European Society of Endodontology position statement: Endodontic management of traumatized permanent teeth

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Abstract

European Society of Endodontology developed by: Krastl G, Weiger R, Filippi A, Van Waes H, Ebeleseder K, Ree M, Connert T, Widbiller M, Tjäderhane L, Dummer PMH, Galler K European Society of Endodontology position statement: Endodontic management of traumatized permanent teeth

This position statement represents a consensus of an expert committee convened by the European Society of Endodontology (ESE) on the endodontic management of traumatized permanent teeth. A recent comprehensive review with detailed background information provides the basis for this position statement (Krastl *et al.* 2021, International Endodontic Journal, https://doi.org/10.1111/iej.13508). The statement is based on current scientific evidence as well as the expertise of the committee. Complementing the recently revised guidelines of the International Association of Dental Traumatology, this position statement aims to provide clinical guidance for the choice of the appropriate endodontic approach for traumatized permanent teeth. Given the dynamic nature of research in this area, this position statement will be updated at appropriate intervals.

Keywords: Dental trauma, diagnosis, endodontic management, tooth injuries, tooth fracture, avulsion

Introduction

Traumatic dental injuries (TDIs) are often associated with complex injury patterns, where correct diagnosis is of great importance as it forms the basis for developing the appropriate management strategy. Most TDIs can be broken-down into smaller components and related to the affected tissues, namely dental hard tissues, dentine-pulp complex, periodontium, alveolar bone or gingiva. As one of the five oral tissues which can be affected by TDIs, the pulp plays a key role and its management has a substantial impact on the long-term survival of the tooth, particularly in severe cases (Krastl *et al.* 2021).

Assessing the status of the traumatized pulp

Assessing the status of an injured pulp is particularly important in order to establish a reference point for later follow up. Vitality tests (e.g. laser Doppler flowmetry, ultrasound Doppler flowmetry, pulse oximetry) aimed at measuring the perfusion of the pulp would be ideal as true indicators of the actual state of pulpal health following trauma (Alghaithy & Qualtrough 2017). Despite their superior diagnostic accuracy in clinical studies compared to sensibility tests (Ghouth *et al.* 2018, Balevi 2019, Lima *et al.* 2019), no simple approach is available in routine clinical practice. Therefore, sensibility tests such as thermal or electric pulp testing are commonly used as an indirect indicator (surrogate) of the condition of the pulp. However, several limitations have to be considered including the following:

- A temporary loss of pulp sensibility may occur after luxation injuries or alveolar bone fractures despite a functional vascular supply. In such cases, it may take a few to several weeks before a response to sensibility testing returns (Skieller 1960, Rock & Grundy 1981, Bastos *et al.* 2014);
- In immature teeth, regeneration of a disrupted pulp is possible, but neural regeneration progresses at a slower rate compared to vascular regeneration and in some cases may never occur (Schendel *et al.* 1990, Kvinnsland *et al.* 1992);
- Immature teeth are associated with an increased threshold value determined by electric pulp testing (Fulling & Andreasen 1976), which may result in increased rates of false negative results (Rock & Grundy 1981);
- Patient compliance might be challenging due to the young age of the patient or distress after the traumatic impact, leading to false results. False positive results in particular may lead to wrong treatment strategies.

Colour changes of teeth may also be observed in traumatized teeth as a result of pulpal haemorrhage (Andreasen 1986). Pink colour changes that occur shortly after the accident can be reversible. However, if the crown of the tooth turns progressively grey, this is more likely to indicate pulp necrosis (Malmgren & Hubel 2012).

All these factors have to be borne in mind when performing sensibility testing of the pulp after dental trauma, and obtaining the correct pulp diagnosis is only possible through combining and assimilating findings from the patients' history, analysis of the injury pattern, further diagnostics as well as radiographic assessment, which are all an integral part of the diagnostic process. Thus, thermal tests in combination with clinical and radiologic assessment are recommended to determine the condition of the pulp as accurately as possible (Table 1).

