

Management of Complicated Crown Fractures in Permanent Anterior Teeth: A Systematic Review and Therapeutic Chart Proposal

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Abstract

Original Research Article

This systematic review aimed to evaluate the existing literature on the management of complicated crown fractures in permanent anterior teeth. A comprehensive search of PubMed (MEDLINE) from January 2012 to January 2022 identified 85 relevant articles, with 16 studies meeting the inclusion criteria. These studies comprised 6 case reports, 3 literature reviews, 5 retrospective studies, 1 prospective study, and 1 systematic review. Key factors influencing treatment decisions were the stage of root development, pulp exposure size, and tooth restorability. However, the review found a lack of consensus regarding the optimal treatment approach, particularly concerning the choice between direct pulp capping, partial pulpotomy, or full pulpotomy. The studies revealed variability in outcomes based on age and pulp exposure size, but the time elapsed between trauma and treatment did not consistently influence the choice of therapy. Our findings align with the 2020 International Association of Dental Traumatology (IADT) guidelines, which advocate for vital pulp therapy in managing traumatic crown fractures. Nevertheless, more recent studies (2020-2024) suggest further refinement is needed to establish precise treatment protocols. Future research should focus on providing actionable clinical guidelines and exploring long-term outcomes to inform better clinical decision-making.

Keywords: Complicated crown fracture, Permanent anterior teeth, Pulp therapy, Dental trauma, Clinical guidelines.

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INTRODUCTION

Traumatic dental injuries (TDIs) are common in dental practice and can significantly affect both the function and aesthetics of affected teeth [1]. Among these injuries, complicated crown fractures, which involve enamel, dentin, and pulp exposure, are particularly challenging to manage due to the variety of clinical factors that influence treatment decisions. These fractures account for approximately 20% of all traumatic dental injuries, with the majority occurring in young permanent teeth, especially maxillary incisors, which are the most frequently affected due to their anterior position in the dental arch. Specifically, 80% of complicated crown fractures occur in the central incisors, followed by 16% in the lateral incisors. The prevalence of these injuries, coupled with their complex nature, necessitates a clear understanding of the optimal treatment approaches available [2-5].

Despite the frequency of complicated crown fractures, high-quality evidence-based guidelines for their management remain limited [1-6]. Current treatment options include direct pulp capping, partial pulpotomy, full pulpotomy, or root canal therapy, depending on factors such as the stage of root development, the size of the pulp exposure, and the time elapsed since the injury. However, there is no consensus in the literature regarding the most appropriate treatment for different clinical scenarios. Some studies suggest that the stage of root development is a critical factor in determining treatment, while others argue that pulp exposure size or the time between injury and treatment may play a more significant role. Additionally, there is ongoing debate about the relative effectiveness of vital pulp therapy (VPT) techniques such as direct pulp capping, partial pulpotomy, and complete pulpotomy in preserving pulp vitality and promoting continued root development, particularly in young patients with immature teeth. The importance of resolving these

treatment ambiguities cannot be overstated. A lack of clear guidelines can lead to inconsistent treatment outcomes and potentially compromise the long-term prognosis of the affected teeth [1-7]. Therefore, this systematic review aims to evaluate the various therapies explored in the literature for managing complicated crown fractures in permanent anterior teeth and to analyze the factors that influence treatment decisions. By synthesizing the available evidence, this study seeks to provide a simplified and actionable treatment protocol that can assist clinicians in making informed decisions and improve patient outcomes in cases of complicated crown fractures. Our study is particularly focused on addressing the gaps in the current literature and offering clarity on key factors such as pulp vitality preservation, root development, and the timing of interventions.

METHODOLOGY

This systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and rigor in the selection and analysis of relevant studies. The primary aim of the review was to evaluate the management of complicated crown fractures in permanent anterior teeth, with a focus on identifying the most effective treatments and the factors influencing treatment decisions.

The working group contributed to the development of the systematic material and methods review through the search for articles, the critical reading of these ones and the independent extraction of data from selected articles. In all cases, disagreements among the reviewers were resolved through discussion until a consensus was obtained.

Search Strategy

A comprehensive literature search was conducted using the PubMed (MEDLINE) database from January 2012 to January 2022. The search was limited to articles published in English. The search terms used were a combination of MeSH terms and keywords related to traumatic dental injuries, pulp exposure, pulp capping, pulpotomy, and other relevant topics. The Boolean search equation was as follows: ("Therapeutics"[Mesh] OR "Treatment Outcome"[Mesh] OR "Dental Restoration Permanent"[Mesh] OR "Age Factors"[Mesh] OR "Time Factors"[Mesh]) AND ("Tooth Injuries"[Mesh] OR "Crowns"[Mesh]) AND ("Dental Pulp Exposure"[Mesh] OR "Dental Pulp Capping"[Mesh] OR "Pulpotomy"[Mesh] OR "apexification"[Mesh] OR apexogenesis [Text Word]). Additional searches were conducted on Google Scholar to locate conference papers and grey literature.

The Cochrane and Embase databases were not included in this review due to resource limitations and the focus on PubMed as the primary source of relevant literature for the management of traumatic dental

injuries. Future research could benefit from including these databases to enrich the evidence base further.

