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Traumatic Dental Injuries

Current Emergency Interventions and
Treatment Approaches

Edited by Hülya Erten Can and Özgür Er



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Aims and Scope of the Series

This book series will offer a comprehensive overview of recent research trends as well as clinical applications within different specialties of dentistry. Topics will include overviews of the health of the oral cavity, from prevention and care to different treatments for the rehabilitation of problems that may affect the organs and/or tissues present. The different areas of dentistry will be explored, with the aim of disseminating knowledge and providing readers with new tools for the comprehensive treatment of their patients with greater safety and with current techniques. Ongoing issues, recent advances, and future diagnostic approaches and therapeutic strategies will also be discussed. This series of books will focus on various aspects of the properties and results obtained by the various treatments available, whether preventive or curative.

Meet the Series Editor



Dr. Sergio Alexandre Gehrke is a doctorate holder in two fields. The first is a Ph.D. in Cellular and Molecular Biology from the Pontificia Catholic University, Porto Alegre, Brazil, in 2010 and the other is an International Ph.D. in Bioengineering from the Universidad Miguel Hernandez, Elche/Alicante, Spain, obtained in 2020. In 2018, he completed a postdoctoral fellowship in Materials Engineering in the NUCLEMAT of the Pontificia Catholic University, Porto Alegre, Brazil. He is currently the Director of the Postgraduate Program in Implantology of the Bioface/UCAM/PgO (Montevideo, Uruguay), Director of the Cathedra of Biotechnology of the Catholic University of Murcia (Murcia, Spain), an Extraordinary Full Professor of the Catholic University of Murcia (Murcia, Spain) as well as the Director of the private center of research Biotecnos – Technology and Science (Montevideo, Uruguay). Applied biomaterials, cellular and molecular biology, and dental implants are among his research interests. He has published several original papers in renowned journals. In addition, he is also a Collaborating Professor in several Postgraduate programs at different universities all over the world.

Meet the Volume Editors



In 1988, Hülya Erten Can graduated from the Faculty of Dentistry at Gazi University. Between 1989 and 1995, she earned a doctoral degree (Ph.D.) in restorative and endodontic dentistry at the same university. She was appointed as an Associate Professor in 1999 and a Professor in 2005. In 2021, she started working in the newly established Dokuz Eylul University Faculty of Dentistry, Restorative Department. She also studied at the Public Relations and Publicity Department and the Disabled Care and Rehabilitation Department at Anadolu University. For the past ten years, she has worked with students as a life and education coach. Her professional interests include dental caries and prevention methods, saliva, bleaching treatments, and dental trauma. She also manages social responsibility initiatives.



Özgür Er graduated from the Faculty of Dentistry at Gazi University in 1999. In the same year, he began his Ph.D. in the Department of Restorative Dentistry and Endodontics at the same university, completing it in 2004. He became an Associate Professor in 2010 and a Professor in 2015. Since 2023, he has been working in the Department of Endodontics at the Faculty of Dentistry, Dokuz Eylul University. His special areas of interest are clinical endodontics and the management of dental trauma.

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Preface

Dental trauma encompasses injuries affecting the teeth, periodontal tissues, and associated oral soft tissues such as the lips, tongue, and oral mucosa. These injuries may occur unexpectedly due to falls, traffic accidents, sports-related impacts, or daily-life incidents, and they often present as emergencies requiring prompt, accurate clinical decision-making. Traumatic dental injuries can manifest in various forms, including enamel and dentin fractures, crown–root fractures, luxation injuries, avulsion, and damage to the surrounding supporting structures. Beyond their immediate clinical presentation, dental traumas may have long-term consequences on oral function, esthetics, psychological well-being, and overall quality of life.

One of the most critical aspects of dental trauma management is the timing and appropriateness of the initial intervention. Early and accurate assessment, pain control, proper management of the injured tooth and tissues, and rapid referral to professional dental care are decisive factors in determining prognosis. Even minor delays or inadequate emergency responses may lead to irreversible complications such as pulp necrosis, root resorption, or tooth loss. Therefore, dental trauma requires not only theoretical knowledge but also clinical experience, critical thinking, and adherence to evidence-based treatment protocols.

This book aims to provide a comprehensive and up-to-date overview of traumatic dental injuries, covering their etiology, classification, diagnostic approaches, and contemporary treatment modalities. Our goal is to improve clinical outcomes and raise awareness of the importance of timely, accurate trauma management in dental practice.

As the editor of this book, I sincerely hope that this collective work will not only function as a scientific guide but also inspire clinicians to approach dental trauma with confidence, precision, and a patient-centered perspective. I would like to express my deepest gratitude to all contributing authors for generously sharing their expertise and scientific knowledge, and to everyone who supported the preparation and publication of this book. Their invaluable contributions have made this work possible.

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Chapter 1

Crown Fractures

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Abstract

Dental trauma (DT) constitutes approximately 5% of all reported traumatic injuries. Within the permanent dentition, crown fractures are the most frequently observed lesions. Predisposing factors, such as increased overjet and inadequate lip coverage, have been identified as significant contributors to the incidence of DT. Moreover, gender-based violence represents an important etiological consideration, often associated with injuries including crown fractures, contusions, luxations, and avulsions. Crown fractures accompanied by periodontal ligament involvement in teeth with complete root development present a higher risk of adverse outcomes, with pulp necrosis being the most common complication. These injuries are classified according to the extent of tissue involvement as enamel fractures, enamel–dentin fractures (uncomplicated), and enamel–dentin–pulp fractures (complicated). A comprehensive diagnostic protocol is essential to exclude concomitant injuries associated with crown fractures. Prompt intervention is particularly critical when dentin exposure is present, especially in complicated cases, as timely management improves prognosis. The primary objective of treatment is the preservation of pulp vitality and, in immature teeth, the promotion of apical closure. Both the International Academy of Dental Traumatology and the European Society of Endodontology advocate conservative treatment modalities, including pulp capping and partial pulpotomy, irrespective of apical status. Given the inherently unpredictable prognosis of DT, continuous follow-up is imperative. Patients must be thoroughly informed of the importance of ongoing monitoring to ensure optimal treatment outcomes and long-term oral health.

Keywords: complicated crown fracture, dental trauma, enamel fractures, infraction, tooth, tooth crown fractures, tooth fracture, uncomplicated

1. Introduction

Dental trauma (DT) is frequently observed in children and adolescents, accounting for approximately 5% of all bodily injuries. Epidemiological data indicate that nearly one-quarter of school-aged children experience some form of DT, while about one-third of adults report traumatic injuries to the permanent dentition, with the majority occurring before 19 years of age. In primary teeth, luxation injuries are the most prevalent, whereas crown fractures are more common in permanent dentition. Accurate diagnosis, timely intervention, and consistent follow-up are essential to ensure optimal clinical outcomes [1].

Trauma affecting the dentoalveolar region can lead to tooth fractures and displacement, with or without associated alveolar bone fractures, as well as soft tissue injuries such as contusions, abrasions, or lacerations. When a single tooth sustains multiple types of injuries simultaneously, the combined damage may exceed that caused by individual trauma, resulting in a negative synergistic effect. In cases where crown fractures occur alongside periodontal ligament injuries – such as concussion, subluxation, or luxation – the likelihood of pulp necrosis and subsequent periapical infection increases substantially. Additionally, teeth with fully developed roots exhibit a higher risk of pulp necrosis compared to teeth possessing immature apices [2].

2. Classification of crown fractures

According to the classification system proposed by Andreasen [3], crown fractures are divided into the following categories:

- Enamel fracture
- Enamel–dentin fracture (uncomplicated crown fracture)
- Enamel–dentin–pulp fracture (complicated crown fracture)

Although Andreasen's classification includes crown–root fractures as a subset of crown fractures, these injuries will not be addressed in this chapter, as they are discussed in a separate chapter of this work.

3. Etiology, pathogenesis, and epidemiology

Dental trauma accounts for approximately 85% of injuries within the oral region, while representing around 5% of all bodily injuries, despite the oral cavity comprising only 1% of the total body surface area [4]. Among dental injuries, crown fractures of permanent teeth are the most frequently encountered, representing between 26% and 76% of all cases of trauma. Both uncomplicated and complicated crown fractures warrant particular attention due to their high prevalence, the variety of etiological factors involved, and the wide range of clinical management strategies recommended for their treatment [5].

It has been reported that, during childhood, the main causes of traumatic dental injuries are falls [6, 7]. Among adolescents, trauma is mainly due to sports-related accidents [8]. In the adult population, traffic accidents, work accidents, and aggressions occur with similar frequency [9].

With respect to gender, uncomplicated crown fractures are more frequently observed in boys (71%) than in girls (29%), while complicated crown fractures occur in 68.5% of boys compared with 31% of girls. Children under 12 years of age represent the age group most commonly affected [10]. For crown fractures without pulp involvement and without subluxation, the average age is around 12 years, while for uncomplicated fractures with subluxation, the average age is slightly lower, around 10 years [6]. Lifestyle and a lack of knowledge of preventive measures may explain the high incidence in this group [11].

Some oral factors, such as overjet and incomplete lip coverage, influence the prevalence of DT [12]. Gender-based violence should not be overlooked as a cause of DT, with crown fractures, contusions, subluxations, luxations, and avulsions being the most frequent injuries [13].

From a pathogenic perspective, fractures of the teeth and alveolar bone may occur when the traumatic force exceeds the elasticity of the supporting structures. The characteristics of the resulting injury are influenced by multiple factors, including the magnitude and direction of the applied force, as well as the shape of the object responsible for the trauma [14, 15].

4. Clinical findings

Depending on the type of injury sustained, it can range from near-complete integrity of the tooth with a total absence of clinical symptoms to the loss of a large portion of the tooth crown with considerable spontaneous pain due to pulp involvement. Each of the lesions and their clinical characteristics will be described [3].

4.1 Enamel infraction or incomplete fracture

The tooth is intact; only some cracks are visible in the enamel, which do not extend beyond the enamel–dentine junction and are described as vertical, horizontal, or diagonal (**Figure 1a**). Although they are usually asymptomatic, their presence should prompt an investigation for the coexistence of other injuries, as they are often the only sign of trauma but may be associated with luxation or root fracture, especially if sensitivity is present.

These lines can be made more noticeable by shining a light parallel to the tooth's axis or by transillumination with a fiber optic on the palatal surface of the tooth.

When only an infraction is present, there is no mobility, and sensitivity tests are generally positive. There are no radiographic changes. If there is doubt about a possible association with other injuries, different radiographic projections will be required.

4.2 Enamel fracture

In enamel fractures, only the enamel layer is affected, with the extent of the loss varying from minimal to more substantial. These fractures most commonly involve the incisal angles (**Figure 1b**), although, in some cases, only the central lobe of the incisal edge is affected. Clinical signs are generally minimal or absent, and patients may occasionally report slight dental sensitivity. Tooth mobility remains normal, and pulp vitality tests typically produce positive results.

It is essential to exclude the possibility that the fractured fragment has become embedded in the soft tissues, particularly the lips. Therefore, careful palpation of the lips should be performed, and if there is any uncertainty, a radiographic examination should be undertaken to confirm the presence of any displaced fragment.

A periapical radiograph, oriented parallel to the long axis of the tooth, is recommended, with additional projections obtained when there is doubt regarding possible associated injuries.



Figure 1.
Fracture extent: (a) infrafracture, (b) enamel fracture, (c, d) enamel–dentin fracture (uncomplicated), and (e, f) complicated fracture.

The rough edge of the fractured enamel may cause trauma to the adjacent oral mucosa, either on the lips or on the tongue; therefore, any sharp enamel margins should be smoothed.

4.3 Enamel and dentine fracture (uncomplicated crown fracture)

This type of coronal fracture is generally the most frequently observed in permanent dentition (**Figure 1c** and **1d**). In addition to the loss of a significant portion of the dental crown, hypersensitivity is often present. This may range from sensitivity to cold, sweet, hot, or tactile stimuli, through to spontaneous pain. The fracture may involve a single incisal angle or run horizontally, parallel to the incisal edge.

In some cases, the dentine layer overlying the pulp is so thin that the pulp appears translucent. Caution should, therefore, be exercised when using an explorer or probe to avoid perforating the dentine and causing pulp exposure. Palpation and percussion are usually non-tender, and there is no abnormal mobility of the tooth.

It is important to exclude the possibility that the fractured fragment has become embedded in the soft tissues through careful clinical examination and, when indicated, radiographic assessment. As in other cases, any additional associated

injuries should also be evaluated. Radiographic imaging is essential not only for accurate diagnosis but also for monitoring the healing process and for ruling out luxation or root fractures.

4.4 Enamel, dentine, and pulp fracture (complicated fracture)

Both the enamel and dentin are involved, with exposure of the pulp (**Figure 1e and 1f**). As in the previous case, there is a loss of dental substance; however, in this instance, the pulp is also exposed to a greater or lesser extent. This is accompanied by spontaneous sensitivity and pain. Palpation and percussion are negative for pain.

As with the previous cases, it is essential to rule out the embedding of the fractured fragment in the soft tissues, as well as any concomitant dental or periodontal injuries. Radiographic evaluation is crucial for establishing an accurate diagnosis, monitoring healing progress, and excluding the presence of luxation or root fractures.

5. Extraoral and intraoral examination

This section will address the specific aspects of the dental, periodontal, and soft tissue examination. All these elements will be included, as in the event of a crown fracture, it is always necessary to rule out the coexistence of other possible injuries, which, if present, may alter the prognosis. The examination will follow a systematic approach, as detailed below. Once any life-threatening injuries have been excluded, the loco-regional examination should begin [16].

- a) *Examination of extraoral wounds and palpation of the facial skeleton.*
- b) *Examination of oral mucosa and gingival injuries.* For an accurate assessment of soft tissue injuries, the area should first be thoroughly cleaned, and any bleeding controlled. Injuries to the lips or tongue are common, and the presence of tooth fragments or other foreign bodies embedded in the soft tissues should be carefully evaluated through palpation and, if necessary, confirmed using radiographic imaging. Gingival lacerations are frequently associated with tooth displacement. Bleeding from the gingival sulcus may indicate involvement of the periodontal ligament, with or without rupture of its fibers. Submucosal hematomas in the sublingual region or vestibule may indicate an underlying bone fracture.
- c) *Examination of the dental crown.* The crown should first be cleaned to allow for a thorough clinical inspection. The presence of fissures should be sought, which may be visualized by directing a light source parallel to the vertical axis of the tooth or by transillumination, applying the light from the palatal aspect. It should be assessed whether the fracture involves only the enamel, both enamel and dentine, and whether there is pulp exposure.

In some cases, the pulp may appear translucent without clear evidence of exposure; in such situations, micro-exposures are often present. Care should be taken during the examination to avoid enlarging the perforation with a probe or other instruments. If pulp exposure is present, its size should be recorded.

In cases of indirect trauma, it is important to recognize that crown–root fractures in one quadrant are frequently accompanied by similar injuries in the opposing quadrant. Therefore, a thorough examination of the molars and premolars is essential to identify any additional lesions.

The color of the tooth should be recorded to monitor subsequent changes, which are often more evident on the lingual or palatal surface than on the labial surface. In addition, transillumination may reveal alterations in translucency.

- d) *Tooth displacement.* This is often evident on visual examination, although in some cases the displacement is minimal and must be assessed in occlusion, with radiographs taken in different projections for an accurate evaluation. In cases of luxation, both the direction and the extent should be recorded in millimeters. This is particularly important in the primary dentition, as displacement of primary teeth may cause disturbances in the formation or eruption of permanent teeth. Dental displacements may interfere with occlusion, particularly lateral luxation and extrusions. Intruded or laterally displaced teeth often present with minimal symptoms and are generally firm in their displaced position. Radiographically, changes in the periodontal space and displacement of the root may be observed.
- e) *Occlusal abnormalities.* These findings may suggest a fracture of the alveolar process, mandible, or maxilla. In such cases, the teeth move in conjunction with the supporting bone, and mobility of adjacent teeth may also be observed when a single tooth is manipulated. Palpable steps or crepitus may be present, and displacement of bone fragments can often be detected.
- f) *Tooth mobility.* Mobility should be assessed in both the horizontal and from crown to apex directions. When axial mobility is present, rupture of the neurovascular bundle should be suspected. It should be remembered that a certain degree of mobility is normal in an erupting tooth or in a primary tooth undergoing physiological resorption. In cases of root fracture, the mobility of the fragment will depend on the level of the fracture. Radiographic evaluation is essential to ascertain whether the observed tooth mobility is due to a root fracture or luxation.
- g) *Response to percussion.* Vertical and horizontal percussion should be carried out using the handle of a dental mirror. Periodontal ligament injuries produce pain on percussion. The sound elicited can also assist in diagnosis: A metallic sound suggests a possible lateral or intrusive luxation, whereas extrusion or subluxation produces a dull sound. Apical lesions may also result in a dull percussion sound. In young children, percussion with a mirror handle should be replaced with gentle tapping using the fingertip; however, in very young children, this may not be useful.

6. Radiological examination

For the assessment of any traumatized tooth, intraoral radiographs are essential. These examinations serve several purposes: To determine the degree of apical

closure, evaluate the presence of root injuries, assess periodontal structures, identify previous lesions, determine the size of the pulp chamber and root canal, detect fragments embedded in soft tissues, and reveal bone lesions. Mesioangular and distoangular projections are required to rule out root fractures that may be missed on a perpendicular projection. At present, cone beam computed tomography (CBCT) serves as a valuable tool in the diagnosis of DT.

Teeth that have undergone extrusion or lateral displacement will show widening of the periodontal space, whereas in intruded teeth, the periodontal space disappears, and the tooth appears impacted within the alveolus. An occlusal projection of the anterior teeth aids in assessing the direction of displacement, especially in cases of intrusions and lateral luxation.

The ideal radiographic protocol for a traumatized tooth consists of three periapical radiographs (at 90 degrees, in the mesioangular and distoangular angles) and one occlusal radiograph.

Foreign bodies embedded in the lips or cheeks can be visualized by positioning the radiographic sensor between the soft tissue and the alveolar bone. To detect foreign objects located on the floor of the mouth, an occlusal radiograph with the X-ray beam directed from the submental region is recommended, with adjustments such as reduced exposure time or lower kilovoltage, as needed.

CBCT is highly valuable for excluding injuries to maxillofacial structures, evaluating dental displacement and its relationship with adjacent tissues, and identifying potential trauma-related complications. Although CBCT is not required in every case, it is particularly useful in situations involving polytrauma, teeth with multiple fractures, suspected root fractures, or dental displacement. It should be noted, however, that image quality may be affected in teeth that have undergone endodontic treatment or possess metallic crown restorations [17].

7. Extraoral and intraoral photographs

It is highly useful to have photographic records in cases of DT, both to evaluate clinical progress and for legal purposes that may arise. Informed consent should be obtained prior to taking these images.

Photographic documentation should include initial clinical images, both extraoral and intraoral, of the face and the soft and hard dental tissues, taken before and after cleaning the traumatized area. Intraoperative and postoperative clinical photographs are necessary during and after the therapeutic intervention, whether this involves repositioning or splinting the injured teeth, replacing the original crown fragment, covering exposed pulpal tissue, or suturing soft tissues [18].

8. Sensitivity and pulp vitality tests

In a recently traumatized tooth, the response to sensitivity tests is questionable. Performing these tests requires patient cooperation and a relaxed attitude to avoid false results. Mechanical, electrical, and thermal tests are used to assess dental sensitivity.

Generally, negative pulp sensitivity tests immediately after trauma may normalize after weeks or months, especially following luxation. Likewise, a positive

initial response does not guarantee pulp health, as these tests only indicate the response of nerve fibers to stimuli; these nerve structures are the last to be destroyed. Tests should be performed on a clean, dry tooth, always comparing with the contralateral tooth [19, 20].

Despite these limitations, pulp vitality tests should be performed both initially and at each follow-up visit to monitor changes over time. It is widely recommended that sensitivity testing be conducted as early as possible to establish a baseline for future comparison and ongoing evaluation. Initial test results also provide valuable information regarding the long-term prognosis of the pulp [21].

- a) *Mechanical tests:* In coronal fractures without pulp exposure, tests can be performed by gently passing a blunt-ended explorer probe (preferably a periodontal probe PCP 11 5B). If there is pulp exposure or translucency, a cotton pellet soaked in saline solution should be utilized.
- b) *Thermal tests:* Various methods exist to deliver thermal stimuli to the dental pulp, either heat or cold. These tests cannot measure the graded intensity of the pulp's response; even a healthy pulp may give false negatives, and conversely, pulp necrosis may yield a positive response to thermal tests due to pressure changes in the pulpal fluids, as if the tooth were healthy.

Cold application stimulates the A- δ nerve endings, whereas heat initially stimulates the same fibers causing mild discomfort; if heat application continues, sustained pain occurs due to stimulation of the C fibers.

 - **Hot gutta-percha test:** A gutta-percha stick, approximately 5 mm in diameter, is briefly heated over a flame for about two seconds and then applied to the mid-vestibular surface of the tooth.
 - **Ice:** Application of an ice cone is to the center of the vestibular surface for 5–8 seconds.
 - **Carbon dioxide snow:** It provides more consistent results than previous methods, even in immature teeth or in teeth restored with a splint or crown. The working temperature is -78°C . A positive response may occur in both normal and inflamed pulps; persistence of pain after removal of the stimulus, or a markedly reduced response, is indicative of irreversible pulpitis. Recently traumatized teeth may exhibit a mild or absent response, which does not necessarily imply pulp damage; the test should be repeated after several weeks or months. A disadvantage of this method is the potential for enamel cracking due to the extremely low temperature.
 - **Dichlorodifluoromethane:** Cools to -40°C and is applied either via a cotton pellet impregnated with the substance or directly as a spray to the tooth surface. It presents the same advantages and limitations as carbon dioxide snow.
- c) *Electrical tests.* These primarily assess the response of A- δ fibers, as C fibers may not respond to the stimulus. They are based on the use of instruments known as pulp testers, which generate an electric current and are equipped

with a rheostat to gradually increase the current intensity. The recommended stimulus duration is approximately 10 milliseconds or more. These tests have demonstrated reliability in reproducing identical results in the same patient at different time intervals. Electrical testing is performed using the following procedure:

- The patient is informed about the purpose of the test and the sensations they may experience during its application.
- The tooth surface is dried and isolated with cotton rolls.
- The electrode is placed on the tooth, with a conductive medium interposed, as far from the gingival margin as possible. The neutral electrode may be held by the patient. A variation of this technique is for the operator to close the circuit by touching the patient's mouth with their finger or with a mouth mirror.
- The pulp tester's rheostat is used to increase the current until the patient reports a tingling sensation. Once the threshold value is reached, it should be recorded for comparison with subsequent examinations.
- In teeth with crowns or splints, the threshold for electrical stimuli may be elevated, and results unreliable; the electrode should be positioned at least 1 mm from the metal margin of the crown.

Recently traumatized teeth may yield a negative response, making results unreliable in such cases; they should be used for baseline comparison when the test is repeated after several weeks or months. Immature teeth may also give false-negative results, as neural structures are the last to develop. Teeth undergoing orthodontic movement tend to have a higher excitation threshold.

- d) *Laser Doppler flowmetry* [22]. This method is based on the absorption of light by tissues and detects the movement of red blood cells within the pulp capillaries. When a laser light is directed toward the crown, it is reflected at different frequencies depending on the presence or absence of red blood cell movement – that is, pulp blood flow – which correlates with the cardiac cycle. Signals recorded from teeth with pulp necrosis are significantly lower than those obtained from vital teeth. This method is more reliable than electrical testing, with optimal accuracy achieved using a wavelength of 810 nm and a bandwidth of 3.1 kHz in recently traumatized teeth, and it can also be used to assess revascularization following the reimplantation of avulsed teeth. However, some limitations remain: The presence of pigments within the crown, for example, from extravasated blood, can interfere with laser measurements.
- e) *Photoplethysmography*. This technique involves directing a beam of light from a diode onto the tooth, which is detected on the opposite side by a photodiode sensor. The wavelength, after absorption by hemoglobin is measured, allowing assessment of blood flow.