Endodontic management following crown fractures and crown-root fractures

Enamel cracks

Although a laboratory study identified enamel/dentine infractions as potential pathways for the invasion of microorganisms (Love 1996), an infection of a healthy pulp via such a defect leading to necrosis is unlikely (Stalhane & Hedegard 1975, Ravn 1981a). Adhesive sealing of enamel cracks has been reported to prevent pulp infection in laboratory studies (Love 1996). However, there is no clinical evidence whether sealing cracks increases the fracture resistance of the crown, prevents the pulp becoming infected and then necrotic or prevents discolouration of the crack lines.

Dentine exposure

Fractured dentine is highly permeable (Mjor 2009). Therefore, any exposed dentine should be sealed immediately. If a definitive adhesive restoration (reattachment of a fractured fragment or direct composite restoration) is not feasible during the initial emergency treatment, the dentinal wound should be sealed temporarily using a dentine bonding agent and a layer of flowable composite (Table 1). Temporary dentine protection with a calcium hydroxide cement or a glass ionomer cement may be less effective but can be applied if subsequent treatment takes place within the next few days (Krastl *et al.* 2020).

Pulp exposure

In teeth with traumatic pulp exposures, the conditions for vital pulp treatment (VPT) are favorable. Direct pulp capping aims to maintain the vitality of the entire pulp after application of a biomaterial directly onto the exposed tissue (European Society of Endodontology 2019) and is usually recommended for small pulp exposures which are treated shortly after the injury (Cvek 1978, Krastl & Weiger 2014). Partial pulpotomy is preferable for the majority of cases (Table 1), particularly if a wide area of the pulp is exposed and the treatment cannot be performed within the first few hours after the injury (Dammaschke *et al.* 2019). Vital pulp extirpation followed by root canal treatment and placement of a root canal post may be necessary for restorative reasons in cases of insufficient coronal tooth structure (Krastl *et al.* 2021).

Factors Influencing pulp survival

After crown fracture of a previously intact tooth, it can generally be assumed that the pulp is healthy and capable of healing. This is particularly true in young patients without pre-existing pulpal damage caused by caries or by earlier dental trauma. Nevertheless, vital pulp treatment after trauma should not be reserved for children and adolescents only but should also be considered for adults. However, particularly in teeth with completed root formation, even minor luxation injuries can compromise the perfusion of the pulp, and therefore affect the success of vital pulp treatments (Ravn 1981b, Robertson *et al.* 2000, Lauridsen *et al.* 2012a,b,c). In contrast to VPT of cariously exposed pulps where hydraulic calcium silicate-based cements (HCSCs) clearly outperform calcium hydroxide in terms of clinical success (European Society of Endodontology 2019), in the treatment of traumatically exposed pulps, the capping material (calcium hydroxide vs. HCSC) does not seem to be a decisive factor (Dammaschke *et al.* 2019). Thus, non-setting calcium hydroxide can still be used but specific non-staining HCSCs are considered first choice (Haikal *et al.* 2020).

Endodontic management following root fractures

Intra-alveolar root fractures of permanent teeth with vital pulps result in an injury to the pulp tissues, primarily compromising the neurovascular supply coronal to the fracture line. The condition of the pulp following displacement of the coronal tooth fragment can only be estimated at the first clinical examination and continuous monitoring is necessary to make a final pulpal diagnosis. Therefore, root canal treatment should not be initiated in teeth with intra-alveolar root fractures (below the alveolar bone crest level), after splinting (Table 1).

Clinical signs indicating a loss of pulp vitality appear within the first three to six months, in some cases even later. Pulp necrosis is followed by infection of the coronal pulp tissue and inflammatory changes between fragments and occurs in 20% of cases (Andreasen *et al.* 2004). In these cases, a lateral lesion at the level of the fracture line is detected radiographically as a result of an infection of the coronal root canal system (Andreasen & Hjorting-Hansen 1967). The pulp tissue apical to the root fracture remains unaffected and vital in nearly all cases (Cvek *et al.* 2008). Thus, root canal treatment should be limited to the coronal segment and should be performed using suitable strategies, just as with treatment of immature teeth. However, if there is an initially undiagnosed communication of the fracture line to the oral environment via the gingival sulcus, root canal treatment will fail, and extraction of the coronal fragment is inevitable (Andreasen *et al.* 2012).