Eligibility Criteria

The inclusion criteria for this review were as follows:

- Studies involving human subjects.
- Published between January 2012 and January 2022.
- Focused on the management of complicated crown fractures of permanent anterior teeth (mature and/or immature).
- Articles that analyzed the effects of therapeutic interventions on pulp vitality, root development, and overall tooth restorability.

Studies were excluded if they:

- Were published in languages other than English.
- Were not accessible in full text.
- Focused on pulpal exposure due to carious lesions rather than trauma.
- Addressed periodontal injuries associated with complicated crown fractures.
- Involved the management of complicated crown fractures in deciduous teeth.

Study Selection Process

The initial search identified 85 articles, which were independently screened by two reviewers. Articles were first evaluated by title and abstract, and full-text reviews were conducted for those that met the inclusion criteria. Discrepancies between reviewers were resolved through discussion until a consensus was reached.

Data Extraction

For each included study, the following data were extracted and organized into a spreadsheet:

- Study design (e.g., case report, literature review, cohort study).
- Number and demographics of participants (age, sex).
- Clinical details such as pulp exposure size, root development stage, time elapsed between injury and treatment, and therapeutic approach.
- Outcomes related to pulp vitality, tooth restorability, and follow-up duration.

Risk of Bias Assessment

The risk of bias for each study was assessed using the Cochrane Risk of Bias Tool. This tool evaluates bias based on several criteria, including random sequence generation, allocation concealment, blinding of participants and personnel, incomplete outcome data, and selective reporting. Studies were classified as having a low, unclear, or high risk of bias depending on the fulfillment of these criteria. The overall quality of evidence was taken into account when synthesizing the results.

Data Synthesis

The data from the included studies were synthesized qualitatively due to the heterogeneity of study designs and outcomes. Where possible, subgroup analyses were conducted to explore treatment outcomes based on patient age, pulp exposure size, and stage of root development. The synthesis aimed to identify trends in treatment success and failure, as well as factors

influencing clinical decision-making in managing complicated crown fractures.

RESULTS

The initial search yielded 85 articles, of which 16 met the inclusion criteria and were included in this systematic review. These 16 studies comprised 6 case reports, 3 literature reviews, 5 retrospective studies, 1 prospective study, and 1 systematic review. (figure 1)

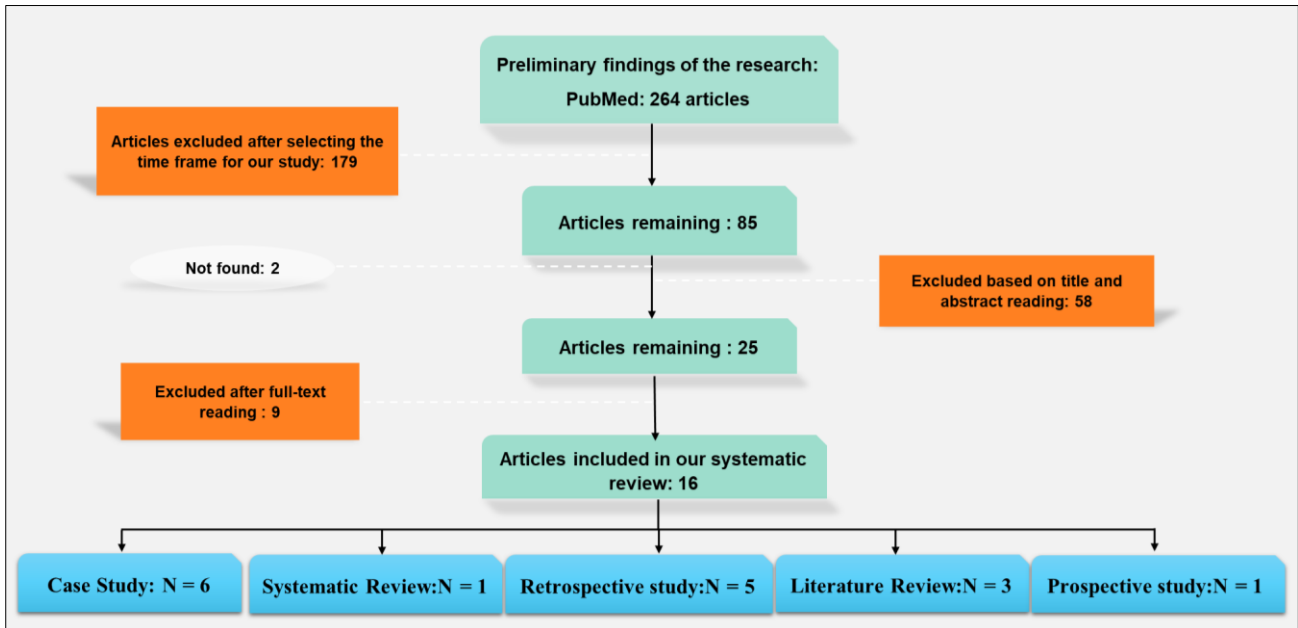


Figure 1: Results of the data search

The included studies investigated various therapeutic approaches for managing complicated crown fractures in permanent anterior teeth and examined the factors influencing treatment decisions. These factors included the stage of root development, the size of pulp exposure, and the time elapsed between trauma and treatment. We have established a reading grid to

facilitate the comparison of therapeutic approaches across the included studies. This reading grid allows for an organized comparison of the different therapeutic approaches explored in each study, highlighting how these factors contribute to the overall understanding of managing complicated crown fractures in permanent anterior teeth. (figure 2)

