

ABSTRACT In an overview of traumatic injuries in the permanent dentition, the authors describe the classification of, assessment of and treatment strategies for managing such injuries. They explore pulpal and periodontal considerations, as well as methods of minimizing complications. In addition, they suggest preventive strategies and future directions for trauma management.

TRAUMATIC DENTAL INJURIES: CURRENT TREATMENT CONCEPTS

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A recent survey funded by the National Institute of Dental Research¹ indicated that dental trauma affects at least one-quarter of the U.S. population. Specifically, the report showed that 25 percent of Americans aged 6 to 50 years had sustained some sort of injury to the upper and lower incisors.¹ The most common injury is fracture of tooth crowns.¹ Studies in other countries have yielded similar findings.² It has been suggested that the incidence of dental trauma soon will exceed that of dental caries and periodontal disease among children and teenagers.³ This article presents current treatment recommendations for traumatic dental injuries.

CLASSIFICATION OF DENTAL INJURIES.*

ENAMEL FRACTURE

Involves enamel only and includes enamel chipping and incomplete fractures or enamel cracks.

CROWN FRACTURE WITHOUT PULPAL INVOLVEMENT

An uncomplicated fracture involving enamel and dentin; no pulpal exposure.

CROWN FRACTURE WITH PULPAL INVOLVEMENT

A complicated fracture involving enamel, dentin and exposure of the pulp.

ROOT FRACTURE

Fracture of root only—cementum, dentin and pulp. Also referred to as “horizontal root fracture.”

CROWN-ROOT FRACTURE

Tooth fracture that includes enamel, dentin and root cementum, and may or may not include the pulp.

LUXATION

There are several subcategories of this type of injury.

Concussion. The tooth is sensitive to percussion but has not been displaced and is not abnormally mobile.

Subluxation. The tooth has increased mobility but has not been displaced.

Lateral luxation. The tooth has been displaced and may be very firm.

Extrusive luxation. The tooth is very mobile because of partial displacement out of the socket.

Intrusive luxation. The tooth has been forced apically and is firmly embedded in bone.

AVULSION

Complete displacement of a tooth from its socket.

FRACTURE OF THE ALVEOLAR PROCESS (MANDIBLE OR MAXILLA)

Fracture or comminution of the alveolar socket or the alveolar process; if the fracture involves a tooth socket, the blood supply to the tooth pulp may be compromised.

*Based on the World Health Organization system.⁵

GENERAL CONSIDERATIONS

In the 1950s, pediatric dentist G.E. Ellis was the first to promote a universal classification of dental injuries.⁴ Late in the next decade, the World Health Organization, or WHO, developed a classification for dental traumatic injuries that is descriptive, easily understood and gaining international acceptance.⁵ Acceptance of this system would benefit both patients and the profession by allowing a

better understanding of various traumatic injuries and the selection of appropriate treatment. Additionally, universal application of this system would improve reporting to insurance carriers and for research purposes. The WHO system was slightly modified by Andreasen and Andreasen² to clarify variations in the original WHO categories of luxation and intrusion (Box, “Classification of Dental Injuries”).

Regardless of whether a pa-

tient has an isolated injury or a combination of traumatic injuries, the following general considerations apply.

■ The outcome of dental injuries is influenced by patient age, severity, treatment and timely follow-up. In most instances, immature permanent teeth with injuries have a better prognosis for recovery than fully formed teeth that have experienced the same injuries. By contrast, if pulp necrosis develops as a result of trauma in immature teeth, the long-term prognosis is poor because of weakened root structure that results from necrosis-induced lack of root development. A good example is shown in Figure 1.

■ Proper treatment of dental injuries can have a significant effect on outcome and prognosis, particularly in cases of severe injuries. For example, the timely replantation of an avulsed tooth followed by appropriate endodontic treatment can make the difference in whether the tooth is retained or ultimately lost.

■ Follow-up evaluation is likewise essential for a good long-term prognosis. For example, root resorption that is detected early can often be arrested. Root resorption that is missed can lead to loss of a tooth.

ASSESSMENT

Traumatic injuries are unexpected and inconvenient. A thorough examination is essential in arriving at an accurate diagnosis, selecting appropriate treatment and predicting prognosis, but the time such an examination requires is often not available. Consequently, it is essential that we be prepared to assess such patients both rapid-

ly and comprehensively. Often, the patient not only has a physical injury, but also is in emotional distress, which further complicates the process. Use of a checklist or form that encourages a systematic and thorough assessment (Box, "Trauma Checklist") should minimize the clinician's omission of key information.^{6,7}

Trauma assessment should include medical history, clinical examination, radiographic examination and, ideally, photographic documentation. While thoroughness and accuracy are sound clinical practice, they also are important in helping patients secure appropriate insurance benefits and for providing reports in situations that involve or potentially involve litigation. A thorough description of trauma assessment can be found elsewhere^{6,7}; we have chosen some important aspects to highlight below.