- f) *Pulse oximetry*. This method assesses the oxygen concentration in the pulp tissue, quantifying both hemoglobin levels and oxygen saturation in the circulating blood. A system of diodes emits light at different wavelengths, while a photoreceptor positioned parallel to, and on the opposite side of, the tooth receives the transmitted signals. This technique is highly reliable for evaluating the vascular status of recently traumatized teeth.
- g) *Thermography*. Measuring tooth temperature is another approach to estimating vitality: A non-vital tooth generally has a lower pulp temperature than a vital tooth. However, this method is also of limited value in recently traumatized teeth.
- h) *Other methods*. Experimental approaches include assessing pulp hypoxia using isotopes or the marker ^3H -misonidazole, which preferentially binds to oxygen-deficient cells.

A systematic review comparing different methods of assessing pulp sensibility and vitality concluded that pulse oximetry is the most accurate for determining pulp vitality. Cold testing and electrical testing were the sensibility methods most closely approximating a reliable diagnosis of pulp status, although their sensitivity and specificity remained below those of pulse oximetry [24, 25].

9. Clinical records

A standardized clinical record is essential during emergency care, throughout treatment, and at follow-up visits to ensure the collection of comparable data. Such documentation provides critical information for evaluating treatment progression and outcomes. Moreover, standardizing procedures is necessary not only for clinical consistency but also to facilitate research [23].

The Eden Baysal Dental Trauma Index [24] is a proposed system for coding traumatic dental injuries, offering a standardized approach that supports both clinical follow-up and research. The index utilizes a five-digit code to document the type of fracture – coronal or radicular – the involvement of the periodontal ligament and alveolar process, as well as the stage of apical maturity.

To validate this index, the RAND-modified e-Delphi method was employed, a consensus-based technique that integrates scientific evidence with expert opinion and clinical experience.

In this index, the number of the tooth, according to the FDI notation, is first recorded in parentheses, followed by each of the codes described in Eden E, et al. [24]. For instance, an uncomplicated crown–root fracture affecting the right maxillary central incisor, without periodontal involvement, with a closed apex, and no alveolar bone involvement, would be coded as follows: (11) 4 0 N m -.

This index has been validated in subsequent studies, demonstrating good reliability and reproducibility [25,26].

10. Management of crown fractures

Patient compliance with follow-up appointments and prescribed home care plays a crucial role in promoting healing and improving the prognosis of DT. Both patients and their parents or guardians should receive guidance regarding the care of the

injured tooth or teeth and surrounding tissues. Recommendations should include measures to support optimal healing, prevent further injury – such as avoiding participation in contact sports – maintain meticulous oral hygiene, and use an antibacterial rinse, for example, 0.12% chlorhexidine gluconate, in cases involving injuries to the periodontal ligament or soft tissues.

The treatment options are summarized in **Table 1** and are based on the 2020 International Academy of Dental Traumatology recommendations [27].

10.1 Enamel infraction

No treatment is required, although some authors suggest applying a liquid resin or a flowable composite to prevent the appearance of stains, which may cause esthetic concerns, as well as bacterial contamination through the infraction line.

Sensitivity tests are usually positive from the outset and remain so at follow-up appointments. However, if the initial test is negative, it is not advisable to indicate endodontic treatment immediately; instead, it is preferable to wait until clinical signs (pain or crown discoloration) or radiographic signs (apical radiolucency) appear.

In immature teeth, continued apical closure is an indicator of favorable healing.

Infraction	Enamel fracture	Uncomplicated enamel and dentin fracture	Complicated enamel and dentin fracture
Treatment needs			
• No treatment. • In cases of severe infractions, the affected area should be etched and sealed using a bonding resin.	• Polish the enamel margin. • Bond the fragment. • Restoration with composite resin and an adhesive technique.	• Rehydration of the fragment and reattachment using an adhesive technique. • If the exposed dentin is within 0.5 mm of the pulp, a calcium hydroxide liner or a hydraulic cement should be applied, followed by restoration using an adhesive technique.	• Mature and immature root and vital tooth: Partial pulpotomy or pulp capping is recommended, using non-setting calcium hydroxide or hydraulic cements applied directly to the pulp exposure. • Immature necrotic tooth: apexification or revascularization techniques. • Mature necrotic tooth: Root canal treatment is the preferred option. • The restoration will be done by bonding the tooth fragment, if available. In the absence of an intact crown, restoration using an adhesive technique is the best option.
Follow-up			
No follow-up is required if it is certain that the tooth sustained only an infraction injury.	Clinical and radiographic evaluations are recommended at the following intervals: • After 6–8 weeks • After 1 year	Clinical and radiographic evaluations are necessary at the following intervals: • After 6–8 weeks • After 1 year	Clinical and radiographic evaluations are necessary at the following intervals: • After 6–8 weeks • After 3 months • After 6 months • After 1 year

Table 1.
Treatment and follow-up.

No follow-up is required if it is certain that the tooth has sustained only an infraction. In cases where an associated injury, such as a luxation, is present, the specific follow-up protocol for that injury should take precedence. However, since it is not always possible to accurately determine the depth of infraction lines, sensibility testing is recommended – using adjacent teeth for comparison – as a baseline for monitoring the tooth's condition over time.

If healing is unfavorable, clinical and radiographic signs of pulp necrosis, apical periodontitis, or, in the case of immature teeth, arrested apical development may be observed.

10.2 Enamel fracture

In cases of minor fractures, the affected tooth can be polished to prevent irritation of the adjacent soft tissues. Subsequent recontouring of the incisal edge, and occasionally of the adjacent tooth, may be performed to achieve an optimal esthetic outcome. Achieving such results can be particularly challenging at the mesial angle of the maxillary central incisors due to their right-angled anatomy.

When these approaches are not feasible, or when the fractured segment is larger, the recommended treatment is restoration using a conventional adhesive technique.

The absence of clinical signs and symptoms, along with continued apical closure in immature teeth, are indicators of favorable healing.

Follow-up appointments should be scheduled at 6–8 weeks and again at one year. In cases involving an associated luxation injury or suspected root fracture, the follow-up period should be extended according to the protocol for the more severe injury.

If healing is unfavorable, clinical and radiographic signs of pulp necrosis, apical periodontitis, or, in immature teeth, arrested apical development may be observed. It is also essential to monitor the condition of the restoration, as loss or marginal deterioration can compromise the long-term prognosis of the tooth.

10.3 Enamel and dentine fracture (uncomplicated)

The priority is to cover the exposed dentine [28]. If the fractured fragment is available and fits well, it can be rehydrated in saline for approximately 20 minutes and repositioned using an adhesive technique. Rehydration is very important as it strengthens fracture resistance when using adhesive techniques [29].

If the fragment is not available, the tooth can be reconstructed with composite resin. When the fracture extends to 0.5 mm or less from the pulp (a pink area may be visible, but there is no bleeding), it is advisable to apply calcium hydroxide and glass ionomer cement before placing the composite resin, or alternatively, a hydraulic cement followed by composite restoration. Other options, such as crowns or ceramic veneers, should only be considered once the development and eruption of the affected tooth are complete.

Figure 2 illustrates the coating of the exposed dentin, with the pink dot indicating the proximity of the pulp, using a glass ionomer material until the restoration can be performed.

Follow-up should be carried out at 6–8 weeks and subsequently at one year. As with all cases, if there is suspicion or certainty of coexisting injuries, follow-up should adhere to the protocol for the most severe lesion.

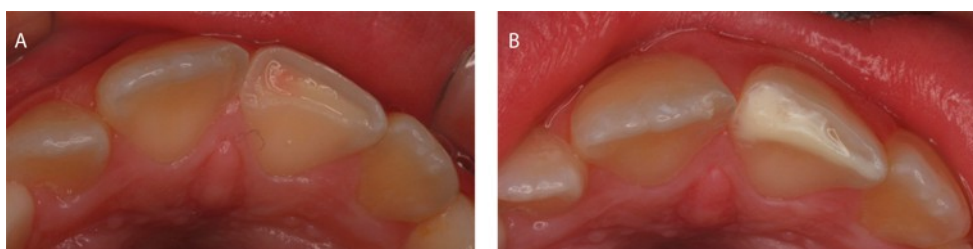


Figure 2.
Enamel and deep dentine fracture. (a) Visible pink spot indicating proximity to the pulp. (b) A glass ionomer cement was placed.

Favorable healing is indicated by a positive response to pulp sensibility tests, the absence of pain, inflammatory signs, or tooth discoloration, and normal root development in immature teeth.

Conversely, the presence of clinical signs or symptoms of pulp necrosis, apical periodontitis, or loss of the restoration signifies an unfavorable outcome. Compromise or deterioration of the restoration may negatively affect the long-term prognosis of the tooth.

10.4 Complicated fracture

In these fractures, where the pulp is exposed to the oral environment, there are several treatment options [27]:

- Direct pulp capping
- Partial pulpotomy (superficial or cervical)
- Apexification
- Revascularization
- Conventional endodontic treatment

As in these cases, the primary goal is to preserve pulp vitality; several factors must be considered when choosing the appropriate treatment:

- Time elapsed between the traumatic event and the initiation of dental care is critical; shorter intervals are associated with a higher likelihood of pulp survival.
- Size of the pulp exposure: Smaller exposures are associated with a better prognosis.
- Degree of apical development: Due to increased vascular supply, if the pulp does not become necrotic, an open apex has a better prognosis.
- Involvement of the periodontal ligament: If apical development is complete and the tooth has been displaced, pulp vascularization may be compromised, thereby affecting its survival.

The choice of treatment depends on the combination of these factors. If the lesion is small, only a short time has passed since the trauma, the apex is open, and there is no periodontal involvement, direct pulp capping and restoration of the tooth are indicated. If the pulp exposure is of intermediate size, more time has elapsed since the trauma, and the apex is still immature, a superficial partial pulpotomy (removing 2–3 mm of coronal pulp) is recommended. However, if the pulp exposure is large or more than 24 hours have passed since the trauma, a cervical pulpotomy (up to the entrance of the root canal) is indicated. Currently, the placement of a hydraulic cement followed by composite restoration is considered the first-line treatment for a vital tooth, whether the apex is open or closed [30]. **Figure 3** illustrates the therapeutic procedure for a coronal fracture complicated with a hydraulic cement and adhesion of the fractured fragment.

The clinical procedure involves cleaning the exposed pulp with saline, performing the pulpotomy when necessary, using sterile instruments, controlling bleeding with sterile cotton and pressure, placing the hydraulic cement, and, once set, restoring with composite resin or reattaching the fragment if available [31].

Follow-up evaluations should be conducted at 6–8 weeks and at 3, 6, and 12 months. Continued apical closure, together with the absence of clinical signs and symptoms, indicates a favorable outcome.

When signs of pulp necrosis or a periapical lesion appear, further treatment is required according to the clinical situation.

- a) *Immature teeth (open apex) with pulp necrosis.* In cases of immature teeth with pulp necrosis, apexification is indicated. The pulp is carefully removed using endodontic files, and the canal is thoroughly irrigated with sodium hypochlorite. The canal is then dried with paper points and filled with a paste of calcium hydroxide and saline, sealed with glass ionomer. When

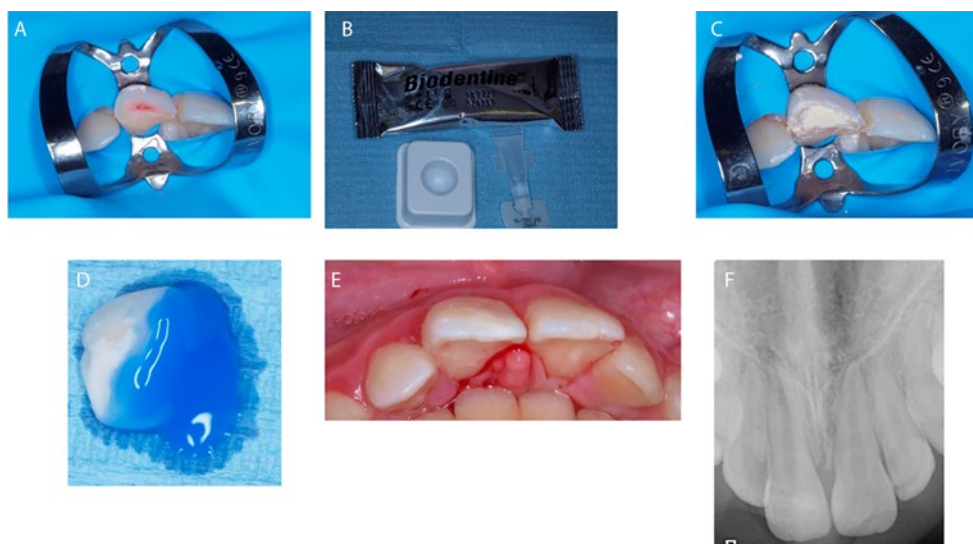


Figure 3. Bonding of the fractured fragment in a complicated crown fracture. (a) Isolation and cleaning of dentin and pulp. (b) Hydraulic cement. (c) Application of hydraulic cement on the exposed pulp. (d) Fragment preparation for bonding. (e) Incisal view of the attached fragment. (f) Xray image of the evolution after two years.

apexification is performed using calcium hydroxide alone, the patient is reviewed every three months, and the calcium hydroxide is replaced until apical closure is achieved, allowing for conventional root canal obturation with thermoplastic gutta-percha. This method is now less frequently used, as modern bioinductive materials are more effective in promoting apical closure.

- b) *Procedure using hydraulic cement.* One month after the initial calcium hydroxide placement, and once purulent drainage has ceased, the calcium hydroxide is removed. The canal is thoroughly irrigated with sodium hypochlorite and dried with paper points. Hydraulic cement is introduced and compacted with paper points to form an apical barrier. Once the cement has set, the canal is filled with gutta-percha, and the crown is restored. Modern hydraulic cements that minimize tooth discoloration can be used to fill the canal up to 3 mm below the dentin–enamel junction, with the remaining space restored using flowable composite.
- c) *Revascularization in immature teeth.* Following appropriate chemo-mechanical cleaning and disinfection with calcium hydroxide, a second session is scheduled 2–4 weeks later. The canal is reopened, irrigated again with sodium hypochlorite and saline, and apical bleeding is induced using a sterile file. The canal is partially filled with blood, and hydraulic cement is placed 2–3 mm below the cement–enamel junction. A collagen matrix or platelet-rich plasma may be positioned beneath the cement, and the crown is conventionally restored. For this second session, anesthesia without a vasoconstrictor is recommended, although evidence supporting its facilitation of apical bleeding is limited [32–34].
- d) *Mature teeth (closed apex) with pulp necrosis.* Conventional root canal treatment is the standard approach. However, some authors have proposed revascularization techniques, although evidence of success is limited [35].

11. Conclusions

Crown fractures are the most common form of dental injury, particularly in children and adolescents. When preventive measures fail and a crown fracture occurs, it is essential to perform an accurate diagnosis and evaluate the extent of the lesion while ruling out any associated injuries to adjacent teeth or surrounding tissues. Initial management should include measures to prevent the margins of the fractured tooth from causing trauma to the surrounding soft tissues, such as careful polishing. Assessing pulp status and striving to preserve pulp vitality are fundamental objectives. This text outlines an organized sequence of clinical actions designed to achieve these goals.

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Chapter 2

Cracked Teeth and Uncomplicated Enamel Fractures Following Dental Trauma: Diagnostic and Treatment Approaches

Aslı Silkkü and Hülya Erten Can

Abstract

Dental trauma, particularly cracked teeth and uncomplicated enamel fractures, is a common clinical condition that requires accurate diagnosis and intervention. This section provides a detailed discussion of the etiology, classification, clinical and radiographic evaluation methods, and current treatment protocols for the aforementioned types of injuries. Cracked teeth range from craze lines to vertical root fractures and are clinically significant. This section presents a detailed algorithm for the use of the transillumination technique, staining technique, functional stress tests (bite test), and three-dimensional (3D) imaging methods (Cone-beam computed tomography [CBCT]), which are the gold standard in the diagnosis of cracked teeth. For uncomplicated enamel fractures, follow-up protocols aimed at preserving restorative and periodontal health in the long term with minimally invasive approaches are systematically explained. This section also includes treatment flow charts and complication management strategies based on the current guidelines of the International Association of Dental Traumatology (IADT). The importance of early intervention, even in mild forms of dental trauma, is emphasized, supported by patient education and preventive measures, providing readers with a practical guide.

Keywords: dental trauma, cracked tooth, enamel fracture, transillumination, minimally invasive approach, adhesive restoration

1. Introduction

Cracked teeth and enamel fractures that develop after dental trauma are clinical conditions commonly encountered in modern dentistry but require special expertise for diagnosis and treatment. These pathologies, which are particularly prevalent in children and young adults, can lead to serious complications such as pulp necrosis, periodontal problems, and tooth loss if not diagnosed correctly. Thanks to recent advances in adhesive dentistry and minimally invasive approaches, significant progress has been made in the management of these cases. In this section, the

etiopathogenesis, current classifications, evidence-based diagnostic methods, and treatment protocols for cracked teeth and uncomplicated enamel fractures will be discussed from a multidisciplinary perspective. This content, prepared in accordance with the guidelines of the International Association of Dental Traumatology (IADT), aims to guide clinicians in their daily practice. The importance of early diagnosis and preventive approaches will be emphasized, and the strategies necessary to achieve successful treatment outcomes in the long term will be examined in detail.

1.1 Definition and importance of dental trauma

Dental trauma refers to sudden damage to teeth and surrounding tissues caused by various physical factors; it is an important public health issue with a high prevalence among children and young adults from an epidemiological perspective. Traumatic injuries affecting anterior teeth, in particular, require a multidisciplinary approach due to their esthetic and functional loss, psychosocial effects, and treatment costs. These conditions, which range from simple cases such as enamel fractures to complex cases such as avulsions requiring urgent intervention, are clinical scenarios where the risk of complications can be reduced with accurate diagnosis and timely intervention.

1.2 Epidemiology

Dental trauma is an important public health issue, particularly prevalent in the pediatric and adolescent populations. Epidemiological studies indicate that the prevalence of trauma in permanent teeth ranges from 15% to 30% and that the likelihood of experiencing at least one dental trauma in a lifetime is approximately 25% [1–3]. When examining age distribution, it has been reported that the 8–12 age group constitutes the highest risk group, with maxillary central incisors being the most commonly affected teeth [4]. Studies on gender differences have shown that the incidence of dental trauma is 1.5–2 times higher in boys than in girls, and this difference becomes more pronounced during adolescence [4, 5]. Etiological factors vary by age, with falls (62%) being the most common cause in preschool-aged children, sports injuries (38%) and bicycle accidents (25%) in school-aged children, and violent incidents (29%) and traffic accidents (17%) in adolescents [6–8]. When occlusal risk factors are evaluated, it has been reported that the risk of trauma increases by 3.2 times in the presence of an overjet exceeding 5 mm, and that this risk can be significantly reduced with protective orthodontic treatments [9, 10]. In terms of geographical and socioeconomic factors, the incidence is 40% higher in urban areas than in rural areas, and a low socioeconomic status is associated with a 1.8-fold increased risk [11, 12]. Sports-related dental injuries are observed in 18–40% of school-age children, but the use of appropriate mouthguards has been shown to reduce this risk by 82–93% [13, 14]. These findings clearly highlight the importance of preventive dentistry practices and multidisciplinary approaches in the prevention of dental trauma.

1.3 Clinical relevance in modern dentistry

Cracked teeth and uncomplicated enamel fractures represent not only a common clinical challenge but also a critical aspect of modern dental practice due to their

direct impact on function, esthetics, and long-term oral health. In contemporary dentistry, where patient expectations have significantly increased, even minor enamel fractures are no longer considered solely as esthetic concerns but as potential precursors of more complex structural damage. Early detection of microcracks and minimally invasive management strategies, supported by advancements in adhesive materials, digital diagnostics, and preventive protocols, enable clinicians to preserve natural tooth structure while maintaining functional and esthetic harmony. Furthermore, the integration of interdisciplinary approaches involving restorative, endodontic, and orthodontic perspectives underscores the clinical relevance of these injuries in providing comprehensive patient care.

1.4 Advances in adhesive and minimally invasive dentistry

The management of cracked teeth and uncomplicated enamel fractures has undergone a significant paradigm shift in recent decades with the development of adhesive materials and minimally invasive techniques. Traditional restorative approaches often required extensive tooth preparation and removal of healthy dental tissue, which inevitably weakened the tooth structure and increased the risk of future complications. In contrast, contemporary adhesive dentistry allows clinicians to preserve the maximum amount of sound enamel and dentin by relying on micromechanical and chemical bonding principles, resulting in restorations that are both esthetically pleasing and biomechanically stable. The introduction of nanofilled and bioactive composites, alongside improvements in bonding agents, has enhanced not only the longevity of restorations but also their ability to mimic natural tooth properties [3, 15]. Furthermore, minimally invasive protocols such as selective enamel etching, resin infiltration of microcracks, and the use of glass ionomer cements in high-risk pediatric populations emphasize the importance of conservative management strategies [10]. These advances are particularly critical in the treatment of young patients following dental trauma, as the preservation of pulp vitality and periodontal health directly influences long-term outcomes. From a clinical perspective, the integration of adhesive dentistry principles with preventive measures represents one of the most impactful developments in modern dental traumatology, aligning with the overarching goal of enhancing patient comfort, reducing costs, and ensuring sustainable oral health.

2. Etiology and risk factors of dental trauma

Dental trauma is multifactorial in origin, with the primary etiological factors being falls (40–58%), sports injuries (15–32%), traffic accidents (5–18%), and violent incidents (8–12%) [3]. Risk factors are shaped by developmental, environmental, and behavioral parameters. Anatomical predispositions, particularly an overjet exceeding 5 mm, increase the risk of trauma by 2.5–3 times [9]. When behavioral factors are examined, the incidence of dental injuries in athletes ranges from 22% to 35%, and this risk increases by 7.6 times in those who do not use protective mouthguards [14].

Among environmental factors, urban living (63%), low socioeconomic status, and unsafe playground structures play a significant role [11]. Systemic diseases (such

as epilepsy and osteogenesis imperfecta) and parafunctional habits, such as bruxism, also emerge as other critical factors increasing the risk of dental trauma [12]. This multifactorial structure highlights the need for personalized planning of protective measures.

2.1 Mechanical and environmental factors

Mechanical forces and environmental conditions play a central role in the etiology of dental trauma, particularly in the development of cracked teeth and uncomplicated enamel fractures. Direct impacts, such as accidental falls, collisions during sports, and traffic-related injuries, are among the most common causes of enamel and dentin damage [2, 4]. Beyond acute trauma, repetitive mechanical stress – such as parafunctional habits, including bruxism or clenching – has been shown to increase the risk of microcrack propagation and cusp fractures by nearly threefold [16]. Environmental factors also exert a significant influence: children living in urban areas are more likely to experience trauma due to high population density, unsafe playground structures, and greater exposure to traffic accidents [11]. Seasonal variations have similarly been reported, with a higher incidence of dental injuries during summer months when outdoor activities intensify [1]. Moreover, occupational risk factors, such as participation in contact sports without adequate protective equipment, can further exacerbate mechanical stress on anterior teeth. From a preventive standpoint, the use of custom-fitted mouthguards has been demonstrated to reduce the incidence of trauma by up to 90% in athletes [14]. Taken together, mechanical and environmental risk factors highlight the importance of early recognition and targeted preventive measures in high-risk populations, ensuring not only the preservation of dental structures but also a reduction in long-term restorative needs.

