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Non-surgical Retreatment Following Failed Apicoectomy with Re-use of Intra-radicular Restoration – A Case Report

Dr. Imran Cassim

The aim of this article is to highlight the possibility of the successful outcome of non-surgical retreatment involving disassembly of a cast restoration then orthograde MTA obturation, following failed surgical retreatment of a maxillary central incisor.

Introduction

Several studies have documented that bacterial infection of the root canal is the primary cause of apical periodontitis; therefore, eradication of micro-organisms from the infected tooth is essential for healing. Schilder outlined the principles of 3-D cleaning, shaping and obturation of the root-canal system, which are the foundations for predictable endodontic success. Some of the reasons for failure of primary endodontic therapy are persistent intraradicular infection owing to incomplete debridement and obturation of the root-canal system, which can occur as a result of missed anatomy, ledges, blockage, canal transportation, fractured instruments, strip perforation and damage to the apical foramen. Other causes of apical periodontitis following root-canal therapy are a lack of coronal seal, secondary caries, vertical root fractures and coronal cracks, trauma, and periodontal disease, which can allow the ingress of bacteria into the root-canal system. Other extra-radicular causes of periapical infection include cellulose-containing materials from paper points or cotton pellets, which are known to cause a chronic inflammatory reaction if present in the periapical tissue, periapical actinomycosis, an unresolved cystic lesion or the accumulation of cholesterol crystals in the periapical area.

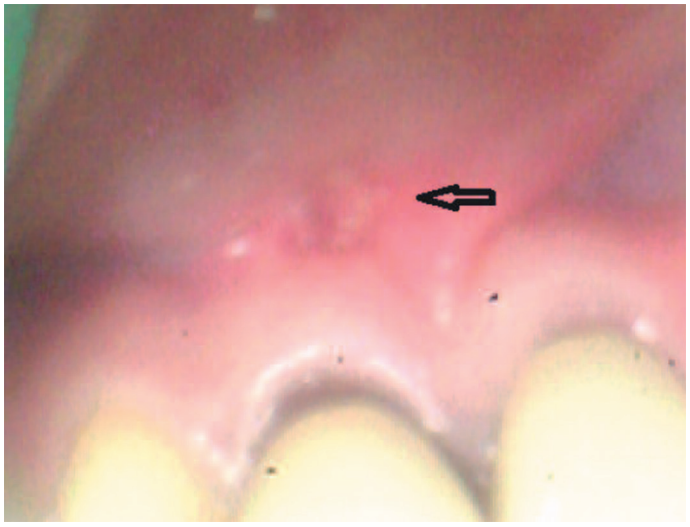

Fig. 1 Draining sinus in gingiva above tooth #11 and recession of gingiva.

The treatment modalities for teeth that have symptoms of apical periodontitis after endodontic treatment are endodontic surgery or non-surgical retreatment if the tooth is to be saved. Non-surgical retreatment is an attempt to remove the micro-organisms from within the canal system and isolate micro-organisms from extra-radicular areas, whereas endodontic surgery is an attempt to confine the micro-organisms within the root-canal system and remove micro-organisms from the extra-radicular areas. Endodontic surgery shows a more favourable initial success but non-surgical retreatment shows a better long-term success. Extraction of teeth with failed root-canal treatment and replacement with implants has increasingly become more popular than surgical and non-surgical endodontic retreatment. Technological advances, such as the use of magnification and ultrasonics, and the development of new materials promise greater efficiency and improved treatment outcomes. The decision of whether to ex-tract or retain a tooth should be based on its suitability for further restoration after retreatment, as long as it is periodontally sound. It is important that in patients with high aesthetic expectations and a thin mucosal biotype that greater efforts be made to save a questionable anterior tooth in order to ensure preservation of the soft-tissue architecture.

In non-surgical retreatment, the presence of cast restorations and posts may pose technical difficulty in accessing the root-canal space. Cast and prefabricated metal posts can be removed with ultrasonics and post-pulling devices; fibre posts can be drilled out. The simplest means of removing a screw post is to use the corresponding wrench—if the head of the post has been damaged, a piece of cotton wool can be placed in the wrench to provide a tighter fit. Ultrasonic vibration applied to posts reduces the force needed to remove the post. It is important to use a water spray to prevent overheating the tooth during ultrasonic vibration of the post. The risk of root fracture during post removal has been reported to be less than 1%. Traditionally, teeth with failed apicoectomies without retrograde fillings were retreated surgically or a combination of non-surgical and surgical procedures was employed. Retreatment of teeth with previously apically resected roots was first reported by Stewart in 1975. In these cases, the existing root filling should be removed carefully in order to avoid extruding the filling into the periapical area when a retrograde filling is absent. Pannkuk demonstrated a method for removal of amalgam root-end fillings during retreat-