History. The medical history should provide sufficient information regarding the patient's ability to receive treatment for the injury.

The injury history should document several important pieces of information:

- the time of injury, which may influence both the treatment choice and prognosis;
- the place of injury, which may determine issues of liability;
- how the injury occurred, as knowledge of the nature of the force or blow can guide the clinician in broadening the scope of the examination;
- why the injury occurred—



Figure 1. Cervical root fracture of immature tooth no. 10 undergoing apexification following traumatically induced pulp necrosis.

whether it is something that is likely to reoccur, whether future injury can be prevented, and therefore whether treatment should be ambitious or transitional;

- any history of injury to this tooth, which can be important in interpreting radiographic findings, determining treatment and prognosis, and ascertaining any possible history of abuse⁸;
- whether the patient has been treated elsewhere before coming to the dental office.

Chief complaint. The patient's chief complaint should be recorded in detail. While it frequently involves pain and other physical disturbances of the teeth, the clinician must be careful not to overlook less obvious injuries. For instance, soft-tissue injuries could be more noticeable than a displaced tooth.

Neurological screening. Several authors have stressed the importance of performing a brief neurological screening to rule out concussion and other sequelae resulting from intracranial bleeding.⁹⁻¹¹ We refer readers to these publications for a more detailed review.

Examination.

Extraoral examination should rule out facial bone fractures and should include a thorough assessment of soft-tissue injuries.

Lacerations of the lips and intraoral soft tissues must be carefully explored for tooth fragments and other foreign bodies.

The occlusion and temporomandibular joints also should be assessed. The clinician should ask the patient, "Do your teeth come together the way they did before the injury?" A negative response can reveal anything from a subtle displacement injury of one tooth to a mandibular or subcondylar fracture.

The patient's periodontal status can influence the clinician's decision to attempt any heroic measures in instances of luxation or avulsion injuries.

The teeth and their supporting structures need to be examined carefully—not only the obviously injured tooth, but adjacent and opposing teeth as well.

Documentation. Record all findings such as fractures, infractions, color changes and pulp exposure. Describe luxation injuries in terms of direction and degree of displace-

TRAUMA CHECKLIST.

I. PATIENT'S HISTORY

- A. Medical
- B. Dental: Ask patient if he or she has experienced dental injuries in the past
- C. Injury
 1. How?
 2. Where?
 3. When?
 4. Why?

II. BRIEF NEUROLOGICAL EXAMINATION

- A. Cranial nerve assessment
- B. History
 1. Headache
 2. Lethargy
 3. Nausea/vomiting
 4. Unconsciousness
 5. Amnesia
 6. Orientation as to person, place and time: Ask patient, "Do you know who you are, where you are and what time of day it is?"

III. HEAD EXAMINATION

- A. Skin
 1. Abrasions
 2. Contusions
 3. Lacerations
 4. Edema
 5. Ecchymosis
- B. Bones
 1. Mobility
 2. Crepitus
 3. Tenderness
 4. Asymmetry
- C. Nose
- D. Ears
- E. Eyes

IV. TEMPOROMANDIBULAR JOINT ASSESSMENT

- A. Joint pain
- B. Muscle pain
- C. Intraoral opening

- D. Deviation on opening
- E. Open/closed lock
- F. Chewing difficulty

V. INTRAORAL EXAMINATION

- A. Oral mucosa, gingiva, tongue
 1. Abrasion
 2. Contusion
 3. Laceration
- B. Periodontal status
- C. Occlusion
 1. Classification
 2. Open bite
 3. Overjet
 4. Disruption: Ask patient, "Do your teeth come together the way they did before the accident?"
- D. Teeth
 1. Color changes
 2. Mobility
 3. Pain
 - a. On biting
 - b. With exposure to cold
 - c. On percussion
 - d. Unstimulated
 4. Response to electrical pulp testing
 5. Infraction
 6. Crown fractures
 7. Crown-root fractures
 8. Root fractures
 9. Concussion
 10. Subluxation
 11. Extrusion
 12. Intrusion
 13. Lateral luxation
 14. Avulsion

VI. RADIOGRAPHS

VII. PHOTOGRAPHIC DOCUMENTATION

VIII. FOLLOW-UP

ment. Note any mobility of teeth and of the alveolar process. Percussion helps identify traumatized teeth.