Endodontic management following luxation injuries

Through mechanical trauma following luxation injuries, the pulp can be subjected to tension, compression or separation at the apical constriction. The main parameters influencing pulp survival are the type and severity of the luxation injury as well as the width of the apical foramen.

Pulp repair may occur in immature teeth, with a return of sensibility within weeks to months (Andreasen 1970, 1989, Andreasen & Vestergaard-Pedersen 1985, Andreasen *et al.* 1986). In teeth with fully formed roots and severe traumatic displacement of the tooth from its original position, pulp necrosis, followed by root canal infection and apical periodontitis is a common consequence (Humphreys *et al.* 2003). Additionally, in cases with considerable traumatic mechanical damage to the cementoblast layer on the root surface (particularly severe intrusions), external infection-related root resorption (EIR) may be an inevitable consequence (Kenny *et al.* 2003). Thus, the endodontic management after luxation injuries varies with root canal treatment not indicated if preservation of the pulp is a realistic scenario and revascularization of a damaged pulp is likely to occur. On the other hand, early root canal treatment is crucial in cases of high risk of developing external infection-related root resorption (EIR) (Table 1 and 2). This is particularly relevant for severe intrusions. Repositioning of the intruded tooth is usually necessary to obtain access to the root canal system. While there is no clear evidence whether the repositioning strategy (immediate surgical repositioning or orthodontic repositioning) has an influence on the survival of intruded teeth (Andreasen & Vestergaard-Pedersen 1985, Costa *et al.* 2017), from an endodontic perspective a repositioning method which allows early adequate root canal treatment is preferable.

During the follow-up visits, a number of signs may indicate infected pulp necrosis; however, due to the ischaemic mechanism of pulp necrosis in luxation injuries, most patients do not have pain or swelling. Tenderness to percussion is evident only in teeth with acute periapical inflammation. The presence of two of the three main signs (discolouration, negative sensibility testing, increasing periapical radiolucency) justifies root canal treatment (Jacobsen 1980, Andreasen & Andreasen 2007). Further clinical signs may include a fistula/sinus tract, mucosal swelling, formation of an abscess or persistent mobility. During the first weeks after dentoalveolar trauma, apical bone resorption or incomplete repositioning of the tooth may imitate an apical periodontitis.

In immature teeth, arrest of root development indicates (infected) pulp necrosis. Rapid external infection-related root resorption (EIR) mainly occurs after intrusion and is a rare finding after other types of luxation injury (Andreasen & Vestergaard-Pedersen 1985).

Last but not least, regular follow-ups are needed to ensure the current pulpal diagnosis was made correctly, especially in cases with PCO and/or negative sensibility. Follow-ups, including clinical and radiographic examination are recommended at least 2 weeks, 4 weeks, 6-8 weeks, 3 months, 6 months, 1 year after trauma and annually for the following 5 years post trauma. If there is any concern or doubt, shorter intervals should be chosen (Bourguignon *et al.* 2020)

Endodontic management after avulsion

Avulsion of a tooth inevitably leads to necrosis of the disrupted pulp. In mature teeth (with closed root apex), revascularization cannot occur after replantation. Instead, regardless of whether the crown is intact or not, bacteria contaminating the root surface or the intra-alveolar blood clot will enter the necrotic pulp tissue (Cvek *et al.* 1990) and infection of the pulp space is believed to be established as early as 2 - 3 weeks after replantation (Tronstad 1988). There is consensus that in mature teeth, early root canal treatment is mandatory and should be initiated within the first 2 weeks post-replantation in order to prevent EIR (Fouad *et al.* 2020). Calcium hydroxide or an antibiotic-corticosteroid paste can be used as intracanal medication.

If calcium hydroxide is used, the dressing should ideally be applied 7-10 days post-replantation (Andersson *et al.* 2012) in order to await the initial healing processes and avoid any negative effect resulting from the increased pH (Lengheden 1994, Lengheden & Jansson 1995) and left for 2 weeks in the root canal before root canal filling.

