussion are not particularly helpful; periodontal probing patterns are more diagnostic. Significantly, some teeth with vertical root fractures have normal probing patterns (89). However, most show significant probing depths with narrow or rectangular patterns, which are more typical of endodontic-type lesions (Fig. 19) (89, 92, 96, 102, 119). These deep probing depths are not necessarily evident on both the facial and lingual aspects. Overall, probing patterns are not in themselves totally diagnostic, but they are helpful.

Radiographic findings

Radiographs also show a variety of patterns. At times there are no significant changes (R. J. Michelich, personal communication). However, when present, bone resorptive patterns tend to be marked, extending from the apex along the lateral surface of the root and often include angular resorption at the cervical root (Fig. 17) (89, 105, 120). As well, many of the resorptive patterns related to vertical root fracture mimic other entities. The resorptive pattern may extend over the apex and along one root surface, described as a 'J-shaped' or 'halo' pattern (89, 105, 120). Lesions may resemble failed root canal treatment; that is, they have an apical 'hanging drop' appearance (89, 105, 120). There are visible separations of fractured root segments in only a small percentage of teeth (R. J. Michelich, personal communication). Interestingly, vertical root fractures may be more readily identified using computed tomography rather than with conventional radiography (63–66).

The idea that a radiolucent line separating the root canal filling material (i.e. gutta-percha or Resilon) from the canal wall is diagnostic has been advocated. However, this radiolucent line may be a radiographic artifact, incomplete root canal filing, overlying bony pattern, or other radiographic structure that is confused with a fracture. Therefore radiographs are helpful but are not solely diagnostic except in those few instances in which the fracture is obvious.

Dental history

Virtually all teeth with a vertical root fracture have had root canal treatment (10); many have been restored with cast or prefabricated posts. Conventional tapered, wedging posts and cores have higher failure thresholds, but potentially result in greater destructive forces involving tooth fracture (121, 122). Interestingly, the newer fiber post and core systems have lower failure thresholds and are more likely to fail by core fracture rather than by tooth fracture (81, 122–126). Posts that are poorly designed (too long or too wide) are a frequent culprit (9).

Interestingly, endodontic and restorative treatment may have been done months or years before the fracture. Forces (without fracture) are established at the time of treatment or restoration (95, 102, 103, 108–110). These forces are stored in root dentin but may not result in an actual fracture until later; neither patient nor dentist may relate the fracture to earlier procedures.

Other findings

Signs, symptoms, and radiographs all give variable findings. However, having a sinus tract and a narrow, isolated periodontal probing defect in association with a tooth that has had root canal treatment, with or without a post-placement, is considered to be pathognomonic for the presence of a vertical root fracture (89, 92, 127). Flap reflection is the only reliable diagnostic approach. Surgical exposure of soft tissue and bone overlying the root surface is the best method of identification (91). Vertical root fractures have consistent patterns (Fig. 21). There is usually a 'punched-out' bony defect that tends to be oblong and overlies the root surface. This defect may take the form of a dehiscence or fenestration at various root levels. The defect is filled with granulomatous tissue.

After inflammatory tissue has been removed, the fracture is usually (but not always) visible on the root (Figs. 19 and 21). The operating microscope is useful. If not obvious, the fracture line may be hidden or very small and undeveloped. However, the characteristic punched-out, granulomatous tissue-filled defect is diagnostic of vertical root fracture, which should be strongly suspected (R. J. Michelich, personal communication). Transillumination or staining with dye is helpful (Fig. 21). Also, the root-end could be resected

and examined under magnification to detect the fracture.

Fracture characteristics

Histological fracture characteristics have been described with vertical root fracture after removal (93). All fractures extended from the canal to at least one root surface but not necessarily to both (Fig. 4). Usually, fractures extended to facial and lingual surfaces (Figs. 4 and 18). Similarly, fractures often extended only the partial length of the root, usually to the apex but not always to the cervix.