2.2 Systemic diseases and predisposing conditions

Systemic diseases and predisposing medical conditions are increasingly recognized as critical contributors to the susceptibility of cracked teeth and enamel fractures. Disorders such as osteogenesis imperfecta, Ehlers-Danlos syndrome, and amelogenesis imperfecta directly impair the biomechanical integrity of dental tissues, making them more prone to trauma-induced fractures even under relatively low-intensity forces [17]. Similarly, osteoporosis has been shown to reduce enamel elasticity and dentin mineral density, resulting in a 1.8-fold increase in the prevalence of cracked teeth among affected individuals [18]. Patients with systemic conditions like epilepsy also present an elevated risk, as sudden seizure-induced falls frequently lead to traumatic injuries of the anterior teeth [12]. In addition, nutritional deficiencies – particularly hypocalcemia and vitamin D deficiency – have been linked to increased enamel fragility and delayed healing responses after trauma [8]. Beyond systemic disease, iatrogenic dental procedures themselves can act as predisposing factors: aggressive cavity preparation, excessive occlusal reduction, and postcore restorations significantly increase the risk of vertical root fractures, with incidence rates reaching up to 18% in some clinical studies [19]. These findings underscore the necessity of a personalized treatment approach, in which clinicians evaluate not only the local trauma characteristics but also the systemic and medical history of the patient. Preventive strategies, such as dietary supplementation, night

guards in bruxism patients, and atraumatic restorative techniques, therefore, become integral in reducing the likelihood of fracture progression and long-term complications.

2.3 Behavioral and lifestyle-related risk factors

Behavioral patterns and lifestyle choices are critical determinants in the occurrence and prognosis of dental trauma, particularly in cracked teeth and uncomplicated enamel fractures. Among these, bruxism and clenching are the most significant contributors, exerting repetitive parafunctional forces on enamel and dentin that gradually propagate microcracks into clinically significant fractures [16]. Stress-induced bruxism, which has been shown to affect up to 20% of adults, not only accelerates tooth wear but also predisposes individuals to vertical root fractures [17]. In adolescents, sports participation without protective equipment remains a prominent lifestyle risk factor; studies report that up to 40% of dental trauma cases in school-age children are directly linked to contact sports [14]. Beyond mechanical forces, dietary habits such as frequent consumption of hard foods (ice, hard candies) or sudden temperature changes in food intake (very hot or cold beverages) have been associated with increased enamel stress and crack formation [20]. Moreover, substance abuse, particularly chronic alcohol consumption, has been correlated with higher trauma incidence due to impaired motor coordination and increased risk-taking behavior [1]. Collectively, these findings demonstrate that behavioral and lifestyle factors not only influence the initial occurrence of trauma but also significantly affect long-term treatment outcomes, underscoring the importance of comprehensive patient education and the promotion of healthy lifestyle modifications as part of trauma prevention strategies.

2.4 Preventive approaches in high-risk groups

Prevention remains the cornerstone of managing dental trauma in high-risk groups, particularly children, adolescents, and athletes. Epidemiological data clearly show that individuals with increased overjet (>5 mm), untreated malocclusions, or parafunctional habits such as bruxism have up to a threefold higher risk of traumatic fractures [9, 20]. In pediatric patients, early orthodontic correction of excessive overjet and lip incompetence has been demonstrated to significantly reduce trauma prevalence, highlighting the importance of preventive orthodontics [10]. For athletes, especially those engaged in contact sports such as football, basketball, and martial arts, custom-made mouthguards are considered the gold standard, offering up to 90% protection compared to stock devices [14]. In patients with systemic risk factors like osteoporosis or enamel hypoplasia, preventive strategies include fluoride varnish applications, resin infiltration techniques, and the use of minimally invasive adhesive restorations to strengthen enamel against microcracks. Furthermore, patient education plays a critical role: awareness programs in schools and sports clubs have been shown to increase compliance with preventive measures by more than 60% [21]. Collectively, these preventive approaches, ranging from orthodontic interventions to behavioral counseling and protective gear, form a comprehensive strategy that not only reduces the incidence of dental trauma but also minimizes long-term complications, treatment costs, and esthetic concerns in vulnerable populations.

3. Andreasen classification, Eden trauma classification, or other current classifications

Dental trauma classifications play a critical role in standardizing diagnosis and treatment protocols. The Andreasen classification is considered the most comprehensive classification, categorizing dentoalveolar injuries based on tissue type (enamel, dentin, pulp) and the type of displacement (luxation, avulsion) [22].

The Eden Trauma Classification, on the other hand, offers a three-tiered approach to simplify clinical practice: simple (enamel-dentin fractures), moderate (fractures exposing the pulp), and complex (avulsion/root fracture) [23].

In the current literature, the modified classification proposed by the IADT is designed to be integrated with treatment algorithms, particularly for luxation injuries [20].

The fundamental difference between these classifications is that Andreasen's is histologically focused, Eden's is clinically focused, and IADT's is treatment-oriented.

3.1 Comparison of different classification systems

The classification of dental trauma has evolved over time, with each system offering unique perspectives that serve different clinical purposes. The Andreasen classification remains the most comprehensive, dividing injuries based on histological involvement of enamel, dentin, pulp, and periodontal tissues, and is particularly useful in academic and epidemiological contexts [3]. In contrast, the Eden trauma classification simplifies the categorization into three clinical tiers – simple, moderate, and complex – providing a more straightforward framework for general practitioners in daily practice [23]. Meanwhile, the IADT-modified classification emphasizes treatment-oriented categories, integrating diagnostic findings with clinical decision-making pathways and flowcharts that are highly valuable for trauma management in emergency settings [20]. Comparative studies suggest that while Andreasen's system allows for detailed research-oriented data collection, Eden's model improves communication and consistency among clinicians with varying levels of expertise. The IADT system, however, bridges both diagnostic accuracy and practical applicability by linking classification directly to evidence-based treatment algorithms [4]. Thus, no single classification can be considered universally superior; rather, their combined application – academic, clinical, and guideline-driven – provides the most holistic approach. In modern practice, clinicians often rely on Andreasen for academic reporting, IADT for treatment planning, and Eden for quick chairside decision-making, highlighting the complementary nature of these systems.

3.2 Practical use of classifications in daily clinical practice

In daily clinical practice, the use of trauma classifications serves as more than an academic exercise; it provides a structured framework for diagnosis, communication, and treatment planning. For example, the Andreasen classification is particularly helpful in documentation and referral cases, allowing specialists to clearly identify the histological extent of an injury, which can later guide prognostic evaluation [3]. In contrast, the Eden classification facilitates rapid chairside decisions, particularly in primary care or emergency settings where time is limited,

and straightforward categorization can assist general practitioners in deciding whether a case requires referral or immediate intervention [23]. The IADT system, however, has the most direct impact on treatment pathways, as it integrates diagnostic criteria with step-by-step therapeutic recommendations, thus reducing variability in treatment decisions among clinicians [20]. From a practical perspective, many clinicians combine elements of these systems: they use Andreasen for record-keeping and academic reporting, Eden for initial triage, and IADT guidelines for definitive treatment protocols [4]. This layered approach not only enhances diagnostic accuracy but also improves patient safety by ensuring that no aspect of trauma evaluation is overlooked. Importantly, the effective use of classification systems in daily practice also enhances interdisciplinary collaboration, as a common diagnostic language allows restorative dentists, endodontists, and orthodontists to coordinate seamlessly in complex trauma cases.

4. Trauma and cracked teeth

Dental trauma is one of the most important etiological factors in the formation of cracked teeth. Acute traumatic forces, such as falls, sports injuries, or traffic accidents, particularly in anterior teeth, can cause damage ranging from microscopic cracks in the enamel and dentin to vertical root fractures. Epidemiological data indicate that the incidence of cracked teeth in individuals who have experienced dental trauma ranges from 18% to 25% [20]. The clinical significance of cracks formed after trauma is directly related to the proximity of the fracture line to the pulp and periodontal ligament involvement. In addition to acute impacts, chronic traumatic forces (bruxism, abnormal occlusal contacts) can also cause progressive stress fractures in enamel and dentin tissue. Clinical studies have shown that traumatic forces increase the risk of crack formation by 3.5 times, particularly in teeth with large restorations [24].

4.1 General classification of cracked teeth

Teeth cracked as a result of dental trauma are classified according to their clinical appearance, depth, and prognosis. According to the classification accepted by the American Association of Endodontists (AAE; 2020), cracked teeth are examined in four main categories [25]:

- Craze lines (superficial enamel lines): These are microscopic cracks that affect only the enamel layer. They are usually asymptomatic and do not require treatment.
- Wedge fractures (cuspal fractures): These are fractures that extend from the occlusal surface to the enamel-dentin junction but do not affect the pulp. Sharp pain during chewing is characteristic.
- Split tooth (two-part separation): An irreversible condition in which the fracture line extends to the pulp chamber and often reaches the root surface.
- Vertical root fractures: The most complex form, progressing from apical to coronal and involving the periodontal ligament.

Treatment selection for cracked teeth is determined based on critical factors, such as the proximity of the fracture line to the pulp and periodontal ligament involvement. This classification serves as a guiding reference for clinicians throughout the entire clinical process, from diagnosis to treatment planning.

4.2 Types of cracked teeth

Cracked teeth are classified into five main categories based on clinical appearance, depth, and prognosis. Craze lines are the mildest form, affecting only the enamel layer and are usually asymptomatic. Cusp fractures are fractures that extend from the occlusal surface to the enamel-dentin junction but do not affect the pulp, manifesting as sensitivity during chewing. A split tooth is an irreversible condition where the fracture line extends into the pulp chamber and often reaches the root surface. Vertical root fractures are the most complex form, progressing from apical to coronal and showing periodontal ligament involvement, requiring radiographic examination. Finally, fractured root syndrome is a type of crack that damages the microvascular network, particularly in teeth that have undergone endodontic treatment.

The AAE supports this classification, noting that 67% of crack types are confirmed by transillumination and 89% under a microscope [15]. Clinically, 45% of cracked teeth are molars, 38% are premolars, and 17% are anterior teeth, with the risk increasing by 3.2 times in teeth with bruxism and large restorations [16]. Treatment options vary from adhesive methods to extraction, depending on the type and depth of the crack.

Multifactorial etiology plays a role in the formation of cracked teeth. Epidemiological studies show that the most common causes include occlusal trauma (42–58%), large restorations (35%), and a history of dental trauma (22%) [16]. Bruxism and teeth-grinding habits are important predisposing factors that increase the risk of crack formation by 3.2 times [26]. When iatrogenic causes are examined, it has been reported that the incidence of vertical root fractures increases by 15–18% after postcore applications, and this risk increases by 2.7 times in teeth with excessive cavity preparation [19].

Among anatomical risk factors, deep fissured occlusal morphology (38%) and thin enamel layer (25%) stand out [17]. When systemic factors are evaluated, it has been found that the prevalence of cracked teeth is 1.8 times higher in patients with osteoporosis and 2.3 times higher in those with nutritional disorders [18]. The decrease in enamel elasticity with the aging process increases the incidence of cracks by 40% in individuals over the age of 50 [17]. Acute forces, such as sports injuries and traumatic occlusion, can cause sudden fractures, particularly in premolar teeth [20]. This multifactorial structure highlights the need for personalized preventive measures.

4.3 Diagnosis of cracked teeth

The diagnosis of cracked teeth requires a multidisciplinary approach. Clinical evaluation should begin with a detailed medical history; the mechanism and duration of the trauma, as well as symptoms such as sharp pain during chewing, should be carefully questioned. The transillumination technique is considered the gold standard for identifying crack lines, with 89% sensitivity – homogeneous light

transmission is observed in intact teeth, while light absorption is observed in the presence of cracks. The bite test (78% specificity) involves applying specific cusp pressure using a rubber rod or Tooth Slooth device to determine the location of pain.

In radiographic evaluation, periapical radiographs can detect vertical root fractures with 60–70% sensitivity, while CBCT provides 3D evaluation with 94% accuracy. In the percussion test, the vertical test is usually negative (65–70% of cases) in cracked teeth, while positive horizontal percussion (40–45% of cases) suggests periodontal ligament inflammation and a fracture reaching the root surface [20]. Sensitivity in the apical region during palpation may be an early indicator of pulp necrosis or periapical pathology [21]. Tests performed within the first 24–48 hours after acute trauma may yield false-positive results; therefore, it is recommended to wait 48 hours for a reliable assessment [27].

4.3.1 Differential diagnosis in cracked teeth

In the differential diagnosis of cracked teeth, reversible/irreversible pulpitis and dentin hypersensitivity should be considered first. Reversible pulpitis is characterized by short-term pain in response to cold stimuli, while irreversible pulpitis is distinguished by spontaneous pain and a prolonged pain response. Dentin hypersensitivity typically presents as short-term sharp pain and, unlike cracked teeth, responds more distinctly to mechanical stimuli. Current IADT guidelines (2022) emphasize the importance of early intervention in cracked teeth when symptoms are present. New-generation Diagnodent devices provide a significant diagnostic advantage with an 82% accuracy rate in detecting microcracks.

4.3.2 Modern imaging techniques (CBCT, microscopy, AI-based tools)

The diagnostic accuracy of cracked teeth has been greatly enhanced in recent years through the integration of advanced imaging technologies and digital tools. CBCT, in particular, has emerged as the gold standard for 3D assessment, offering up to 94% accuracy in detecting vertical root fractures that remain undetectable on conventional periapical radiographs [28]. The ability of CBCT to visualize fracture lines in multiple planes not only improves diagnostic precision but also assists in treatment planning by clarifying the extent of pulpal and periodontal involvement [29]. Dental microscopy has further improved the detection of microcracks and craze lines, with magnification enabling clinicians to identify subtle fracture propagation that may otherwise go unnoticed [15]. In addition, transillumination coupled with digital photography allows for real-time chairside confirmation of suspected cracks, providing both the clinician and the patient with a clear visualization of the defect. More recently, the integration of artificial intelligence (AI)-assisted diagnostic tools has shown promising results, with machine learning algorithms capable of identifying early enamel and dentin cracks with sensitivity rates exceeding 80% [17]. These technologies collectively represent a paradigm shift, moving diagnosis from subjective, experience-based judgment toward objective, data-driven accuracy. Importantly, the combination of CBCT, microscopy, and AI provides a complementary diagnostic workflow, ensuring that even the most subtle fractures are identified early, thus improving prognosis through timely and minimally invasive interventions.

4.4 Treatment of cracked teeth

The treatment approach for cracked teeth is planned gradually according to the type, depth, and symptoms of the crack. Treatment is not required for minimal cracks, such as superficial enamel lines (craze lines). However, in cases of bruxism, night guards and regular fluoride applications should be used to prevent wear [30]. In moderate cracks (cusp fractures, split teeth), direct composite bonding (45% success rate) or full crown restorations (78% success rate) are indicated; fiber postsupported resin restorations should be preferred, especially in cracks deeper than 2 mm [15]. In advanced cases (split tooth, vertical root fracture), tooth extraction is inevitable in 92% of cases after 3D evaluation with CBCT [28].

Critical factors affecting prognosis include the proximity of the crack to the pulp (65% risk of necrosis at a distance of less than 1 mm), the presence of occlusal forces (3.2 times increased complications in bruxism), and the timing of treatment (88% success rate when intervention occurs within the first three weeks). Complications include pulp necrosis in 22–35% of cases, periodontal defect development in 18% of cases, and restoration fracture in 12% of cases over a five-year follow-up period [29]. In selective cases where the root can be preserved using microsurgical approaches (GTR membranes), the seven-year survival rate has been reported as 71% [31]. In the clinical decision-making process, patient age (37% better prognosis in younger patients), tooth position (42% more complications in molars), and oral hygiene status must be evaluated.

4.5 Complications in cracked teeth and long-term follow-up

Long-term success in cracked teeth is closely related to regular follow-up and early diagnosis of complications. Clinical studies show that pulp necrosis may develop in 15–22% of cases during a five-year follow-up [32]. This risk increases threefold in cases where the crack is close to the pulp and bruxism is present. From a periodontal perspective, localized periodontal defects are observed in 18–25% of cases over a seven-year follow-up period, and this rate can reach up to 45% in cases where vertical root fracture is suspected [33].

Patient-specific preventive measures include:

- Use of night guards in patients with bruxism (65% reduction in pulp necrosis risk).
- Early detection of subclinical complications with annual bite-wing radiographs.
- Clinical check-ups every six months are recommended, especially for children and young adults.
- As a follow-up protocol, clinical and radiographic evaluation every three months in the first year, followed by annual check-ups in subsequent years, is appropriate.

4.6 Preventive and protective strategies

Preventive and protective strategies are essential in reducing the incidence and progression of cracked teeth following dental trauma. Occlusal adjustment remains a fundamental preventive measure, particularly in patients with high occlusal stress or parafunctional habits such as bruxism. By selectively reshaping premature contacts and balancing occlusal forces, the likelihood of cusp fractures and propagation of existing microcracks can be significantly reduced [16]. For patients with persistent bruxism, the use of custom-fitted night guards has been shown to decrease crack-related complications by more than 60% over a five-year follow-up period [19]. In addition, sports-related trauma prevention relies heavily on the use of protective devices; evidence suggests that athletes using individually fabricated mouthguards have up to 82–93% lower risk of anterior tooth fractures compared with those using stock devices or no protection at all [14]. Beyond occlusal and mechanical interventions, orthodontic treatment plays a preventive role in high-risk populations, as early correction of increased overjet and malocclusion can reduce trauma prevalence by up to threefold [9]. Importantly, preventive strategies should not only focus on mechanical protection but also integrate patient education and regular monitoring, ensuring early detection of subclinical fractures. When applied in combination, these measures create a comprehensive protective protocol that significantly improves long-term prognosis and preserves tooth vitality in trauma-prone individuals (**Table 1**).

5. Enamel fractures and trauma

Dental trauma is the most common cause of enamel fractures in children and young adults. These fractures, which occur mainly in the front teeth, are usually caused by falls, sports activities, and accidents. While fractures with limited enamel tissue usually only cause esthetic problems, deeper fractures can lead to sensitivity and functional disorders.

Crack type	Clinical findings	Diagnostic methods	Treatment options	Prognosis
Craze lines	Asymptomatic White lines on the enamel surface	Transillumination Direct visual examination	No treatment needed Night guard (for bruxism)	Excellent
Cuspal fracture	Pain during chewing Cold sensitivity	Bite test Periapical radiography	Composite restoration Onlay/crown	Good (with early intervention)
Split tooth	Severe pain Tooth mobility	CBCT Microscopic examination	Endodontics + crown or extraction	Poor
Vertical root fracture	Apical swelling - “J-shaped” radiolucency on radiograph	CBCT (gold standard) Surgical exploration	Hemisection or extraction	Poor (high risk of tooth loss)
Cracked tooth syndrome	Persistent pain Localized sensitivity	Microscope Transillumination	Root resection or retreatment	Variable

Table 1.
Summary table related to trauma and cracked teeth.

The severity and direction of the trauma determine the size and shape of the fracture. Minor impacts cause small cracks on the edges of the teeth, while severe trauma can result in more extensive enamel loss. In clinical evaluation, smoothing and polishing the edges of the fracture are usually sufficient, but in some cases, esthetic restorations may be necessary.

Treatment planning should take into account the self-renewal capacity of enamel tissue in young individuals [4]. Preventive measures include the use of mouth guards during sports activities and regular dental check-ups. With the right approach, long-term success rates are quite high in treated enamel fractures.

5.1 General classification of enamel fractures

Enamel fractures are divided into two main groups based on the depth of tissue affected, according to the Andreasen classification [3]:

- Uncomplicated fractures (Class I): Fractures that involve only the enamel tissue and do not affect the pulp. Clinically, they are sharp-edged, irregular in surface, and typically localized on the incisal edges of anterior teeth.
- Complicated fractures (Class II): Fractures that affect the enamel-dentine complex but do not expose the pulp. Cold sensitivity may be observed due to the exposure of the dentine layer.

The treatment approach for enamel fractures is shaped by factors such as the sharpness of the fracture edge, restorative requirements, and esthetic concerns. The remineralization potential of enamel tissue should be considered in treatment planning, especially in young patients [4]. This classification provides a basic framework for clinicians to evaluate enamel fractures in a standardized manner.

5.2 Uncomplicated enamel fractures (fractures involving only the enamel and not affecting the pulp)

Uncomplicated enamel fractures (Class I fractures) are the most common (23–35%) and have the best prognosis [3]. These fractures are limited to the enamel tissue and do not penetrate the dentin layer or pulp tissue. Clinically, they are characterized by sharp edges, irregular surfaces, and are typically localized on the incisal edges of anterior teeth. They are characterized by preserved light transmission on transillumination testing and negative percussion and palpation tests. Radiographically, they appear as a radiolucent line but do not require radiographic depth measurement as they do not reach the dentin-pulp border [34].

5.3 Diagnosis of uncomplicated enamel fractures

Macroscopic examination with a 20x magnifying dental loupe is essential for the diagnosis of uncomplicated enamel fractures. The sharpness of the fracture edges, the presence or absence of dentin exposure, and the direction of the fracture line are carefully evaluated. In the transillumination test, light transmission is preserved

in enamel fractures. Pulpal vitality should be assessed using an electric pulp test (EPT) and thermal tests, and EPT values should be compared with those of the contralateral healthy tooth.

Bite-wing radiographs help assess the proximity of the fracture line to the enamel-dentin junction. A negative percussion test in both directions is expected; a positive finding should raise suspicion of a complex fracture or luxation injury. The palpation test must be asymptomatic; otherwise, alveolar fracture or root fracture should be ruled out. The timing of tests after acute trauma is important in enamel fractures – waiting 48 hours for the inflammatory response to subside is recommended [35]. When standardized test protocols are applied, false-positive rates are reduced by 35% [36].

5.3.1 Differential diagnosis of uncomplicated enamel fractures

In the differential diagnosis of uncomplicated enamel fractures, complicated fractures (enamel-dentin-pulp involvement) and amelogenesis imperfecta should be considered first. While dentin exposure and pulp reaction are seen in complicated fractures, these findings are not present in uncomplicated fractures. Amelogenesis imperfecta, on the other hand, is typically characterized by bilateral symmetrical enamel defects and no history of trauma. The IADT guidelines (2022) recommend a six-month follow-up period for asymptomatic enamel fractures. Transillumination and radiographic evaluation play a critical role in differential diagnosis. While the prognosis for enamel fractures is better in primary teeth, esthetic concerns are more prominent in permanent teeth.

5.4 Treatment of uncomplicated enamel fractures

The current approach to the treatment of uncomplicated enamel fractures is based on three fundamental principles: Conservative intervention, esthetic restoration, and long-term protective follow-up. In clinical practice, enamel retouching and polishing are the first choices in cases where the fracture size is less than 0.3 mm. This method is of great importance, especially in pediatric and adolescent patients, as it preserves the natural remineralization capacity of the enamel tissue. In cases of larger fracture areas, modern techniques of adhesive dentistry come into play; selective enamel etching (application of 37% phosphoric acid only to the fracture surface) and restorations using nanofill composite resins provide excellent results in terms of both function and esthetics (**Table 2**).

Posttreatment follow-up protocols play a decisive role in the long-term success of uncomplicated enamel fractures. Clinical check-ups every three months for the first six months are recommended, including pulp vitality tests and functional evaluations. Especially for individuals who engage in active sports, the use of custom-made mouth guards significantly reduces the risk of recurrence. Within the scope of preventive dentistry practices, the application of fluoride varnishes every six months and patient-specific oral hygiene education are critical factors in increasing the durability of the treatment. Thanks to this comprehensive approach, the five-year success rate for uncomplicated enamel fractures can exceed 95%.