Pulp testing. While pulp testing immediately after trauma can produce a high incidence of false-negative responses, it can provide a baseline measurement for readings taken during follow-up appointments.¹²

Radiographs. Radiographs obtained at the time of injury not only assist in arriving at a correct diagnosis but also serve to establish a baseline for monitoring changes, both positive

and negative, throughout the healing period. Andreassen and Andreassen¹³ documented the value of using multiple exposures, types of films and standardized techniques to ensure maximum detection of injuries as well as accurate identification of injury type. For injuries to the maxillary anterior region, they recommended the taking of three bisecting-angle periapical films plus an occlusal film.¹³

Photographs. Taking clinical photographs is encouraged as an additional means of documenting injuries for insurance

and legal reasons, as well as establishing a clinical record for monitoring patient and treatment progress.

Evaluation. At the conclusion of the assessment, it is important for the clinician to step back and evaluate whether the clinical and radiographic findings are consistent with the history of the injury provided by the patient or by whomever accompanies him or her—a parent, caregiver, spouse or friend. If what has been related as the cause of the injury is not congruent with the clinical find-

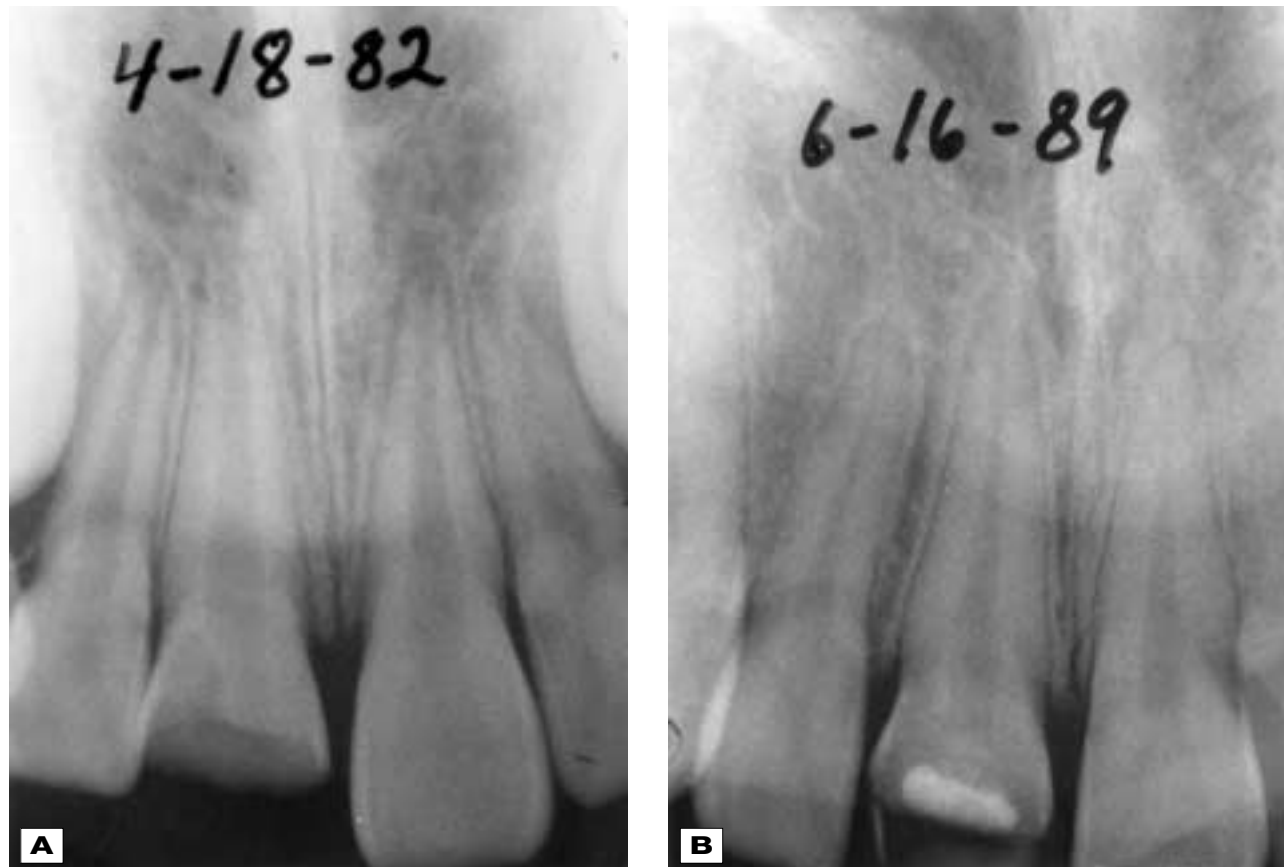


Figure 2. Successful treatment of vital pulp in an immature injured tooth. A. Crown fracture with pulp exposure of tooth no. 8 in an 8-year-old patient. B. Tooth no. 8 seven years after shallow pulpotomy. Note the continued root development and dentin bridge formation.

ings, the clinician's index of suspicion regarding abuse must be raised. Again, reports in the literature explore this issue in far more depth.^{8,13-16}

TOOTH FRACTURES

The three types of fractures—crown, root and combination crown-root—require different approaches.