Many irritants occupy the fracture space and adjacent canal (93). Fractures harbor bacteria, sealer particles, and amorphous material. Canals adjacent to the fracture often contain necrotic tissue as well as concentrations of bacteria. Periodontal tissues adjacent to the fracture are chronically inflamed. Occasionally, connective tissue grows into the fracture toward the canal; this is often associated with resorption at the root surface.

Thus, profound irritants related to the fracture, with resulting inflammation at the surface, were identified in the study (93). Vertical root fractures resemble a very long apical foramen that communicates with necrotic pulp containing bacteria; thus the hopeless prognosis.

Treatment

As stated earlier, the only predictable treatment is removal of the fractured root or extraction of the tooth (Fig. 1).

In multi-rooted teeth, removal of the fractured root may be performed by root amputation (root resection) or hemi-section (Figs. 20 and 21) (128). It is suggested that if these procedures are elected, a restoration be in place in the chamber that extends deeply into the canal spaces, which will be resected. The purpose of this deeply placed restoration is to ensure a seal when the root is removed. Root canal filling materials must be replaced by a better-sealing restoration when exposed to the oral cavity as they provide poor sealing capabilities when exposed to bacteria. It is difficult to gain access and place new restorations in this area after the root is resected; therefore, having a better-sealing restoration than a root filling material already in place upon resection makes this an easier procedure to accomplish. One disadvantage of this technique is the

scatter of fine restoration particles that may lodge in the surgical site.

Other modalities have been suggested in attempts to reduce the fracture or retain the root, such as placement of calcium hydroxide, ligation of the fractured segments, or cementation of the fractured segments, trying to bind them by adhesive resins, epoxies, or glass ionomer (129, 130). A unique approach is to extract the tooth, repair the fracture with a laser, cement or bonding agent, and then replant the tooth. Many of these suggested methods are impractical and their long-term effectiveness has not been shown. Surgical repairs such as removal of one of the fractured segments or repair with amalgam, resin, or adhesives after surgical exposure and preparation have also been suggested, but there has been limited documentation of successful results.

Prognosis

At present, prognosis is virtually hopeless for a tooth with a vertically fractured root.

Prevention

Because the causes of vertical root fracture are well known, prevention is not difficult. The cardinal rules for safety are to (1) avoid excessive removal of intraradicular dentin and (2) minimize internal wedging forces. The binding strength of root dentin is considerable but is easily compromised. Treatment and restorative procedures that require minimal dentin preparation should be selected. Canal preparation techniques that overenlarge the canal, and overly aggressive instruments such as nickel-titanium files that are more tapered, must be further evaluated with respect to their effect on changing the fracture resistance of teeth (98, 112, 131, 132).

Condensation of root canal filling materials should be carefully controlled. More flexible and less tapered finger pluggers or spreaders are preferred because they are safer than stiff, conventional hand-type spreaders (109, 110, 133). Posts weaken roots and should not be used unless they are necessary to retain a foundation. The post-design least likely to cause stress and to fracture dentin is the flexible (including carbon-fiber) or cylindrical (parallel-sided) preformed post (100, 122), although these designs are not suitable in all restorative situations. Cast posts or some of the tapered

preformed posts may be necessary; their shape may exert wedging forces that readily split roots or cause dentin strain, particularly if they lack a stop or ferrule on the root seat (134–139). Any post used should be as small as possible, have a passive fit, and not lock or grip the root internally with threads (100). Cementation should be done carefully and slowly; an escape vent for the cement is probably helpful.

Summary

This article has classified and reviewed the essential clinical features as well as outlined the differential diagnosis of craze lines, fractured cusps, cracked teeth, split teeth, and vertical root fractures. Identifying each type of longitudinal fracture is critical; treatment approaches differ with each, as does prognosis. Also reviewed were the various treatment modalities and the prognosis of each. The final entry in each section was prevention. Many etiologies are either caused, or at least contributed to, by the dentist. Therefore most can be minimized as to incidence and severity.

These longitudinal fractures that occur over time and distance have frequently been confused or combined in clinical articles, creating misunderstanding and resulting in incorrect diagnosis and inappropriate treatment. This classification has been devised to provide global definitions that researchers and clinicians can use to eliminate this confusion.

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