Article

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Review Article

Crown fractures in the permanent dentition: pulpal and restorative considerations

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KEYWORDS
trauma • crown fracture • permanent teeth • histopathology • restoration • treatment • prognosis

ABSTRACT

Abstract – Crown fractures account for the highest percentage of all traumatic injuries in the permanent dentition. This review paper will discuss the different types of crown fracture, from the uncomplicated to complicated, including crown-root fractures. It will focus on two different aspects: the pulp, with an attempt to correlate epidemiological, experimental, histopathological and clinical studies, so that the clinician can better understand the underlying processes accounting for success or failure to maintain pulp vitality. Also, we will consider the restoration: knowledge about bonding to dentin and new material is evolving extremely quickly making it difficult for the clinician to keep up with the developments. If handled properly, prognosis of the pulp, after traumatic crown fracture, is good. Prognosis of the restoration has also improved considerably over the last few years, and it appears that this trend will continue in the future.

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Crown fractures account for the majority of dental trauma in the permanent dentition (26–76% of dental injuries), while crown-root fractures represent only 0.3–5% (1–5). The dentist plays a key role in the prognosis of the traumatized tooth. It depends on his accurate diagnosis and treatment procedures at two separate levels: the pulp level and the restoration level.

At the pulp level, understanding of the underlying mechanisms of histopathology and healing processes are of first importance. Most articles are limited to epidemiological, experimental, histopathological, or clinical data. Very few (1, 2, 6, 7) deal with two or more of these approaches together. Thus, a compilation of all of these would give the clinician a broader perspective and better comprehension of the subject. How does a pulp react to trauma? What effects are induced by clinical procedures? What can the clinician expect about the prognosis of the traumatized tooth?

On the other hand, at the restoration level, information about bonding to enamel and dentin is growing at a very rapid rate. New materials, including adhesive systems and resin composites, are coming onto the market almost every month. The clinician must be sensitive to these new developments, in order to choose appropriate treatment alternatives, materials, and be conscious of technique limitations.

The aim of this review article is, firstly, to gather the recent knowledge arising from epidemiological, experimental, histopathological and clinical studies regarding pulp reactions to crown fractures and crown-root fractures. This way, the dentist can evaluate the prognosis of the pulp in a more accurate way. Secondly, it will deal with restorative materials and their clinical application. The clinician will then be able to better predict the prognosis of the restoration.

Type of treatment and its subsequent success or failure is related to the dental tissue involved. Thus, the different levels of fracture considered is based on the International Classification of Diseases to dentistry and stomatology (8), given in Table 1. The case of root fractures and multiple fractures is not being discussed.

Table 1. Application of International Classification of Diseases to dentistry and stomatology (WHO, 1995)

Classification	Description	Tissues involved
S.02.5	Fracture of tooth (primary and secondary teeth)	
S.02.50	Fracture of enamel of tooth only + enamel infraction	Enamel
S.02.51	Fracture of crown of tooth without pulpal involvement	Enamel, dentin
S.02.52	Fracture of crown of tooth with pulpal involvement	Enamel, dentin, pulp
S.02.53	Fracture of root of tooth	Cementum, dentin, pulp
S.02.54	Fracture of crown with root of tooth, with or without pulpal involvement	Enamel, cementum, dentin, ±pulp
S.02.57	Multiple fractures of tooth	Unspecified
S.02.59	Fracture of tooth, unspecified	Unspecified

Crown fractures

Enamel infraction and enamel fractures

Diagnosis

Enamel infraction is defined as microcracks in the thickness of the enamel. Therefore, diagnosis is made by reflecting light off its surface, or by transillumination. Differential diagnosis should exclude cracks due to thermal attacks (hot coffee, cold ice-cream); a thorough dental history is required.

Diagnosis of enamel fractures is made by clinical examination of missing tooth structure from the crown. This type of trauma generally involves the anterior region, and is located at the incisal edge, or at a proximal angle. Furthermore, the tooth is not sensitive to variations in temperature, dehydration and pressure. Temporarily, pulp testing can become negative and tooth color may darken, especially with concomitant luxation injuries (1).

Histopathology

To our knowledge, there are no reports dealing with histology of the pulp after enamel infraction or fractures. One can assume that it goes through a transcient inflammatory phase, transcient sectioning of nerve fibers in the apical region (negative response to pulp sensitivity testing), and/or a local hemorrhage (change of color).