Crown fractures. Crown fractures can be uncomplicated, involving only enamel and dentin, or complicated, involving enamel, dentin and pulp. Pulpal involvement indicates direct pulpal exposure with bleeding. The treatment for crown fractures without pulp exposure consists of protecting the exposed dentin and restoring the normal contour of the

tooth. The sooner this is done, the better. As long as the dentin is kept clean and free of plaque, the pulp usually is not compromised. If the tooth has been luxated concomitantly and the pulp's blood supply has been compromised, then so too has the pulp's ability to resist bacterial infection. Bacteria can invade through exposed dentinal tubules at the fracture site.

Recommended treatment options include use of calcium hydroxide, or CH, covered temporarily by glass ionomer or composite, which is replaced four to six weeks later with bonded composite resin; immediate repair using bonded composite resin, using the "total-etch" technique; and reattachment of the fractured

crown fragment if available.¹⁷

Crown fractures with pulpal exposure in teeth with complete root formation are most often treated endodontically, then an esthetic crown is placed. Immature teeth with incompletely formed roots will be weakened significantly by early loss of radicular pulp; hence, every effort should be made to maintain pulp vitality. Teeth without extensive previous injuries or restorations have pulps with excellent survival potential provided that they can be protected from bacterial invasion. This can be accomplished by a vital pulp therapy procedure referred to as shallow pulpotomy or "Cvek-type" pulpotomy.¹⁸ Shallow pulpotomy has been described in the litera-



Figure 3. Treatment of horizontal root fractures. A. Horizontal root fractures in teeth nos. 8 and 9, shown immediately after injury. B. Wire-and-composite splint stabilizing horizontal root fractures of teeth nos. 8 and 9. C. Healing root fractures in teeth nos. 8 and 9, 20 months after the three-month stabilization.

ture¹⁹ and consists of gently removing, with the use of a water-cooled round diamond bur, pulp tissue to a depth of 2 millimeters subjacent to the exposure site. Bleeding will cease within a few minutes, following which the blood clot is rinsed off and the wound dressed with CH, covered by a thin layer of cement; the tooth is then restored with bonded composite resin or by bonding the fractured crown segment, if available.

Recently, a new material was introduced that has shown promise as a replacement for CH: mineral trioxide aggregate, or MTA.²⁰ The pulpal response to this material is favorable.²⁰

And since MTA does not appear to disintegrate over time, it might not be necessary to replace the restoration after dentin bridge formation.

The prognosis for teeth with crown fractures is good even when pulps are exposed.¹⁸ In young, immature teeth, successful treatment of vital pulp will allow continued root formation, thus ensuring retention of the injured tooth (Figure 2).

Root fractures. The prognosis for teeth with horizontal root

fractures is usually good.²¹ Healing favors young, immature teeth, but, properly treated, many teeth can recover from a traumatic root fracture.

It is important to differentiate between vertical and horizontal root fractures. Vertical fractures, splitting roots along their long axes, have a poor prognosis. Fortunately, they

occur only rarely as a result of acute trauma. Horizontal, infrabony fractures involve cementum, dentin and the pulp. As long as the fracture is infrabony with no communication to the gingival sulcus and the patient exhibits meticulous oral hygiene, appropriate treatment results in a high degree of successful outcomes in both immature and mature teeth. Treatment consists of reducing the fracture and then firmly stabilizing the tooth to adjacent teeth for at least three months (Figure 3). No further treatment is indicated, unless clinical or radiographic evidence demonstrates development of pulpal necrosis.

Should pulpal infection occur, current evidence suggests that endodontic treatment need only involve the coronal segment of the root; the apical segment will usually contain vital pulp tissue, which need not be removed.²² The coronal segment should be treated with an interim dressing of CH to arrest inflammation and to stimulate apexification, which will permit adequate obturation with gutta-percha and sealer. The exception involves cases in which the root fracture is close to the alveolar crest and the coronal segment is mobile. If endodontic treatment can be done on both segments—if they are suitably aligned for instrumentation—an intraradicular splint can be placed, thus reducing the mobility of the coronal segment.¹⁹

Crown-root fractures. This type of dental injury is considered one of the more complex types of injuries because of the severity; the fracture may extend subcrestally and often the pulp is exposed.²³

In immature teeth with

crown-root fractures, the most important concern is to preserve pulp vitality for continued root development. The shallow pulpotomy is indicated, as failure to preserve pulp vitality greatly reduces long-term success.

Restoration of the fractured crown can be accomplished in a similar manner to that described for crown fractures; the complicating feature is control of soft-tissue bleeding.

