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Review Article

Endodontic Management of Traumatized Permanent Teeth in the Pediatric Patient: Narrative Review

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Abstract

Traumatic dental injuries in children and adolescents commonly affect the anterior permanent teeth and can threaten pulp vitality, root development and long-term survival. Management is more challenging in immature teeth, where the right choice depends on the type of injury, the state of the pulp and the extent of root formation. Diagnosis is the decisive first step: sensibility tests should be read over several visits rather than judged at a single visit and cone-beam computed tomography is used only when it will change the plan. When the pulp can be kept alive, vital pulp therapy, particularly partial pulpotomy, gives high success rates, with mineral trioxide aggregate and biodentine performing comparably. For necrotic immature teeth, mineral trioxide aggregate apexification produces a reliable apical barrier in fewer visits than calcium hydroxide does, while regenerative procedures also allow the root to continue developing. Early treatment, biologically driven planning and consistent long-term follow-up remain the basis of a good outcome.

Keywords: Traumatic Dental Injuries; Permanent Teeth; Pediatric Dentistry; Pulp Capping and Pulpotomy; Apexification; Regenerative Endodontics; Tooth Injuries; Dental Pulp

Introduction

Traumatic Dental injuries (TDIs) in the pediatric population represent a well-documented clinical and public health challenge [1]. Their impact is particularly significant when they affect the anterior incisors during critical stages of craniofacial development, eruption of the permanent dentition and formation of the child's psychosocial identity, thereby compromising both function and aesthetics during vulnerable periods [2]. Recent pediatric literature indicates that TDIs affect a considerable proportion of children worldwide, with the maxillary central incisors most frequently involved owing to their anterior position and exposure to direct impact [1]. Population data reinforce this burden; in a cohort of insured individuals in Switzerland, dental injuries were reported throughout childhood and by age 16, nearly three in five insured children had sustained at least one dental injury, with permanent teeth increasingly involved as the dentition matured [3].

In the permanent dentition, TDIs span a wide spectrum, from uncomplicated enamel-dentin fractures to severe injuries such as luxations and avulsions. The most common patterns, enamel-dentin fractures and avulsion of maxillary central incisors, have

been consistently documented across different study designs [4]. A 20-year retrospective analysis at a specialized trauma center identified avulsion as one of the principal presentations while a registry-based cohort study in Lithuania corroborated this distribution and further noted that permanent teeth accounted for more than half of all treated TDI cases [3,5].

The clinical impact of a TDI, however, rarely ends at the moment of impact. Depending on severity, the pulp and the periodontal ligament are the structures most frequently compromised, producing sequelae that range from transient loss of pulp sensibility to irreversible necrosis, progressive root resorption, and, in the most severe cases, premature tooth loss [6]. Complications related to pulp necrosis were the most frequently observed events in a record-based pediatric study, which also noted recurrent delays in emergency care [4]. Studies on avulsion and intrusion further highlight the influence of root maturity and the extent of displacement, showing that anterior permanent teeth are commonly affected and that consequences can include pulp necrosis, ankylosis and tooth loss [6,7].

Because traumatic injuries vary with the tissues involved and their prognosis, a standardized classification is essential for diagnosis, communication, research and treatment planning. The Andreasen classification, now incorporated into ICD-11 as NA0D (injury to teeth or supporting structures), categorizes dental trauma based on injuries to the hard tissues of the tooth and pulp, the periodontal tissues and the supporting structures. This framework provides the clinical basis for assessing pulp status after trauma and for selecting appropriate endodontic strategies [8]. Building on this foundation, the present review sequentially addresses pulp diagnosis following traumatic injury, vital pulp therapy and management of the open apex, concluding with regenerative endodontic procedures and long-term follow-up criteria.

This article aims to review biologically driven approaches to the diagnosis and endodontic management of traumatic dental injuries in immature permanent teeth, including pulp diagnosis, vital pulp therapy, apexification and regenerative procedures, as well as the long-term follow-up required for a favorable outcome.

Pulp Diagnosis and Treatment Planning After Trauma

Pulp diagnosis following a traumatic dental injury in children is one of the most complex stages of post-traumatic care, because the biological response of the pulp does not always match the clinical findings observed immediately after injury [9]. Unlike inflammatory pulp disease driven by caries, traumatic injuries may produce transient vascular and neural disturbances that alter clinical responses without necessarily indicating irreversible damage. This situation is greatly complicated in immature permanent teeth, where the root is not yet fully formed and the pulp retains an active nerve supply [10]. Accurate diagnosis after trauma, therefore, requires interpretation of clinical signs over time rather than reliance on a single examination [11].