Treatment and prognosis

For enamel infraction, treatment in severe cases consists of sealing of the cracks, as Love (9) found in an *in vitro* model that enamel–dentin cracks might account for a portal for bacterial invasion of seemingly intact teeth. That sealing may be performed with any adhesive system after cleaning and enamel etching, or with the use of the new self-conditioning etching systems in order to simplify the clinical procedures (Prompt L-Pop, Espe, Germany). For enamel fractures, treatment depends on the amount of tissue lost. Simple contouring may be enough; in more severe cases compromising aesthetics, a composite resin restoration may be performed following etching and adhesive application.

Prognosis is very good for both types of injuries (10–13). Prevalence of pulp survival after enamel infraction ranges from 97 to 100%; after enamel fractures, it ranges from 99 to 100%. Possible explanations for necrosis can be concussion or subluxation injuries that have been overlooked.

Enamel–dentin fracture, without pulpal involvement: uncomplicated crown fractures

Diagnosis

Diagnosis is made by clinical examination of missing tooth structure from the crown. The tooth is generally sensitive to variations in temperature, dehydration and pressure due to the sectioning of the dentinal tubules; thus, the patient feels the airflow through the syringe. This sensitivity increases on younger teeth, closer to the pulp, as the number and diameter of the tubules increase (14). Temporarily, pulp testing can become negative and tooth color may darken, especially with concomitant luxation injuries (1).

Histopathology

To understand underlying mechanisms, the clinician must recall some histophysiological and histopathological basics.

Bacteria and bacterial products have been suggested as one of the most important etiological factors in inflammatory reactions of the human dental pulp; there is clear evidence that pertinent pulpal inflammation cannot develop in the absence of bacterial infection (15–17). After the trauma, bacteria can potentially invade the sectioned dental tubules, and therefore, cause inflammation (Fig. 1).

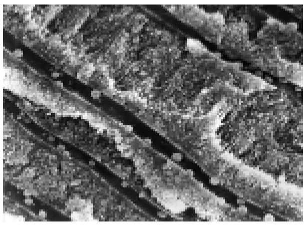

Fig. 1. SEM view of bacteria in dentinal tubules (magnification 4000×).
[Normal View]

Luckily, the pulp has several defense mechanisms: one 'passive' mechanism, consisting of an outward flow of dentinal fluid within the tubules due to positive pulpal pressure (18). That flow resists bacterial invasion through a gradient of hydrostatic pressure. The 'active' mechanism consists of the ability of the pulp to elicit an immediate inflammatory response to outside stimuli, bacteria toxins or bacteria through the blood circulation. Any factor that affects these protective mechanisms, such as alteration of pulpal circulation (as seen in concomitant luxation injuries), or age of the tooth (and its subsequent potential for repair) will have to be taken into account for the emergency treatment plan and for the prognosis of the traumatized tooth.

Treatment and prognosis of the pulp

Inflammatory changes are transcient as long as the pulpal vascular supply remains intact and bacterial invasion prevented (19). This may be achieved by an efficient sealing of the dentin: only in the case of improper sealing will further irreversible pulpal lesions occur. Therefore, indirect pulp capping, as it used to be performed to protect the pulp, is not necessary, because it would prevent resin tag penetration into the tubules, and hence reduce sealing efficacy and bond strength of the future restoration.

Clinically, the first step is insuring a dry operative field by placing a rubber dam. After disinfecting with a sterile saline solution, the dentin is further decontaminated with a 37% phosphoric acid gel applied for 10 s, and air-dried lightly to keep the surface slightly moist. The bonding agents are then used according to the manufacturer's instructions.

Prognosis of the pulp is very good. Long-term clinical studies show very little response to enamel–dentin fractures and subsequent restorative procedures, as long as there is no concomitant periodontal injury, and that the restoration is efficiently sealed (6, 13, 20): prevalence of pulp survival equals 94–98%. Ravn (20) reports a lower prevalence (as low as 75%) by taking into account the extent of fracture into dentin and the time deeply exposed dentin was left unprotected. Pulp canal obliteration has been occasionally reported: prevalence ranging between 0.2 and 0.5%.

Those results are in accordance with experimental studies (7); histology observations show very little changes in the pulp, subsequent to induced traumatic fractures.

Restoration by composite build-up and prognosis

The major challenge for the clinician is to re-establish the natural aesthetics of the traumatized tooth, thus its form and dimensions, shade, opacity and translucency, and more recently, fluorescence and opalescence.

With the materials available today, in conjunction with an appropriate technique, these goals can be accomplished with predictable results (21); a reference guide in a silicone material is made out of a 'composite mock-up'– this allows the clinician to assess the thickness and the size of different increments of composite to be applied, from a more opaque composite in the dentin region to a more translucent one in the incisal edge region. Form and texture is achieved during the finishing procedures (Fig. 2).