Treatment options for mature teeth with crown-root fractures include extraction and re-

Root resorption, once initiated, can proceed very rapidly, destroying root structure in a matter of weeks.

placement with a bridge or implant. If the remaining tooth structure is adequate for retention, endodontic therapy and crown restoration are possible with the help of crown-lengthening procedures. Additionally, in selected cases in which a favorable crown-to-root ratio can be maintained and periodontal surgery might compromise attachment of adjacent teeth, orthodontic root extrusion can be considered.

LUXATION INJURIES

The classification of luxation injuries by Andreasen and Andreasen describes five categories of injury in increasing order of severity, based on anatomic, therapeutic and prognostic considerations (Box,

“Classification of Dental Injuries”).² Following is a general discussion of such injuries.

Sequelae. Management of luxation injuries should include careful consideration of both the pulpal and the periodontal responses to trauma.

The more severe the luxation injury, the more frequent the complications. Pulp necrosis usually occurs within the first year after injury, but may not manifest itself until years later. Root resorption, once initiated, can proceed very rapidly, destroying root structure in a matter of weeks. Conversely, external root resorption might not become evident until years after the trauma. Given both the frequency and oftentimes-delayed nature of complications, it is important to monitor the healing events for several years and to advise patients of the possible outcomes.

The pulp’s response to luxation injuries includes pulp survival, pulp necrosis, pulp canal obliteration and, in rare instances, internal resorption.^{24,25} The occurrence of such sequelae is related to the type of luxation injury (severity) and the stage of root development (capacity for repair).²⁶ The occurrence of pulp canal necrosis ranges from 2 percent in concussion injuries to nearly 100 percent in intrusions.^{26,27} Pulp canal obliteration is more frequent in teeth with immature apices, can occur up to 20 years after the injury and has been reported in 7 to 16 percent of luxation injuries.^{28,29}

Additionally, Andreasen described a condition referred to as “transient apical breakdown,” which appears as an apical radiolucency that resolves over time without endodontic intervention.³⁰ It is thought to

represent a reparative response on the part of the pulp and periodontal ligament, or PDL. Its frequency is highest, 11 to 12 percent, in extrusive and lateral luxation injuries.

The major complications of PDL repair in luxation injuries are inflammatory and replacement resorption. Both these processes are well-described under avulsion injuries, and these complications generally occur more frequently with intrusion and severe lateral luxation injuries.^{26,28,31}

Another complication of lateral luxation and intrusion is the loss of marginal bone. Its occurrence is highest in intrusion injuries at 31 percent, then in lateral luxations at 5 percent.⁴

Treatment.

Concussion. Generally, a concussion injury requires little more than relieving the occlusion and monitoring pulpal vitality.

Subluxation. The tooth will be tender to percussion and chewing and will exhibit slight mobility. Treatment is directed at relieving the occlusion and patient discomfort; a light wire-and-composite splint also can be placed for one to two weeks. These teeth should be monitored biannually in the first year and annually thereafter.

Extrusive luxation. Teeth that have been partially displaced in a vertical direction from the alveolar socket should be gently repositioned and splinted. If there is resistance to repositioning because of clot organization, the patient should



Figure 4. Inflammatory root resorption after replantation of avulsed teeth nos. 23, 24 and 25. Needed endodontic therapy was not initiated after replantation. Note resorption of both root and adjacent alveolar bone.

be instructed to apply gentle but steady pressure for 15 to 20 minutes by biting on a gauze compress. If there has been significant delay in seeking treatment, orthodontic repositioning may be necessary. A short period of immobilization (up to two weeks) is desirable to achieve PDL healing and to reduce the risk of replacement resorption.^{32,33} Permanent teeth with open apices should be monitored for pulpal revascularization. Permanent teeth with closed apices are most likely to develop pulp necrosis and require endodontic treatment.³⁴ A two-week course of treatment with CH before obturation with gutta-percha and sealer can

help minimize the risk of inflammatory resorption.

Lateral luxation. In this type of injury, the root tip is forced through the alveolar plate and becomes locked between the alveolar process and the displaced, fractured alveolar plate. Consequently, the tooth must be forcefully disengaged from its eccentric, locked position by downward pressure on the root and then repositioned into the socket. Gingival tissues are sutured as necessary and a splint is applied. Again, guidelines vary as to the duration of splinting, but given that bone healing as well as PDL healing is necessary, a longer immobilization period—at least three weeks and as many as eight weeks if there is marginal

bone breakdown—is suggested.³² For teeth with open apices, there is a chance of pulp survival. In teeth with closed apices, the incidence of pulpal necrosis has been reported to be in excess of 75 percent.³² Treatment recommendations are the same as those for extrusive luxation.

Intrusive luxation. Because of the severity of injury to the PDL, pulp and alveolar bone, the management of intrusions is more challenging and is fraught with a higher incidence of complications. There is no single agreed-on approach to treatment; however, the following considerations apply in most instances.