Authors and year	Type of study	Clinical examination	Radiological examination	Factors influencing the treatment decision	Pulp therapy indicated	Pulp capping material used in Vital Pulp Therapy	Restoration of the coronary fragment	Follow-up	Results
2012 ↓ 2022	<ul style="list-style-type: none"> Case Study Literature review Retrospective study Prospective study Systematic review 	<ul style="list-style-type: none"> Age of patient Date and circumstances of the trauma Emergency procedures performed The tooth affected by the trauma Situation of the fracture line The size of pulp exposure Pulp testing Condition of the dental fragment 	<ul style="list-style-type: none"> Situation of the fracture line Pulp volume Root development Stage The state of the root: Fracture? The state of the periapex Associated alveolar bone fracture? 	<ul style="list-style-type: none"> The age of the patient The time elapsed since the trauma The extent of the coronary fracture The size of pulp exposure Vitality of the pulp The root development stage 	<ul style="list-style-type: none"> Direct pulp capping Partial pulpotomy Complete pulpotomy Pulpotomy Apexification Revascularisation 	<ul style="list-style-type: none"> Calcium Hydroxide MTA Biodentine Root Repair Material (RRM) 	<ul style="list-style-type: none"> Resin composite restoration Fragment collage With or without fiber post 	<ul style="list-style-type: none"> Follow-up period Failure Success of the procedure 	

Figure 2: Reading grid of included articles

Study Characteristics

The majority of the studies focused on both mature and immature permanent teeth, with treatments ranging from vital pulp therapies (e.g., direct pulp capping, partial pulpotomy, full pulpotomy) to root canal treatment. The case reports typically highlighted the clinical decision-making process for individual patients, while the retrospective studies provided broader insights

into treatment outcomes across larger patient populations. Follow-up periods varied among studies, with some reporting short-term (weeks to months) and others long-term outcomes (up to 4 years).

Studies characteristics are detailed in tables below (**Table 1,2,3,4**).

Table 1: Case reports

Study and year	Study DESIGN	Clinical situation	Factors affecting the treatment choice	Treatment decision	Results
Riccardo tonini 2016 [8]	Case report	Mature permanent incisor [21]	-Pulp vitality. -The stage of root development or resorption. -The extent of the fracture line.	Root canal treatment and Rebonding of the tooth fragment using a fiber post.	The patient remained asymptomatic, with no signs of tooth sensitivity and maintained both proper function and aesthetics throughout the four-year follow-up period.
Renato lenzi, <i>et al.</i> , 2012 [9]	Case report	Immature permanent incisor [22]	-Age of the patient. -Pulp vitality. -The stage of root development (wideness of the apical foramen).	Revascularization procedure with blood clot.	-No evidence of revitalization could be seen after 11-month of follow-up
Nishtha patel <i>et al.</i> , 2013 [10]	Case report	Mature permanent incisors [21]	-The location and extent of the fracture line. -The need for endodontic therapy. -The quality of fit between fragments and the fracture pattern.	- RCT of the affected teeth was carried out with surgical crown lengthening to expose the line of fracture palatally - Tooth fragment reattachment with the use of prefabricated post. - To provide additional reinforcement, two vertical grooves were created on the reattached tooth, extending across the fracture line, and filled with micro-hybrid composite.	Successful technique restoring immediate esthetics and function.
L. Martens <i>et al.</i> , 2015 [11]	Case report	Immature permanent teeth Case one : [21,22] Case two : [11]	-The time between the trauma and treatment of the patient. - Degree of root development. - The size of pulp exposure.	Partial pulpotomy with Biodentine in cases one. Complete Pulpotomy in case two.	Following the initial treatment, the patient reported no pain symptoms. Clinical assessments indicated the vitality of the tooth was maintained. Radiographic examinations revealed no pathological findings, and further maturation of the teeth was observed.
Nuraytuloglu <i>et al.</i> , 2016 [12]	Case report	immature permanent teeth [11-21] Mature permanent teeth [21]	-The size of pulpal exposure. -The condition of the pulp. -The time elapsed between trauma and treatment.	Partial pulpotomy using BioAggregate The tooth was permanently restored using composite resin.	During follow-ups at six weeks, 12 months, and 24 months, the teeth remained clinically asymptomatic and exhibited normal coloration. Radiographic evaluations revealed a

			-The degree of root development. -The restorability of the tooth.		closed apex and the formation of a dentin bridge at the pulpotomy site in the immature permanent teeth.
Michael r.meharry 2012 [13]	Case report	Mature permanent tooth [21]	No Factors involved in the therapeutic decision.	-Partial pulpotomy using calcium hydroxide powder -Reattachment of the fragment was then performed using micro hybrid composite resin.	Follow-up at 1, 2, and 5 weeks. The treatment was successful; the tooth had a normal pulpal response and no evidence of pathosis.

