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CLINICAL SECTION

Dental trauma: an overview of its influence on the management of orthodontic treatment. Part 1

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This is the first of two papers discussing the implications of dental trauma for patients requiring orthodontic treatment. This paper will focus on the factors the orthodontic specialist should consider when contemplating movement of traumatized teeth. The prevalence of dental trauma and the recognition and prevention of traumatic injuries are discussed. The evidence available in the literature relating to orthodontic tooth movement in vital and endodontically treated traumatized teeth is explored. The interdisciplinary management of root fractured and intruded teeth receive special attention. The second paper will look at the role of the specialist team in the management of failing anterior teeth and will outline possible treatment options for children and adolescents encountering such situations. Avulsion injuries and tooth transplantation are considered in particular detail.

Key words: Dental trauma, orthodontic tooth movement, endodontic treatment, root resorption

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Introduction

The Children's Dental Health Survey 2003,[1] revealed the proportion of children in the United Kingdom sustaining accidental damage to their permanent incisors increased with age from 5% at age 8 to 11% by age 12 with boys sustaining injuries more frequently than girls. Epidemiological data indicates that the majority of traumatized incisors remain untreated. Indeed previous studies have given cause for concern regarding the level of knowledge pertaining to the treatment of dentoalveolar trauma amongst dental professionals in the primary care sector.[2–4]

The high prevalence of previous dental trauma in an orthodontic patient population has recently been reported, with 10.8% of patients sustaining dental injuries before the onset of orthodontic treatment.[5]

Objectives

As a result of the high proportion of child patients with previous dental trauma attending for orthodontic treatment, orthodontists need to take into account both the implications of tooth movement for these injured teeth and consider the long-term prognosis of any traumatized teeth before embarking on treatment. Close liaison, therefore, between orthodontists and paediatric dental specialists or treating dental practitioners is crucial. Unfortunately most of the dental literature surrounding the subject of dental trauma and orthodontic treatment comprises anecdotal case reports and retrospective review articles incorporating small patient numbers. This paper aims to elucidate the best evidence currently available for the management of the orthodontic patient who has sustained dental trauma, following the last review of the literature in 1999.[6] Excellent resources exist relating to the management of dental injuries[7–10] and it is not the purpose of this paper to discuss treatment of specific injuries in detail but to give the reader a general overview of current thinking in the field of dental traumatology and its interface with orthodontic management.

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Risk factors associated with dental trauma

Increased overjet and inadequate lip coverage of maxillary incisors are considered significant risk factors for dental trauma.[11–13] In an epidemiological survey 45% of upper incisor teeth were reported to have sustained visible damage by the age of 12 years in children with an overjet greater than 9 mm (IOTN5a), compared with 23% of those with an overjet less than 9 mm.[14] The orthodontic specialist should also note that children treated for dental injuries often sustain repeated episodes of trauma to teeth, particularly when the initial trauma occurs at an early age.[15]

Assessment and diagnosis of dental trauma

It is essential that the orthodontist providing care takes a comprehensive dental history which includes specifically asking about previous episodes of dental trauma and the treatment, if any, provided. Patients may not always recall a trauma incident and thus even in the absence of a clear history a comprehensive clinical and radiographic assessment is essential prior to commencing orthodontic treatment and should include:

- assessment of colour; transillumination can reveal enamel infraction lines and colour changes in traumatized teeth that are indicative of pathology or repair. Coronal yellow discolouration may be a sign of pulp canal obliteration (PCO), whilst a darkening hue may be evidence of either pulpal haemorrhage or necrosis, with blood or necrotic material taken up by surrounding dentinal tubules.
- examination for sinus or swelling.
- examination of tooth mobility in both a horizontal and vertical direction.
- palpation over the tooth apex for tenderness.
- reaction to percussion tests; a high metallic percussion note is often diagnostic of ankylosis, whilst a duller note may be suggestive of a root fracture.
- radiographs; reproducible long cone periapical radiographs are best for the accurate diagnosis of dental trauma, although two radiographs taken at different angulations may be required to detect a root fracture and some authors advocate multiple radiographs.[10] Continued root growth is the most convincing clinical sign of continued pulpal vitality in an immature tooth following trauma, therefore it is often very helpful if periapical radiographs of traumatized central incisors include both the injured tooth and its uninjured counterpart for direct comparison.
- sensibility tests; currently the most useful test to assess the neurovascular supply to the pulp of a traumatized tooth is the use of an electric pulp tester (EPT).[10] The placement of the electrode should be as close to the incisal edge as possible. It is, however, recognized that the use of the EPT in developing teeth or an anxious child is unreliable with false negative and false positive responses occurring. Sensibility tests, therefore, should never be considered in isolation from other clinical and radiographic findings.