Pulpal necrosis approaches 100 percent in closed-apex teeth and is more than 60 percent in open-apex teeth.²⁶ Additionally, because of the severe crushing injury to the PDL, the frequency of both inflammatory and replacement resorption is high.²⁶

An immediate consideration is whether to reposition the intruded tooth or allow it to re-erupt on its own. Orthodontic re-eruption over a three-week period allows timely endodontic access and is associated with diminished marginal bone breakdown and a reduced incidence of external root resorption.^{32,35,36} Watchful waiting for re-eruption of minor intrusions in teeth with open apices must be tempered by the realization that inflammatory resorption can appear as early as three weeks after injury.

If mobility persists after re-eruption, a short period of splinting (one to two weeks) is indicated. Endodontic therapy includes CH therapy followed by obturation with gutta-percha and sealer. The considerations regarding short vs. long treatment with CH that we discussed under avulsion injuries apply to intrusions as well.

The status of intruded teeth should be monitored indefinitely, as the risk of late complications is significant.³²

Chlorhexidine rinses should be prescribed for patients with extrusive, lateral and intrusive luxation injuries. Use of a systemic antibiotic has not been



Figure 5. Replacement resorption of tooth no. 9 in a 20-year-old patient four years after replantation and endodontic therapy. Note the almost total resorption of root and replacement with alveolar bone. The tooth had been extraoral and dry for more than two hours before replantation.

shown to be beneficial.

AVULSION

Tooth avulsion results in severance of both the neurovascular bundle and the PDL, as well as damage to the alveolar bone, cementum and gingival tissues. While replantation of the avulsed tooth is of immediate concern to both patient and clinician, both the short- and long-term goals of treatment are to minimize the complications associated with healing. Therefore, the dentist must direct all efforts at preserving the viability of the PDL cells remaining on the root of the avulsed tooth and managing the

damage to the dental pulp in a timely manner.

Sequelae. Long-term retention of replanted teeth may be jeopardized by inflammatory root resorption and by replacement resorption. Inflammatory resorption occurs as a result of the necrotic pulp's becoming infected in the presence of a severely damaged cementum, thus allowing bacterial toxins to migrate out through the dentinal tubules into the PDL.³⁷⁻⁴⁰ The resultant inflammatory process causes resorption of both the root and adjacent bone. This process proceeds rapidly and appears as radiolucencies in both the root and alveolar bone (Figure 4).

Replacement resorption occurs when there is substantial damage to both the PDL and ce-

mentum.^{41,42} Rather than connective-tissue cells participating in repair of the PDL, cells from the alveolar bone replace the periodontal attachment; this results in ankylosis. As this process progresses, the root likewise is ultimately resorbed and replaced by alveolar bone (Figure 5). Radiographically, there is an absence of the lamina dura, and the root assumes a moth-eaten appearance as dentin is replaced by bone.⁴³ Clinically, the tooth will lack mobility and when percussed will have a metallic sound.⁴³ Treatment will not halt or reverse replacement resorption. It appears to proceed more slowly

in older patients, thereby allowing retention of replanted teeth for considerable periods of time. Replacement resorption in younger patients can interfere with the normal growth and development of the alveolar process. Additionally, since the ankylosed tooth is unable to move with the downward growth of the alveolus, there will be a subsequent infraocclusion or submergence. Consequently, the retention of replanted teeth with replacement resorption in younger patients is short-term.⁴⁴

Treatment. Studies over a 30-year period strongly suggest that the most important factor in a successful outcome is the timeliness of replantation.⁴⁵⁻⁴⁷ Treatment, when possible, begins before the patient arrives at the dental office. If contacted by phone, the clinician should give the following instructions:

- Avoid handling the root.
- Gently rinse the tooth in tap water if the root is grossly contaminated.
- Replace the tooth in the socket.
- Proceed directly to the dental office.

Storage medium. If circumstances preclude immediate replantation, the tooth should be transported in a suitable storage medium. The most recent guidelines established by the American Association of Endodontists, or AAE, list Hank's Balanced Salt Solution, or HBSS, a tissue culture medium (available in the Save-A-Tooth transport system [Smart



Figure 6. Significant inflammatory root resorption evident on tooth no. 8. The tooth was replanted within 30 minutes after its avulsion, but endodontic therapy was never initiated. Apical lesions are evident on teeth nos. 7 and 8.

Practice]), as the medium of choice. However, its lack of availability at the accident site greatly limits its use.⁴⁸

Milk has been shown to be successful in maintaining PDL cell viability for about three hours, and its relatively universal availability further enhances its utility.⁴⁹⁻⁵¹ Skim or low-fat milk at a cool temperature is preferred for ensuring PDL cell viability.⁵²⁻⁵⁴ In decreasing order of suitability, physiological saline, saliva and water can be used in the absence of milk.⁴⁶ Ultimately, the latter two may be detrimental to cell viability owing to the presence of bacteria, unfavorable pH and osmolarity. Recent studies found both contact lens solution and

Gatorade (Gatorade Co.), available at many sporting events, to be unsuitable transport media.⁵³⁻⁵⁵

First appointment.