One of the principal limitations in pediatric trauma assessment is the interpretation of pulp sensibility tests. Following luxation, avulsion, intrusion and relatively severe crown trauma, a temporary disruption in nerve signaling may produce false-negative results despite maintained pulpal circulation [12]. Such findings are particularly common in immature permanent teeth, since neural maturation lags behind vascular development during root formation; the absence of a response at early follow-up should not be read as pulp necrosis [13]. Conventional sensibility tests evaluate sensory function and thus carry important diagnostic limitations in traumatized teeth. Cold testing remains useful during follow-up because repeated testing over time helps clinicians track recovery patterns and supports a cautious, conservative approach [14]. Recent regenerative concepts also emphasize that traumatic pulp necrosis disrupts the formative, nutritive, reparative, vascular and neural functions of the pulp-dentin complex, reinforcing the value of preserving vitality whenever it is biologically feasible [15]. Because sensibility tests alone cannot define pulp status after trauma, imaging plays an essential role in diagnosis and planning. Periapical radiographs remain the standard initial examination, as they allow evaluation of root development, periodontal ligament changes, root fractures and early periapical alterations at relatively low radiation exposure [10]. Conventional two-dimensional imaging may, however, underestimate the extent of damage and miss early inflammatory complications. Evidence shows that Cone-Beam Computed Tomography (CBCT) can meaningfully change endodontic decision-making in immature traumatized teeth with suspected necrosis by improving visualization of root resorption and developmental changes not seen on periapical images [16]. Even so, radiation exposure remains a relevant concern in children, supporting recommendations that CBCT be prescribed only when the additional information is expected to influence diagnosis [17].

Finally, clinical urgency after trauma is determined by the type of injury and the time elapsed since the event. Crown fractures with pulp exposure, luxation injuries with displacement and avulsion all require immediate evaluation, because delay can compromise pulpal healing and long-term prognosis [11]. Indicators such as discoloration, tenderness to percussion and progressive radiographic findings should be interpreted collectively and over time [15]. Given the dynamic nature of post-traumatic healing, contemporary diagnosis integrates serial clinical examination with sensibility testing to guide conservative, biologically based decisions [18].

Vital Pulp Therapy in Traumatized Permanent Teeth

Traumatic injuries to permanent teeth often result in pulp exposure, posing a significant clinical challenge. In these cases, preserving pulp vitality is a primary objective, particularly in young permanent teeth where continued root development and long-term survival depend on a healthy pulp-dentin complex [19]. In recent years, international guidelines have increasingly supported conservative Vital Pulp Therapy (VPT) as an alternative to routine root canal treatment [20].

VPT encompasses procedures such as Direct Pulp Capping (DPC) and partial (Cvek) pulpotomy, both aimed at preserving vitality by minimizing contamination and supporting healing. Direct pulp capping places a biocompatible material over a small exposure without removing underlying pulp tissue [21]. Although highly conservative, its outcomes in traumatic exposures vary widely because the superficial pulp may already be inflamed or contaminated even when this is not clinically apparent. Current endodontic consensus documents stress that the biological status of the pulp is a more critical factor than the size or features of the exposure [13].

Partial pulpotomy removes approximately 1-3 mm of the superficially inflamed pulp to expose healthy tissue before a bioactive material is placed [22]. This offers better control of the wound environment and reduces the risk of leaving inflamed tissue behind, so it generally yields more predictable results than direct pulp capping in traumatized permanent teeth [23].

The choice of capping material is another important determinant of success. Mineral Trioxide Aggregate (MTA) has long been regarded as the gold standard for its biocompatibility, sealing ability and capacity to stimulate hard tissue formation; its drawbacks include a long setting time, handling difficulty and the potential for tooth discoloration, a notable concern in anterior teeth [24]. Biodentine was developed to address several of these limitations, offering comparable biocompatibility and reparative dentin formation while providing easier handling, faster setting and a lower risk of discoloration. Evidence from traumatized permanent teeth shows that both materials achieve comparably high success rates, often exceeding 90%, which suggests that appropriate case selection and adherence to protocol matter more than the specific material chosen [25].