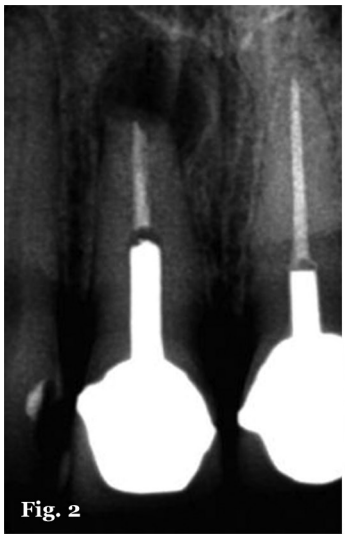

Fig. 2

Fig. 3

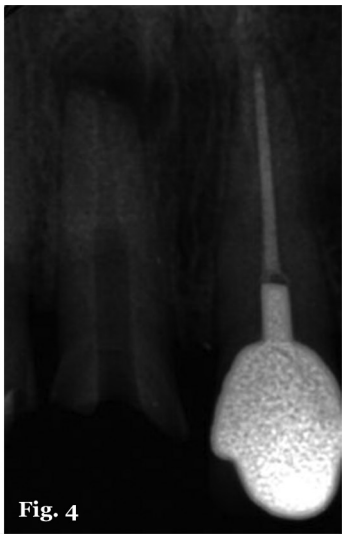

Fig. 4

Fig. 2 Pre-op X-ray showing periapical radiolucency and post crowns on teeth #11 and 21.

Fig. 3 A gutta-percha point tracking the draining sinus to the periapical radiolucency.

Fig. 4 X-ray showing removal of intra-canal contents.

ment. Once the previous filling material has been removed, further treatment proceeds as in the treatment of immature teeth with open apices. MTA has been proposed as the material of choice for apical barrier formation in teeth with open apices and necrotic pulps. It is biocompatible, osteoinductive, cementogenic and has antifungal and antibacterial properties.

Case Report

A 61-year-old female patient was referred for treatment of a symptomatic maxillary right incisor. Her chief complaint was that she had had an apicoectomy done by a maxillofacial surgeon on her anterior tooth (#11) one year previously and three months after the procedure she kept getting a swelling in the gum above the tooth and recently the swelling had become painful and the tooth was painful when biting. She had seen her dentist two days previously and he had prescribed clindamycin 150mg. Her other concern was the dark cervical margin exposed above her crown on the tooth owing to the receding gum line.

On clinical examination, the gingiva above tooth #11 was inflamed and a draining sinus was noted in the gingiva 10mm above the cervical margin of the incisor. There was recession of the gingiva above the cervical margin of the crown of tooth #11 and a PFM crown on tooth #21 (Fig. 1). Thermal tests were negative. Tooth #11 was tender to percussion and palpation. Periodontal probing showed 2mm pockets around teeth #11, 12 and 21. No pathological mobility of tooth #11 was detected. Radiographic examination demonstrated that there was a post crown on tooth #11, periapical radiolucency and no retrograde filling placed at the apex (Fig. 2). The crown–root ratio was approximately 50:50. The draining sinus was at the apical level of the post, and a root fracture was suspected. A gutta-percha point was inserted into the draining sinus and a periapical radiograph showed the gutta-percha point tracking the sinus to the periapical radiolucency (Fig. 3).

Treatment options were discussed with the patient. The following options were suggested: non-surgical retreatment, surgical retreatment, extraction followed by implant placement, denture or bridge. She was motivated to keep her tooth, refused another apicoectomy procedure and could not afford an implant and bone augmentation and the possible replacement of the neighbouring crown because of gingival recession following extraction. A decision was made to attempt non-surgical retreatment and the patient was warned that there was a possibility of fracture.

The patient was scheduled for a two-hour appointment. Following anaesthesia, a polyvinyl siloxane impression (PRESIDENT, Coltène/Whaledent) was taken of the maxillary arch. The crown was sectioned off using a tapered crown preparation diamond bur (Komet) and a tungsten carbide bur (Tri Hawk). A minimum 2mm ferrule was observed around the cast post core. A rubber dam was placed and secured with wedges placed between teeth #12 and 13, and between #21 and 22.