It must always be remembered that adjacent or opposing teeth may have been injured at the time of the dental trauma[16] and thus clinical examination of these teeth is warranted.

Endodontic intervention is required when there are clinical and radiographic signs of pulpal necrosis and infection in the post-traumatized tooth. Failure of continued root formation, external inflammatory root resorption or sinus tract formation is indicative of root canal infection spreading periapically and requires referral for appropriate endodontic treatment.

In addition, it is important that the quality of any existing root canal filling is appraised prior to the commencement of orthodontic treatment. Consideration should be given to requesting re-root treating of a tooth if the existing obturation is unsatisfactory.

In summary the status of the traumatized tooth is drawn from a detailed history and comprehensive clinical and radiographic examination. It is imperative that all patients be questioned about any previous dental trauma prior to commencing on a course of orthodontic treatment. This will allow the orthodontist to anticipate any potential complications which may occur and to carefully monitor the traumatized tooth during orthodontic tooth movement. Liaison with paediatric, dental or endodontic colleagues will help to determine the prognosis of the tooth and aid overall treatment planning.

Prevention of dental trauma

Interceptive treatment and use of sports mouthguards

It has been suggested that early mixed dentition orthodontic treatment for children with an overjet greater than 9 mm (IOTN 5a) could reduce the risk of damage to incisors.[17]

In an observational study Brin *et al.*[13] concluded that prominent incisor position and inadequate lip coverage

were the most consistent risk factors related to dental trauma and suggested that early interceptive treatment should be considered to reduce the risk of dental trauma.[13]

However Koroluk *et al.*[18] compared the incidence of incisor trauma in children with an overjet greater than or equal to 7 mm who had early interceptive treatment with the incidence in those where treatment had been delayed until the permanent dentition, finding no significant difference.

Early treatment of Class II patients with an increased overjet ensures an extended treatment time and often requires two distinct phases of orthodontic treatment. Patients need to be carefully chosen and excellent compliance, motivation, oral hygiene and dietary practices must be ensured for treatment to be successful. In particular it is important that young patients should not become despondent with treatment carried out over an extended time period. As a result of these disadvantages early interceptive treatment of the Class II malocclusion is not usually recommended in the United Kingdom.

The routine provision of mouthguards for use when playing contact sports is recommended although it should be appreciated that the greatest proportion of injuries to incisor teeth occurs as a result of other accidental damage. Techniques for the construction of custom-made mouthguards for patients undergoing orthodontic treatment are available in the literature.[19]

Effects of orthodontic tooth movement on traumatized teeth

There are few studies in the literature relating to possible adverse sequelae of traumatized teeth undergoing orthodontic tooth movement. In those that do exist patient numbers are small and involve a heterogeneous collection of traumatic injuries from which definitive conclusions are hard to draw.

Pulp vitality

One retrospective study[20] has attempted to examine the influence of orthodontic movement per se, on previously traumatized teeth with respect to risk of loss of pulp vitality and replacement resorption. Although the authors found a higher prevalence of non-responsiveness to sensibility testing in previously traumatized teeth undergoing orthodontic treatment the study numbers are too small to be conclusive.

In summary, with the evidence currently available it is not possible to say whether orthodontic tooth movement of traumatized teeth increases the risk of pulp necrosis above that of uninjured teeth undergoing tooth movement.

Root resorption

There are three main types of root resorption: surface resorption, inflammatory resorption and replacement resorption.[21]

For any type of resorption to occur there must first be damage to the protective cementum surrounding the root. Essentially, a race between cementoblasts adjacent to the area of damage and osteoblasts in the surrounding bone, ensues.[21] A critical size defect of 4 mm^2 has been reported above which osteoblastic healing will preferentially occur.[22] A high metallic percussion note is detectable once 20% of the root surface is affected by replacement resorption[23,24] and is usually the earliest clinical indication that replacement resorption is occurring. Ankylosis usually occurs initially on the buccal and palatal surfaces of the root surface and therefore, whilst the process is present at a cellular level it is not visible on conventional radiographs until much later (up to a year).[25,26]