Precise case selection remains one of the most critical factors. Clinicians must perform a thorough clinical and radiographic evaluation to confirm vitality and exclude necrosis or periapical pathology. During the procedure, achieving hemostasis within a few minutes is a reliable indicator of favorable biological status; difficulty controlling bleeding may indicate deeper inflammation and a poorer prognosis [26]. Although exposure size was traditionally emphasized, current evidence suggests it is less important than the biological condition of the pulp and partial pulpotomy can still succeed when treatment is slightly delayed, since the superficially inflamed tissue is removed [23]. Overall, the literature supports a conservative, biologically based approach; partial pulpotomy is more predictable than direct pulp capping, both MTA and biodentine remain highly effective and success depends far more on accurate diagnosis, careful case selection, infection control and a reliable coronal seal than on the specific material or technique [28].

Apexogenesis And Apexification: Managing the Open Apex

Mineral Trioxide Aggregate (MTA) was introduced as an alternative to traditional apexification techniques in order to address their inherent limitations. As a biocompatible material that promotes hard tissue formation and provides an effective apical seal, MTA has become widely used in the management of immature permanent teeth with open apices [29]. These biological properties represent a notable advance over conventional protocols, since they facilitate apical barrier formation while preserving conditions favorable to periapical healing [30]. Unlike calcium hydroxide, placement of an MTA apical plug produces an immediate apical barrier, substantially reducing overall treatment duration [31].

Current evidence consistently supports the efficacy of MTA for apexification of immature permanent teeth. Clinical and radiographic success rates with MTA are comparable to and in some cases superior to, those achieved with calcium hydroxide, while requiring considerably less time for barrier formation [32]. Systematic reviews and meta-analyses also indicate superior outcomes for apical barrier formation and periapical healing when MTA is used in immature teeth with necrotic pulps. Together, these findings suggest that MTA provides predictable apical closure while fostering biological conditions conducive to repair [33].

Treatment duration is one of the most clinically significant factors in selecting an apexification technique. Contemporary MTA protocols can frequently be completed within one to two visits, reducing overall treatment time, improving patient compliance and minimizing the risk of inter-appointment reinfection [34]. By contrast, calcium hydroxide apexification often requires several months and in some cases up to twenty-four months, before completion [22,23]. This disparity is one of the principal reasons for the current preference for MTA over conventional calcium hydroxide apexification [35].

Long-term outcomes are equally important. A twenty-year longitudinal study showed that teeth managed with contemporary apexification techniques had superior survival and fewer complications than teeth treated with prolonged calcium hydroxide therapy [22]. These findings underscore the importance of selecting modalities that achieve not only apical closure but also preservation of tooth structure and an improved long-term prognosis [36].

In summary, apexogenesis remains the preferred approach whenever pulp vitality can be preserved, as it permits continued physiological root maturation, dentinal wall thickening and natural apical closure [37]. When pulpal necrosis occurs before root development is complete, apexification becomes necessary to establish an adequate apical barrier and allow subsequent obturation. Although calcium hydroxide has historically shown favorable success rates of 74 to 100%, its main limitations are extended treatment times of 9 to 24 months, multiple appointments and an increased risk of root fracture [38]. MTA-based apexification offers immediate barrier formation, predictable clinical and radiographic outcomes, completion within one to two visits and favorable long-term survival [39]. On current evidence, MTA is regarded as the preferred material for apexification of immature permanent teeth with open apices, owing to its combination of efficiency, predictable healing and improved long-term outcomes [40].

Regenerative Endodontic Procedures in Immature Traumatized Teeth

Regenerative Endodontic Procedures (REPs) have become an important option for immature permanent teeth with pulp necrosis caused by traumatic injury [41]. Unlike traditional apexification, which primarily creates an apical barrier and prevents further root development, REPs are designed to promote tissue regeneration within the root canal system. This encourages continued root maturation, thickening of the dentinal walls and apical closure, ultimately improving long-term prognosis and reducing the risk of root fracture [42].

The success of REPs rests on the basic principles of tissue engineering: stem cells, growth factors and a scaffold that supports regeneration. Current recommendations from the American Association of Endodontists (AAE) and the European Society of Endodontology (ESE) emphasize effective disinfection while preserving stem cell viability [43]. The recommended protocol includes irrigation with low-concentration sodium hypochlorite, followed by 17% EDTA to release growth factors from dentin and intracanal medication with calcium hydroxide or a low-concentration antibiotic paste to reduce bacterial contamination while limiting harm to stem cells [44,45].