To increase the chance of periodontal healing following replantation and reduce the risk of root resorption (Bryson *et al.* 2002, Wong & Sae-Lim 2002), intracanal medicaments containing an antibiotic-corticosteroid paste, such as Ledermix (Riemser, Greifswald, Germany) or Odontopaste (Australian Dental Manufacturing, Brisbane, Australia) have been proposed as initial root canal medication (Trope 2011). However clinical evidence is inconclusive (Day *et al.* 2012). If they are used, antibiotic-corticosteroid pastes should be placed immediately or shortly after replantation (Andersson *et al.* 2012) for 2 weeks followed by calcium hydroxide for additional 2 weeks before root canal filling (Table 1). In teeth with wide-open apices and favourable extra-oral storage conditions, root canal treatment should not be initiated. Instead, the treatment approach is directed toward the re-establishment of a blood supply as these teeth may have the potential to revascularize and continue their root development (Trope 2011). However, revascularization should only be considered as an option if the individual rescue chain (storage conditions of the avulsed tooth) suggests that there is a reasonable chance for periodontal healing (Trope 2011).

The revascularization process is influenced by the size of the apical foramen and particularly by the length of the root and can only occur in the absence of bacteria (Andreasen *et al.* 1995). Thus, topical treatment of the root surface with doxycycline before replantation has been recommended to increase the frequency of complete pulp revascularization by decreasing the number of microorganisms in the pulpal lumen (Cvek *et al.* 1990); however, evidence from clinical studies is lacking (Tsilingaridis *et al.* 2015).

In general, after replantation of immature teeth, the risk of EIR should be balanced against the chance of revascularization (Andersson *et al.* 2012). Thus, frequent follow-ups are mandatory for early detection of pulp necrosis and EIR if revascularization is awaited but fails (Fouad *et al.* 2020).

Endodontic management of teeth located at the bone fracture line

Extraction of teeth associated with fracture lines should be avoided unless there is an absolute indication for their removal (Krastl *et al.* 2021). Endodontic diagnostics of teeth at the bone fracture line do not differ from the general dental trauma diagnostics. If the pulp is vital but exposed, or if the pulp is infected, endodontic treatment (pulp capping, partial or full pulpotomy, or pulpectomy with root canal medication or filling) should be initiated without delay to prevent infection of the bone fracture line. Similarly, loss of pulp vitality during the follow-up or other clinical or radiographic indications of necrosis/pulpal infection should result in root canal treatment. In the absence of other indications for endodontic treatment, permanent teeth maintained in the line of fracture should be followed up clinically and radiographically for at least one year even if the response to pulp vitality tests are negative in order to ensure that any unnecessary endodontic treatment is avoided, as the initially negative response may return to normal within one year (Aulakh *et al.* 2017). If there is direct or indirect trauma to a tooth in a bone fracture line, such as fractures, luxation or intrusion, the prognosis for survival of the tooth is dictated by the dental trauma rather than the alveolar bone fracture itself (Table 1).

Endodontic management in cases of external infection-related resorption (EIR)

Infection-related root resorptions (also referred to as inflammatory root resorptions) typically occur after severe luxation injuries (mainly avulsions and intrusions) and are initiated by a combination of severe damage to the protective cementum layer on the root surface and pulp space infection. In teeth with EIR, early endodontic intervention is mandatory because tooth preservation is unpredictable if large parts of the root are already affected. To arrest EIR, elimination of the microorganisms from the root canal system is crucial and involves thorough canal debridement and irrigation with sodium hypochlorite. The standard approach for root canal medication is placement of a calcium hydroxide dressing (Table 1). The recommendations for the duration of calcium hydroxide medication vary between 4 weeks (Darcey & Qualtrough 2013) and several months (Trope 2002). There is no consensus on whether long-term calcium hydroxide dressing up to the point when there is radiographic evidence of resorption control is needed in cases of established EIR (Patel *et al.* 2016, Whitworth 2018) but the minimum recommended duration is 4 weeks.