Table 2: Literature reviews

STUDY AND YEAR	Study design	Factors involved in the treatment	Conclusions			
			Direct pulp capping	Pulpotomy	Pulpectomy	Regenerative Endodontics
Dennis j mctigue 2013 [14]	Literature review	-Time elapsed between trauma and treatment -The vitality of the pulp. -The maturation of the root.	-In Mature permanent teeth: indicated for small exposures that can be treated soon after an injury. - In Immature permanent teeth : direct pulp capping is not a preferred option.	-It's the preferred treatment in pulp exposures of immature permanent teeth.	<u>In mature teeth:</u> is indicated when no vital tissue remains or when the permanent restoration requires a post build-up.	The best option for long-term success in treating necrotic, immature teeth following trauma.
Enrique bimstein <i>et al.</i> , 2016 [15]	Literature review	- The time elapsed from coronal fracture and treatment. - Size of pulp exposure.	Time factor -The time between the accident and Cvek pulpotomy is not critical if the inflamed superficial pulp tissue is amputated to a healthy pulp may have limited value. -The success will most likely take place when the delay in treatment is within 9 days.	Exposure size -Exposure size of up to 4 mm is not critical for healing of a healthy pulp. -Pulp capping being recommended only for cases with pinpoint exposures in fractured permanent teeth that are treated within a few hours after the accident.	Open Vs Closed apex - The age of the patient may negatively affect the outcome of conservative pulp treatments -It appears that teeth With open apices have a better prognosis.	
Jekaterina gudkina <i>et al.</i> , 2012 [16]	Literature review	-Age of patient. -Duration of the pulpal exposure.	Direct pulp capping -Is indicated when a healthy pulp has been exposed. -Pinpoint exposure -The interval before first treatment must be short (<24 h).	Partial pulpotomy -It is indicated in mature and immature teeth, with a pulp exposure size that is more than pinpoint.	Cervical pulpotomy -It is indicated when inflammation has spread to deeper levels of the coronal pulp. - The time between the trauma and treatment is > 72 hours.	

Table 3: Cohort studies

STUDY AND YEAR	Study Design	Method	Results
Katharina bücher <i>et al</i> 2016 [17]	Retrospective study	-Total of 98 teeth in 79 patients who had completed endodontic apexification treatment with MTA between September 2005 and January 2014 at a university dental clinic were considered. -45/98 of cases were teeth with endodontic treatment related to trauma with complicated fractures (45.9%)	Younger patients, who often have traumatic exposure of the pulp, tend to show an overall better clinical-radiographic outcome than older patients.
Guiyan wang <i>et al.</i> , 2017 [18]	Retrospective study	-Complete dental records of teeth with complicated crown fractures treated from January 1, 2000, to December 31, 2014, with conservative pulp treatment were obtained. -The study involved 375 teeth treated with direct pulp capping, partial or coronal pulpotomy, and direct pulp capping retreated by pulpotomy (partial or coronal).	-Partial or coronal pulpotomy, employed either as a primary pulp treatment or secondary to emergency pulp capping, had similarly satisfactory pulp survival rates. -Direct pulp capping can be a good emergency treatment, but for good pulp prognosis in the long term, partial or coronal pulpotomy is needed. -Teeth with immature root development had a better pulp prognosis than those with mature roots.
Alberto caprioglio <i>et al.</i> , 2014 [19]	Retrospective study	-Thirty immature permanent incisors with complicated crown fractures in twenty-nine patients were treated in endodontic private practice between 2003 and 2011.	Partial pulpotomy was an effective treatment in maintaining pulp vitality in children and young adults with complicated fractures. MTA was a suitable pulpotomy agent in promoting root development and apexogenesis in immature permanent teeth.
Ricarda bissinger <i>et al.</i> , 2021 [20]	Retrospective study	-This retrospective study collected information from patients suffering from dental trauma who were treated between January 2004 and June 2017. -The study population consisted of 434 patients including 127 complicated crown fractures.	No statistically significant superiority of MTA or calcium hydroxide as pulp capping material in cases of complicated crown fracture was detected. -Most complications occurred within the first 2 years after dental trauma
Cağdaş Cınar <i>et al.</i> , 2013 [21]	Retrospective study	A total of 154 questionnaires were evaluated. The questions were related to knowledge of how to manage different types of TDIs in children and answered by 133 general dental practitioners (GDPs) and 21 specialists.	This survey showed a low level of knowledge of TDI management among the participants and highlights the need to improve dentists' knowledge of TDI treatment protocols.
Léa haikal <i>et al.</i> , 2020 [22]	Prospective study	This study was carried out in two hospital-based dental departments in Quebec, Canada INCLUDING Children seeking emergency care following trauma to anterior permanent teeth	The study showed survival rate of 100% and a success rate of 91% of partial pulpotomy with Biodentine

Table 4: Systematic review

STUDY AND YEAR	Study design	Method	Results
Aisling donnelly <i>et al.</i> , 2022 [1]	Systematic review	A systematic literature using key search terms was conducted from inception to May 2021 including articles that studied patients with mature or immature permanent incisors, which had a traumatic complicated crown fracture.	Pulpotomy rather than pulp capping, should be considered as the most appropriate treatment for both immature and mature teeth that have undergone complicated crown fractures.