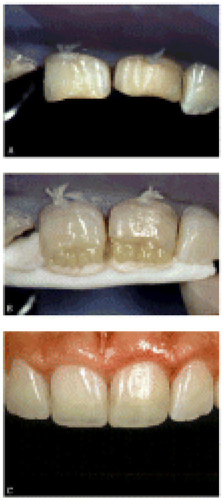

Fig. 2. Restoration by composite build-up of an uncomplicated enamel–dentin fracture. After confection of a reference guide, rubber dam is placed and cavity preparation finished (A). Increments of composite material of different opacities are applied and light-cured, to simulate the natural tooth (B). Restoration is finished and polished (C) (by courtesy of Dr Dietschi).
[Normal View]

However, long-term prognosis of class IV composite resin restorations remains questionable, as regards to durability and aesthetics. Robertson *et al.* (6) report that over a period of 15 years, 19% of the restorations were changed 10 times, and that 25% were judged unsatisfactory at the final examination. Browning and Dennison (22) give an overview of the failure modes affecting these restorations. The main reasons for failure are in relation with the adhesive system used (bond failure leading to fracture of composite, marginal failure, marginal discoloration); other reasons are either dependent on the materials and techniques used (cohesive fractures of composite, shade instability, recurrent decay), or independent of the materials and techniques used (fracture of tooth). According to Browning and Dennison, mean age of replacement of class IV restorations is about 5 years. In any case, the clinician should warn the patient that if failures occur, a less conservative treatment alternative should be preferred: porcelain veneers or crowns.

Compared to the classes III and V restorations, class IV shows the highest failure rates (23, 24).

However, with latest generation adhesive systems and optimized composite materials, one can expect to increase the longevity (25).

Treatment with reattachment of coronal fragment

An alternative, which is becoming more attractive due to the technology of new dentin bonding agents, is fragment bonding.

It offers a number of advantages, such as psychological ones for the patient and/or parents, reduced chair time, exact restoration of morphology and texture, and use of a tissue that abrades the same as the antagonist tooth (Fig. 3).

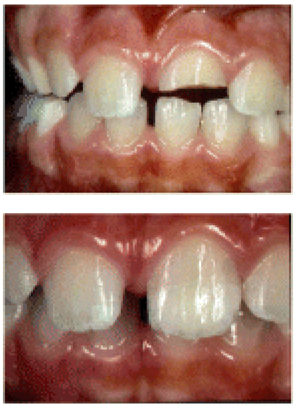

Fig. 3. Restoration by fragment bonding of an uncomplicated enamel–dentin fracture.
[Normal View]

This option should be preferred over composite build-ups, under certain conditions: the fragment is available, adaptation to the tooth surface is accurate, size is reasonable (the bigger, the easier it is to manipulate the fragment), multiple fragments are difficult to manage. Therefore, the dentist should educate the patient and his/her parents about this conservative treatment alternative in case of tooth fracture and fragment recovery.

In an *in vitro* investigation, Farik *et al.* (26) measured the fracture strength of fragments bonded with different adhesive systems. Products, such as Panavia 21 (Kuraray Co., Japan) or Scotchbond 1 (3M Santé, France) showed results similar to those of an intact tooth, but at a low cross-head speed (1 mm min^{-1}), which does not represent the situation of a trauma. Fracture strength decreased, as velocity of the cross-head speed rose (27, 28), 30% lower at 500 mm min^{-1}, nil at 2 m min^{-1}. Higher results can be expected from last generation bonding agents.

An extensive long-term clinical study (29) revealed that fragment retention was considerably higher by using a total etch technique and dentin bonding agents, rather than enamel acid-etching alone: 50% fragments retention at 30 months, and at 12 months, respectively. They also pointed out that reinforcement of fracture line did not prolong fragment retention. Cause of fragment loss was due to new trauma, nonphysiological use and horizontal traction. Furthermore, results from fragment bonding versus resin composite build-up did not differ significantly.

A new clinical approach may be proposed to enhance fragment retention: the use of a groove in the fragment, which would increase the bonding surface, and thus the bonding strength. After cleaning with a sterile saline solution, the fragment is held with a Vivastick (Vivadent, Liechtenstein) for handling purposes; a small groove is made with a round diamond bur within the dentin at the fractured interface (Fig. 4). Then enamel is acid etched for 30 s and dentin for 10 s with a 35% phosphoric acid gel. After conditioning the dentin, the prepared fragment is left uncured, in the absence of light. The remaining tooth is prepared in the same way. Then, resin composite is applied into the groove of the fragment, and it is fitted against the fractured surface. Excess is removed, and resin composite is light cured 40 s buccally and 40 s lingually by using a high-power halogen light-curing device. Polishing procedures are performed using fine diamond burs, disks and strips.