Once the canal is disinfected, bleeding is induced beyond the apical foramen to create a blood clot that serves as a natural scaffold for new tissue [46]. Alternative scaffolds such as Platelet-Rich Plasma (PRP) and Platelet-Rich Fibrin (PRF) have been proposed for their higher concentrations of growth factors; however, current evidence has not demonstrated consistent clinical advantages over the traditional blood clot technique [24]. Clinical evidence supports the effectiveness of REPs in immature permanent teeth. In a systematic review and meta-analysis, Li, et al., reported clinical success rates above 90%, with favorable outcomes including resolution of periapical lesions, increased root length, thicker dentinal walls, and, in some cases, recovery of pulp sensibility [25]. Likewise, Sabeti, et al., concluded that REPs provide better biological outcomes than apexification because they allow continued root development while maintaining high tooth survival [43].

Despite these encouraging results, prognosis is still shaped by several preoperative factors, particularly the type and severity of the traumatic injury. Vitali, et al., found that severe luxation and avulsion may compromise regenerative outcomes by damaging the stem cells of the apical papilla and Hertwig's epithelial root sheath, both essential for root development [47]. Similarly, Sheng, et al., reported favorable periapical healing in delayed-replantation immature teeth treated with REPs, although continued root maturation was less predictable, especially when extraoral dry time was prolonged [48]. Overall, REPs represent a predictable and conservative approach for immature traumatized permanent teeth; current evidence supports their use in appropriately selected cases, yet additional long-term studies are needed to optimize protocols, evaluate new scaffold materials and improve outcomes after severe injuries [49].

Prognosis, Failure Predictors and Long-Term Follow-Up

The management of traumatized permanent teeth in pediatric patients has progressively evolved toward biologically based strategies aimed at preserving pulp vitality, supporting continued root development and maintaining long-term tooth survival [50]. As discussed throughout this review, Vital Pulp Therapy (VPT), apexification and Regenerative Endodontic Procedures (REPs) offer valuable options depending on the pulpal status and the stage of root development [51].

Current evidence indicates a generally favorable prognosis when treatment is prompt and case selection is appropriate. A recent systematic review reported high success rates for VPT in traumatized permanent teeth, particularly after partial pulpotomy, ranging from approximately 83% to 100%, supporting the preservation of vitality whenever feasible [14]. Even teeth presenting with delayed management of a traumatic pulp exposure can show favorable healing when treated with a biologically based protocol [52]. Preserving a vital pulp is especially important in immature teeth, since it allows continued root maturation, dentinal wall thickening and apical closure, all of which improve long-term structural integrity [53].

Several factors are associated with treatment failure. Delayed intervention, severe luxation, pulp necrosis, persistent infection, inflammatory root resorption and damage to Hertwig's epithelial root sheath may compromise healing and impair root development. In immature teeth with necrotic pulps, interruption of normal maturation results in thin dentinal walls and increased susceptibility to fracture [54]. Injuries involving both pulpal and periodontal tissues generally carry a more guarded prognosis due to a higher risk of neurovascular disruption and external root resorption [55].

Long-term follow-up remains a critical component of success. Clinical and radiographic monitoring should include assessment of pulp vitality, root development, apical closure, periapical healing, mobility, discoloration and the presence of root resorption or ankylosis [56]. Evidence from revitalization studies shows that meaningful radiographic change may continue for several years after treatment, underscoring the need for extended observation [33]. Interdisciplinary management reports involving severe intrusive luxation likewise show that favorable outcomes can be achieved through coordinated orthodontic and endodontic care, but only when careful long-term monitoring is maintained [57].

Conclusion

In conclusion, successful management of traumatized permanent teeth depends on early diagnosis, biologically oriented treatment planning and comprehensive long-term follow-up. Preservation of pulp vitality should remain the primary objective whenever possible, while regenerative procedures offer promising alternatives for necrotic immature teeth. Future prospective studies with standardized protocols and longer follow-up are needed to strengthen the evidence base and further optimize clinical decision-making in pediatric dental trauma.

Conflict of Interest

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Ethical Statement

The project did not meet the definition of human subject research under the preview of the IRB according to federal regulations and therefore was exempt.

Informed Consent Statement

Not applicable.

Authors' Contributions

All authors contributed equally to this paper.

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