Key Outcomes

Articles included in our systematic review showed common points and differences in the management of this type of trauma. While these studies highlighted areas of agreement, controversies emerged,

particularly concerning the factors that may be involved. It is noteworthy that one study, conducted by “Michael R. Meharry” [13], did not consider any specific factor (**figure 3**).

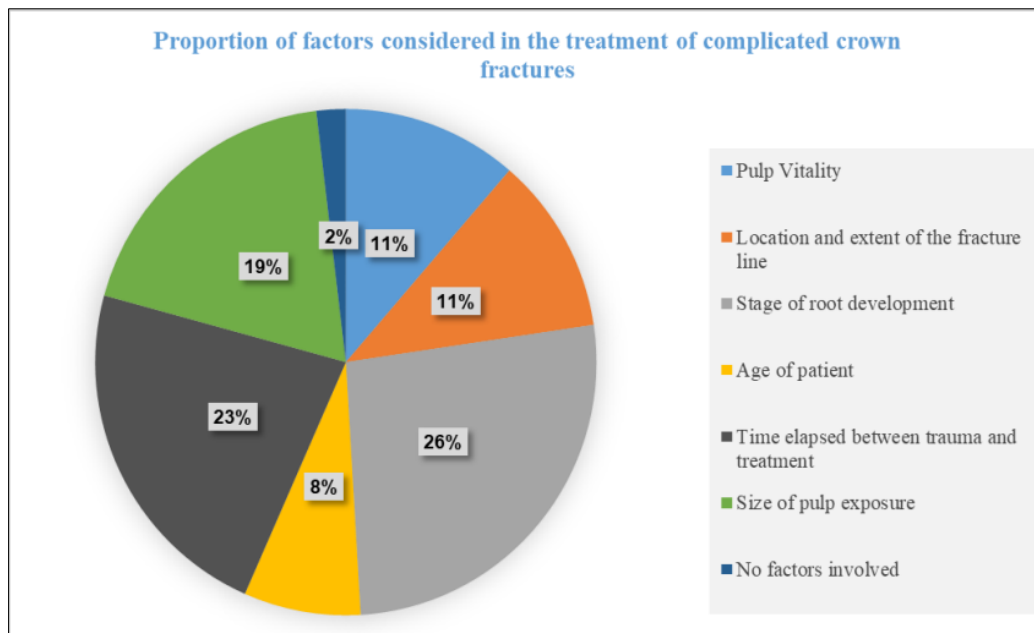


Figure 3: Diagram showing overall percentage of factors considered by included articles in the treatment of complicated crown fractures

The stage of root development emerged as the most significant factor in treatment decision-making. Teeth with incomplete root formation (immature teeth) responded better to VPT than teeth with fully developed roots (mature teeth). In cases where the root development was incomplete, partial pulpotomy was shown to maintain pulp vitality and promote apexogenesis, which is critical for the long-term survival of the tooth.

Subgroup Analyses

Age-Based Analyses

Age-related differences in treatment outcomes were observed across several studies. Younger patients (under 25 years of age) with immature teeth showed better clinical and radiographic outcomes following VPT, particularly when partial pulpotomy or complete pulpotomy was performed. These teeth demonstrated continued root development and apex closure. In contrast, older patients with mature teeth exhibited less favorable outcomes with VPT and were more likely to require root canal treatment. This difference is likely due to the reduced regenerative capacity of the pulp in older patients.

Pulp Exposure Size

The size of pulp exposure also played a critical role in determining the success of treatment. Studies indicated that smaller pulp exposures (less than 2 mm) had a higher likelihood of successful outcomes with direct pulp capping or partial pulpotomy, provided that

treatment was initiated soon after the injury. Larger pulp exposures (greater than 4 mm) were more likely to result in pulp necrosis, especially if treatment was delayed, and often required more invasive procedures such as full pulpotomy or root canal treatment. The likelihood of success decreased as the size of pulp exposure increased, particularly in mature teeth.

Time Elapsed Between Trauma and Treatment

The time elapsed between trauma and treatment did not consistently influence the choice of therapy across studies. Some studies reported that immediate treatment (within 24 hours) improved outcomes for VPT, especially in cases of partial pulpotomy. However, other studies suggested that delayed treatment, even up to 9 days post-trauma, could still result in successful outcomes as long as the pulp remained vital and uncontaminated. These findings highlight the need for further research to determine the optimal timing for intervention, particularly in cases of large pulp exposures or delayed presentation.

DISCUSSION

The results of this systematic review provide valuable insights into the management of complicated crown fractures in permanent anterior teeth. These findings highlight the complexity of treatment decisions influenced by various factors. Currently, dental professionals face challenges in determining the most suitable treatment for these fractures, whether it be direct

pulp capping, partial or complete pulpotomy, or root canal treatment. While the overarching goal remains to preserve pulp vitality, the rationale guiding the preference for one therapeutic approach over another in current clinical guidelines warrants further scrutiny [1].

Despite the guidelines provided by the International Association of Dental Traumatology [30], there remains a lack of consensus on the optimal treatment approaches [36].