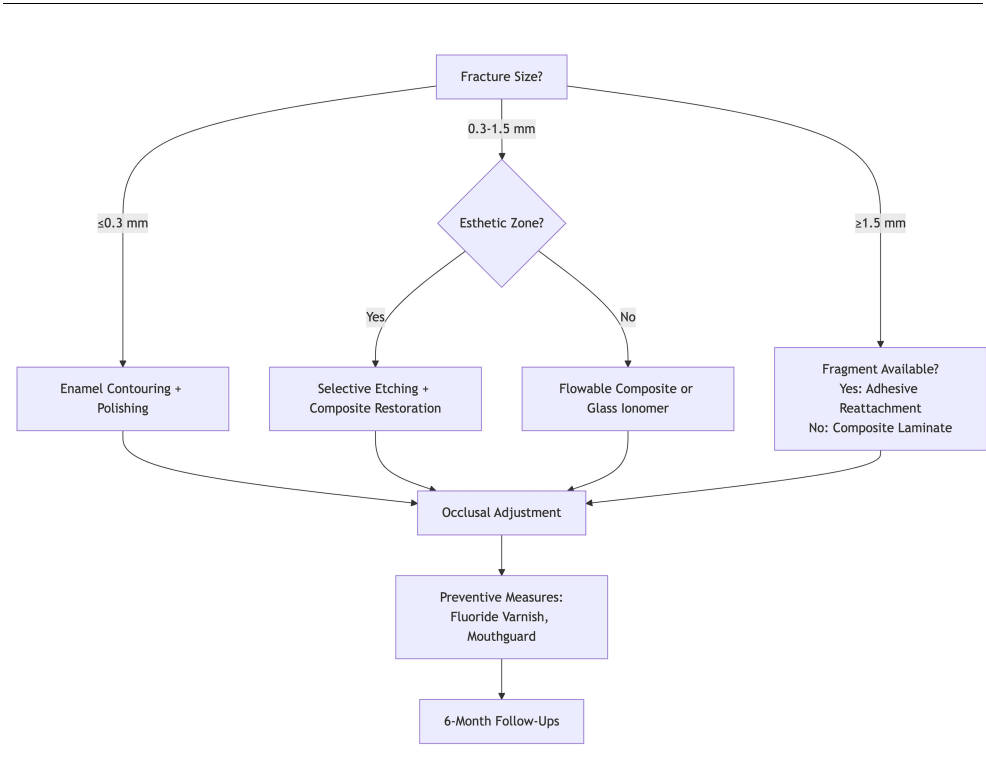


Table 2.
Treatment protocol for enamel injuries.

5.5 Complications and long-term follow-up in uncomplicated enamel fractures

The most common complication in uncomplicated enamel fractures is secondary caries, which develops in 8–12% of cases [37]. This complication is particularly observed at the edges of adhesive restorations and in cases of poor oral hygiene. Other complications that may occur in the long term include esthetic problems and enamel fragmentation.

Preventive measures:

- Six-monthly fluoride varnish applications (60% reduction in caries risk).
- Specially designed 3 mm thick mouth guards for athletes (85% reduction in the risk of new trauma).
- Regular oral hygiene education
- As a follow-up protocol, clinical examinations every three months for the first six months, followed by annual check-ups, are recommended. More frequent follow-ups may be necessary, especially in young patients, due to the potential for enamel remineralization. In cases involving restorations, it is important to evaluate the integrity of the restoration margins.

6. Conclusion

The management of cracked teeth and uncomplicated enamel fractures associated with dental trauma is an important clinical condition requiring a multidisciplinary approach and evidence-based protocols. The current data presented in this book chapter highlight the importance of transillumination and microscopic evaluation in the classification of cracked teeth, as well as selective acid etching and adhesive techniques in enamel fractures. Thanks to early diagnosis and appropriate treatment approaches, 10-year tooth survival rates can reach 88% in cracked teeth and 97% in uncomplicated enamel fractures. However, it should be noted that successful treatment outcomes are directly related to regular follow-up protocols, the careful application of preventive measures, and the accurate assessment of patient-specific risk factors. Clinicians should not neglect six-monthly periodic check-ups, especially in high-risk patients (bruxism, increased overjet, athletes), and should place the most up-to-date IADT guidelines at the center of their treatment planning. The adoption of preventive dentistry practices in dental trauma management will both increase patient comfort and reduce treatment costs in the long term.

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Chapter 3

Prevention of Dental Traumatic Lesions

Leopoldo Forner, José Luis Sanz and Carmen Llena

Abstract

Prevention of traumatic dental injuries is feasible. For greater effectiveness in reducing trauma-related dental pathology, it is essential to identify the relevant risk factors. Various epidemiological studies and clinical case reports contribute to this identification, including age (linked either to insufficient psychomotor development or to increased risk-taking in physical activities), sports participation, traffic or occupational accidents, dental malpositions, anesthetic maneuvers, situations of violence or domestic abuse, systemic diseases, among others. Each of these etiological conditions requires a distinct preventive approach. Sports activities account for a particularly high prevalence of dental trauma. In this context, prevention relies on the use of protective devices, such as mouthguards and/or helmets, depending on the specific characteristics of each sport. These devices have demonstrated substantial efficacy in reducing both the incidence and severity of such injuries. Moreover, intraoral mouthguards can be individually fabricated to adapt to the dental arch, allowing proper occlusion with the antagonist arch, ensuring ease of use, and not interfering with physiological functions such as speech, swallowing, or breathing. They are manufactured in various materials, predominantly ethylene-vinyl acetate (EVA), but also polyvinyl chloride (PVC), polymethyl methacrylate (PMMA), or polyethylene terephthalate (PET), in single- or bilaminar forms. The available scientific literature on the prevention of dental trauma is extensive; however, further research is needed to clarify differences in the effectiveness of various types of mouthguards and to optimize material selection and design for specific sports. International organizations and scientific societies provide protocols to guide their appropriate use.

Keywords: custom-fitted, dental injury, dental trauma, mouthguard, prevention, sports dentistry, sports medicine

1. Introduction

Traumatic pathology of the teeth is characterized by injuries that may involve, in some cases, the loss of dental structure (coronal, radicular, or coronoradicular) and, in severe instances, the displacement of the tooth from its alveolar socket. In milder cases, cracks or fissures may occur in the mineralized structure of the tooth. In any situation, the vitality of the dentin–pulp complex may be

irreversibly compromised, depending on the intensity of the trauma and the stage of root development of the affected tooth.

Dental trauma not only affects the tooth itself but may also lead to complications in adjacent tissues: the periodontium, alveolar bone, oral mucosa, tongue, gingiva, lips, and skin. Additional clinically relevant consequences include functional impairment due to pain or tooth displacement/loss, esthetic alterations, and the occurrence of other local or regional injuries.

These characteristics of traumatic dental injuries highlight the importance of treatment – not only in terms of quality but particularly in terms of the speed with which it is initiated. Such treatments are often complex and multifaceted, involving dental, periodontal, osseous, and esthetic considerations. Therefore, as with other oral and systemic conditions, prevention plays a crucial role in reducing both the occurrence of such injuries and the subsequent need for treatment. This preventive emphasis is further justified by the high prevalence of traumatic dental injuries [1, 2]. An appropriate preventive approach entails identifying at-risk populations, implementing suitable preventive measures, and ensuring adequate knowledge and training among dental professionals [3], who must inform patients about the available protective strategies and prescribe them when indicated.

The term "trauma" is commonly associated with a sudden, unexpected, and accidental event, which may suggest that prevention is impossible. However, this is not the case. To establish preventive measures against potential dental trauma, it is necessary to understand the circumstances surrounding such injuries, particularly how and when they occur. These aspects will be reviewed below, with special emphasis on the use of mouthguards in association with sports activities.

2. Etiology-based prevention

First, it is essential to understand how traumatic dental injuries occur. Such injuries may arise through two main pathogenic mechanisms: (i) a direct blow from an external structure (another person's body part, an object, or the ground) to the tooth, or (ii) the indirect transmission of an impact to the oral region, leading to the abrupt closure of the mouth and, consequently, the collision of one or more teeth with their antagonists.

The second issue to be addressed in establishing effective prevention is when (i.e., under which conditions or circumstances) dental trauma is most prevalent. Identifying its etiology is equivalent to determining the risk factors for these injuries. The most significant situations are summarized below.

2.1 Age

Although dental trauma can occur at any age, children represent the group with the highest prevalence [4]. Nevertheless, permanent dentition is most frequently affected [2], with the peak incidence occurring between 7 and 11 years of age [1, 5].

2.2 Sports

Nearly one-third of all dental traumatic injuries occur in the context of sports activities [5]. While such injuries are often associated with team sports,

they are also observed in individual disciplines, most frequently due to falls (e.g., cycling, skiing, equestrian sports). As with other causes of dental trauma, rapid treatment according to established protocols is critical to avoid complications [6].

2.3 Dental malpositions

An increased overjet is considered a risk factor, as it places the maxillary anterior teeth in the direct line of potential impact, further exacerbated by the lack of palatal support from mandibular anterior teeth. Similarly, incomplete lip closure also contributes to the etiology of dental trauma [7], as seen in patients with other associated conditions [8].

2.4 Traffic accidents

After falls, road traffic accidents and vehicular collisions represent the second most frequent risk factor for traumatic dental injuries [9]. The systematic use of protective measures, such as helmets and seatbelts, plays an indisputable role in preventing oral, facial, cervical, and cranial injuries, among others [10].

2.5 General anesthesia

Endotracheal intubation maneuvers during general anesthesia may cause various types of dental trauma, particularly in patients with poor oral conditions, such as untreated caries, periodontal disease, or partial edentulism. Preanesthetic diagnostic evaluation and the use of mouthguards contribute to prevention in this setting [11]. A recent survey of anesthesiologists reported that dental injuries during anesthesia are frequent, highlighting the need for improved training in dental assessment and the implementation of protective measures [12].

2.6 Domestic violence

Violence within the home may result in dental, oral, and facial injuries of varying severity. Education and awareness are crucial for preventing these situations. Accurate diagnosis and identification of their etiology are vital, both for healthcare professionals and social services [14, 15].

2.7 Self-injury

Customized dual-layer mouthguards have been used to prevent attritional dental lesions in patients with neurological disorders [13]. Dental trauma has also been reported in individuals with ADHD and ASD [8]. Lesch–Nyhan syndrome, a genetic disorder, is associated with severe self-injury involving the lips, tongue, and oral mucosa; management in such cases may include pharmacotherapy and botulinum toxin injections [14]. Protective devices fabricated in PET have also been proposed to prevent lip, tongue, or oral mucosa injuries following local anesthesia in children [15].

2.8 Musicians

Professionals who play wind instruments may experience dental wear and tooth movement [16].

2.9 Other risk factors

Additional factors identified include a history of previous dental trauma, tongue piercings, alcoholism, and being overweight [17].

3. Mouthguards in sports

As previously noted, much of the prevention of traumatic dental injuries lies in the use of protective devices – cranial, facial, oral, or combinations thereof. These devices reduce not only the incidence of traumatic dental pathology but also the severity of injuries and their complications [18]. Mouthguards, therefore, constitute the most effective measure for preventing sports-related dental trauma, as emphasized in the recent position statement of the European Association for Sports Dentistry (EA4SD) [19].

The American Dental Association (ADA) has provided a comprehensive list of both individual and team sports in which mouthguard use is recommended: acrobatics, extreme sports, lacrosse, skydiving, weightlifting, equestrian sports, inline skating, skiing, water polo, boxing, ice hockey, skateboarding, volleyball, cycling, handball, shot put, surfing, basketball, gymnastics, rugby, squash, baseball, field hockey, racquetball, wrestling, American football, track and field events, martial arts, soccer, and softball [20]. Mouthguards thus represent not only a preventive measure but also a broader health-promoting intervention.

Despite the well-established importance of protective devices in reducing sports-related orofacial injuries, their acceptance among athletes remains low. In a recent large-scale study of football players, regular use was reported by 48% of players during matches but only 22% during training sessions. The most frequently cited reasons for nonuse were discomfort and difficulties with speaking or breathing [21]. However, prior evidence has demonstrated that mouthguard use does not significantly affect phonation, respiration, concentration, or athletic performance [22]. A similar pattern was observed in another study of elite athletes: although 55% reported having sustained orofacial injuries in high-risk sports, only 25% reported using protective devices [23].

3.1 Description

Mouth protection devices are commonly classified into two major groups: intraoral and extraoral protectors. The latter includes facial protection masks, helmets, or a combination of both. Importantly, the use of extraoral devices does not exclude but rather complements the simultaneous use of intraoral protectors. While intraoral devices are generally more versatile and can be used across a wide range of sports, extraoral protectors tend to be more sport-specific.

The primary purpose of extraoral protectors is to mitigate the consequences of impacts to the face or skull. These devices are typically prefabricated and manufactured from polymeric or metallic materials.

In contrast, intraoral protectors are designed to safeguard the teeth from contact with either an external object or opposing teeth. This is achieved by covering one dental arch with a resilient material capable of absorbing and dissipating traumatic forces. When proper occlusion with the antagonist arch is maintained, the mandible can be positioned in a stable manner, thereby increasing the likelihood of preventing bone fractures (e.g., condylar fractures), although this is not always possible. In this way, intraoral protectors shield the dental structures and other oral tissues, reducing the risk of cracks, tissue loss, or dentin–pulp complex exposure, as well as dental displacements or bone fractures. Additional benefits of intraoral mouthguards have been reported, including enhanced perceived safety among athletes and a potential protective effect against cervical injuries [24].

Beyond their functional role, intraoral protectors must also meet several requirements to ensure ease of use and user acceptance. They should not cause discomfort or irritation, and they must allow drinking. Desirable characteristics include a pleasant texture, softness, ease of insertion and removal, stability, and the absence of unpleasant taste or odor.

In patients with prostheses, splints, fixed orthodontic appliances, or partial edentulism, intraoral protectors must respect and adapt to these conditions. Various alternatives have been explored to address such clinical situations.

3.2 Types

Mouthguards can generally be classified into three categories according to their method of fabrication: stock (prefabricated), boil-and-bite (adaptable), and custom-made.

Stock mouthguards are the most economical option, but they cannot be adjusted to the individual's oral anatomy, even though they are available in different sizes, typically designed for use on the maxillary arch. They are manufactured from elastic and resilient materials, but their retention depends on maintaining close contact between the upper and lower arches to prevent displacement. This limitation often leads to poor control, impaired speech, possible respiratory difficulties, reduced concentration during sports activities, and mucosal, gingival, or lingual irritation.

Boil-and-bite mouthguards offer improved adaptation to the dental arches. Two varieties are distinguished: (i) thermoplastic protectors, which soften when heated and can be molded to the shape of the dental crowns, becoming more stable upon cooling; and (ii) devices consisting of a rigid external layer combined with a semiadaptable internal lining that conforms to the occlusal and incisal surfaces. Like stock mouthguards, these are generally used on the maxillary arch. However, their shock absorption capacity is lower than that of custom-made mouthguards [25], and some studies have reported no significant difference in injury prevalence between athletes who use these devices and those who use no mouthguards at all [26].

Custom-made mouthguards provide the best performance characteristics. Fabricated on dental models obtained from impressions or intraoral scans, these devices are designed to deliver effective protection against traumatic dental injuries

while ensuring good retention, avoiding irritation of the gingiva, mucosa, tongue, or frenula, and minimizing respiratory or speech interference. These qualities lead to better user acceptance, although higher costs compared to boil-and-bite protectors may limit their use [27].

Custom-made devices may be designed for either one or both dental arches (maxillary and mandibular). Their effectiveness also depends on their occlusal relationship with the antagonist teeth [28] and on the wear of the material over time. In general, the design of a custom mouthguard should include: (i) a semirigid consistency; (ii) coverage of the dental crowns on the supporting arch; (iii) extension toward the gingival margin without reaching the buccal fold, with possible palatal extension to improve stability and retention; (iv) relief for the labial and buccal frenula; and (v) imprints of the occlusal and incisal surfaces of the antagonist arch to facilitate proper intercuspation, improving stability and comfort. Retention is further enhanced if the design extends to the second molar [27]. In the anterior region of the maxilla, positive occlusal contact with the mandibular arch should be provided [29].

Design requirements must also be adapted to specific clinical conditions. In edentulous patients, the mouthguard should occupy the space of the missing teeth to maintain stability and initial tooth positions. For individuals with removable prostheses, these devices should be removed during sports activity to avoid displacement or fracture. Similarly, removable orthodontic appliances must be taken into account. Fixed orthodontic treatments (bands and brackets) do not preclude mouthguard use, although adaptation is more complex, and care must be taken to prevent excessive pressure on the orthodontic hardware or loss of retention [30]. Various alternatives using dual-layer polyolefin protectors have been described: creating space for brackets, protecting them with silicone wax, or applying a second PET-G layer [31]. Solutions have also been proposed for athletes with dental implants [32].

Regardless of type, mouthguards must be properly maintained. Before use, they should be rinsed with water; after sports activity, they must be removed, cleaned, and brushed with soap or toothpaste, or treated with cleansing tablets. They should be dried and stored in a ventilated protective case until their next use. Disinfection with hydrogen peroxide or 0.5% sodium hypochlorite has also been recommended [33], following manufacturer instructions [19].

In athletes with developing dentition, mouthguards must be replaced frequently to avoid interfering with the eruption process.

3.3 Materials

The composition of a mouthguard must provide a series of properties – elasticity, impact and wear resistance, deformability, thickness, and retention – which must be balanced to ensure effectiveness, safety, and optimal user acceptability.

Ethylene–vinyl acetate (EVA) is the most widely used material for mouthguard fabrication and has been the subject of numerous investigations. EVA has also been tested in combination with other materials: polyvinyl chloride (PVC) [34], polymethyl methacrylate (PMMA) [35], cobalt–chromium reinforcements [36], lip inserts made of polyethylene terephthalate with glycol (PET-G), which increases resistance [37], sorbothane (a polyether-based polyurethane) [38], silicone [39], olefinic polystyrene (an alkene, i.e., an unsaturated hydrocarbon with at least one carbon–carbon double bond) [40], polyolefin [41], polyurethane [42], and acrylic resin [43].

EVA and its variants are appropriate materials for mouthguard construction because they demonstrate effective impact absorption capacity. However, performance may vary depending on mouthguard thickness [44, 45], the shape and consistency of the impacting object, and the angle of incidence. A thickness of 3 mm has been shown to provide adequate protection [46–48], although 4 mm thickness yields greater protection and reduced deformation [45, 49], albeit at the cost of increased discomfort [30].

The incorporation of EVA with other, more rigid materials, such as PVC – which reduce deformation – has been recommended for high-collision sports [50]. Conversely, mouthguards fabricated with less rigid materials may lose protective efficacy for the alveolar portion of the maxillary bones [44].

3.4 Analysis of the scientific output on the use of mouthguards in sports

The following is a brief scientometric study aimed at highlighting the evolution and current state of research on the prevention of dental trauma during sports activities.

The first part of this analysis was conducted using the Web of Science Core Collection, without time restrictions, in August 2025. The search equation applied was: “(mouthguard OR mouth protector) AND sport AND (dental OR teeth OR tooth OR buccal OR oral).”

This yielded 387 results, 97% of which were research articles. The most frequently used MeSH terms were “Mouth Protectors” (appearing in nearly 80% of cases), “Athletic Injuries”, and “Tooth Injuries.”

In general, scientific output tends to follow Price’s Law [51], which states that research publications on a given topic increase exponentially over time. However, this is not the case here. The first reference appeared in 1963 (1 publication), and although there is a slight upward trend overall, the annual number of publications shows no pronounced growth. Two peaks were identified: 2016, with 11 publications, and 2020, with 17.

Another principle of bibliometrics, Lotka’s Law [52], posits that a small group of authors accounts for the majority of publications. This pattern is confirmed in our analysis: most authors are linked to a single bibliographic record, while four authors have published between 8 and 18 studies on the topic.

The journals publishing research on mouthguards span a variety of disciplines: dental traumatology, endodontics, general dentistry, and medicine, as well as engineering, sports sciences, and materials science. Notably, 98% of the articles were published in English. The three leading contributing countries were Japan, the United States, and Brazil.

The second part of the analysis involved the use of VOSviewer software (Centre for Science and Technology Studies (CWTS), Leiden University, Leiden, Netherlands) to map and visualize bibliometric networks derived from these publications.

The analysis of keyword cooccurrence using VOSviewer resulted in a total of 62 keywords with a minimum of 10 appearances in articles related to the field of study. The most used keywords were “mouthguard” (163 occurrences), “prevention” (98 occurrences), and “dental trauma” (76 occurrences). The keywords that have been used most recently (shown in yellow) are “luxation,” “tooth fracture,” “avulsion,” and “shock absorption capacities” (**Figure 1**).

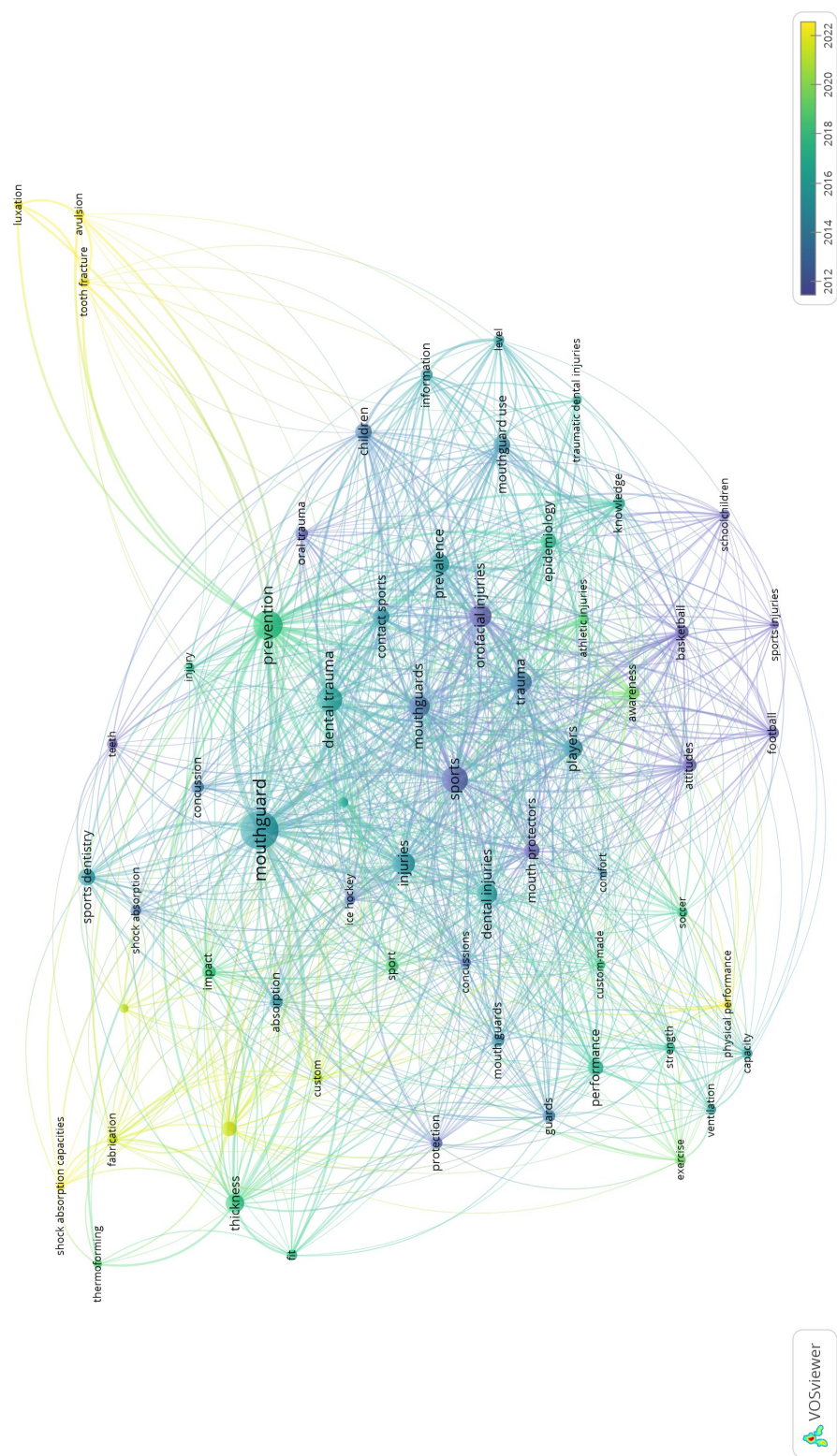


Figure 1.
Keyword cooccurrence map.