Fig. 4. Groove performed with diamond bur in the dentin of the fragment.
[Normal View]

In a preliminary SEM study, no gap at the dentin–composite interface was detected with the use of a groove, whereas some gaps were seen when no groove had been performed.

It seems that the procedure of fragment bonding does not alter the prognosis of pulp vitality: in experimentally induced crown fractures in monkeys, Robertson *et al.* (7) reported, after 3 months, pulps in good condition, with hard tissue formation. Inflammatory infiltrates were rare. This is in accordance with the clinical study of Andreasen *et al.* (29), which showed absence of pulp necrosis, as long as there was no concomitant luxation injury. This would also confirm the importance of dentin sealing preceding the step of fragment bonding.

Enamel–dentin fracture, with pulpal involvement: complicated crown fractures

Diagnosis

Diagnosis is made by clinical examination of missing tooth structure from the crown and pulp exposure. The tooth is generally sensitive to variations in temperature, dehydration and pressure due to the sectioning of the dentinal tubules, and the opened pulp.

Pulp testing is positive, unless there is a concomitant luxation injury.

Histopathology and indications for direct pulp capping

It is now well established that the teeth have the potential to form hard tissue subsequent to pulpal exposure, leading to a dentinal bridge, under a biocompatible pulp-capping agent (Figs. 5 and 6).

Fig. 5. Formation of a dentinal bridge at 42 days after pulp exposure, under a calcium hydroxide pulp capping agent (magnification 63×, by courtesy of Prof Holz).
[Normal View]

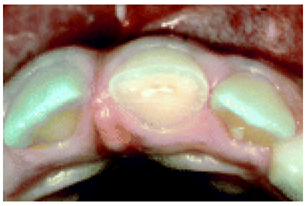

Fig. 6. Clinical view, 6 months after direct pulp capping and fragment bonding: formation of a hard tissue barrier. The patient lost the fragment after a second trauma.
[Normal View]

A conservative approach should thus be encouraged, as long as a certain number of criteria are taken into account. They are linked to the natural potential of defense of the tooth; the indications for pulp capping follow.

1 *Time spent with an exposed pulp*: The longer the time, the reduced the chances of healing, because of the quantity of bacteria that invade the pulp and irreversible inflammatory reactions such as microabscesses (30).

2 *Healthy pulp before trauma*: Potential for healing is diminished in a pulp which has had previous traumas and/or large carious lesions (31), or one which is inflamed.

3 *Diameter of pulp exposure*: The larger it is, the lower the chances of healing through the formation of a dentinal bridge. Clinical experience seems to give 1.5 mm diameter of pulp opening as the higher limit for a reasonable success rate, although no literature can confirm this.

4 *Age of the tooth*: This factor is controversial. Apparently, an aged tooth with a reduced pulpal lumen will not have an adverse effect on healing, although blood circulation is diminished (31).

5 *No concomitant luxation injuries*: If that is the case, one can expect a rupture of the vascular tract, which will compromise the nutritional supply to the pulp and lead to its loss of vitality. In the case of enamel–dentin fractures without pulp implication, Andreasen and Andreasen (1) showed that incidence of pulp necrosis for apexified teeth rose from 5 up to 75% if there was a concomitant luxation injury.

6 *Stage of root development*: Chances of success are much greater if the tooth has an opened apex, rather than one with a complete root formation. The biggest difference reported by Andreasen and Andreasen (1) apply to crown fractures combined with a concomitant lateral luxation: pulp survival rises from 15 to 60% when the apex is open.

Pulp capping agents

Since the 1980s, calcium hydroxide has clearly been the material of choice, because it elicits the formation of a dentinal bridge, following a number of phenomena (32). Calcium hydroxide would cause a coagulation necrosis; the latter induces a low-grade irritation that leads to differentiation of the undifferentiated cells of the pulp. They synthesize predentin, which is subsequently mineralized, while the coagulated tissue is calcified. Finally, predentin is transformed into dentin by further mineralization. Furthermore, calcium hydroxide has the ability to assure a sterile 'operating field' and reduce bleeding.

In the past years, many new products have come onto the market. While some are still made of calcium hydroxide, but incorporated in resins or hard setting agents, others are of a different nature: adhesive resins, glass ionomers, calcium phosphate cements, hydroxyapatite. The great majority of the studies testing these products are based on histological observations of animal experimentation, whether formation of a hard tissue barrier is confirmed or not. Although results are promising, extensive research with human teeth is needed to confirm these findings. Heitmann and Unterbrink (33) report that, after 6 months, human teeth capped with a glutaraldhehyde-containing dentinal adhesive remained vital and without symptoms; but, Schuster *et al.* (34) point out *in vitro* the changes in cell phospholipid metabolism in the presence of HEMA and its degradation products. As results on animals cannot be directly extrapolated to human clinical conditions, resins as pulp capping agent should still be used with precaution (35). Needless to say, at the present time, the subject is highly controversial.