The latest recommendations advocate for pulp capping, the partial pulpotomy, or the complete pulpotomy in the management of teeth presenting complicated crown fractures. Despite these recommendations, the rationale behind selecting a specific treatment approach remains ambiguous, influenced by a multitude of factors [18].

Stage of Root Development

Based on the articles reviewed, the stage of root development is identified as the most significant factor in managing complicated crown fractures of permanent teeth. This stage is assessed through radiological examinations utilizing various projections and angles; clinicians must evaluate each case to determine the necessary radiographs [2-23]. Roots with an apical foramen measuring less than 1 mm in diameter are classified as complete or mature, whereas those with an apical foramen larger than 1 mm are classified as incomplete or immature [18].

Inflammatory changes in the tissues of traumatically exposed pulps in permanent teeth can be harmful, potentially leading to pulp necrosis or tooth loss, which can have lifelong implications for young patients with immature teeth. Therefore, every effort should be made to preserve pulp vitality to facilitate ongoing root development [24, 25]. Research indicates that pulpotomy can still be performed on these teeth even after prolonged pulp exposure, provided the pulp remains healthy [18]. Moreover, the functional capacity, proliferation, differentiation, and immune response of cells are significantly greater in teeth with open apices, highlighting their remarkable healing potential following traumatic pulp exposure [26, 2].

Vital pulp therapy is also a preferred approach for mature teeth in younger patients. In contrast, root canal treatment is often the most suitable option for older patients [27, 14], due to the decline in pulp cell population with age, which affects the tooth's response to injury [28]. Studies have demonstrated that immature permanent teeth possess a greater healing capacity compared to mature ones, owing to their natural defense mechanisms and rich blood supply, making the likelihood of successful outcomes higher when the tooth has an open apex rather than complete root formation [27-36]. However, some researchers argue that the stage of root maturation does not significantly influence

treatment outcomes following complicated crown fractures [1-22].

Time Elapsed Between Trauma and Treatment

It is considered the second most significant factor in treatment decisions. Authors are divided in their opinions on whether the timing influences the treatment approach for complicated crown fractures. Within the literature, pulp exposure presents a significant challenge to treatment. If left uncovered, the pulp becomes vulnerable to bacterial contamination, which may result in necrosis. Nevertheless, existing guidelines do not define a specific timeframe (days, months, or years) for treatment following trauma [7-15], a topic that has generated ongoing debate among researchers [36].

Evaluating whether a delay in treatment could affect decision-making is essential; however, there is a limited amount of research on this issue ⁽¹⁾. Some authors suggest a link between the duration between fracture and treatment and the risk of microbial invasion of the pulp. Therefore, this timeframe is critical for assessing the extent of coronal pulp involvement and the need for subsequent intervention [16-18]. In contrast, other researchers argue that accurately determining the depth of disease progression is clinically difficult, and timing does not significantly impact the choice of treatment method [15, 13].

In this regard, histological studies of traumatized pulps indicate that the depth of inflammatory response does not exceed 2 mm from the exposed surface within the first 48 hours [11-13]. The exposed pulp may exhibit a favorable defensive hyperplastic tissue reaction, which facilitates the rinsing action of saliva and prevents the accumulation of contaminated debris [7-15]. Moreover, the coronal pulp is more cellular compared to the radicular pulp, which is fibrous and composed of fewer cells, resulting in lower healing capacity. Thus, it may not be necessary to perform treatment for complicated crown fractures immediately following trauma in every case. However, if the patient experiences pain, prompt treatment is warranted [15].

Regarding outcomes, the literature indicates that there are differences in success rates for vital pulp therapies when considering the time from trauma to treatment; however, these differences are not statistically significant [2, 1]. In partial pulpotomy cases, "Cvek" [15], found that the timing does not significantly affect the recovery of initially healthy pulp, reporting a treatment success rate of 96.7%. Other studies suggest that a waiting period of up to 9 days may have minimal impact on the results of Cvek's pulpotomies [15-31]. However, evidence regarding the outcomes associated with longer waiting periods remains lacking [32, 12].

Size of Pulp Exposure

This factor has been extensively discussed in relation to vital pulp therapy, with exposure sizes ranging from pinpoint (0,5mm) to over 4 mm [5, 36]. Historically, it has been suggested that the size of the exposure can play a critical role in determining whether direct pulp capping or pulpotomy is the more appropriate treatment option [15, 1].

Direct pulp capping is typically indicated for pinpoint exposures in fractured permanent teeth [15, 16]. In instances where the exposure exceeds a pinpoint size, the clinician's judgment becomes crucial in deciding whether to perform a partial or full pulpotomy. This decision should be informed by evaluating the depth of the pulpotomy, the degree of pulpal hemorrhage, the clinical appearance of the pulp, and the amount and color of blood from the pulp stump [15-33].

Theoretically, the removal of compromised exposed pulp tissue should allow for the preservation of remaining vital pulp tissue [33]. When hemorrhage is controlled within 1 to 10 minutes, the formation of reparative dentin and pulpal repair can proceed normally, making a partial pulpotomy sufficient [15-26]. It has been reported that an exposure of up to 4 mm is not detrimental to the healing of a healthy pulp following this procedure.