4. Conclusions

The prevalence of traumatic dental injuries and their significant clinical consequences make their prevention indispensable and underscore the need to promote its implementation. Although these situations are often unexpected, they are preventable, provided that risk factors are recognized.

Current research on the prevention of dental trauma is abundant, yet there remain areas requiring further exploration. Numerous studies have focused on custom-made mouthguards, whereas other types of devices have been less investigated. More clinical research is needed, as most existing studies are laboratory-based. In addition, certain sports remain underexplored. In this regard, it is highly relevant to continue research on materials, designs, clinical follow-ups, and the sharing of experiences across all risk situations described in this chapter.

Equally important is the reinforcement of university teaching on the prevention of traumatic dental injuries, ensuring that students are made aware of the different available options. Likewise, social dissemination – and dissemination across other healthcare domains – of the preventive services that dentistry can provide is essential, particularly in the context of sports activities.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 4

Post-Traumatic Tooth Resorptions

Nestor Tzimpoulas and Vasileios Molonis

Abstract

Tooth resorption is a frequent healing complication following traumatic dental injuries (TDI), occurring within weeks or even years after the initial trauma. Under normal conditions, predentin and precementum protect teeth from resorptive processes; however, disruption of these layers during TDI creates favorable conditions for resorption to initiate. Tooth resorption can be classified by its origin into two main categories: external resorption, beginning on the root surface, and internal resorption, initiating from the root canal wall. Each category includes distinct subtypes, which will be analyzed in this chapter. Many cases progress silently and are detected incidentally on radiographs or during routine dental examinations. Others present with clinical signs such as pain, discoloration, or mobility. Symptomatic lesions tend to be diagnosed earlier, while asymptomatic ones often progress unnoticed, delaying intervention. Radiographically, the appearance varies with the type and extent of resorption, but in all cases, untreated progression can lead to significant tooth structure loss and poor prognosis. Certain types of traumatic injuries are especially prone to resorptive complications, underlining the importance of early and appropriate emergency management. Despite advances in understanding the mechanisms and treatment of post-traumatic resorption, several aspects remain unclear. This chapter aims to summarize current knowledge on the etiology, classification, diagnosis, and management of post-traumatic tooth resorption. Therapeutic approaches and their potential to improve prognosis will also be highlighted through illustrative clinical cases.

Keywords: dental trauma, internal resorption, external resorption, predentin, precementum

1. Introduction

Tooth resorption is characterized by the pathological or physiological loss of dental hard tissues, specifically cementum and dentin, due to osteoclastic activity [1, 2]. Tooth resorption is a physiological process essential for the transition to permanent dentition in deciduous teeth [3]. Similarly, bone remodelling is a physiological process involving continuous resorption and bone formation in response to stimulation and loading [4]. However, tooth resorption in permanent teeth is regarded as a healing complication following traumatic dental injuries (TDI) and in some cases if left untreated, can result in the premature loss of the affected tooth [1, 5]. The prevalence varies significantly based on the type and severity of the

injury [6, 7, 57, 61, 108, 112, 115]. Although most resorption defects can be identified shortly after the injury and within the first year, their occurrence can be very late, with resorption activity potentially observed up to 10 years after the injury [8]. The long-term prognosis and survival of traumatized teeth is dependent not only on the effectiveness of emergency management but also on the timeliness of its implementation and post traumatic care [9].

TDIs are more prevalent than previously assumed, occurring in 85% of cases involving injuries to the oral region, with oral injuries constituting 5% of all bodily injuries across all age groups [10]. The world TDI frequency for permanent dentition is reported to be 15.2% [10]. It has been demonstrated that the complexity of TDI and the involvement of different tissue types can result in late complications in 65% of cases [11, 12]. Depending on the severity of the injury, post-traumatic complications such as pulp necrosis, pulp canal obliteration (PCO), marginal bone loss, or various types of root resorption can be anticipated. Root resorption is therefore more common than initially thought and that's why understanding its origin and pathology is crucial.

Despite significant progress in understanding the pathogenesis and management of post-traumatic tooth resorption, several aspects remain poorly understood. These include the molecular mechanisms underlying the initiation and progression of different types of resorptions, the role of genetic factors in susceptibility to resorption, and the potential for regenerative therapies in managing extensive resorptive defects. This chapter aims to synthesize current knowledge on post-traumatic tooth resorption, focusing on its etiology, classification, diagnosis, and management. By critically examining recent research and clinical evidence, this article is sought to provide a thorough understanding of this complex condition and identify areas for future investigation. In addition, emerging therapeutic approaches and their potential to improve outcomes in post-traumatic tooth resorption will be explored.

2. Histopathology

Several hypotheses have been suggested to explain the etiology of tooth resorption in permanent teeth. The most widely accepted theory suggests that permanent teeth are naturally resistant to tooth resorption under normal physiological conditions, owing to the presence of anatomical protective barriers such as precementum, predentin, enamel and the lining cells of odontoblasts, cementoblasts and epithelial cells. The non-collagenous organic components found in predentin and odontoblasts play a crucial role in preventing the attachment of odontoclasts to the underlying dentin and the root canal wall. Similarly, the precementum layer acts as a shield for the underlying cementum and the external root surface against clastic activities [5, 13, 14, 15, 109, 116, 118, 120, 122]. Clastic cells are unable to adhere to or resorb unmineralized surfaces like predentin, precementum or enamel- thereby maintaining the tooth's integrity under typical conditions [8, 15, 16]. Odontoclasts, which are similar to osteoclasts, are responsible for resorbing dental tissue and can be classified into dentinoclasts and cementoclasts [2]. These cells share a common origin with osteoclasts, deriving from hematopoietic stem cells (HSCs) that undergo a series of differentiation stages to form circulating peripheral blood monocytes and tissue macrophages, which eventually fuse into mature multinucleated resorptive cells [17–19]. This differentiation process is

regulated by various cytokines and growth factors, predominantly M-CSF and RANKL [20]. Although odontoclasts are similar to osteoclasts in morphology and function, they are smaller, with fewer nuclei and sealing zones [21]. An alternative hypothesis proposes that odontoclasts originate from immature dendritic cells present in the dental pulp, which have the potential to differentiate into clastic cells [22].

From a molecular perspective, it has been identified that the receptor-ligand signaling pathway involving RANK (Receptor Activator of Nuclear Factor Kappa-B), RANKL (RANK Ligand), and OPG (Osteoprotegerin) is implicated in the process of root resorption [23]. These proteins are members of the TNF family and play a crucial role in regulating both the physiological and pathological resorption of mineralized tissues [19]. OPG, also known as osteoclastogenesis inhibitory factor, is a cytokine receptor produced by osteoblasts, among other cell types. It modulates the activation of the RANK signaling pathway by functioning as a decoy receptor that binds to RANKL, thereby preventing its interaction with the RANK receptor, which is present on osteoclasts and odontoclasts. The binding of RANKL to RANK results in the release of NF κ B, which subsequently leads to the transcription of odontoclast precursors into multinucleated cells. RANKL is expressed in various tissues and organs, including the periodontal ligament [PDL], cementum, and dental pulp, thereby playing a significant role in the differentiation and fusion of odontoclast precursor cells and in activating the resorptive activity of mature odontoclasts [17, 24, 25, 106, 111, 119].

Odontoblasts and dental pulp cells express macrophage colony-stimulating factor (M-CSF) [17], a hematopoietic growth factor that is involved in the differentiation and activation of localized preodontoclasts, which upregulates RANK and downregulates OPG [20, 23]. The regulation of clastic activity through the interactions between RANKL and RANK in preclastic cells is described as the canonical pathway. However, odontoclastogenesis can also be initiated via a non-canonical pathway, which is regulated by elevated levels of proinflammatory cytokines and growth factors that bind to clastic cells, with or without the activation of the canonical RANK pathway, leading to pathological root and bone resorption [17]. Nonetheless, this pathway requires further confirmation *in vivo* [17].

The protective organic layer of cementum is susceptible to direct mechanical damage following traumatic dental injury (TDI) or indirect damage through an inflammatory response in the adjacent periodontal ligament subsequent to TDI [8]. TDI results in tissue damage, leading to the local release of cytokines and chemokines that attract T-cells, which subsequently recruit and activate macrophages and granulocytes. Macrophages ingest tissue debris and microbes and produce cytokines such as IL-1 β and TNF α , which stimulate the expression of RANKL in periodontal ligament fibroblasts and T-cells [26, 27]. RANKL can bind to RANK, activate odontoclasts, and induce subsequent root resorption [28, 29]. The RGD motif is crucial in facilitating odontoclast adhesion to the dentin matrix with the assistance of integrin adhesion proteins. RGD-peptides bind to calcium salt crystals on mineralized surfaces of dentin or cementum when the protective layers of the predentin and precementum are compromised following TDI [8]. Bacterial infections, particularly in the root canal or periodontal ligament, can exacerbate the inflammatory response and further stimulate the resorptive process [19]. Bacterial toxins and inflammatory mediators penetrate damaged root surfaces, providing a continuous stimulus for clastic cell activity [30].

3. Classification

Numerous classification systems have been proposed to define root resorption, focusing on histological, etiological, or origin-based criteria [8, 15, 22, 31, 32]. However, a universally accepted classification has yet to be established, often resulting in confusion and potential misdiagnosis of resorptive defects [2].

Based on the initiation point of the resorption, two basic categories of root resorption arise, namely: (a) internal root resorption and (b) external root resorption. Internal resorption occurs following the destruction of the protective barriers of odontoblasts and predentin, with the initiation point located within the pulp or dentin of the root canal walls. It progresses outward towards the cementum and, if not addressed promptly, may result in perforation and communication with the periodontal ligament (PDL) and surrounding bone. The mineralized matrix of dentin becomes exposed to dentinoclasts, which replace dentin with resorptive granulation tissue [13, 33, 34]. There are three types of internal tooth resorption, repair-related (surface), infection-related (inflammatory) and ankylosis-related (replacement).

External tooth resorption commences on the cementum after injury of the protective layer of precementum and progresses inwards towards the dental pulp. If left untreated it can result in communication between the pulp and the surrounding bone. The following types of external tooth resorption will be analyzed in this chapter, repair-related (surface), transient apical breakdown, infection-related (inflammatory), ankylosis-related (replacement) and cervical.

4. Internal resorption

4.1 Internal repair-related (surface) resorption

Internal repair-related resorption (IRRR) is an uncommon, self-limiting condition characterized by minor resorption of the dentin walls within the root canal. This condition typically results from transient pulp irritation, which may be induced by trauma [33, 35] or external bleaching [36]. Histologically, it is distinguished by the absence of odontoblasts and predentin, alongside the presence of inflammatory cells and dentinoclasts within the resorption lacunae. The resorption process is transient, generally lasting approximately 2–3 weeks, unless the stimulus persists [22, 33, 36, 37]. This condition is asymptomatic and often undetectable through clinical or radiographic examination, possibly due to the minor nature of the defects [38]. Although it generally does not necessitate treatment, persistent resorption caused by bacterial stimuli, such as caries or concomitant crown fracture, and exposed dentin may progress to internal inflammatory resorption.

4.2 Internal infection-related [inflammatory] resorption

Internal infection-related resorption (IIRR) is an inflammatory process characterized by the loss of intraradicular dentin. This condition typically occurs in teeth with chronic pulp inflammation and damage to the protective predentin layer [17, 39, 40]. Dental trauma is a primary predisposing factor for IIRR, alongside

bacterial infections (such as caries and periodontal disease), tooth transplantation, restorative treatments, cracks or fractures, and viral infections [2, 35, 39]. For IIRR to manifest, the coronal portion of the resorption must be necrotic and infected, providing a continuous stimulus, while the apical portion remains vital, supplying nutrients to the odontoclasts [31].

Histological findings reveal the presence of coronal necrotic pulp, with the underlying resorptive defect characterized by dentinoclasts and granulation tissue [8, 22]. In more advanced stages, bacterial invasion occurs in the apical region of the resorption, leading to infection of the entire pulp system and potentially resulting in apical periodontitis [22, 41]. As the remaining pulp undergoes necrosis, the resorption process halts due to the absence of blood supply within the defect.

The location of internal infection-related resorption (IIRR) varies and can be identified from the coronal to the apical third of the root canal system. When situated near the coronal aspect of the tooth, it may induce pink discoloration due to the formation of granulation tissue in the underlying coronal dentin [22]. However, pink tooth discoloration is not exclusively indicative of IIRR, as it can also be observed and distinguished from external cervical resorption (ECR) [42]. Sensitivity tests may yield variable results depending on the stage, location, and progression of IIRR. If the pulp is not entirely necrotic and resorption is ongoing, sensibility tests may produce positive results, and allodynia may be present, with patients potentially experiencing spontaneous or continuous pain indicative of irreversible pulpitis. Conversely, if the apical portion of the root canal becomes necrotic and the resorption process halts, sensitivity tests will yield negative results. Additional clinical manifestations include abscess or sinus tract formation, tenderness to percussion, and/or discoloration [5]. The presence of clinical symptoms is not always necessary, which can result in delayed diagnosis and an unfavorable prognosis if IIRR progresses undetected. Patients are typically asymptomatic or may exhibit symptoms of pulpitis, eventually progressing to apical periodontitis symptoms in later stages when the entire pulp system becomes infected and necrotic [38] or when tooth perforation occurs (**Figure 1**) [43].

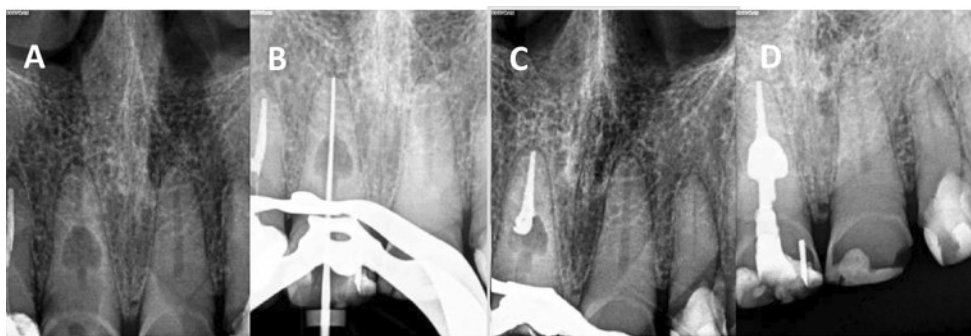


Figure 1.
Internal infection-related resorption on tooth 11 with history of traumatic dental injury (TDI) A. Initial periapical radiograph reveals a well-defined, round-shaped radiolucency centrally located within the root canal of tooth 11, indicative of internal infection-related resorption. The tooth responded positively to pulp sensibility tests. B. Working length radiograph C. Endodontic treatment was initiated and completed in a single visit. The apical third of the canal was obturated using a custom-fitted gutta-percha cone and bioceramic sealer. The remaining canal space and the resorption cavity was filled with thermoplasticized gutta-percha and bioceramic sealer using the warm vertical compaction technique. D. Post-operative radiograph showing the completed root canal obturation and composite build-up.

Radiographically, a well-defined round or oval radiolucency is typically identified within the pulp chamber, often located in the cervical area [8, 22]. This appearance may suggest external invasive cervical resorption (ECR), making differential diagnosis critical for determining the appropriate treatment plan. Therefore, it is recommended to obtain multiple radiographs, adjusting the beam horizontally at various angles. In cases of IIRR, the resorption defect will remain centered on the radiograph despite changes in the beam's horizontal angle. In contrast, with ECR, the defect will shift to either the distal or mesial side of the tooth, also indicating the buccolingual position of the resorption according to the Same Lingual Opposite Buccal (SLOB) rule. In IIRR, the root canal wall's outline is compromised or distorted, whereas in ECR, the root canal lumen remains intact. Cone-beam computed tomography (CBCT) serves as a vital diagnostic tool, accurately distinguishing between internal and external cervical root resorption and providing precise details on the lesion's size and its relationship with the root canal wall [44, 45, 117].

The management of internal infection-related resorption begins with an evaluation of the extent of hard tissue destruction and the identification of potential perforations, utilizing CBCT if necessary [44, 46]. In instances where the tooth is deemed restorable without perforations, endodontic treatment is advised to terminate the apical blood supply to the resorptive cells. This treatment may be conducted in one or two appointments, contingent upon the clinical symptoms of the patient, the extent of the resorption, and the presence or absence of perforation.

In cases of active IIRR after chemomechanical preparation the root canal and the resorption defect may be dressed with calcium hydroxide dressing for 4 weeks and refreshed periodically until hard tissue barrier is created at the perforation side before final obturation of the root canal system. Alternatively, a corticosteroid-antibiotic paste (CS-AB) can be used for 6 weeks followed by calcium hydroxide for two to four weeks until symptoms subside and periradicular inflammation, if a perforation is present, is controlled [2, 9, 47]. The root canal and the resorption defect can be obturated with appropriate materials, depending on the size of the defect and the presence or absence of a perforation. In cases of small resorption defects without perforation, the use of thermoplasticized gutta-percha and sealer with warm compaction is considered a suitable obturation technique. In the presence of a perforation, the resorption defect and the perforation site can be managed using contemporary calcium silicate cements (CSCs), which are suitable for sealing perforations and may be employed in one or two sessions to repair the perforation [46, 48]. In situations where perforating internal resorption defects are inaccessible for internal repair, a surgical approach is warranted. Ultimately, extraction is the recommended treatment for teeth with extensive IIRR, ideally performed surgically due to the high risk of fracture [5].

4.3 Internal ankylosis-related resorption (internal replacement resorption)

Internal ankylosis-related resorption (IARR) is a condition characterized by the replacement of dentin and pulp with a mixture of granulation and bone-like tissue. This condition is extremely rare and is hypothesized to commence following dental trauma at the site where the protective layer of predentin is compromised [22, 33]. Typically, IRR is identified incidentally through radiographic examination, as patients often remain asymptomatic depending on the progression stage of the resorptive process. Histological analysis indicates areas of resorption accompanied

by the deposition of metaplastic hard tissue, which resembles cancellous bone or cementum rather than dentin [22, 38]. Radiographic assessments reveal an irregular bone-like lesion exhibiting mild to moderate radiodensity [22]. The preferred management strategy is monitoring, and the long-term prognosis and survival of the affected tooth are generally favorable.

5. External resorption

5.1 External repair-related resorption (external surface resorption)

External repair-related resorption (ERRR) manifests as superficial resorption located on the cementum of the root surface which can sometimes extend into the dentin [49]. This resorption type occurs transiently after TDI due to localized damage of the PDL and precementum layer [50, 51]. Most dental injuries are brief in duration; thus, in the absence of bacterial stimuli which exacerbates resorption, the process will naturally cease. Consequently, ERRR is not progressive; it is a self-limiting process that exhibits spontaneous repair [8]. Cementum possesses the ability to regenerate and repair through remodeling in response to physiological or pathological conditions. This capability is attributed to the cementum's proximity to the periodontal ligament and alveolar bone which provide an adequate blood supply. ERRR can occur after all types of TDI but especially after extrusive and luxation injuries in mature teeth (Tables 1, 2)

RESORPTION TRAUMA	External repair related resorption	External infection related resorption	External Angylosis related resorption
Concussion	0%	0%	0%
Subluxation	0%	0-1.7%	0%
Extrusive luxation	0%	2.9%	0%
Lateral Luxation	2.3%	0%	0%
Intrusion	24%	33%	5.6%

Table 1.
Prevalence of root resorption according to the type of injury for teeth with open apex.

RESORPTION TRAUMA	External repair related resorption	External infection related resorption	External Angylosis related resorption	TAB
Concussion	0-3%	0%	0%	
Subluxation	2-4%	0%	0%	43,8%
Extrusive luxation	15-27%	0%	0%	62,5%
Lateral Luxation	28-33.6%	3.3%	1%	75%
Intrusion	2-5%	4.8%	37.5%	

Table 2.
Prevalence of root resorption according to the type of injury for teeth with closed apex.

Typically, clinical signs and symptoms are absent while two-dimensional radiographic findings are contingent upon the extent and location of the traumatized surface. Although there are mostly no radiographic findings, small lacunae on the root surface can occasionally be recognized, located laterally or apically [47]. A cone-beam computed tomography (CBCT) or histological evaluation can accurately determine the amount and depth of the damaged surface [2]. This type of resorption requires no management and should only be monitored as long as the stimulus is brief and without bacterial contamination. However, in case of pulp necrosis and infection, external surface resorption can turn into external infection-related resorption which requires a different approach and will be analyzed later in this chapter.

5.2 Transient apical breakdown

Transient apical breakdown (TAB) is a temporary resorption of dentin which occurs within the apical foramen and the bone surrounding the root apex in luxated or avulsed teeth [52]. In this way, the apical foramen and the surrounding tissues provide space for pulp revascularization followed by pulpal healing and cementum and bone remodeling [53]. TAB refers exclusively to mature teeth, as teeth with an open apex inherently allow for the ingrowth of new vessels and nerves in the pulp [52, 54, 55]. Clinically, transient signs such as crown discoloration and loss of pulpal sensibility may be observed. Crown discoloration is noted in 80% of TAB cases and gradually improves within 6–12 months [53]. Radiographic characteristics include the enlargement of the apical foramen, widening of the canal lumen apically, apical surface resorption and periapical radiolucency or widening of the periodontal ligament space. These temporary clinical and radiographic changes are associated with healing but may lead to misdiagnosis of pulp necrosis, apical periodontitis, or external infection-related resorption, underscoring the importance of differential diagnosis [8]. A negative vitality test should not directly lead to endodontic treatment as tenderness to percussion or buccal palpation are signs more frequently associated with pulp necrosis than sensitivity tests (**Figure 2**) [56].

Transient apical breakdown is mostly expected in mild traumatic dental injuries with minimal dislocation. Spontaneous healing is expected as long as 12 months after the traumatic injury which includes the recovery of dark discoloration of the crown, disappearance of the periapical radiolucency and return to normal response to pulp sensibility tests [53]. Mineralization of this type of resorption results in a physiological radiographic image, normalization of the periodontal ligament, normalization of coronal discoloration, and/or restoration of pulpal sensibility. The pulp typically undergoes pulp canal obliteration (PCO) following its revascularization [52, 54, 57, 58]. TAB is usually self-healing, consequently, treatment is generally confined to routine follow-up appointments. During these sessions, periapical radiographs, sensibility tests, and clinical evaluations are conducted to monitor the resolution of the lesion. The initiation of endodontic treatment may be deferred until there is definitive evidence of persistent clinical and radiographic signs of infection [52, 53]. It is important to note that CBCT scans provide greater accuracy than two-dimensional periapical radiographs in detecting small areas of apical bone resorption and apical surface root resorption, as observed in transient apical breakdown [8].