An alternative approach for treating established EIR, involves the use of antibiotic-corticosteroid combinations such as Ledermix (Riemser) or Odontopaste (Australian Dental Manufacturing) for eliminating the inflammatory reaction in the periodontal membrane (Pierce & Lindskog 1987, Heithersay 2007). However, there is no evidence whether antiresorptive corticosteroid dressings in the root canal (possibly followed by calcium hydroxide) increase success rates compared to the use of calcium hydroxide alone. A case series used regenerative endodontic procedures for treating teeth with EIR (Yoshpe *et al.* 2020); however, there is insufficient evidence to support this

approach for routine clinical practice in such cases. After successful arrest of EIR, depending on the degree of trauma-induced PDL damage, periodontal healing may occur, or the process may develop into ankylosis.

Endodontic management of teeth with pulp canal obliteration

Pulp canal obliteration (PCO) following luxation injuries is considered a sign of a vital pulp and therefore root canal treatment is not indicated in asymptomatic teeth as long as there is no evidence of irreversible pulpitis or apical periodontitis. Due to a decreased translucency, teeth with PCO often have a yellow discolouration of the crown (Patterson & Mitchell 1965, Robertson *et al.* 1996). To recover aesthetics, extracoronal bleaching techniques should be preferred over intracoronal bleaching (with or without forgoing intentional root canal treatment) (McCabe & Dummer 2012). In the long term, teeth with PCO may develop pulp necrosis and apical pathosis in up to 27% of the cases (Robertson *et al.* 1996, Oginni *et al.* 2009). In these cases, root canal treatment is indicated (European Society of Endodontology 2006) (Table 1). However, root canal location without technical failures may be challenging particularly for less experienced operators (Cvek *et al.* 1982). To avoid technical failures caused by perforation of the root or missing canals, guided access to the root canal is an option (Krastl *et al.* 2016, Connert *et al.* 2017, Buchgreitz *et al.* 2019)

Endodontic treatment of immature teeth with non-vital pulps

When root canal treatment of immature teeth is indicated following dental trauma, the apical barrier technique with HCSCs such as MTA should be preferred over apexification procedures with long-term calcium hydroxide dressing in order to reduce the risk of fracture (Andreasen *et al.* 2002) (Table 1). Further, any restorative treatment should aim at reinforcing the thin-walled and weak roots. Adhesively bonded composite resin restorations extended into the root canal space are recommended for this purpose. Root canal posts can be used as long as no dentine is removed during post space preparation.

Even though placing an apical plug is a reliable treatment option with high success rates (Ree & Schwartz 2017), completion of root formation cannot be expected after this procedure. An alternative treatment to the apical barrier technique with MTA plug is revitalization. Research and clinical experience has led to the publication of treatment protocols from regional Endodontic Societies such as the European Society of Endodontology (2016) and the American Association of Endodontists (2018). In contrast to the apical barrier technique further root maturation may occur, even though the results regarding root lengthening and thickening are variable and not predictable (Kahler *et al.* 2017) with the healing best described as reparative rather than regenerative.

Conclusion

The endodontic management of traumatized teeth should aim to avoid root canal treatment if preservation of the pulp is a realistic scenario but at the same time should be directed towards early endodontic intervention in teeth of high risk of developing infection-related root resorption.

Conflict of Interest

The European Society of Endodontology and the authors state explicitly that there is no conflict of interests related to this ESE position statement.

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Table. 1 Summary of key recommendations

Position statement area	Recommendations for endodontic management
Assessing the status of the traumatized pulp	• No reaction to sensibility testing after trauma does not necessarily indicate pulp necrosis. • Thermal test as standard sensibility test. • Immature teeth are not fully innervated and therefore associated with an increased excitation threshold and false negative results, particularly after electric pulp testing. • False positive results particularly in children should be considered • Combination of clinical and radiologic findings are essential to estimate the chances for the pulp to heal depending on the stage of root development. • Vitality tests are desirable to assess the perfusion of the pulp but still no simple approach available for routine clinical practice. • The diagnostic value of post-traumatic colour changes of the crown is low and the decision on whether to perform root canal treatment or not should not rely on crown discoloration alone.
Enamel cracks	• No treatment. • Adhesive sealing may be considered, although clinical data is lacking.
Dentine exposure	• Immediate definitive adhesive restoration if feasible during emergency treatment. • As emergency treatment: preferably adhesive sealing or temporary dentine protection with a calcium hydroxide cement or a glass ionomer cement if subsequent treatment takes place within the next few days.