In traumatized teeth with limited damage to the cementum, adjacent cementoblasts will repopulate the damaged area and surface or cemental healing occurs. This is the same type of healing as seen following resorption secondary to orthodontic tooth movement. Where there is extensive damage to cementum, osteoblasts infiltrate the area and osseous healing or replacement resorption occurs. This is ankylosis and although it has been reported as transitory in a few cases,[24,26] in the vast majority it is permanent and the tooth is slowly replaced by bone. The speed of replacement resorption is related to the speed of bone turnover and whilst this is slow in an adult, in young children bone remodelling is rapid. When replacement resorption (ankylosis) occurs in a young child the ensuing lack of vertical growth in the anterior maxilla results in progressive infraocclusion.[27]

If a traumatic injury results in pulpal necrosis and subsequent bacterial infection, toxins within the pulp canal space have a pathway through the dentinal tubules directly to the area of root surface damage resulting in external inflammatory resorption of the root surface which will continue until the inflammatory stimulus has

been removed (e.g. pulp extirpation and disinfection of the root canal space). During the post-traumatic healing phase further damage to the protective cemental layer is not advised as this will only increase the inflammatory stimulus and prolong the destructive phase, increasing the risk of osseous healing. A period of observation to allow for periodontal ligament healing, is therefore required prior to orthodontic tooth movement.

Periodontal injuries can be ordered in severity from those producing minor cemental damage to those inflicting more severe trauma: concussion, subluxation, extrusion, lateral luxation, avulsion and finally intrusion.[21] Recommended observation periods prior to orthodontic tooth movement are dependent on the severity of the injury and a summary of current best practice is outlined in Table 1.

Root resorption receives great attention in the orthodontic literature as there is appreciable evidence that orthodontic treatment results in surface (cemental) root resorption. The length of orthodontic treatment time, root morphology, force applied and previous dental trauma may all have an effect on the prevalence and severity of root resorption seen. It has been shown for teeth which exhibit minor resorption after six to nine months of orthodontic movement, the risk of severe root resorption after further orthodontic tooth movement is significantly increased. When the effect of tooth anatomy is taken into account the degree of root resorption in teeth with blunt or pipette shaped roots is significantly greater than in teeth with a normal root form.[28] It has been recommended that radiographs are taken three months after the commencement of orthodontic treatment in teeth with blunt or pipette shaped apices.[29]

Studies investigating the influence of previous dental trauma on root resorption during orthodontic treatment are few in number and results have been conflicting. Malmgren *et al.*[30] found that traumatized teeth did not have a greater tendency to root resorption than uninjured teeth however they suggested previously traumatized teeth which show signs of root resorption prior to orthodontic treatment may be more prone to root resorption during treatment. They suggested an initial observation period of four to five months be allowed prior to the institution of orthodontic forces for any injured teeth.[30]

One study has shown the average change in root length for traumatized teeth undergoing orthodontic tooth movement was 1.07 mm compared to 0.64 mm for uninjured teeth.[31]

Brin *et al.*[20] looked carefully at the reaction of previously traumatized teeth to the application of orthodontic forces. Moderate root resorption was noted in 27.8% of previously injured teeth receiving orthodontic treatment compared to 7.8% in the orthodontic treatment only group and 6.7% in the trauma only group. An increased frequency of root resorption was noted in teeth that had experienced multiple episodes of trauma. The authors suggested previous trauma may be predictive of an increased risk of root resorption during orthodontic treatment, although they concede a small sample size and a heterogeneous collection of injuries may render findings inconclusive.

Radiographic monitoring of traumatized teeth or teeth with pre-treatment root resorption

Current recommendations for radiographic assessment of traumatized teeth or teeth showing signs of pre-treatment root resorption, during orthodontic treatment are baseline periapical radiographs or an upper standard occlusal radiograph with repeated views six to nine months into treatment. If minor root resorption is noted and a decision made to continue with orthodontic treatment, further radiographs should be taken after three months.[32] In the case of severe root resorption a rest period of three months is recommended prior to recommencing orthodontic treatment.[33]

In a long term follow-up of maxillary incisors with severe apical root resorption a risk of permanent tooth mobility has been shown to occur if the total root length is less than or equal to 9 mm.[34] This risk is reduced if more than 9 mm of tooth root remains in the presence of a healthy periodontium.[34]