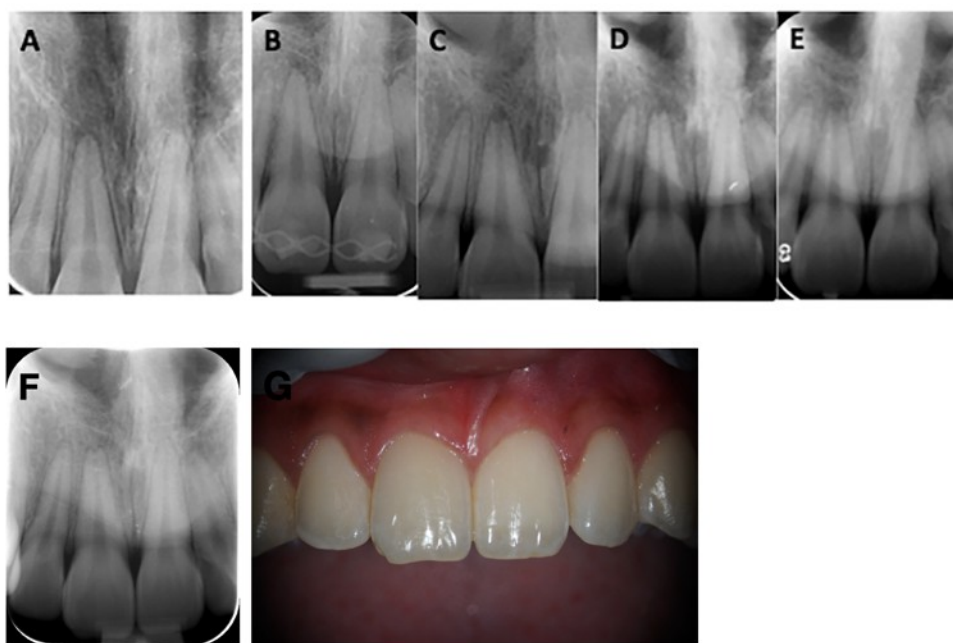


Figure 2.

Lateral luxation injury on tooth 11 in a 14-year-old male patient A. a 14-year-old male patient presented following a lateral luxation injury to tooth 11. The initial periapical radiograph revealed displacement of the root. Immediate repositioning and flexible splinting using titanium trauma splint (TTS) were performed. B. Radiograph taken 4 weeks post-repositioning and splinting shows a widening of the periodontal ligament apically and a closed apex. Pulp sensibility testing was negative; however, the tooth remained asymptomatic. The splint was removed to allow restoration of physiological mobility. C. At the 3-month follow-up, radiographic evaluation showed periapical radiolucency formation. The tooth remained non-responsive to pulp sensibility testing. D. Six months after the injury, the tooth remained asymptomatic but still not responding to the sensitivity testing. The periapical radiolucency persisted. E. At the 8-month review, the tooth started to respond positive to cold testing. The apical space of the root canal was widened suggestive of ongoing revascularization, part of the transient apical breakdown indicating that healing is ongoing. The current treatment approach is careful clinical and radiographic monitoring every 3–6 months. If signs of infection or symptoms appear, endodontic treatment will be initiated. At this stage, no endodontic intervention is required. F, G: Radiographic and clinical examination of 14-month recall. No signs of periapical radiolucency. The tooth responds positive to cold testing.

5.3 External infection-related resorption (external inflammatory resorption)

External infection-related resorption (EIRR) following traumatic dental injury (TDI) requires the coexistence of two conditions: an infected root canal system and external damage to the precementum and cementoblast layer resulting from the direct impact from force of the injury or indirect from the inflammation process initiating at the PDL (Fig. 6) [9]. After luxation injuries, the root canal system may become necrotic and subsequently infected by bacteria, either during the injury or thereafter. Bacterial infiltration into the root canal system can occur through caries, cracks, fractures, lost restorations, deep periodontal pockets, reinfection following root canal treatment, or infection during the injury [9]. Consequently, the mineralized dentin matrix is exposed, leading to the formation of small resorption cavities in a manner similar to external repair-related resorption (ERRR) [8]. Bacterial infection provides a persistent stimulus through the exposed dentinal

tubules, which induces and sustains an inflammatory response in the adjacent periodontal ligament region, thereby advancing the resorption process on the external surface of the tooth [9]. Based on the location, EIRR is further subdivided into lateral and apical. However, mostly the lateral type refers to trauma related EIRR and will be developed in this article.

Histologically, odontoclasts, osteoclasts and macrophages migrate to the injury site and bind to the underlying mineralized hard tissue initiating resorption which progresses due to the constant microbial diffusion from the infected necrotic pulp. EIRR is characterized by bowl-shaped resorption cavities which contain numerous Howship's lacunae occupied by odontoclasts [51]. Dense inflammatory cell infiltrate is present, particularly in the surrounding periodontal tissues, which consists of polymorphonuclear leukocytes, lymphocytes and plasma cells [8].

Clinical examination reveals no response to the pulp sensibility testing and most of the times patients are asymptomatic or may present symptoms of irreversible pulpitis and/or apical periodontitis such as pain, swelling, tenderness to percussion or palpation, sinus tract and discolouration [5, 31, 59]. Radiographically, radiolucent bowl shaped cavitations along the root surface are detected along with an adjacent periradicular radiolucency which varies in shape and size depending on the extent of the resorption [2]. The outline of the root canal wall remains intact except from advanced cases where the root canal is perforated. Another radiographical finding is the loss of lamina dura which can be seen as early as 3–4 weeks after the traumatic injury [5]. In cases of avulsed teeth radiographic changes can be present as early as 2 weeks after replantation usually located in the cervical third of the tooth [59]. It is widely accepted that the conventional 2D radiograph does not accurately determine the extent of EIR and its relation with the root canal wall. Therefore CBCT is recommended providing sufficient information for the exact extent of EIRR (even for initial small-sized defects) as well as the possible perforation in the root canal system in more advanced cases [46, 60].

In fully developed teeth, EIRR is anticipated in instances of severe luxation injuries, such as intrusive, lateral, and extrusive luxation, and avulsion injuries, particularly when pulp necrosis is expected alongside concomitant crown fractures [61, 62]. In the presence of necrotic pulp or microbial infection EIRR can progress rapidly. Intrusive luxation injury exhibits the highest prevalence of EIRR, affecting up to 38% of cases [61], contingent upon the stage of root development, the extent of intrusion, and the method of repositioning (no repositioning, surgical, or orthodontic) [8]. Additionally, EIRR is more frequent and aggressive in young patients aged 6 to 10 years, attributed to the severity of the injury and the presence of wide open tubules, which facilitate easier penetration of bacteria and their toxins compared to adult patients with fully formed roots and smaller tubules [30, 51].

In cases of avulsion, the most critical factors influencing the development of EIRR include the extra-oral dry time, the type of storage used until replantation, the stage of root development, and bacterial contamination of the root surface [63, 64]. The treatment plan is based on the maturity of the root and the condition of the PDL cells. Minimizing the dry time is crucial for the survival of PDL cells which have a high chance of remaining vital within the first 15 minutes after the accident but become compromised and most likely non-viable after a dry time of 30 minutes [65, 66]. In cases where avulsed permanent teeth remain untreated post-replantation, EIRR can lead to the primary loss of the tooth within as little as three months [59]. Therefore, prompt intervention is essential to mitigate further damage and preserve

the affected tooth. Endodontic treatment should be initiated expeditiously to halt the progression of resorption. The necrotic tooth should be accessed 7–10 days following reimplantation and stabilization with a passive flexible splint, even in the absence of radiographic signs of resorption, succeeded by root canal disinfection using intracanal medicaments. The intracanal medicaments that can be used are calcium hydroxide and a corticosteroid-antibiotic mixture (CS–AB). Calcium hydroxide is the medicament of choice which can be placed within the first 7–10 days after replantation for four weeks followed by periodical change (every 3 months) to maintain its antibacterial efficacy. By absence of clinical and radiographic findings of EIRR final obturation of root canal system with sealer and guttapercha can be done. In cases where the EIRR is already established, a corticosteroid-antibiotic paste can be used for the first 3 months to arrest the resorption process, followed by calcium hydroxide before the final obturation of the root canal system with sealer and gutta-percha [9, 67]. For the first months, a second or even a third placement of CS–AB may be necessary. This approach aims to mitigate the inflammatory response in the injured periodontal ligament (PDL), inhibit clastic cells, and eradicate bacteria [9, 67–69, 105]. After this period, the PDL is repaired and treated with calcium until radiographic or clinical evidence indicates the cessation of resorption and the formation of hard tissue [9, 70]. It is important to note that there is currently insufficient evidence supporting the superiority of the corticosteroid paste over calcium hydroxide [5, 71]. A similar approach should be adopted for immature teeth with combined TDI, such as avulsion or intrusive luxation injuries with concomitant crown fracture, where there is a significant likelihood of pulp necrosis and bacterial infection, to prevent the onset of EIRR [9, 47, 67, 71]. However, in the case of immature teeth, careful consideration is required when assessing the elevated risk of EIRR and the potential for spontaneous revascularization. For teeth with wide-open apices and favorable extraoral storage conditions, endodontic treatment should not be immediately initiated. Instead, regular follow-ups should take place. If spontaneous revascularization does not occur or in case resorption is detected, apexification, pulp revitalization/revascularization, or root canal treatment should be initiated as soon as pulp necrosis and infection is identified (**Figure 3**) [71, 72, 121].

5.4 External ankylosis-related resorption (external replacement resorption)

External ankylosis-related resorption (EARR) is a pathological process characterized by the resorption of cementum and dentin, which are subsequently replaced by bone (Figure. 7) [2]. EARR is more commonly observed following severe dental injuries, such as avulsion and intrusive luxation, with prevalence rates of 51–87.2% and 57.1%, respectively [73, 74] (see **Tables 1, 2**). This increased occurrence is attributed to the potential partial or complete loss of vital PDL tissue covering the root surface and damage to the cementum layer [57, 75–77, 113]. Following injury to the PDL and/or cementum, the direct contact between adjacent bone and the exposed root surface can facilitate ankylosis followed by osseous healing. Ankylosis is defined as the pathological fusion of the root into the surrounding alveolar bone due to the absence of PDL. In some cases where damage to the PDL is minor ankylosis can be self-limiting and can be repaired through new cementum formation by PDL-fibroblasts. In cases where the PDL-damage is more severe, osseous healing is favoured which is the process wherein osteoclasts from the

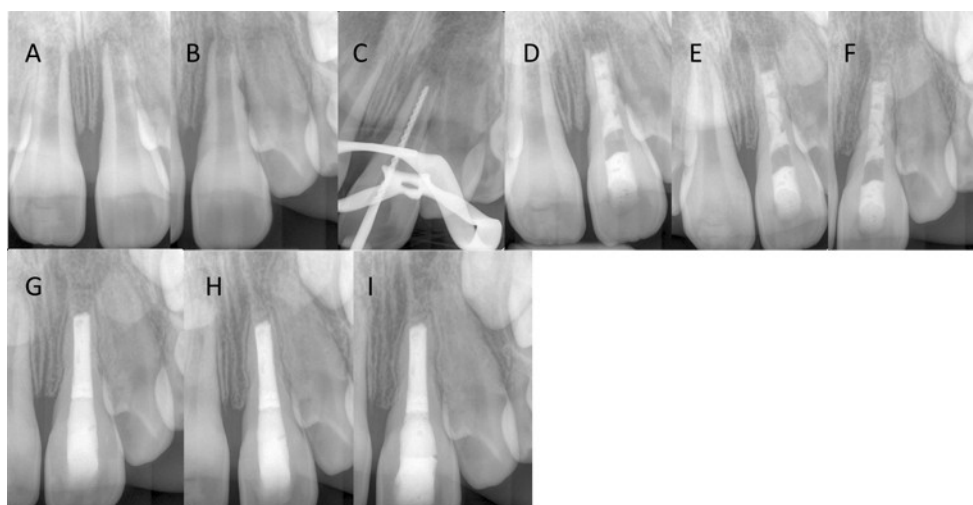


Figure 3.

Management of tooth avulsion and external infection-related root resorption on tooth 21. A patient presented one month after avulsion and replantation of tooth 21. The avulsed tooth had remained dry for approximately 45 minutes before it was stored in saline for an additional 15 minutes and reimplanted in the socket. The tooth was then repositioned and stabilized using a flexible splint. B. Radiographic examination 6 weeks post-reimplantation revealed signs of external infection-related root resorption. C, D. Endodontic treatment was initiated. Working length was determined, and the root canal was instrumented and irrigated with sodium hypochlorite 3%. A bioceramic intracanal medicament (BIO-C Temp) was placed and left in situ for six months. F. At the 6-month follow-up, radiographic evaluation showed arrest of the external infection-related resorption. However, early signs of external ankylosis-related resorption were noted. The tooth remained asymptomatic. The treatment plan included completion of endodontic treatment and regular monitoring. G. Final obturation was carried out using bioceramic sealer and warm gutta-percha since apically apexification occurred and a barrier was formed, followed by placement of a definitive composite restoration. H. At the 1-year recall, there was no radiographic evidence of resorption progression, and the tooth remained asymptomatic. I. At the 30-month recall, the tooth continued to be asymptomatic with no further progression of the resorption process.

bone resorb mineralized dentin structures, which are subsequently replaced by new bone formation deposited by neighboring osteoblasts. The progression of EARR is usually aggressive, eventually leading to resorption of the entire root and finally tooth loss [50, 59, 63]. However, in some cases where the PDL is slightly injured and can repair itself through the action of fibroblasts, EARR may be transient.

Clinical characteristics are similar with ankylosis and include a dull sound to percussion and lack of physiological mobility. Normally the patient presents no symptoms and there is history of a previous traumatic dental injury. Most of the times the tooth responds positively to pulp sensitivity testing. However, a lack of response to sensitivity testing is not an indication for RCT in the affected tooth, as EARR is not pulp-related but determined by the affected periodontium [5]. In young patients during developmental years characterized by active skeletal growth and vertical growth of the alveolar bone, ankylosis will lead to inhibition of growth of the alveolar bone. There will be a change in the vertical position of the ankylosed tooth in relation to the adjacent teeth. Over time, the ankylosed tooth will appear to be in “infra-occlusion” or “shorter” than the adjacent teeth due to the lack of vertical downgrowth of its alveolar bone. This can become increasingly pronounced as growth continues, leading to malocclusion of the adjacent teeth [59, 63, 78–81].

Radiographic findings include a moth-eaten appearance on the root surface and irregular outline due to bone replacement [51]. The absence of the periodontal

ligament space and lamina dura is attributed to the fusion of bone with dental tissues [5, 59]. The PDL is absent and the root surface appears to fuse with the surrounding bone. Conventional radiographic examination reveals EARR only on the proximal aspects of the root. A CBCT is essential to accurately assess the true nature and extent of EARR [60].

In some cases EARR can be self-limiting which is clinically seen as a return to normal mobility, percussion sound once the resorption deactivates and the PDL has repaired. However, severe TDI and particularly in cases of avulsion, where the entire or majority of the periodontal ligament is considered necrotic following extended extra-oral dry time, progressive ankylosis-related resorption is highly probable [75, 82]. The aggressive type of EARR continues resorbing the root and replacing it with osseous tissue for years, leading to the resorption of the entire root. There is no treatment to arrest EARR and monitoring is the indicated method [5, 83, 107, 110]. Therefore, preventing the occurrence of EARR is crucial. Regarding that EARR is more frequently seen in cases of severe TDI such as avulsion, attention should be paid to the emergency management of the tooth. The most important preventive measures include minimizing the extra-oral dry time of avulsed teeth, the use of an appropriate storage medium until replantation, atraumatic repositioning of the tooth back to its socket, using a functional (i.e. flexible) splint, avoiding extra-oral root canal treatment and using proper root canal medicaments [9, 47, 114]. Delayed replantation has a poor long-term prognosis and often leads to EARR as the PDL becomes necrotic and is no longer expected to regenerate [84]. Moreover, it has been found that during the splinting period, physiologic movement promotes healing with less chances for ankylosis and EARR [85, 86]. The splinting time should also not exceed the period of 10 days [87]. Regarding the root canal treatment, it is necessary to clarify that EARR is not pulp-related and therefore a root canal treatment will not cease its growth. However in many cases where EARR can occur, EIRR is also expected such as after avulsion or intrusion. In these cases RCT should be conducted to prevent EIRR (**Figure 3**) [2]. In older patients where EARR progresses slowly, replanted teeth with EARR remain functional for a long time without the need for any intervention [63, 88]. The early detection and management of EARR and ankylosis are crucial in children and adolescents before or during their pubertal growth spurt to prevent the cease of the alveolar growth and possible infraocclusion as described above. Alternative methods which have been suggested for ankylosed teeth with EARR for pediatric patients include decoronation, autotransplantation and surgical repositioning. Decoronation aims to preserve the buccal-palatal dimension of the alveolar ridge, to allow for vertical growth and facilitate new bone formation above the decoronated root. Autotransplantation aims to replace a lost tooth with a functional tooth within the same patient. Most of the times, the donor tooth needs additional treatment such as RCT or reshaping before being positioned into its new socket. Although it has recently become more of a recognized and viable treatment approach in dentistry, the long-term outcomes are still not well-documented [89–91].

5.5 External cervical resorption (external invasive resorption)

External cervical resorption (ECR), also known as external invasive resorption, is a dynamic and evolving process, with destructive and reparative phases which affects dental and periodontal tissues due to clastic activity [42, 92, 93]. ECR

predominantly occurs in the cervical region, below the epithelial attachment of the root, although it may initiate at any subgingival location of the root. The aetiopathogenesis of ECR remains incompletely clarified which can contribute to misdiagnosis and mismanagement of such cases [92]. However, prior traumatic injuries are considered the second most relevant predisposing factor for external cervical resorption after history of orthodontic treatment [92, 94]. Additional contributing factors include intracoronal bleaching, periodontal surgery, parafunctional habits, and inadequate oral hygiene [95]. Notably, 25–29% of teeth exhibiting external cervical resorption have a history of dental trauma [92, 94]. Severe traumatic events, such as luxation and avulsion, can cause localized damage or rupture of the periodontal ligament [PDL], thereby facilitating external cervical resorption [96]. ECR may occur under conditions such as cementum and PDL damage, PDL compression, hypoxia, or chronic irritation or a combination of the above [42, 92]. This happens because more than one potential predisposing factors may coexist when ECR occurs [95].

The three basic processes which take place in ECR are: initiation, progression and repair of the resorption. In the first phase, damage of the PDL and precementum occurs after the presence of one or more predisposing factors such as TDI. The initiation of ECR follows a common pattern through one or more portals of entry, which may be located on the buccal, palatal, lingual, or interproximal surfaces, or a combination of these areas. The initial tissue that invades the tooth is a highly vascular fibrous connective tissue that bleeds profusely when probed. The destructive phase may progress with the proliferation of granulation tissue, which can ultimately lead to tooth loss if it advances rapidly. During the repair stage, reparative bone-like tissue may develop and grow into the lesion, resulting in local fusion of the adjacent alveolar bone with resorbed dentine and enamel [92]. The location of the portals of entry is crucial as it determines access into the resorptive lesion and consequently the complexity of treatment. ECR progresses towards all directions, horizontally, coronally, apically and around the pulp space, creating several resorption channels and interconnections with the PDL (portals of exit). ECR is restricted from perforating the pulp canal space by the Pericanalar Resorption Resistant Sheet (PRRS). PRRS consists of dentine and sometimes bone-like tissue, includes an inhibitory resorptive factor and lacks RGD proteins which makes it resistant to resorption [13, 97]. This layer is detectable only via cone-beam computed tomography (CBCT) [42, 98] and it aims to keep the vitality of the pulp tissue [42]. However, in advanced cases of ECR, the root canal may become perforated. The repair phase of the dental hard tissues occurs by ingrowth and apposition of reparative bone-like tissue through the portal[s] of entry into the tooth. It is necessary to notice that in the same tooth and at the same time, active resorption of dentine, active repair by osteoid formation and remodelling of the bone-like tissue can take place (**Figure 4**) [42].

ECR is classified into four categories based on its extent, as depicted in **Figure 5** [94]. Nevertheless, due to the limitations of this two-dimensional classification, a recent three-dimensional classification has been proposed to more accurately document the true nature of ECR, considering the lesion's height, circumferential spread, and proximity to the root canal [99]. After a complete assessment of these factors the complexity of the ECR can be identified and the appropriate treatment plan can be established.

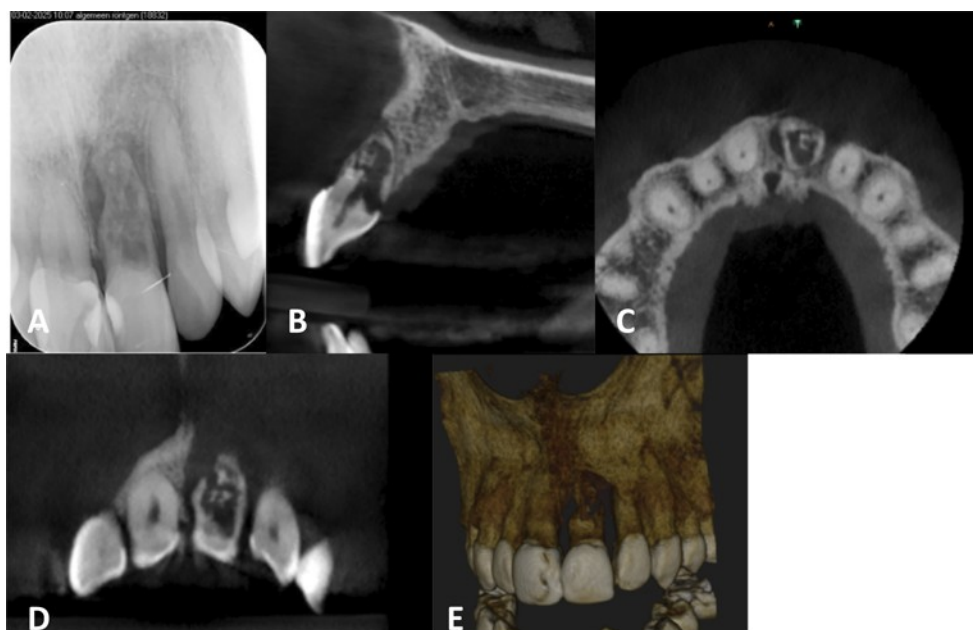


Figure 4.

Advanced external cervical resorption (ECR) of tooth 21. A. Periapical radiograph of the maxillary lateral incisor (#22) reveals radiographic features consistent with external cervical resorption (ECR). the lesion presents as a heterogeneous mix of radiolucent and radiopaque areas within the tooth structure, reflecting the coexistence of fibro-vascular and fibro-osseous tissue and the dynamic nature of the resorptive process. B. Coronal CBCT view of tooth 21 shows multiple portals of entry and exit, illustrating the complex and infiltrative path of the resorption. C. An axial slice in the apical third of the maxillary incisors demonstrates the preservation of the pericanalar resorption-resistant sheath (PRRS), which surrounds the pulp and provides temporary resistance to the resorptive process, while the surrounding periradicular dentin is destroyed. D. The invasive resorption has extended into the root canal space. Based on the extent of the lesion, a diagnosis of ECR class IV according to heithersay was established for tooth 21. E. A 3D reconstruction confirms extensive involvement of nearly the entire root structure. Due to the severity and prognosis, the tooth was deemed non-restorable. Extraction was indicated, and the patient was referred to a periodontist for comprehensive treatment planning, including potential implant placement along with necessary soft tissue and bone augmentation procedures.

Clinical characteristics of ECR include the occasional appearance of a pink spot due to the thin enamel loss of the periodontal ligament (PDL), profuse bleeding upon probing, a hard and scratchy sensation during probing. The tooth typically responds positively to pulp sensibility tests [42]. Patients are generally asymptomatic; thus, ECR is often incidentally diagnosed during a routine dental examination or as a radiographic finding [38]. In more advanced cases, where the pulp is affected, patients may exhibit symptoms of irreversible pulpitis and/or apical periodontitis, such as pain, swelling, gingival discomfort, and/or the presence of a sinus tract [92, 95].

Radiographic images of ECR vary depending on the stage and may appear radiolucent or mottled due to fibro-osseous tissue [42, 100]. This variation occurs because ECR is a dynamic process, wherein different areas of the same tooth may simultaneously undergo active resorption of dentin, active repair through osteoid formation, and remodeling of bone-like tissue [92], all of which contribute to diverse radiographic images. The borders of ECR lesions are irregular and poorly defined, and the lesion's position relative to the canal shifts when angulated X-rays are taken, employing the parallax technique.