Pulp exposure	• Vital pulp treatment preferably with non-staining HCSC as capping material but favourable results can also be achieved with calcium hydroxide.
	  ○ *Approach 1:* Partial pulpotomy (preferred treatment particularly for large exposures and cases with treatment delay)
	  ○ *Approach 2:* Direct pulp capping (for minor exposures treated within the first hours after trauma)
	• Root canal treatment only if indicated due to concomitant luxation injury or dictated by restorative reasons (placement of a root canal post).

Root fracture	• No immediate endodontic intervention irrespective of response to initial sensibility test. • Close clinical and radiologic follow-ups in order to identify pulp necrosis. • In case of pulp necrosis: root canal treatment restricted to the coronal fragment and no intervention on the apical fragment.
Luxation injuries	• No immediate endodontic intervention irrespective of initial sensibility test for minor luxations and in immature teeth with prospect of pulp healing. • Close follow-ups to identify early signs indicating a loss of pulp vitality and of root canal infection. • Root canal treatment for teeth with fully formed roots, and severe displacement of the tooth from its original position. • Early endodontic intervention in cases of high risk of developing external infection-related root resorption (e.g., cases of severe intrusion) following the guidelines for avulsed teeth.

Avulsion	• Mature teeth: early root canal treatment within 2 weeks post-replantation.
	  ○ *Approach 1:* immediate medication with antibiotic-corticosteroid paste for 2 weeks followed by calcium hydroxide for additional 2 weeks before root canal filling.
	  ○ *Approach 2:* medication with calcium hydroxide initiated 7-10 days post replantation for 2 weeks before root canal filling.
	• Immature teeth: No endodontic intervention but close radiologic follow-ups particularly during the first year (2 weeks, 4 weeks, 6-8 weeks, 3 months, 6 months) to identify early signs of external infection-related root resorption.

Teeth located at the bone fracture line	• Extraction should be avoided unless there is an absolute indication for the removal. • Pulp sensibility may return within one year. • Endodontic management and prognosis of the teeth is dictated by the state of the traumatized pulp rather than the alveolar bone fracture itself.

External infection-related resorption (EIR)	• Immediate initiation of root canal treatment with enhanced protocol for root canal disinfection aiming to arrest EIR.
	  ○ *Approach 1:* intracanal medication with calcium hydroxide for at least 4 weeks.
	  ○ *Approach 2:* antibiotic-corticosteroid pastes may be used as an alternative intracanal medication for a duration of 2 weeks followed by calcium hydroxide but no clinical evidence suggesting a benefit over calcium hydroxide alone.

Pulp canal obliteration following trauma	• No endodontic intervention needed if no signs of irreversible pulpitis or apical pathology. • If pulp pathosis is indicated by irreversible pulpitis or apical pathology: negotiation of root canal and root canal treatment (if necessary guided endodontics).

Immature teeth with necrotic pulps following trauma	• Mechanical removal of root dentine should be limited to a minimum. Instead, the focus lies on copious irrigation using sodium hypochlorite to remove necrotic pulp tissue and disinfect the root canal. Irrigant activation is highly recommended. o *Approach 1:* Root canal treatment with apical plug with HCSC followed by reinforcement of the tooth instead of traditional calcium hydroxide apexification. o *Approach 2:* Revitalization.

Table. 2 Relevant decision factors for and against root canal treatment following luxation injuries

Factors favoring pulp survival **NO endodontic intervention**	**Factors favouring root canal treatment** **endodontic intervention**
• Minor luxation injury • Immature tooth with (wide) open apex / realistic scenario for revascularization • Radiologic evidence of continued root development or pulp canal obliteration during the follow-up appointments	• Severe luxation injury, high risk for infection-related root resorption (particularly severe intrusion) • Closed apex (largely completed root formation) • Concomitant crown fracture with dentine or pulp exposure