In summary, orthodontic tooth movement is known to cause root resorption in teeth; blunt or pipette-shaped roots, jiggling orthodontic forces and previous tooth trauma may increase the susceptibility to root resorption. Retrospective studies examining resorption in traumatized teeth are inconclusive, based on small patient numbers and a heterogeneous collection of injuries, orthodontic appliances and operators.[20,30] The clinician should however acknowledge that traumatized teeth which display signs of root resorption before orthodontic tooth movement are at a high risk of increased root resorption as a result of orthodontic forces.[28] Good clinical and radiographic assessment is thus essential and appropriate patient information and consent should be obtained prior to the commencement of orthodontic treatment. Reliable communication and teamwork between the orthodontist and paediatric dentist or general dental practitioner is

Table 1 Summary of recommended observation periods prior to orthodontic tooth movement.

Type of dental injury	Observation period
Crown and crown/root fractures without pulpal involvement	3 months.[32]
Crown and crown/root fractures with pulpal involvement	After coronal pulpotomy and radiographic signs of establishment of a hard tissue barrier (approx. 3 months).[32]
Root fractures	1–2 years.[32,57] Shorter period if asymptomatic. If healing is by connective tissue the coronal fragment must be treated as a tooth with a short root. If granulation tissue interposed teeth should not be moved until successful endodontic treatment and connective tissue healing of the coronal fragment has occurred.
Minor damage to the periodontium[21] Concussion Subluxation Extrusion Lateral luxation (minor displacement)	3 months.
Moderate to severe injury to periodontium[21] Lateral luxation (moderate/severe displacement) Intrusion Avulsion and replantation	1 year if no ankylosis can be detected.[32] Orthodontic tooth movement is not recommend before complete periodontal healing has occurred (6 months). If teeth are orthodontically moved between 6 and 12 months keep a strong suspicion that the tooth is ankylosed where tooth movement is not as expected.
Immature traumatized teeth	Await radiographic evidence of continued root development. Clinical and radiographic controls should be carried out after 6 months, 1 year and 2 years.[32]
Teeth requiring endodontic treatment due to caries	Immediate orthodontic movement provided no periapical pathosis is evident. We would recommend definitive obturation with gutta-percha[43] rather than maintenance of calcium hydroxide in the root canal.[47–49]
Teeth requiring endodontic treatment due to inflammatory resorption	Await radiographic evidence of healing and allow at least 1 year to elapse before commencement of orthodontic tooth movement. Teeth with evidence of root resorption appear to be more liable to further resorption during orthodontic tooth movement.[33]
Teeth requiring endodontic treatment due to trauma	In a mature closed apex tooth, following an initial dressing of calcium hydroxide a definitive gutta-percha root filling should be placed.[43] This contradicts previous advice given by others.[6,32] The observation period depends on the nature of the original traumatic injury.
Autotransplanted teeth	3–9 months[65] i.e. after PDL healing[66] (8 weeks) and before complete alveolar bone repair. Extrusion may be commenced earlier than rotation or bodily tooth movement.[67] Ankylosis must be excluded when tooth movement does not occur as expected.

necessary for an optimal outcome.[35] Despite evidence of root resorption or continued uncertainty regarding the prognosis of a traumatized tooth it may still be in the best interest of the patient to proceed with orthodontic treatment. However, this is of course influenced by other factors too, e.g. severity of malocclusion, patient motivation, etc. If the prognosis of the traumatized anterior tooth is poor, it may be that orthodontic treatment is intended to align the arches and maintain space for a future premolar transplant, adhesive bridge or implant.

The paramount issue is that the patient is given all the available information and warned that the prognosis of the tooth is guarded with or without orthodontic treatment.

Orthodontic tooth movement in root treated teeth

The results of research involving orthodontic movement of endodontically treated teeth are conflicting. Some authors have reported an increased risk of root resorption[36] whilst others have reported equal[37] or reduced risk.[38,39] More recently a retrospective study has been carried out evaluating the radiographic findings in patients who concurrently had one endodontically treated maxillary incisor, with the adjacent incisor tooth available as a control. No statistically significant difference in the apical root resorption was seen in the root treated teeth compared to vital control teeth.[40]

In an animal model it has been shown that vital and non-vital teeth moved similar distances when subjected to the same forces.[41] Histologically, root-filled teeth showed greater loss of cementum after orthodontic tooth movement than vital teeth, but there was no significant difference in radiographic root length.