Currently, there are no studies evaluating the success rates of partial pulpotomy in teeth with pulp exposures greater than 4 mm [15, 6]. However, if bleeding persists and cannot be controlled after 10 minutes of hemostasis, sodium hypochlorite (NaOCl) is an effective agent for achieving hemostasis without disrupting the pulp's repair mechanisms. In such cases, the coronal pulp is considered irreversibly inflamed, necessitating a full pulpotomy [26-33].

Age of the Patient

Our systematic review identified only four studies that considered this factor in the treatment approach for complicated crown fractures: Renato Lenzi *et al.*, [9], Jekaterina Gudkina *et al.*, [16], Guiyan Wang *et al.*, [18], and Katharina Bücher *et al.*, [17]. Their results indicate that young patients with either mature or immature permanent teeth, who often face traumatic pulp exposure, should be treated using vital pulp therapies. These patients demonstrated significantly better clinical and radiographic outcomes compared to their older counterparts.

Consistent with the literature, a patient's age may serve as a critical factor in determining the therapeutic strategy for this type of trauma. Research has shown a significant positive correlation between age and the count of dental pulp cells (including odontoblasts, sub-odontoblasts, and fibroblasts) in individuals aged 6 to 25 years, while a negative correlation was observed in those aged 26 to 80 years [28]. In younger patients with

mature or immature permanent teeth, the pulp remains well vascularized and contains a higher concentration of active immune cells, facilitating better healing and the formation of secondary and tertiary dentin in the cervical region⁽¹⁾. Therefore, efforts should be made to preserve pulp vitality after trauma, as these teeth have shown considerable success rates with vital pulp therapy [15-18]. In contrast, in older patients, age can adversely impact the outcomes of conservative pulp treatments such as direct pulp capping and partial or complete pulpotomy. Between the ages of 26 and 80, a significant negative correlation has been established between age and the counts of odontoblasts and sub-odontoblasts, while the correlation for fibroblasts is negligible. This leads to a pulp that is less cellular, more fibrotic, has reduced blood supply, and exhibits diminished repair capacity [15-31].

Pulp Vitality

After a dental trauma, it is crucial to quickly evaluate the condition of the pulp to develop a suitable treatment plan that restores both aesthetics and functionality of the injured teeth. Although its usefulness after traumatic dental injuries is debated, pulp vitality testing remains the most commonly used method to assess pulp health. However, this approach presents significant challenges in the context of dental trauma, mainly due to the temporary loss of tooth sensitivity and the limitations of traditional pulp testing techniques [34-36]. Indeed, shortly following the trauma, restorative mechanisms begin almost immediately, aiming to regenerate nerves and blood vessels, and repair damaged pulp tissue. Interestingly, the tooth can maintain vitality despite not responding to initial sensitivity tests. Therefore, a negative result from these tests immediately after trauma should not be directly associated with the development of pulp necrosis. Clinicians must carefully monitor for additional indicators such as changes in crown color and radiographic evidence during follow-up before deciding to start endodontic treatment [35, 23]. Conventional pulp tests show limited accuracy shortly after trauma. Accurate vitality assessment requires tools that measure pulpal blood flow, such as laser Doppler flow meters (LDF). Additionally, pulse oximetry has emerged as a reliable, non-invasive method for detecting blood flow in the pulp. Consequently, pulp should only be considered non-vital when one or more of the following signs are observed: crown discoloration, fistula formation, periapical bone loss, or inflammatory external root resorption [34-36].

The Restorability of the Tooth

The implications of dental tissue loss resulting from trauma have not been thoroughly explored in many studies included in this systematic review. Authors who recognized the significance of coronal tissue loss as a critical factor in treatment planning concluded that fractures involving two-thirds or more of the crown, or those with fracture lines that are subgingival or

intraosseous, may necessitate the use of a post-retained crown [10-12].

- **Proposed Decision-Making Chart for Managing Complicated Crown Fractures in Anterior Permanent Teeth**

To assist clinicians in navigating the complexities of treatment decisions for complicated crown fractures, we propose a decision-making chart

based on the findings of our systematic review (**Figure 4**). This chart outlines procedural steps that incorporate key factors influencing treatment choices, such as patient age, pulp exposure size, and the stage of root development. By providing a visual representation of the recommended protocols, this chart aims to facilitate more informed and consistent treatment strategies, ultimately enhancing patient outcomes in clinical practice.