The different protocols, products used as capping agents and results are given in Table 2 (36–52).

Table 2. Products under investigation as pulp capping agents

Authors	Products/experimentation	Results
Kitasako *et al*. (2000)	1. Bondwell LC[a]	1. Dentin bridge (day: 60)
	2. Clearfil Liner Bond II[b]	2. Dentin bridge (day: 60)
	3. Dycal[c]	3. Dentin bridge (day: 30)
	Monkey; cl.V cavities sealed with composites; days: 3, 7, 14, 30, 60	
Hayashi *et al*. (1999)	Hydroxyapatite rat; days: 1, 3, 5	Formed mineralized tissue; no dentin bridge
Hebling *et al*. (1999)	1. $Ca(OH)_2$	1. Coagulation necrosis → dentin bridge (day: 60)
	2. All bond 2[d]	2. Inflammation → no dentin bridge
	Human; days: 7, 30, 60	
Kitasako *et al*. (1999)	1. Dycal (hard setting $Ca(OH)_2$.[c]	Dentin bridge in all groups
	2. Bondwell LC[a]	Protrusion of pulpal tissue into cavities
	3. Clearfil Liner Bond II[b]	
	4. Superbond C&B[e]	
	Monkey; cl.V cavities sealed with composites; days: 3, 7, 14, 30, 60	
Niinuma (1999)	1. Resinous agent with $Ca(OH)_2$	Dentin bridge (day: 90)
	2. Dycal[c]	Dentin bridge (earlier)
	Beagle dog; days: 7–90	
Kitasako *et al*. (1998)	1. All Bond 2[d]	Dentin bridge in all groups
	2. Bondwell LC[a]	
	3. Liner Bond II[f]	
	4. superbond C&B[e]	
	Monkey; days: 3, 7, 14, 60	
Mochizuki *et al*. (1998)	1. Calvital ($Ca(OH)_2$.	Dentin bridge
	2. Dycal[c]	Dentin bridge, but slower
	Dog; incomplete formed roots; 56 days	
Olmez *et al*. (1998)	1. Optibond[g]	Dentin bridge?
	2. Syntac Classic[h]	Results promising, but further *in vivo* studies recommended
	dog; cl.V cavities sealed with composites; days: 7, 21, 90	
Tarim *et al*. (1998)	1. $Ca(OH)_2$	Dentin bridge
	2. Resin-modified glass ionomer	Dentin bridge
	Monkey; days: 6–7 ,21–27, 90–97	Various degrees of inflammation associated with bacteria
Tarim *et al*. (1998)	1. Optibond[g]	1. Dentin bridge?
	2. XR-bond[i]	2. Some odontoblastic disruption + inflammation, not significant
	3. $Ca(OH)_2$ + IRM[j]	3. Dentin bridge
	Monkey; days: 7, 21–27, 90–97	
Chaung *et al*. (1996)	1. Calcium phosphate cement	1. Dentin bridge
	2. $Ca(OH)_2$	2. Dentin bridge
	Monkey; weeks: 12, 20, 24	
Heitmann and Unterbrink (1995)	Syntac Classic [h]	Teeth remained vital + without symptoms; no histological results
	Human; restoration with composites; 2–6 months	
Yoshimine and Maeda (1995)	1. $Ca(OH)_2$	1. Coagulation necrosis (r) dentin bridge
	2. Tetracalcium phosphate	2. Dentin bridge with no tissue necrosis/inflammation
	Rat; days: 1, 3, 7, 10	
Tsuneda *et al*. (1995)	1. Superbond C&B[e]	1. Slight initial reaction, 2° dentin (day: 30)

	2. Clearfil Liner Bond system[k]	2. Slight pulpal necrosis, 2° dentin (day: 90)
	3. Tokuso Light Bond system[l]	3. Severe pulpal reactions, no formation of dentin
	4. Scotchbond Multi-Purpose One All system[m]	4. Severe pulpal reactions, no formation of dentin
	Rat; days: 3, 7, 30, 90	Results seem to be related to microleakage
Imai and Hayashi (1993)	calcium glycerophosphate	Osteodentin (day: 5), no tubular dentin
	Rat; days: 1, 3, 5	
Subay and Asci (1993)	1. Dycal[c]	1. Dentin bridge
	2. hydroxyapatite	2. No dentin bridge
	Human; days: 2, 30, 60	
Pitt Ford and Roberts (1991)	1. Dycal[c]	1. Dentin bridge
	2. VLC dycal[n]	2. Dentin bridge
	3. Prisma-Bond[o]	3. Incomplete dentin bridge
	Monkey; amalgam restoration sealed with ZOE cement; 2 months	
Zalkind *et al.* (1989)	P-10 composite[p]	Dentin bridge
	Rat molars	
Cox *et al.* (1985)	$Ca(OH)_2$ exposed at three intervals	Recurring pulp inflammation if associated with bacterial contamination
	Monkey; years: 1, 2	