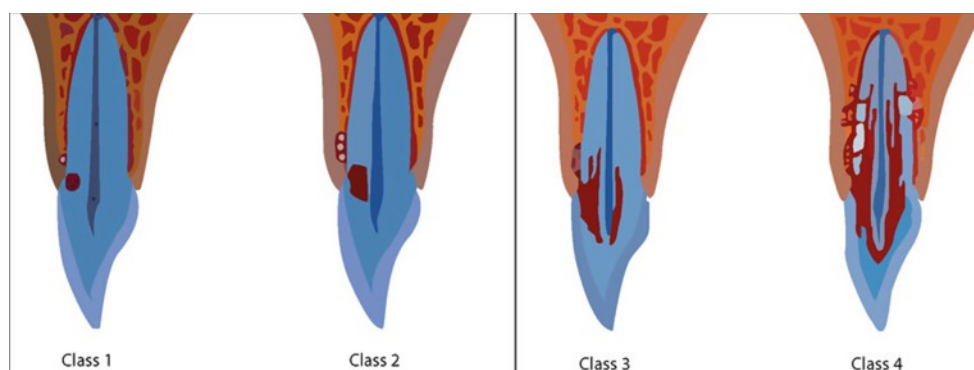


Figure 5.

External cervical resorption (heithersay classification 1999). class 1: a small cervical lesion with shallow penetration into dentine. Class 2: a well defined lesion close to the coronal pulp, but with little or no extension onto radicular dentine class 3: deeper invasion of the lesion onto the coronal third of the root class4: a lesion extending beyond the coronal third of the root.

After locating the possible predisposing factors based on the medical and dental history of the patient and before setting a treatment plan, it is crucial to determine the prognosis of the ECR lesion. Prognostic factors that influence the success of the treatment include the extent of the lesion, the presence of bone-like tissue, pain sensation, and the feasibility of probing [1, 95]. Probing of the portal of entry less than 0.5 mm defines a small size lesion and more than 5 mm a large one. The probing feasibility is determined mostly based on the existence of bone ingrowth, where probing is not technically feasible through the portals of entry [95]. The decision to treat externally with or without crown lengthening is determined by the location and size of the portals of entry [95]. A critical factor in the treatment of ECR is achieving adequate access to the lesion to facilitate the curettage of granulomatous tissue from both the root and periodontium, thereby preventing recurrence of ECR [101]. Buccal access is technically more straightforward than palatal access; however, interproximal access presents greater challenges and may lead to aesthetic complications post-treatment. The morphology of the lesion is evaluated based on the type of tissue involved (granulation and/or bone tissue). An additional prognostic factor is the presence of previous endodontic treatment as it is shown that teeth with a RCT and ECR present with a more aggressive form of ECR. In a recent retrospective study involving 542 teeth affected by external invasive resorption (ECR), the overall survival rates were reported as 84.6% at 3 years, 70.3% at 5 years, 42.7% at 8 years, and 28.6% at 10 years [95]. The study further indicated that a more favorable prognosis was associated with external treatment as opposed to internal treatment [95]. Upon confirmation of the nature and extent of the resorptive lesion using cone-beam computed tomography (CBCT), a treatment plan can be settled.

The objectives of treatment for ECR are excavation of the resorptive tissue, sealing of the hard tissue defect with an aesthetic biocompatible material and prevention of recurrence of ECR [102]. Once ECR is diagnosed, attention should be given in minimizing the effects of the possible predisposing factors that can lead to progression of ECR such as occlusion overloading, parafunctional habits,

bad mouth hygiene. This aims to reduce hypoxia at the periodontal ligament level and to prevent tooth fracture [95]. Treatment options for ECR include microsurgical approach with or without endodontic treatment, gingivectomy/ostectomy with or without endodontic treatment, internal approach with or without endodontic treatment, intentional replantation, monitoring, and extraction [1, 101, 103]. For small lesions without pulp involvement (Heithersay classes I and II), external repair with surgical access is preferred which includes removal of the resorption tissue with 90% of trichloroacetic acid (TCA) and curettage followed by composite resin or glass ionomer cement restoration [95]. In cases of larger lesions where pulp perforation occurs during ECR treatment, direct pulp capping or partial pulpotomy may be performed [95]. It is important to maintain the vital pulp tissue, which helps to maintain the PRRS layer and hinders the progression of ECR. In classes II–IV, we have the options of treatment, monitoring or tooth removal. A combination of internal and external approaches may be employed for large resorption cavities, particularly if external excavation is not possible. If external repair is impractical or results in excessive loss of tooth structure, an internal approach with endodontic treatment followed by defect restoration is recommended [103]. The option of monitoring may be chosen as a less invasive approach in cases where bone ingrowth is observed [and therefore probing of the portals of entry is not feasible]. However monitoring is not indicated in cases where the patient has clinical symptoms of pulpitis/apical periodontitis or periodontal pain or when aesthetic considerations occur for example by the presence of a pink spot in the front teeth [95]. An alternative method when neither surgical nor internal approaches can arrest the resorptive lesion is intentional reimplantation. This technique involves the intentional extraction and reinsertion of the endodontically treated tooth into its socket [103, 104]. When the tooth is no longer restored and the patient presents pain, extraction is indicated and a restorative treatment plan is established.

6. Conclusion

Tooth resorption is physiological in cases of deciduous teeth or pathological often in patients with history of TDI. It is initiated after damage of the protective mechanisms of predentin and precementum and can occur as a late complication, resulting in resorption of dental tissues. Accurate diagnosis and timely intervention are critical determinants of prognosis, yet clinical identification can be challenging and often leads to misdiagnosis. Continuous clinical and radiographic monitoring, supported by cone-beam computed tomography (CBCT), is essential for early detection and management. Trauma-related tooth resorption is broadly classified as internal or external, with internal types including repair-related, infection-related, and ankylosis-related, and external types including repair-related, infection-related, ankylosis-related, and cervical resorption. Preventive management – such as immediate root canal therapy in high-risk injuries or minimizing extra-oral dry time in avulsed teeth – significantly reduces the risk of resorption. Once established, appropriate endodontic treatment can arrest progression and promote hard tissue repair. An evidence-based, multidisciplinary approach remains fundamental to improving the prognosis of trauma-associated tooth resorption.

Conflict of Interest

The authors declare no conflict of interest.

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Chapter 5

Tooth Avulsion: Key Strategies to Prevent Irreversible Loss

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Abstract

Maxillofacial traumatic injuries represent a constant challenge in dental practice, among which dental injuries, especially avulsion, are considered the most severe and clinically relevant emergencies. Avulsion involves the complete expulsion of a tooth from its alveolus, resulting in esthetic, functional, and psychological consequences that can significantly impact a patient's quality of life. Proper management, with rapid action based on standardized protocols and scientific evidence, represents a complex clinical challenge due to the need to preserve the dental organ and prevent long-term complications. Dental avulsion incidence is highest in children and adolescents between 7 and 10 years of age, most commonly affecting permanent anterior teeth, particularly the upper central incisors, followed by upper lateral incisors and lower central incisors. The most frequent causes are falls, traffic accidents, sports activities without protection, and direct trauma, with increased susceptibility in the presence of predisposing factors such as dental protrusion, extensive caries, periodontal disease, shallow alveoli, and systemic conditions like advanced age or immunodeficiency. The prognosis of an avulsed tooth depends on the promptness and type of intervention after trauma. Immediate reimplantation is the treatment of choice to favor healing, considering apical maturity, extraoral time, and the appropriate storage medium for the avulsed tooth. These factors ensure the long-term survival of the tooth in the oral cavity under optimal conditions.

Keywords: dental avulsion, dentoalveolar trauma, reimplantation, prognosis, dental emergency

1. Introduction

Maxillofacial injuries of traumatic origin represent a frequent challenge in dentistry, with dental trauma occupying a significant place among them. Among these injuries, dental avulsion is considered the most severe and complex, as it involves the complete displacement of a tooth from its socket, potentially leading to esthetic, functional, and psychological consequences for the patient [1]. Proper management of this condition is particularly demanding for dental

professionals, given the need to preserve tooth vitality and minimize long-term complications [2].

During childhood, especially between the ages of 7 and 10, dental avulsion most commonly affects the permanent anterior teeth. The maxillary central incisors are most frequently involved, followed by the maxillary lateral incisors and the mandibular central incisors. These injuries often result from falls, traffic accidents, sports activities, or direct physical impacts. Their occurrence is further influenced by certain anatomical and dental characteristics, such as malocclusion, excessive overjet, dental protrusion, and insufficient lip coverage [3, 4].

The prognosis of avulsed teeth depends largely on the immediate response following trauma. Early replantation is the treatment of choice and remains the most effective measure to preserve the tooth. However, certain circumstances, such as extensive caries, advanced periodontal disease, lack of patient cooperation, or complex medical conditions, may prevent immediate reimplantation [5]. In cases where replantation is not feasible at the accident site, the tooth should be preserved in an appropriate storage medium and promptly transported to a dental facility. Timely intervention and correct management from the moment of injury are critical for therapeutic success and the long-term survival of the tooth [6].

In this context, dental avulsion represents not only an odontological emergency but also a condition in which rapid, evidence-based action can make the difference between retaining the natural tooth and its definitive loss.

2. Etiology

Dental avulsion is defined as the complete displacement of a tooth from its alveolar socket due to trauma. This type of injury is most frequently observed in children and adolescents, particularly between 7 and 9 years of age, when the permanent teeth are erupting and their roots remain incompletely formed [7].

It is considered one of the most severe dental injuries, typically caused by high-impact forces such as falls, unprotected sports activities, traffic accidents, or physical violence. Children are especially vulnerable due to the immaturity of the alveolar bone and incomplete root development. Predisposing factors include protrusive incisors, excessive overjet, shallow alveoli, periodontal disease, extensive caries, and systemic conditions such as advanced age or immunodeficiency [8].

The etiology of dental avulsion cannot be attributed solely to trauma; rather, it results from an interaction of anatomical, biological, systemic, and environmental factors that influence both the occurrence of the event and the prognosis of the avulsed tooth. This complexity highlights the importance of prevention, including the use of mouthguards in high-risk activities and public education on the immediate management of an avulsed tooth [9].

3. Diagnosis

The diagnosis of dental avulsion is primarily established by the clinical absence of the tooth in its alveolar socket, which is the hallmark sign of this injury [6]. A detailed medical and dental history is essential, including the time elapsed since

the accident, the storage medium of the avulsed tooth, and the patient's medical history. Intraoral examination typically reveals an empty socket, with or without bleeding, along with possible gingival lacerations, alveolar fractures, or injury to adjacent teeth. If the avulsed tooth is available, it should be examined for crown and root integrity, the condition of the periodontal ligament, and any contamination [9]. Radiographic assessment (periapical and panoramic radiographs) is critical to confirm the absence of the tooth, rule out alveolar fractures, and distinguish avulsion from other traumatic injuries such as intrusion or severe luxation [6].

4. Clinical evaluation

The clinical assessment of an avulsed tooth, according to the guidelines of the International Association of Dental Traumatology (IADT, 2020), should be performed promptly and in a structured manner, taking into account both the patient's systemic condition and the local characteristics of the trauma. A thorough medical and dental history is essential, with specific attention to the extraoral time, the storage medium of the tooth, and any relevant medical history. During the extraoral examination, the presence of facial injuries or fractures should be carefully evaluated, while the intraoral examination must include assessment of the socket, surrounding soft and hard tissues, and adjacent teeth. In addition, radiographic imaging is useful for ruling out alveolar fractures, intrusion of other teeth, or the displacement of the tooth into soft tissues [6, 9].

Furthermore, a review of the literature on the clinical evaluation of dental avulsion emphasizes the importance of focusing on variables that directly influence the prognosis of replantation. Three major groups of prognostic factors have been identified and are summarized in **Table 1** [10].

5. Immediate management

In the pre-hospital setting, an avulsed tooth may either be replanted immediately or stored in a medium that preserves the viability of periodontal ligament (PDL) cells. Recommended storage media include Hanks' Balanced Salt Solution (HBSS) or milk. Saliva should only be used if no other options are available. Water must be avoided because its low tonicity can damage and cause the death of PDL cells. Permanent teeth should be handled exclusively by the crown, avoiding any contact with the root surface to protect the PDL cells. In this context, it is advisable to refer to **Table 1**, which indicates the approximate time a tooth may remain viable depending on the storage medium employed [10].

6. Tooth replantation: The key to prognosis

Immediate replantation in the dental office, ideally within the first two hours after the trauma, offers the highest likelihood of success. After

Category	Aspects to be evaluated	Clinical indications/Prognosis
Non-treatment-dependent factors	• Extraoral time: < 30 min (optimal), < 2 h (acceptable), > 2 h (uncertain). • Storage medium: milk, Hank's Balanced Salt Solution (HBSS), propolis, saline solution, saliva. • Periodontal ligament and cementum damage. • Root apex condition: open (better revascularization) vs. closed (higher risk of necrosis).	• Prolonged extraoral time increases the risk of necrosis and resorption. • Inadequate medium or dry storage worsens prognosis. • Severe periodontal ligament damage increases the risk of ankylosis or external cervical resorption.
Treatment-dependent factors	• Pulp extirpation: intraoral, 10–14 days post-replantation (IADT guidelines). • Splinting: flexible for immediate replantation; rigid for delayed cases. • Systemic antibiotics: recommended, although evidence is limited. • Intracanal medications: calcium hydroxide or other agents to prevent resorption. • Adjunctive therapies: Emdogain, Thymosin α1, hyperbaric oxygen (low evidence). • Decoronation in cases of ankylosis or severe resorption.	• Adequate endodontic control and proper splinting favor healing. • Antibiotics may reduce complications. • Outcomes of delayed replantation are less predictable.
Additional (independent) factors	• Condition of the tooth (fractures, contamination). • State of soft and hard tissues. • General oral health and patient compliance.	• Poor oral hygiene or lack of compliance → worsens the prognosis. • Surrounding tissue conditions significantly influence replantation success.

Legend: The prognosis of replanted teeth depends on a multifactorial interaction of local, systemic, and treatment-related variables. Non-treatment-dependent factors strongly influence biological healing potential, while treatment-dependent and additional factors determine clinical outcomes.

Table 1.
Prognostic factors in the clinical evaluation and management of dental avulsion.

replantation, the tooth must be monitored over an extended period to detect potential late complications, such as PDL damage or pulpal involvement. If the tooth loses vitality, root canal treatment will be required, in addition to consulting **Table 2**, which illustrates the viability of PDL cells in different storage media.

According to Walls [10], if the patient is conscious and there is no risk of aspiration, the following steps are recommended:

Storage Medium	Approximate PDL Cell Viability
None (dry)	Less than 60 minutes
Milk	3–8 hours
Hanks' Balanced Salt Solution (HBSS)	12–24 hours
Oral rehydration solution	Similar to HBSS

Legend: The viability of periodontal ligament cells depends on the medium in which an avulsed tooth is stored. Immediate replantation or storage in an appropriate medium improves the prognosis of the tooth.

Table 2.
Periodontal ligament (PDL) cell viability according to the storage medium.

1. **Local anesthesia** using suprapariosteal nerve block.
2. **Gentle cleaning of the tooth:** rinse lightly with saline if visible debris is present, avoiding manipulation of the root surface. Do not manually remove debris adhered to the root to prevent PDL cell damage.
3. **Alveolar socket preparation:** irrigate gently with sterile saline to remove debris before replanting the tooth into its socket.
4. **Tooth immobilization:** ideally, a definitive splint should be placed by a dentist; if unavailable, a periodontal dressing (e.g., Coe-Pak) can be used as a temporary splint for 24–48 hours. The paste should be molded over the affected tooth and two or three adjacent teeth on each side. Both the gingiva and enamel must be kept dry, and gloves should be moistened or coated with petroleum jelly to facilitate manipulation. Precise anatomical positioning is not mandatory, and the occlusal surface should not be covered. According to the 2020 IADT guidelines, a flexible splint should be maintained for 7 to 10 days to allow periodontal ligament healing while minimizing the risk of complications such as ankylosis or root resorption [11].
5. **Post-operative care and medication:**
 - Soft diet; avoid hot liquids that may soften the splint.
 - **Antibiotic prescription:** doxycycline 100 mg twice daily for 7 days in adults; penicillin 50 mg/kg/day divided into four doses (max 500 mg per dose) for 7 days in children.
 - **Oral hygiene:** careful brushing with a soft toothbrush after meals and rinsing with chlorhexidine twice daily for one week.
6. **Follow-up:** the patient must attend a dental evaluation within 24 hours after replantation for control and possible splint adjustment.

7. Consequences of dental avulsion

Pulpal necrosis is an almost inevitable consequence following dental avulsion. Although necrotic tissue does not cause direct harm, its susceptibility to bacterial contamination can lead to root canal infections if proper revascularization or timely endodontic treatment is not performed. This infection, combined with damage to the external root surface, may trigger external inflammatory root resorption, which, in severe cases, can result in rapid tooth destruction.

Damage to the periodontal ligament (PDL) also determines the severity of complications. If the ligament remains attached to the root and has not dried out, PDL cells retain their viability, allowing favorable healing with limited

inflammation and new cementum formation. However, if the PDL dries prior to replantation, damaged cells provoke an extensive inflammatory response, affecting much of the root surface and increasing the risk of resorption, tissue loss, and failure of the replanted tooth [9].

8. Endodontic considerations in cases of dental avulsion

Dental avulsion represents one of the most complex dental emergencies, as it involves the complete displacement of the tooth from its alveolus, with injury to both the periodontal ligament (PDL) and pulp. From an endodontic perspective, several factors directly influence treatment viability and long-term prognosis [12].

8.1 Root apex maturity

One of the first aspects to evaluate is whether the tooth has an open or closed apex. In teeth with a closed apex, pulpal necrosis is highly likely, and endodontic treatment is recommended between 7 and 10 days after replantation to prevent infection and root resorption [11]. In teeth with an immature apex, there is a higher chance of pulpal revascularization, especially if the tooth was replanted within 60 minutes under favorable conditions. In these cases, clinical observation, vitality testing, and, if necrosis is detected, initiation of regenerative or apical barrier protocols may be appropriate [11, 13].

8.2 Extra-alveolar time and storage medium

The duration that the tooth remains out of the oral cavity, as well as the type of storage medium used (milk, saline solution, physiologic serum, or HBSS), directly affects the survival of PDL cells and the possibility of pulpal regeneration [1, 2]. If the tooth remains dry for more than 60 minutes, revascularization is unlikely, and the risk of ankylosis or replacement resorption increases. In such cases, endodontic treatment should be initiated before or immediately after replantation [12].

8.3 Timing of endodontic treatment

The ideal time to start root canal therapy depends on the apical status:

For teeth with a closed apex, treatment should begin 7–10 days after replantation to prevent the progression of infections that may lead to inflammatory resorption [11]. For immature teeth, if there are no clinical or radiographic signs of pathology, observation is indicated to evaluate potential revascularization [13]. Necrosis or external resorption requires prompt intervention with a regenerative approach [13].

8.4 Intracanal medication

Calcium hydroxide is the most commonly used intracanal medicament due to its antimicrobial properties and ability to prevent external resorption. In some cases,

antibiotic-corticosteroid pastes (e.g., Ledermix) may be indicated, particularly when inflammation or active resorption is suspected [11, 14].

8.5 Canal obturation and sealing

Once the infection is controlled, the root canal is obturated. In teeth with an open apex, the placement of a barrier material, such as MTA or bioceramics, may be necessary to achieve proper apical sealing and promote healing [11, 13].

8.6 Long-term follow-up

Periodic clinical and radiographic evaluations are essential to detect complications such as:

- External inflammatory resorption
- Replacement resorption (ankylosis)
- Progressive loss of alveolar bone support

These complications may compromise the tooth's prognosis and necessitate additional interventions, including possible extraction [11,12].

9. Prognosis of dental avulsion

A retrospective study of 49 replanted permanent teeth reported an average survival rate of 65.3% over a mean follow-up period of 3.5 years [15].

- Among these, only 26.5% (13/49) exhibited functional healing without tooth loss during the follow-up period.
- Replacement resorption (ankylosis) affected 51% (25/49), of which 24% were lost over a mean period of 6.1 years.
- Inflammatory resorption affected 22.5% (11/49), resulting in the early loss of all affected teeth, with a mean survival time of 1.7 years.

Another study [16], involving 60 replanted teeth in children (mean age: 9.6 years), found the following:

- Functional healing/ankylosis: 23.3%
- Replacement resorption: 66.7%, with 62.5% of these teeth eventually lost.
- Inflammatory resorption: 10%
- Estimated 5-year survival: 47.5%
- Prognosis was better in male children and teeth with mature roots.

9.1 Prognostic factors

9.1.1 Root maturity

Teeth with immature roots tend to present more complications, including inflammatory resorption and replantation failure. In contrast, teeth with mature roots have higher survival rates and a lower risk of complications [17].

9.1.2 Extra-alveolar time and early replantation

The key factor for a favorable prognosis in avulsed teeth is the duration the tooth remains out of the alveolus. Replantation within the first 30 minutes significantly increases the likelihood of success, as the periodontal ligament has a higher chance of surviving and promoting revascularization. It is also recommended to avoid placing the tooth in water, as this may damage the PDL cells [16].

9.1.3 Replantation and success factors

The success of replantation also depends on several factors, including tooth type (permanent teeth have higher success rates), patient age, and replantation technique. Avulsed teeth in children generally have a better prognosis due to the high regenerative capacity of developing teeth [18].

9.1.4 Supportive treatments

Following replantation, endodontic treatment is generally required if pulp necrosis is observed or if long-term tooth damage is present. The use of antibiotics and appropriate tooth immobilization are common strategies to prevent infection and ensure treatment success [19].

10. Prevention of dental avulsion

Prevention of dental trauma is a fundamental aspect of dental care, encompassing both education and the implementation of practical measures. Preventive strategies targeting vulnerable populations can help reduce the prevalence of these injuries. The use of mouthguards in young athletes highlights the importance of protection during high-risk activities, emphasizing the role of sports dentistry, which focuses on preventing, diagnosing, and managing oral and maxillofacial injuries in athletes. Therefore, continuous educational and social awareness campaigns are essential to improve long-term outcomes and minimize the impact of such injuries on oral health and patients' quality of life [10].

10.1 Prevention of dental trauma in athletic populations

Athletes often present with more compromised oral health than the general population, which may lead to acute and chronic problems affecting performance. It is, therefore, crucial to implement preventive measures to ensure that acute dental conditions do not interfere with years of training and competition. An

interdisciplinary approach involving dentists, sports physicians, physiotherapists, and other health professionals is recommended. Integrating this knowledge into clinical practice enables appropriate preventive measures and ensures effective management of dental trauma [20].

To minimize the risk of dental trauma in athletes, several preventive measures are recommended. These include the use of custom-made mouthguards, which significantly reduce the risk of fractures and avulsions and can be adapted according to the sport and the athlete's age; maintenance of oral health through regular check-ups, professional cleanings, and targeted oral hygiene education for athletes and coaches; instruction on safe techniques, including proper use of sports equipment and prevention of high-risk behaviors during and outside of training; interdisciplinary planning, coordinating dentists, sports physicians, and coaches to establish preventive protocols and mandate the use of facial or oral protection; and, finally, raising awareness of first-aid measures and immediate management by training all sports personnel on how to respond to dental trauma and ensuring the availability of a dental first-aid kit [21].

11. Future perspectives: Artificial intelligence and dental avulsion

Artificial intelligence (AI) is a rapidly evolving technology with various applications in dentistry, such as diagnosis, treatment planning, and prognosis. Despite its benefits, AI faces challenges, including the need for large datasets, complex mechanisms, and high costs. Nevertheless, the future of AI in healthcare and dentistry is promising, with potential applications in accuracy, research, and the management of repetitive tasks [22].