From the available evidence it can be concluded that there is no significant difference in the root resorption of endodontically treated teeth when compared to vital teeth subjected to the same orthodontic forces.

Orthodontic management of root filled teeth

Choice of root-filling material

The European Society of Endodontology published quality assurance guidelines[42] stating that endodontic treatment can be considered successful one year post-obturation when there is absence of pain or swelling, no sinus tract, no loss of function and radiographic evidence of a normal periodontal ligament space around the tooth.

Since previous guidance found in the literature[6,32] controversy has remained regarding the use of calcium hydroxide as the root filling material of choice during orthodontic tooth movement. Both retention of a calcium hydroxide dressing in the root canal until orthodontic tooth movement is complete[6,32] and obturation of the root canal with a definitive gutta-percha root canal filling prior to orthodontic tooth movement[43] have been advocated. Whilst the former advice is based on clinical experience alone, the latter recommendation is based on findings from an animal model.[44] No significant difference was found in resorption indices of teeth obturated with gutta-percha or those filled with an interim calcium hydroxide dressing. A definitively obturated and coronally sealed root treated tooth would appear to be at no greater risk of root resorption during tooth movement than one in which an interim dressing is maintained.

When there is established external inflammatory root resorption, long-term calcium hydroxide treatment (12 weeks) is significantly more effective than short-term treatment (1 week application prior to obturation) in promoting root surface healing with new cementum.[45] There may, however, be detrimental effects in placing a calcium hydroxide dressing in non-vital teeth over the extended period of time orthodontic treatment requires, particularly in immature teeth. An increased risk of cervical root fracture in traumatized immature teeth treated with calcium hydroxide over prolonged periods of time during apexification has been reported.[46] Several *in vitro* studies have shown the fracture resistance of teeth treated with calcium hydroxide over an extended period to be significantly decreased but unaffected by a dressing placed for up to 30 days.[47–49] Rosenburg *et al.*[49] compared the dentine fracture strength of teeth dressed with an intracanal calcium hydroxide paste and teeth obturated with gutta-percha, finding that the micro-tensile fracture strength of teeth reduced by 0.157 MPa per day, so that by day 84 the strength of dentine was reduced by 43.9%. This suggests that the clinical use of calcium hydroxide as an intra-canal medicament over a prolonged period of time should be re-evaluated.

These findings lend support to the earlier recommendations of completing definitive root canal therapy prior to a prolonged course of orthodontic tooth movement.[43] A well-cleaned and obturated root filling with a good coronal seal[50] allows for enhanced biological control over the tooth during tooth movement and thus

obturation of non-vital traumatized teeth with gutta-percha and sealer should be recommended. The exceptions are when non-setting calcium hydroxide dressing is required for a longer period to allow disinfection of the root canal (e.g. in inflammatory resorption) or for apexification in an immature open apex incisor, although a single visit mineral trioxide appetite technique is becoming a popular alternative.[51]

In conclusion it is recommended that definitive obturation of a non-vital tooth is completed at the earliest opportunity prior to orthodontic tooth movement, in most cases. Exceptions are noted above.

Observation periods following endodontic treatment prior to orthodontic tooth movement

Guidance is based on expert opinion.[32,43] In cases where root canal treatment has been undertaken as a result of pulp necrosis due to caries, orthodontic tooth movement can commence immediately.

Where there has been extensive bone loss, tooth movement should be delayed until there are clinical and radiographic signs of some healing and an interval of at least six months has been suggested.[43]

Where endodontic therapy has been carried out following dental trauma an interval of one year is recommended prior to proceeding with orthodontic treatment to increase the likelihood of complete healing and the absence of ankylosis.[32,43] At one year healing should be complete and the possibility of ankylosis subsequently developing is minimal, although even some years after a significant luxation injury the chance of a future diagnosis of ankylosis cannot be totally eliminated[52] and patients should be warned that this could still occur. The orthodontist should have a high index of suspicion that this has occurred if a previously traumatised tooth fails to move as expected. Recommendations relating to time intervals to be observed prior to orthodontic tooth movement are based on clinical judgement and experience rather than being founded on evidence from well-designed studies. In a review Hamilton and Gutmann[53] reported a lack of well-designed studies to provide definitive guidance relating to the best time to commence orthodontic treatment following root canal therapy in previously traumatized teeth.