[a] Bondwell LC (GC Co., Tokyo, Japan).
[b] Clearfil Liner Bond II (Kuraray Co., Japan).
[c] Dycal (L.D. Caulk, DE, USA).
[d] All Bond 2 (Bisco Dental Products, IL, USA).
[e] Superbond C&B (Sun Medical Co., Japan).
[f] Liner Bond II (Kuraray Co., Japan).
[g] Optibond (Kerr, CA, USA).
[h] Syntac Classic (Vivadent, Liechstenstein).
[i] XR-Bond (Kerr, CA, USA).
[j] IRM (L.D. Caulk, DE, USA).
[k] Clearfil Liner Bond (Kuraray Co., Japan).
[l] okuso Light Bond (Tokuyama Co., Japan).
[m] Scotchbond Multi-Purpose One All system (3M Dental Products, MN, USA).
[n] VLC Dycal (L.D. Caulk, DE, USA).
[o] Prisma-Bond (L.D. Caulk, DE, USA).
[p] P-10 composite (Dental Products, USA).

Treatment and prognosis

During the clinical procedures, chances of pulp survival are greater by taking a certain number of precautions.

1. Isolation of the traumatized tooth with a rubber dam; this shall prevent any contamination during the clinical procedures.
2. Disinfection of cavity with a sterile saline solution. Hydrogen peroxide used to be the product of choice, because of its hemostatic properties; but it should be avoided because the oxygen released inhibits the polymerization of the resin (53, 54). The transcient use of 37% phosphoric acid on the exposed pulp also has astringent properties, but its long-term effects on the pulp are controversial (35, 55).
3. Choice of a biocompatible pulp capping agent and use according to the manufacturer's instructions; this will elicit a positive pulp reaction leading to the formation of the dentinal bridge.
4. Efficient sealing of dentin and tight crown reconstruction; this shall prevent future bacteria invasion shown to produce irreversible damage to the pulp.

After treating the pulp, the tooth is restored similarly to the case of an uncomplicated crown fracture: either with a composite, or by fragment bonding. These procedures have already been discussed above.

Prognosis of complicated crown fractures is good: pulp survival following pulp capping varies between 63 and 88% (13, 56, 57).

Vital amputation (or partial pulpotomy): indications, treatment and prognosis

Vital amputation only involves young teeth with open apices and thin dentinal walls. It is performed when pulp capping is contraindicated, i.e. size of pulpal exposure and/or time elapsed since injury. This procedure is considered a long-term provisory treatment: in many cases, the treatment plan for the traumatized tooth is root canal treatment, followed by restoration.

When using a calcium hydroxide dressing, the tooth remains vital, and thus, constriction of the apical foramen and periradicular dentin apposition can continue. This way, one hopes to prevent cervical root fractures due to thin dentinal walls (13).

Pulpotomy should be performed after rubber dam placement and disinfection with a sterile saline solution; a sterile diamond bur is used, so that pulpal tissue is stretched to a minimum. According to Cvek (58), level of amputation should be 2 mm below the exposure site: it is assumed that at that level, pulpal tissue is healthy.

After rinsing with a saline solution, the dressing and sealing materials are applied, thus calcium hydroxide and a glass ionomer cement, respectively. The latter gives the required mechanical stability. Restoration includes composite or fragment bonding.

Prognosis of vital amputation is good: success of treatment ranges from 94 to 100% (58–60). This high rate is thought to be related to the efficient sealing of the exposure by a glass ionomer cement.

Crown-root fractures

Diagnosis
A crown-root fracture extends below the cemento-enamel junction. It may or may not affect the pulp. Diagnosis is made by clinical examination, mobility testing and radiographic examination.

If the fragment is still kept in place by fibers of the periodontal ligament, the patient will generally complain about sensitivity to pressure and/or percussion due to the slight mobility of the fragment. Otherwise, if the fragment is lost, the tooth will react like uncomplicated or complicated enamel–dentin fractures, whether it involves the pulp or not.

Histopathology
Histopathological reactions involving the pulp are basically the same as those seen with uncomplicated or complicated crown fractures.