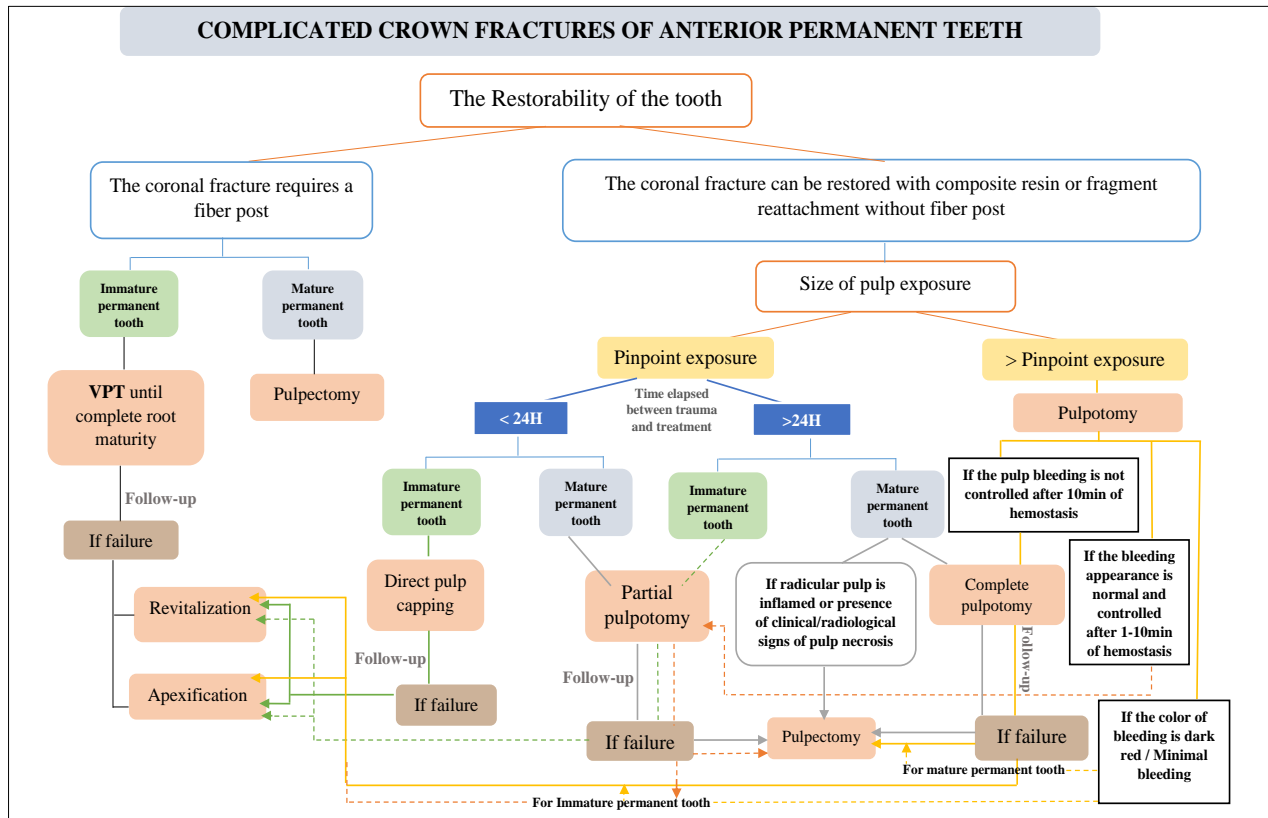


Figure 4: A chart outlining the procedural steps for managing complicated crown fractures in anterior permanent teeth, derived from our systematic review

Limitations of Included Studies

While the included studies present a range of treatment options and outcomes, it is important to recognize the limitations inherent in the existing literature. Many studies were retrospective in nature, which may introduce selection bias. The lack of standardized protocols across studies further complicates comparisons of treatment effectiveness. Additionally, variations in follow-up duration and methodologies for assessing outcomes may have influenced the reported success rates. Acknowledging these limitations is crucial in interpreting the results and understanding the broader implications for clinical practice.

Quality and Risk of Bias Assessment

A limited number of studies have thoroughly investigated the factors influencing the treatment of complicated crown fractures in both mature and immature permanent teeth. However, it is important to recognize the inherent limitations of this body of

research. The potential for bias in the included studies arises from small sample sizes, divergent opinions among authors, a lack of standardized follow-up periods, and a wide variety of study designs. Together, these factors present significant challenges to the comprehensiveness and generalizability of this review. Such limitations underscore the necessity for caution when interpreting the results and highlight critical areas for improvement in future research, aiming to enhance our understanding of the best practices for managing complicated crown fractures.

Recommendations for Future Research

Based on the findings of this review, future research should focus on establishing standardized treatment protocols for managing complicated crown fractures. This includes investigating the optimal timing for intervention, the best materials for pulp capping, and the long-term success rates of various therapeutic approaches. Additionally, prospective studies with

robust methodologies are needed to minimize biases and provide clearer insights into treatment effectiveness.

CONCLUSION

This systematic review highlights the multifaceted challenges faced in the management of complicated crown fractures in permanent anterior teeth. While various treatment options, including direct pulp capping, partial and complete pulpotomy, and root canal treatment, aim to preserve pulp vitality, the decision-making process remains complex and often ambiguous. Our review emphasizes the need for actionable guidelines to aid clinicians in making informed decisions tailored to individual cases.

Furthermore, we recommend that future research focuses on establishing standardized protocols that consider factors such as patient age, pulp exposure size, and the stage of root development. This would not only enhance treatment outcomes but also align clinical practices with evolving evidence.

Additionally, the importance of thorough risk-of-bias assessments in included studies cannot be overstated, as they contribute to the credibility of the findings. Addressing the limitations and biases identified in this review is crucial for advancing the field and improving the management of complicated crown fractures. By establishing a clearer framework for treatment, we can better support dental professionals in navigating the complexities of these cases and ultimately improve patient care.

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