Dentists are not yet fully familiar with artificial intelligence models, their potential applications, or the limitations they present in clinical decision-making. Given the variety of treatment options for dental trauma, a relevant area in endodontics, it is essential to assess whether AI programs can provide accurate and reliable answers to specific queries in this context. Therefore, further research in this field is necessary [23].

The most popular AI application is Chat Generative Pretrained Transformer (ChatGPT). In 2024, Bordin et al. evaluated the responses of ChatGPT-3.5 on dental trauma using five endodontic experts and a Likert scale based on scientific evidence and clinical experience. The study assessed the reliability of ChatGPT in cases of dental avulsion, general dental trauma, and intrusion, showing generally positive results and good acceptance among the evaluators. Although some variability was observed in certain ratings, most scores fell within the "Good" and "Very Good" categories, reflecting an overall favorable evaluation.

Despite its potential as a supportive tool in the management of dental trauma, continuous evaluation is essential to ensure the accuracy and safety of AI-generated content in endodontics. ChatGPT-3.5 should be used with caution and always complemented by professional judgment and evidence-based practice. It is worth emphasizing that ChatGPT undoubtedly cannot, should not, and will not replace dentists in clinical decision-making [24].

Another application that is gaining popularity is Google Bard, or Gemini, which, like ChatGPT, uses large language models (LLMs) to simulate human conversation. In 2024, Özden et al. evaluated the consistency and accuracy of the responses

provided by these two applications regarding questions on dental trauma. The analysis revealed that both applications delivered correct answers to 57.5% of the questions, leading to the conclusion that although ChatGPT and Google Bard represent valuable sources of information, the consistency and accuracy of their responses concerning dental trauma still present limitations, thus supporting the need for further research with artificial intelligence models [25].

12. Conclusion(s)

Dental avulsion represents one of the most complex dental emergencies, with significant functional, esthetic, and psychological consequences, particularly in children and adolescents. The prognosis is highly dependent on the immediate response to the trauma, with early reimplantation within the first 30–60 minutes being critical for periodontal ligament viability and tooth preservation [12, 16].

A comprehensive clinical approach should consider diagnostic, endodontic, periodontal, and restorative aspects, as well as factors such as extraoral time, storage medium, root maturity, and patient cooperation. Even under ideal conditions, the long-term survival of reimplanted teeth is limited by frequent complications, including pulpal necrosis, inflammatory resorption, and ankylosis, which underscores the importance of strict clinical and radiographic follow-up.

Prevention plays a fundamental role. Educating the general population, healthcare personnel, and sports professionals on the immediate management of dental avulsion, along with the use of protective measures such as custom mouthguards, is essential to reduce both the incidence and the impact of these injuries.

Finally, the management of dental avulsion should focus not only on immediate intervention but also on planning supportive therapies, timely endodontic treatment, and interdisciplinary preventive protocols. This integrated approach is essential to optimize clinical outcomes, preserve function and esthetics, and improve patients' quality of life.

Nomenclature

Abbreviation

PDL	Periodontal Ligament
HBSS	Hank's Balanced Salt Solution
IADT	International Association of Dental Traumatology
MTA	Mineral Trioxide Aggregate
Coe-Pak	Periodontal dressing paste
PDA	Pulpal and Dental Anatomy
CBCT	Cone Beam Computed Tomography
Rx	Radiograph
AI	Artificial intelligence
LLMs	Large language models
ChatGPT	Chat Generative Pretrained Transformer

Conflict of interest

The authors declare no conflict of interest.

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Chapter 6

Laser Applications in Traumatic Dental Injury Management

Hazal Özer Ünal, Yasemin Derya Fidancıoğlu and Merve Abaklı İnci

Abstract

Traumatic injuries to the tooth are common in adolescents and children and often induce complicated problems that encompass surrounding tissues and the tooth. While surgical treatment, pulp treatment, and splinting are ordinary treatment methods, outcomes sometimes become unpredictable, and patients experience complications or pain. Dental lasers have come into existence over the past decades as complementary technologies for the treatment of traumas, and many reports highlight their benefits, such as favorable bleeding control, a cleaner surgical field, and improved patient comfort. This chapter provides an overview of the use of various laser systems, such as diode, erbium, CO₂, and Nd:YAG, in the care of trauma patients. Their use for the repair of soft tissue, procedures for hard tissue, surgical exposure, and removal of splints is described with clinical examples. Special emphasis is placed on photobiomodulation, which is particularly useful in minimizing pain and inflammation and accelerating the healing of wounds. This is especially apparent for pediatric patients, for whom minimizing anxiety and maximizing cooperation may be at least as valuable as the biological cure. Despite these promising results, limiting factors such as expense, variability of clinical protocols, and the danger of improper settings nevertheless prevent universal application. Lasers may currently be considered only as useful adjuncts rather than complete replacements for conventional care. Additional educational experiences, clearer guidelines, and more persuasive evidence from clinical studies will make laser technology increasingly reliable elements in the treatment of dental trauma.

Keywords: dental trauma, laser dentistry, soft tissue injuries, traumatic dental injuries, pediatric dentistry, dental emergency management

1. Introduction

Traumatic dental injuries are one of the most frequent dental emergencies predominantly seen in children and adolescents as a result of daily accidents, sports activities, and falls. Oral trauma occurs in an estimated one-third of children and adolescents and usually happens before adulthood, with permanent incisors being the most affected teeth [1, 2]. The initial concerns of pain, hemorrhage, or

dysfunction could be supplanted by more severe long-term sequelae, including pulp necrosis, inflammatory or external root resorption, pulp canal obliteration, ankylosis, and disturbances in root development [1, 2]. These outcomes affect not only the anatomy and function of the stomatognathic system but can also leave a mark on the patient's self-esteem and psychosocial well-being due to compromised dentofacial esthetics, especially in young patients [2].

Conservative treatment modalities, including replantation and splinting of avulsed teeth, endodontic therapy in cases of pulp necrosis or pulpitis, and surgical procedures such as apexification, apical resection, pulpotomy, hemisection, osteotomy of ankylosed teeth, and crown lengthening in immature teeth, are well-established and recommended in international guidelines [1, 2]. Despite their established use, prognosis and complication rates remain unpredictable, which highlights the need for strategies to improve predictability and healing responses [1–3].

Within this context, the use of lasers in modern dentistry extends beyond their traditional role in caries removal and soft tissue surgery. In trauma management, lasers provide additional benefits such as antimicrobial effects, hemostasis, and stimulation of tissue repair [3, 4]. Photobiomodulation (PBM) therapy has further demonstrated potential in reducing inflammation, accelerating wound healing, and alleviating posttraumatic pain [3, 5]. Clinical evidence suggests that the adjunctive use of lasers in endodontic disinfection and vital pulp therapy can result in reduced postoperative discomfort and improved prognosis in traumatized teeth [3, 5].

Taken together, current data support the notion that integrating laser applications into trauma management can complement conventional protocols and enhance patient comfort [2, 3, 5]. However, robust randomized controlled trials and long-term follow-ups are still required to establish standardized, evidence-based guidelines for laser-assisted trauma care [5].

2. Classification and mechanism of dental lasers

Lasers are categorized based on their active medium, emission wavelength, and the type of interaction with biological tissue. Each laser system has specific absorption spectra, which largely determine its applications in the clinic [6].

Argon lasers (350–514 nm) generate visible blue (490 nm) and bluish-green (514 nm) light, and are optimally absorbed by pigmented tissues. Argon lasers have been used for composite polymerization, tooth whitening, and other preventive procedures [7].

Diode lasers operate in the wavelength range of 780–980 nm; they are semiconductor-based devices with limited output power. Diode lasers are particularly well absorbed by hemoglobin and melanin. They have been used mainly for soft tissue surgery, hemostasis, periodontal pocket disinfection, tooth whitening, dentin hypersensitivity treatment, and other procedures [8].

Nd:YAG lasers operate at a wavelength of 1,064 nm, which has high penetration levels and high bactericidal and coagulative effects. They are useful in soft tissue surgeries, endodontic disinfection, removal of dentin smear layer, treatment of dentin hypersensitivity, and other procedures [9].

CO₂ lasers emit at 10,600 nm; the long wavelength leads to high absorption in water, and CO₂ lasers can effectively cut and coagulate soft tissues. Human bleeding is instantly coagulated due to the absorption of CO₂ laser radiation by the water in blood. Bloodless operation is often possible, which encourages the laser to be used for soft tissue surgical applications. However, hard tissue applications are limited due to heat conduction in dental hard tissues, which may cause thermal pulpal damage [10].

Er:YAG lasers emit at 2,940 nm, and Er,Cr:YSGG lasers operate at 2,780 nm; both have high absorption in water as well as in hydroxyapatite, and can be used to effectively remove carious and sound enamel and dentin. They further allow for alveolar osteotomy with a low risk of thermal side effects for the pulp [11].

The interaction of laser light with soft and hard tissues is characterized by reflection, transmission, scattering, and absorption. Absorption plays a crucial role in laser–tissue interaction because it converts the laser light energy into heat and/or photochemical energy, which, in turn, is responsible for the biological effects [12]. Thermal effects on tissues can be understood within three largely overlapping ranges: Very low irradiance induces PBM, which promotes fibroblast proliferation, collagen induction, and neovascularization, resulting in improved healing. Irradiance in the moderate range denatures proteins and induces coagulation in the tissue, in addition to antibacterial effects; as a result, hemostasis may be achieved for soft tissue applications. In treatments with high average irradiance, tissue water is heated rapidly, resulting in vaporization and ablation. This mechanism is mainly responsible for hard tissue applications, such as the ablation of enamel and dentin [13].

The thermal effect of the laser on different sampled tissues depends on the water absorption coefficient, penetration depth, wavelength, mode of emission, and the composition of the sampled tissue. Upon interaction with the GaAlAs light at 940 nm, temperature rises were measured using thermocouples within dental hard tissues, and laser-induced microexplosions in water-rich tissues such as dentin are observed as precise ablative processes with minor collateral damage. In contrast, a Nd:YAG laser penetrates deeper (860 µm) due to its longer wavelength and phosphoresces metals such as gold; it causes more pronounced coagulative and disinfecting effects but also resulted in pulpal damage in 14% of the laser-treated rounds, likely due to periodontal heating or overexposure [14].

3. Laser-assisted management of soft tissue injuries

Oral soft tissue traumas, including gingival lacerations, oral mucosa lacerations, frenulum trauma, and trauma to the lips, tongue, and cheeks, are common types of dental trauma encountered in dental practice, especially in children. Conventional treatment, which requires suturing of the laceration, infiltrative anesthesia, and mechanical hemostasis, is more time-consuming than laser surgery, which is painless and better tolerated by patients [15].

The introduction of laser systems into surgical practice revolutionized the treatment of oral soft tissue traumas. The most widely used laser systems are diode lasers, Nd:YAG, CO₂, and erbium lasers. These systems provide excellent visibility while cutting tissues due to bloodless incisions from the simultaneous coagulation of

all small vessels, reduced intraoperative pain, less scarring, and a faster reepithelialization rate [16]. In pediatric patients, performing surgeries with a laser reduces the need for infiltrative anesthesia and, as a result, is less traumatic for the patient [17].

An additional important advantage of the laser in the treatment of trauma is the sterilization of the operating field. Laser irradiation decreases the number of microorganisms in the wound and prevents the development of postoperative complications due to infection; the coagulation of lymphatics reduces tissue edema; and the coagulation of the nerve endings diminishes the postoperative pain syndrome [18]. The combination of all the advantages of laser cutting can provide a significant decrease in rehabilitation time and an improvement in the quality of recovery in patients.

These advantages were confirmed in a number of clinical studies, which described the results of laser treatment of oral mucocoeles, laser surgeries for traumatic fibromas, and the treatment of traumatic lacerations of the gingiva and lips. In the studies mentioned above, patients who underwent laser surgery experienced a significantly shorter operating time, less bleeding, and a faster healing process compared to those who underwent traditional surgery [19].

At the cellular and tissue levels, the advantages of laser treatment for soft tissue traumas are due to photothermal and PBM effects. Photothermal energy is used to cut and coagulate tissues with minimal thermal damage to adjacent tissues. Low-dose PBM increases the proliferation of fibroblasts, collagen production, and angiogenesis due to the effect of low laser exposure on cytochromes in the mitochondrial respiratory chain [20]. Enhanced cellular activity leads to quicker wound healing and restoration of soft tissues.

The effectiveness of laser treatment is highly dependent on the use of correct parameters, such as power, energy density, time intervals, and wavelength. Deviations from the optimal exposure can lead to unwanted thermal damage to tissues, carbonization and hardening of the area, insufficient stimulation of healing processes, as well as excessive stimulation, which may result in the spread of inflammation in the tissues and prolonged healing. Thus, it is important to have sufficient knowledge, experience, and training in different clinical cases during the treatment to ensure safety and predictability in various situations [21].

In conclusion, the treatment of soft tissue traumas with lasers in oral surgery is a minimally invasive, effective, and less traumatic method when compared to traditional surgery, and it is especially necessary in pediatric practice.

4. Laser-assisted management of hard tissue injuries

Hard tissue traumatic dental injuries include enamel–dentin fractures, complicated crown fractures, and root fractures. Traditional treatment procedures often involve rotary instrumentation to remove fragments, prepare cavities, or gain access during endodontic therapy. However, these methods may inadvertently sacrifice healthy tooth structure, produce vibrations and noise, and cause significant stress in pediatric patients [22].

Lasers of the erbium family, including Er:YAG (2940 nm) and Er,Cr:YSGG (2780 nm), are the only systems with strong absorption in both water and

hydroxyapatite and are, therefore, uniquely suited for hard tissue applications. Their photoablative mechanism allows selective removal of carious dentin and fractured tissue with minimal collateral thermal damage. This enables precise ablation while preserving pulpal vitality [23]. Comparative studies have demonstrated that erbium lasers preserve more sound tooth structure than rotary burs, reduce the risk of microfractures, and decrease postoperative sensitivity through the sealing of dentinal tubules [24].

Clinical applications of erbium lasers in traumatic dental injuries include the following:

- Removal of fractured crown fragments using selective ablation,
- Cavity preparation for adhesive restorations following enamel–dentin fractures,
- Access opening to the pulp chamber of immature teeth with necrotic pulp and instrumentation of canals,
- Decontamination of pulp tissues in open-apex teeth during revascularization procedures,
- Pulp extirpation, disinfection, and canal instrumentation in complicated crown fractures,
- Management of root fractures through debridement and disinfection,
- Hemisection or root resection,
- Laser-assisted pulp capping in traumatic pulp exposures without necrosis,
- Surgical access through enamel–dentin fractures,
- Alvelectomy, alveolotomy, or management of infraoccluded teeth,
- Bone cutting or soft tissue excision/gingivectomy in alveolar fractures or luxated teeth requiring reimplantation, and
- Removal of ectopic teeth in jaw trauma cases, in addition to other soft tissue surgical interventions in the oral and orofacial region [25].

Endodontics of traumatized teeth represents another important field of application. Several studies indicate that lasers improve root canal disinfection by enhancing the penetration and efficacy of irrigants within dentinal tubules through photoactivation. Nd:YAG and diode lasers, when used as adjuncts to chemical debridement, have shown strong bactericidal activity against *Streptococcus* and *Prevotella* species commonly associated with persistent apical periodontitis and pulpal necrosis [26].

Other pathogens, such as *Streptococcus mutans*, nonmutans streptococci, *Lactobacillus* spp., *Actinomyces* spp., *Eikenella corrodens*, and *Fusobacterium nucleatum*, have also been identified in traumatized pulps. Laser-assisted endodontic

disinfection has demonstrated superior clinical and radiographic outcomes compared with conventional therapy, particularly in immature teeth with open apices [27].

Nevertheless, risks such as excessive heat generation, thermal injury, tissue carbonization, and overuse of energy must be considered, as they may jeopardize pulpal vitality, periodontal support, or adjacent structures. In addition, certain procedures – such as cavity margin finishing – still require rotary instruments. For this reason, lasers should be regarded as a valuable adjunct rather than a full replacement for conventional tools in trauma management [28].

In conclusion, erbium laser systems provide important advantages in the treatment of traumatic hard tissue injuries, including high precision, selective ablation, dentin tubule sealing, reduced operative stress, and improved patient comfort, particularly in pediatric practice.

5. Laser applications in surgical exposure and splint removal

Surgical exposure is a common intervention in the management of impacted teeth and traumatic dental injuries. Traditional approaches, such as scalpels and rotary burs, remain effective; yet, they are often accompanied by undesirable consequences, including excessive bleeding, collateral tissue trauma, and reduced patient comfort [4, 9]. With the introduction of laser systems into dentistry, clinicians now have access to methods that are more precise, minimally invasive, and better tolerated by patients [6, 8].

The most widely used systems in surgical exposure are CO₂, Nd:YAG, Er:YAG, and diode lasers. Their clinical applications are shaped by the interaction of each wavelength with water, hemoglobin, and hydroxyapatite. CO₂ lasers are absorbed primarily by water, allowing rapid soft tissue ablation and excellent hemostasis [28]. Nd:YAG lasers, absorbed by pigmented tissues and hemoglobin, penetrate deeper and provide effective coagulation [29]. Er:YAG and Er,Cr:YSGG lasers, absorbed by both water and hydroxyapatite, enable controlled hard tissue ablation with minimal thermal effects [10, 23]. Diode lasers, compact and practical, are especially suited for soft tissue procedures where hemostasis is essential [11].

Clinical evidence consistently demonstrates the advantages of laser-assisted surgical exposure: shorter operative times, clearer surgical fields, reduced bleeding, and diminished postoperative pain and swelling [30–32]. Faster healing is frequently observed due to the limited collateral trauma caused by lasers. In pediatric patients, the absence of noise and vibration further reduces anxiety and promotes cooperation during treatment [13].

Lasers have also gained attention in the removal of splints used for the stabilization of traumatized teeth. Conventional mechanical removal with rotary instruments risks iatrogenic enamel damage and can be stressful for patients [11]. By contrast, Er:YAG and Er,Cr:YSGG lasers selectively ablate resin-based materials in a layer-by-layer fashion, preserving adjacent enamel and dentin [23, 33]. While diode and Nd:YAG lasers are less effective in resin removal, they can assist in adjusting surrounding soft tissues [29]. Reports indicate that laser-assisted splint removal is faster, less invasive, and associated with higher patient comfort and fewer complications [30, 34].

6. Healing, pain control, and psychological advantages in children

In pediatric dentistry, clinical success depends not only on biological healing but also on the child's ability to undergo treatment without lasting psychological distress. Negative dental experiences in childhood are strongly associated with long-term dental fear and avoidance behaviors [35]. For this reason, effective pain management and anxiety reduction are essential elements of pediatric care.

Low-level laser therapy (LLLT), also referred to as PBM, has become a promising modality in this context. LLLT acts by modulating cellular biochemical pathways without producing significant thermal damage, making it noninvasive and well-suited for children [13, 24, 36].

The main benefits of LLLT can be summarized in three domains. Analgesia: LLLT reduces nerve conduction velocity, elevates the pain threshold, and stimulates the release of endorphins. Clinical studies have shown that preinjection LLLT combined with topical anesthetics significantly decreases injection pain compared with topical agents alone [35]. Anti-inflammatory and regenerative effects: By inhibiting pro-inflammatory mediators and enhancing microcirculation, LLLT contributes to reduced edema and faster healing. Its stimulatory effects on fibroblasts and osteoblasts accelerate both soft tissue repair and bone regeneration. Reports indicate that pediatric patients receiving LLLT after surgical or traumatic procedures demonstrate faster epithelialization and less swelling [13, 24, 36, 37]. Psychological advantages: The absence of vibration and high-pitched sounds, typical of rotary instruments, makes the dental experience less intimidating. Painless injections and improved postoperative comfort help build trust in the dental environment and encourage cooperation in future treatments [38]. Furthermore, LLLT has been associated with a shorter duration of soft tissue numbness following local anesthesia, reducing the risk of lip and cheek biting, which is a common postoperative complication in children [36].

Taken together, these biological and psychological benefits highlight the importance of lasers as a child-friendly adjunct in modern dental trauma management. By combining enhanced healing, reliable pain control, and reduced anxiety, LLLT offers pediatric patients a more positive and cooperative treatment experience.

7. Limitations, safety concerns, and clinical recommendations

The evidence base for laser use in traumatic dental injuries is limited by methodological and practical issues. Few randomized controlled trials, a lack of long-term follow-up, and varied protocols hinder standardized guidelines [39, 40]. Additionally, high device costs, limited clinic availability, and dependence on operator experience are significant clinical concerns [41].

These limitations vary by trauma type. Lasers may aid in biostimulation and periodontal healing following avulsion and replantation; however, protocols remain experimental, and incorrect settings can risk root resorption. For luxation injuries, while vascular effects occur, thermal risks are hard to control, especially in impacted teeth. In crown and root fractures, lasers can seal dentinal tubules or reduce sensitivity, but excess heat near fractures may cause complications. Although laser pulpotomy or direct pulp capping in complex crown fractures or pulp exposure shows promise, pediatric cooperation and lack of parameter standardization remain issues [12, 42, 43].

From a safety perspective, incorrect selection of laser parameters can cause damage to the pulp and periodontal tissues through excessive heat transfer. Inappropriate energy levels may increase the risk of enamel cracking, cementum damage, or pulp necrosis [44]. The use of appropriate protective eyewear is mandatory during treatment to protect the eye health of both the patient and the operator. Patient selection must be done carefully, especially in pediatric patients, as cooperation problems increase safety risks [45].

From a clinical perspective, laser applications are effective for specific indications such as hemostasis, biostimulation, and pain control; however, they should not be considered a standalone treatment method and should be combined with traditional methods such as splinting, endodontic treatment, or regenerative procedures [4]. The type of laser and parameters to be used should be carefully adjusted in accordance with the manufacturer's instructions and current literature. In addition, it is critical for the success of the treatment that clinicians have sufficient theoretical knowledge and practical experience [9].

8. Conclusion

Laser technology offers clinically valuable advantages in the management of traumatic dental injuries, such as hemostasis, biostimulation, and reduced risk of infection [46, 47]. However, the lack of randomized controlled trials in the literature and the limited availability of long-term follow-up data restrict the integration of lasers into routine clinical practice [48].

Safety is particularly important; inappropriate parameter use can lead to complications such as excessive heat increase in the pulp, damage to periodontal tissues, and microscopic cracks in restorative materials [47, 48]. Therefore, adherence to manufacturer protocols, selection of appropriate energy levels, and protective measures for patient–operator safety are critical in laser applications [47, 48].

Current data indicate that lasers should not be used alone but as a complementary method to traditional treatments in traumatic dental injuries. It has been reported that laser use for biostimulation, in conjunction with endodontic treatment and splinting, may provide additional benefits, particularly in cases of avulsion and luxation [46–49].

In conclusion, the clinical value of laser technology in traumatic dental injuries is increasing. However, advanced clinician training, parameter standardization, and robust clinical research are needed for effective and safe applications. When these conditions are met, laser applications are expected to be used more widely and reliably in the future [49].

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Conflict of interest

The authors declare no conflict of interest.

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Dental trauma refers to injuries to the teeth and the supporting tissues surrounding them. These injuries can result from external factors, including falls, collisions, traffic accidents, and sports activities. Trauma can manifest in various clinical presentations, such as cracks, fractures, avulsions, or luxations of the teeth, and can significantly affect both oral health and the individual's overall quality of life. Dental injuries are more common during childhood and adolescence. The first steps to be taken after trauma are controlling the pain, accurately assessing the extent of the injury, properly cleaning the traumatized teeth or tissues, and seeking professional dental care as soon as possible. Early intervention is one of the most critical factors determining the prognosis and treatment success of trauma. This book aims to provide clinicians with a scientific, evidence-based guide by comprehensively addressing the etiology, diagnostic principles, and current treatment approaches for traumatic dental injuries. I hope this work will serve as an up-to-date resource for all dentists in trauma management.

Sergio Alexandre Gehrke, Dentistry Series Editor

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