In addition to these, one may see a classical inflammation reaction of the gingiva at the line of fracture, below the cemento-enamel junction due to accumulation of plaque. Cells seen are leukocytes and fibroblasts, typical of the acute phase.

Treatment and prognosis
Crown-root fractures have immediate implications for the endodontic, restorative and periodontal prognosis due to the line of fracture, which is subgingival. Treatment objective must, therefore, be aimed at exposing the fracture margins, juxtagingivally or supragingivally, so that all clinical procedures can be managed with strict moist control and bleeding control. Furthermore, the prognosis of the tooth may be improved through a better plaque control by the patient. This very often implies a multidisciplinary approach, with an endodontist, an orthodontist, a periodontist and a prosthodontist (61).

Before anything, the first clinical procedure is to retrieve the fragment (or fragments) of the traumatized tooth. This will indicate the level of fracture, and whether the pulp is involved. Only at that time, a treatment plan may be decided. For example, that fragment may be used again for reattachment.

Different treatment options exist in the literature (2, 62, 63). It will depend on the extent of the subgingival lesion, the morphology of the lesion (whether the incisal edge is implicated or not), the length and/or the morphology of the root and the situation in an 'aesthetic sensitive' region. Treatment options are summarized in Table 3.

Table 3. Treatment of crown-root fractures

Type of treatment	Advantages	Disadvantages
Fragment removal and status quo	Very conservative. Restoration soon after injury.	Poor pulp/restoration prognosis, due to difficult moist control?
Gingivectomy (+osteotomy if needed)	Relatively easy to perform. Restoration soon after injury.	Not in an 'aesthetic sensitive' region.
Forced orthodontic extrusion	'Aesthetic sensitive' region. Bone and gingival follow the tooth.	Time consuming (thus restoration much later after injury). Root-canal treatment must be performed.
Forced surgical extrusion	'Aesthetic sensitive' region. Rapid procedure. Diagnosis of additional fractures/fissures.	More traumatizing. Root-canal treatment must be performed. Restoration only after contention period. Risk of external resorptions?
Vital root submergence	Preservation of bone support.	Not in an 'aesthetic sensitive' region. Cost for temporary tooth replacement (removable plate).
Avulsion		Loss of bone support for future implant. Cost for temporary tooth replacement (removable plate, adhesive bridge).

(1) Fragment removal and status quo, followed by restoration

This is the most conservative treatment, as long as the lesion extends superficially under the cemento-enamel junction. It is followed by the restoration at a juxtagingival level. The gingiva will then reattach to the exposed dentin, probably by forming a long junctional epithelium.

One can assume that the prognosis of the pulp and of the restoration is poorer than in the case of crown fractures. Loss of fragment or composite build-up is frequent, probably due to difficult moisture control followed by bad adhesion, or to a steep inclination of the fractured surface. Unfortunately, to our knowledge, there are no reports that could confirm this with data; it only results from observations and clinical experience.

Koparal and Ilgenli (64) present one case of fragment bonding after surgical flap. This procedure should not be preferred on a routine basis for the reasons mentioned above: poor prognosis of the restoration, and poor plaque control.

(2) Gingivectomy (and osteotomy if needed)

The objective here is to lower the level of the gingiva, so that the fracture becomes supragingival. This may be achieved in a region, which is not 'aesthetic sensitive' (for example, palatal surface of the traumatized tooth).

(3) Forced orthodontic extrusion without/with gingivoplasty

Treatment objective is to displace all margins of the traumatized tooth more coronal by applying an orthodontic movement to it. This type of procedure is more time consuming than surgery: Malmgren *et al.* (65) report that an average of 5 weeks of active treatment is needed for 2–3 mm of extrusion. This is followed by a retention period of 8–10 weeks (63).

Before deciding this treatment plan, the clinician must watch out for different factors affecting the root: root length supported in the bone must be sufficient, so that even after extrusion, a favorable crown-root ratio (with the restoration in place) of maximum 1 : 1 is maintained. Length must also be considered regarding the size of the future radicular post for sufficient anchorage. Thin dentinal walls may be a serious issue because of the high risk of fracture in the cervical region. Katebzadeh *et al.* (66) propose the use of a composite resin 3 mm below the cemento-enamel junction to strenghten the tooth against fracture, with no radicular post.

After fragment removal, root canal treatment must be performed because orthodontic wires are fixed to a radicular post. In nonapexified teeth, or when the level of fracture is such that root canal filling under strict moist control is impossible, a temporary dressing with calcium hydroxide is recommended. Sometimes, gingivoplasty is required, because the periodontal ligament attachment follows the tooth coronally. A 6-month recall with periapical radiograph will indicate when apexification is complete, and it is time for ultimate root-canal therapy.