An animal model has shown that, although orthodontic forces applied to root-filled teeth delays the periapical healing process in comparison to obturated contralateral incisors it does not prevent it, with a reduced periapical radiolucency visible in orthodontically moved teeth.[54] This work suggests that tooth movement may be commenced prior to complete radiographic resolution of periapical pathosis.

A summary of observation periods recommended prior to the orthodontic movement of endodontically treated teeth is provided in Table 1.

Force levels and mechanics for root-filled teeth

Normal force levels (net force of 50–100 g on a central incisor for bodily movement) using fixed appliances can be used for moving root-filled teeth, providing the periodontal ligament is healthy.[39]

Monitoring root treated teeth during orthodontic tooth movement

There has been no recent literature contradicting previous guidance[32] which recommends initial radiographs prior to the commencement of orthodontic tooth movement followed by radiographic monitoring six months after the start of orthodontic treatment.

Teeth traumatized during treatment

Due to small numbers of patients experiencing dental trauma during orthodontic treatment, there are no prospective or retrospective studies available to recommend best practice for this scenario. Consequently guidance is based on clinical experience, expert opinion and individual case reports. It has been demonstrated that teeth which experience one episode of dental trauma are at increased risk of future episodes of dental trauma.[15] Patients who have experienced dental trauma prior to orthodontic treatment can thus be warned, not only of the possible increased risk of root resorption as a result of orthodontic forces on the tooth, but equally of the risk of future episodes of trauma during treatment which may have an impact on the prognosis of the teeth and the length of time for orthodontic treatment to be completed. This is particularly true if tooth movement needs to be halted whilst endodontic treatment is carried out, a period of observation following trauma is required, or a rest period is necessary if root resorption becomes apparent during treatment. The reader is referred to Table 1 for a summary of current guidance regarding observation periods prior to commencing or restarting orthodontic tooth movement.

Interdisciplinary management of root fractured and intruded teeth

Whilst it is not the remit of this paper to discuss in detail the orthodontic management of the entire spectrum of dental injuries, the treatment of root fractured teeth and intruded teeth deserve special mention as a result of the close liaison required between the specialist in orthodontics and the paediatric dentist or general dental practitioner. Avulsion injuries will be considered in more detail in the next paper.

Root fractured teeth

Root fractures account for 0.5–7% of dental traumatic injuries[55] and may be horizontal, vertical, single or multiple and complete or incomplete. The aims of treatment are to preserve pulp vitality, facilitate periodontal healing and encourage fracture healing with a hard tissue callus rather than connective tissue, bone and connective tissue or granulation tissue (as the result of a necrotic coronal pulp). It should be remembered that the apical root fragment almost always remains vital even if the coronal part becomes non-vital.[56] Diagnosis of root fractures can be problematic and requires radiographic exposure in two or more planes in order to identify or rule out this possible diagnosis. The established protocol for root fractured teeth for over 30 years has been rigid splinting for two to three months but recent guidance advocates physiological splinting for four weeks in the case of apical and mid-root fractures and splinting for four months in the case of cervical root fractures.[9]

If orthodontic movement of previously root fractured teeth is considered it is essential to determine that a hard tissue barrier of dental callus exists between the fragments. If the fracture has healed with connective tissue the coronal fragment alone will move when subjected to orthodontic forces and it should be considered as a tooth with a short root. This has profound implications if further orthodontic root resorption occurs to the coronal fragment thereby shortening the root further. As discussed previously, permanent mobility of the coronal fragment can be expected where the root length is less than 9 mm.[34]

When there are radiographic and clinical signs indicative of coronal pulp necrosis and granulation tissue is interposed between the fragments, appropriate endodontic therapy of the coronal pulp is required prior to orthodontic tooth movement. Following successful endodontic treatment of the coronal fragment only, the healing of the fracture site will be by connective tissue and the tooth should be considered to have a short root. Zachrisson and Jacobsen [57] recommended an observation period of two years prior to commencing orthodontic tooth movement of root fractured teeth, although it has been suggested this could be shortened in the absence of complications, which will usually have become evident by one year.[32]

In the case of orthodontic movement of root fractured teeth it is recommended that light forces be used,[31] treatment is expediently completed[6,32,43] and teeth are appropriately monitored radiographically and clinically for continued signs of pulpal vitality.