The tooth should be placed in a storage medium such as HBSS or saline while the dentist obtains a brief medical, dental and injury history. Additionally, the clinical and radiographic examination should include any associated hard- and soft-tissue injuries as well as other injuries to the tooth itself.

Currently, there are differing recommendations relating to soaking in HBSS vs. immediate replantation. Some authors suggest that any tooth stored dry for more than 15 minutes or stored in a nonreconstituting medium should be

soaked for 30 minutes in HBSS to revitalize PDL cells before replantation and to reduce the risk of replacement resorption.^{56,57} There is no independent study to verify this recommendation. Current AAE guidelines favor immediate replantation of teeth that have been outside the oral cavity for less than one hour, regardless of whether they were stored wet or dry.⁴⁸

Another presoaking agent being recommended before replantation is doxycycline. Research by Cvek and colleagues⁵⁸ showed that a five-minute soak in 1 milligram of doxycycline in 20 milliliters of water resulted in enhanced revascularization of permanent teeth with immature apices.

While revascularization of teeth with closed apices is virtually nonexistent, a five-minute doxycycline soak might further minimize the inflammatory response by reducing bacterial contamination.⁵⁹

Avulsed teeth that have been outside the oral cavity and dry for more than one hour may be replanted with the understanding that the PDL is no longer vital and that the clinical goal is to establish ankylosis. This technique is well-described elsewhere in the literature.^{60,61}

Minimal manipulation of the socket is indicated and usually will not require local anesthesia. The clinician should gently irrigate the socket with sterile saline to remove any clot formation and debris.

If any obstruction is present, gentle manipulation with a surgical curette or periosteal elevator is indicated; this might require anesthetic. In instances of greater damage to the socket wall or alveolar process, a soft-tissue flap might be necessary. The clinician should suture any tears or lacerations of the gingiva and mucosa and should place the sutures interproximally to reduce marginal bone loss.

Once replanted, the tooth should be stabilized with a light passive wire-and-composite splint, which permits regeneration of the PDL while reducing the formation of ankylotic bridges.^{62,63} The splint should be removed in seven to 10 days. The splinting period can be extended for up to eight weeks if there is a concomitant alveolar process fracture. After placing the splint, the clinician should check the occlusion to prevent any interference.

The clinician should instruct the patient to avoid heavy func-

tion on the replanted tooth, and to maintain meticulous oral hygiene. Use of chlorhexidine rinses for one week is recommended to further reduce bacterial contamination in the gingival sulcus. As an alternative to rinsing the entire mouth with chlorhexidine, the patient (or the patient's caregiver) can be instructed to daub the wound around the tooth with a cotton swab soaked in the solution. Most guidelines recommend a five- to 10-day course of systemic antibiotics, although consensus is lacking on both the

Teeth with open apices that have been replanted within one hour of avulsion should be monitored frequently to determine if revascularization is occurring.

drug of choice and the length of treatment. Results of a study by Hammarstrom and colleagues³⁹ suggest that administration of systemic antibiotics acts to minimize infection of the necrosed pulp, thereby minimizing inflammatory resorption.

Finally, the patient's tetanus inoculation status must be verified by a physician.

Second appointment. Seven to 14 days after replantation is the optimal time to remove the pulp and begin the endodontic phase of the treatment. It is an important step in the treatment, and neglecting this aspect usually leads to dramatic and rapid root resorption (Figure 6).⁶⁴

Teeth with open apices that have been replanted within one hour of avulsion should be monitored frequently to determine if revascularization is occurring. Clinical and radiographic evaluation should be performed every three weeks. Since revascularization is a process in which normal pulp tissue is replaced with connective tissue, pulpal response to thermal and mechanical stimuli might be abnormal or absent. If there is evidence of pulpal infection or inflammatory resorption, the pulp should be removed and CH placed immediately. This is aimed at stimulating apexification and halting the inflammatory response. Because of its antibacterial properties, CH promotes healing in instances in which pulpal infection is associated with traumatized teeth.