The case presented in Fig. 7 was treated by orthodontic extrusion. After extirpating the pulp, a calcium hydroxide dressing was left, followed by the sealing of a titanium post, 1 mm in diameter, with a temporary cement (Free Genol, GC Co., Japan). Brackets were bonded from the upper left second deciduous molar to the upper right one, and teeth were ligatured for anchorage. The deactivated elastic thread joining the post to the arch was changed once a week, for 1 month. This was followed by a 6-month retention period.

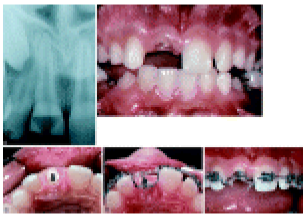

Fig. 7. Crown-root fracture treated by orthodontic extrusion. Radiograph of the traumatized tooth (A). Clinical view after removal of fragments and extirpation of the pulp (B). A titanium post was cemented into the root (C), which provided the anchorage necessary for orthodontic extrusion (D and E).
[Normal View]

Recently, Bondemark *et al.* (67) described a new way for extruding teeth orthodontically, with the use of attractive magnets: the first one is attached to the fractured root, and a larger one is embedded in a removable appliance. A total of 9–11 weeks were needed for 2–3 mm of extrusion, with constant forces, no friction and no material fatigue; results are promising.

(4) Forced surgical extrusion

Treatment objective consists of luxation of the root, positioning the margins at a juxtagingival level and securing it with interproximal sutures in the soft tissues and/or a splint. Endodontic therapy must be performed before this procedure. The fact of luxating the root allows the clinician to look out for other potential fractures/fissures.

Compared to orthodontic extrusion, this type of procedure is rapid, but bone support may be lost around the root. The same clinical criteria of root length and diameter apply.

Prognosis seems good, although risks of external root resorption exist: 12% reported by Tegsjo *et al.* (68) over a period of 4 years, 5% by Caliskan *et al.* (69) up to 3 years. This difference may probably be due to the technique used, as Caliskan used a calcium hydroxide dressing for 3 months before root canal obturation. But, this needs further investigation to be confirmed.

(5) Vital root submergence

This alternative approach is proposed by Johnson and Jensen (70) and Mackie and Quayle (71). Root fragment is retained *in situ* and left vital. Gingival tissue is sutured over the exposed root stump to achieve primary closure.

Although no long-term studies exist on this type of treatment, it may be considered in order to preserve alveolar bone until the time the root is replaced by an implant, with the condition that the trauma has not happened in an 'aesthetic sensitive' region.

(6) Extraction

This treatment procedure is performed if all of the above are not indicated. But, the clinician must be aware of the fact that future prosthetic rehabilitation will be considerably complicated if bone is lost with time.

Conclusion

After traumatic crown fractures, prognosis for pulp vitality is good to excellent. Table 4 summarizes pulp survival rates, at the different levels of fracture discussed.

Table 4. Prognosis of the pulp for different levels of fractures

Level of fracture	Prognosis of pulp
Enamel infraction	Pulp survival: 97–100%
Enamel fracture	Pulp survival: 99–100%
Enamel-dentin fracture, uncomplicated crown fracture	Pulp survival: 75–98% Pulp canal obliteration: 0.2–0.5% (concomitant luxation injury?)
Enamel-dentin fracture, complicated crown fracture	Pulp survival after: direct pulp capping: 72–81% vital amputation: 94–100%
All crown-root fractures	Probably worse than for crown fracture, but no reports available

For all enamel–dentin fractures, an efficient dentinal seal is of first importance to prevent further bacteria invasion to let the pulp cope with the trauma, and to elicit its physiological defense mechanisms. When a small pulp exposure is present, the use of pulp capping agents other than calcium hydroxide remains controversial at this moment in time: although formation of a hard tissue barrier has been described by many authors in experimental models, positive long-term results with humans are still to be confirmed. For larger pulp exposures, partial pulpotomy followed by a calcium hydroxide dressing is the treatment of choice.

In the case of crown-root fractures, prognosis of the pulp is less good. The subgingival level of fracture makes all efficient bonding procedures, and thus dentinal seal, extremely difficult, or impossible. The objective of treatment is to bring the level of fracture at a juxtagingival level.

For the prognosis of the restoration, very few extensive reports exist. Up-to-date clinical research becomes difficult: new products come onto the market at a very rapid rate, with big promises by the manufacturers. Therefore, the mean length of 5 years before replacement of a class IV resin composite can be expected to rise in the upcoming years. Another alternative, fragment bonding, is becoming attractive, especially with more efficient dentin-bonding agents. This approach should be encouraged as often as possible.

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