Intrusion injuries

Intrusion injuries account for about 1.9% of all traumatic injuries.[58] The crushing injury of intrusion causes severe damage to the tooth, periodontium and pulpal tissues. Although periodontal ligament regeneration may occur in mild intrusions healing outcomes for more severe intrusion injuries frequently include replacement resorption, marginal bone loss and pulp necrosis.

Guidelines exist for the management of intruded permanent incisor teeth in children.[9,59]

In essence, all severely intruded teeth and moderately intruded teeth with closed apices, should be repositioned rapidly in order to allow access for extirpation of a non-vital pulp to prevent inflammatory root surface resorption secondary to pulp necrosis. Active surgical or orthodontic repositioning is, however, a further traumatic event for the periodontal ligament and it has been suggested that spontaneous re-eruption should be allowed in mild to moderate injuries in patients up to the age of 17 years.[9] Active repositioning should still be considered if there is no change in the position of the tooth after a two week interval. It should also be remembered that severe intrusion may lock a tooth in position in the alveolar bone and gentle luxation forces may be required before orthodontic extrusion.

A significantly higher prevalence of root resorption and pulp necrosis has been observed in the most severely intruded and in closed-apex teeth.[60,61] Treatment method (surgical repositioning, orthodontic traction or spontaneous re-eruption) have been shown by some authors[60–62] to have no significant effect on the prevalence or rate of root resorption, although there is some agreement that spontaneous re-eruption should be encouraged where possible.[9]

Clinicians should warn patients that discrepancies in the incisal position of teeth and in gingival marginal contour may occur following intrusion injuries due to replacement resorption and resulting infra-occlusion.

Root fractures, intrusion injuries and tooth avulsion all result in a severe insult to the periodontal ligament, cementum and pulp of the tooth. Negative consequences include both loss of pulp vitality and significant damage to the cementum and periodontal tissues, allowing ingress of osteoclasts and osteoblasts to the area of damage and consequent replacement resorption of the root.

It would be of great benefit if it were possible to prevent replacement resorption in the injured tooth. Mine *et al.*[63] used a rat model to examine the role of mechanical stimuli in preventing ankylosis. Mine's group suggested that occlusal stimuli promotes the regeneration of the periodontal ligament and prevents dentoalveolar ankylosis, although excessive initial force may cause severe root and bone resorption. They postulated that an orthodontic archwire may be used to distribute or deliver the appropriate force to a transplanted (and thus it may be inferred, a replanted) tooth to avoid root resorption and ankylosis, whilst stimulating periodontal ligament repair and improving the prognosis. Other authors[64] have shown the beneficial effect of encouraging a hard diet, following dental trauma in a monkey model, and this may well be a simpler way of providing the physiological stimuli discussed previously.[63]

Neither method is able to regenerate cemental healing when very extensive damage has occurred to the periodontal tissues, with replacement resorption being inevitable.

Table 1 outlines the observation periods which would be recommended prior to orthodontic tooth movement given the evidence currently available.

Conclusions

- A history of dental trauma is common in children and is increased in those attending for orthodontic treatment due to the increased prevalence of injuries associated with Class II division 1 malocclusions.
- Custom made mouthguards should be recommended for children participating in contact sports and should continue during appliance therapy.
- Accurate history taking in addition to clinical and radiographic examination are essential prerequisites to successful orthodontic movement of traumatized teeth. It is suggested all patients be specifically questioned regarding a history of trauma.
- Close liaison between the orthodontist and paediatric dentist or general dental practitioner is paramount for the optimum management of the traumatized dentition.
- Informed consent should include information regarding perceived risks of root resorption and risks of repeated episodes of dental trauma. Prolonged treatment may be necessary, especially if traumatized teeth require endodontic therapy during treatment or if further episodes of trauma or evidence of root resorption require rest periods during treatment.
- Where a tooth (i.e. avulsed tooth) is undergoing resorption and has a poor prognosis, the orthodontist may still continue with orthodontic treatment to align teeth for more favourable placement of a future autotransplant, adhesive bridge or implant.
- In light of new evidence regarding the effect prolonged use of a calcium hydroxide paste has on the tensile strength of dentine, it is recommended that this dressing is used for a short period (up to four weeks) in an asymptomatic closed apex tooth prior to definitive obturation with gutta-percha and placement of a good coronal seal. Exceptions to this may occur in the case of a tooth undergoing extensive inflammatory resorption or in an immature tooth where apexification is required, unless mineral trioxide aggregate (MTA) is being used in a one stage technique.

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