When treating teeth with closed apices that have been replanted within one hour of avulsion, the clinician should débride their pulps, clean their canals and fill the canals with CH before removing the splint. It is generally agreed that an interim period of intracanal application of CH has a beneficial effect on the outcome.⁶⁵⁻⁶⁷ Recommendations vary significantly regarding the length of treatment time with CH needed before obturation with gutta-percha and sealer can be performed. A recent study by Dumsha and Hovland⁶⁸ concluded that there is no therapeutic advantage of an interim treatment with CH for avulsed teeth with a 25-minute dry extraoral time and whose pulps are removed within four weeks. They found no significant difference in the incidence of inflammatory resorption between teeth

treated with CH and teeth immediately obturated with gutta-percha and sealer. Recent AAE guidelines recommended a six- to 12-month course of CH before obturation.⁴⁸ In the middle ground are studies by Trope and colleagues,^{69,70} which suggested that if the pulps of teeth that have been replanted within one hour are removed within two to three weeks, then a one- to two-week course of CH should suffice, followed by obturation with gutta-percha and sealer. Trope and colleagues⁶⁹ further suggested that longer treatment with CH is beneficial when there has been a delay in pulp removal or when there is evidence of inflammatory resorption.

All replanted teeth should be monitored at least annually for an indefinite period.

While current guidelines exist for the management of avulsed teeth, Barrett and Kenny,⁴⁴ in an excellent review, emphasized that current protocols have not been tested prospectively in humans; consequently, few outcome data are available. Nonetheless, guidelines serve as standards for clinical treatment and should be subject to modification based upon sound outcome data. In the absence of definitive data, the clinician should take the prudent course in managing avulsion injuries by heeding current guidelines, keeping in mind the reality that individual clinical and patient variables will influence the dentist's ultimate decisions.

PREVENTION

Many dentoalveolar injuries can be prevented by the use of well-fitting, properly constructed mouthguards. There are four

categories of mouth protectors:

- the stock mouthguard;
- the "boil-and-bite" mouthguard;
- the vacuum-formed custom mouthguard;
- the laboratory-processed pressure-laminated protector.

The stock and "boil-and-bite" mouthguards are the least desirable, as they fit poorly and provide little protection against impact injuries both in terms of dental protection and in preventing brain concussion. On the other hand, both the vacuum-formed and pressure-laminated mouthguards offer superior fit, comfort and protection.

Biomimetics, or tissue engineering, may allow replacement of necrotic pulp with tissue capable of assuming the interrupted functions of a traumatized pulp.

Because of its precise fit, resistance to deformation and variable thickness based on the athlete's needs, the pressure-laminated mouthguard appears to provide superior protection against both dentoalveolar and concussion injuries.⁷¹ The use of mouthguards is limited by a lack of perceived need for them and lack of information about them provided to parents of children who participate in contact sports.⁷²

FUTURE DEVELOPMENTS

What developments can we expect in the future that will re-

duce the incidence of dental trauma and enable us to treat such injuries more successfully?

Reducing incidence.

Prevention has been a goal in dentistry for a long time and has resulted in remarkable successes in such areas as caries reduction. Traumatic dental injury can be prevented by the use of well-fitting mouthguards in any sport in which there is a risk of sudden impact to the face.⁷¹ Additionally, properly designed headgear and face protection, such as are used in hockey, can be very effective. Routine use of seat belts in cars can prevent the type of dental trauma that results from forceful contact with the car's steering wheel, dashboard or windshield. It is also likely that early orthodontic intervention in children with extensive malocclusion (either overbite or overjet) will prevent damage to protruding incisors, which often make contact with hard surfaces when children fall while running and playing.

Improved treatment.

Successful treatment in the future probably will include the use of better, stronger and more durable restorative materials that can be applied more easily even in difficult situations, such as with young, uncooperative patients and complex dental injuries. Pulpal protection will undoubtedly become more important as researchers develop new methods to promote pulpal function in young, traumatized teeth. Biomimetics, or tissue engineering, may allow replacement of necrotic pulp with tissue capable of assuming the interrupted functions of a traumatized pulp.

Early orthodontic interventions to prevent teeth from pro-

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truding abnormally could have a great impact on trauma prevention involving maxillary central incisors—the teeth most often involved in any dental injury.

Teeth damaged beyond recovery and avulsed teeth that cannot be replanted present a particularly difficult problem in the growing child. Implants may be ideal in an adult, but are of little benefit in the still-growing child because they can prevent continued alveolar development. An alternative, where suitable, is autotransplantation of teeth—typically the transplantation of a premolar to the site of a missing incisor. When placed at the optimal time, autotransplanted teeth behave like the teeth they replace, allowing normal alveolar development. Combined with orthodontic intervention, autotransplantation can provide a successful treatment option. This procedure has been used more extensively in Europe than in the United States, and with favorable results.⁷³

Root resorption after dental trauma is a significant sequela, resulting in the loss of numerous teeth. Increased knowledge of the mechanisms of resorption and of methods to prevent the process will greatly enhance the treatment of dental injuries.⁴¹

CONCLUSION

The last three decades have witnessed significant improvement in the treatment and prevention of dental trauma. The future, no doubt, will see even greater progress toward the goal of reducing trauma as a cause of tooth loss. ■

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