Fig. 5

Fig. 6

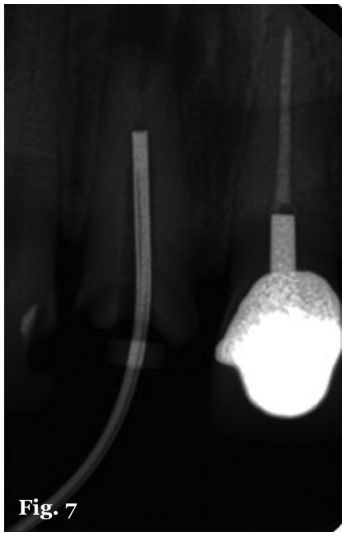

Fig. 7

Fig. 5 X-ray taken at end of first visit showing placement of calcium hydroxide and post core recemented and temporary crown. Note slight extrusion of calcium hydroxide, hole in core and presence of adequate ferrule.

Fig. 6 X-ray after six weeks of calcium hydroxide dressing showing dissolution of the calcium hydroxide.

Fig. 7 Gauging placement of MTA Gun and confirming removal of intra-canal medicament.

Post-core removal was initiated using the Start-X #4 ultrasonic tip (DENTSPLY Maillefer) in a piezoelectric scaler handpiece (NSK), moving the tip anti-clockwise along the longitudinal axis of the post core.The Start-X tip has a lumen for water spray, which prevents over-heating of the post and surrounding periodontal ligament. After 15 minutes of ultrasonic vibration, the post core had not completely loosened. A hole was drilled through the core bucco-palatally using a Great White #2 tungsten carbide bur (SS White). A double-layered dental floss ligature (Satin Tape, Oral-B) was looped into the hole in the core. The cable attachment of the Safe Relax automatic crown and bridge remover (Anthogyr) was looped through the dental floss ligature. The purpose of this is that the dental floss ligature acts as a stress breaker, thereby preventing excessive force on the root and minimising the risk of root fracture or inadvertent extraction of the tooth. The post core was removed without any damage to the root following 30 seconds of low intensity force application with the Safe Relax. The Safe Relax was used because the post was not serrated.

The residual cement in the canal was removed with a #3 Start-X ultrasonic tip (DENTSPLY Maillefer). The gutta-percha was removed using a few drops of chloroform (Allied Drug Company) and a #40 Hedstrom file (DENTSPLY Maillefer). A radiograph was taken to confirm removal of the gutta-percha (Fig. 4). Working length was determined using the iPex digital apex locator (NSK) and the apex was gauged to a size #100 using a K-file (DENTSPLY Maillefer).

The canal was irrigated with 3% sodium hypo-chlorite (Vista Dental) and agitated with the Endo-Activator (DENTSPLY Tulsa) for one minute and this was repeated ten times with fresh irrigant each time. The canal was dried with paper points and then flooded with 17% EDTA and agitated with the Endo-Activator for one minute and then dried and rinsed with distilled water. A 2% chlorhexidine solution was left to soak in the canal while the post core was being prepared for temporary recementation.

The post core was air abraded using the RONDO-flex (KaVo) with 27µ aluminium oxide powder. The post core was then soaked in 2% chlorhexidine (Vista Dental) for two minutes. The hole in the core was etched with 37% phosphoric acid (Ultradent), rinsed and air-dried. Then Monobond Plus primer (Ivoclar Vivadent) was applied to the surface and air-dried after 60 seconds. The Xeno V (DENTSPLY) bonding agent was applied to the core and light cured for 20 seconds using the SmartLite (DENTSPLY) ultraviolet curing light. The QuiXfil (DENTSPLY) resin composite was used to fill the hole in the core and light cured for ten seconds.

The buccal margin of the crown preparation was extended to the gingival margin using a #018 tapered diamond bur (Komet). The canal was air-dried and UltraCal XS (Ultradent), a radiopaque calcium hydroxide paste, was syringed into the canal using a Navi-Tip needle (Ultradent). The post core was recemented with NexTemp temporary cement (Premier Dental) and the rubber dam removed. A temporary crown was fabricated by placing Protemp 4 (3M ESPE) in the polyvinyl siloxane impression and reseating it. The temporary crown was polished and cemented using Meron glass ionomer luting cement (VOCO). A post-operative periapical radiograph was taken (Fig. 5). The patient was scheduled to return for evaluation and further treatment after six weeks.

Second Visit

The patient reported that her symptoms had disappeared within the first week after the first visit. On clinical examination, it was noted that the inflammation and draining sinus in the gingiva above tooth #11 had healed. A periapical radiograph showed some dissolution of the calcium hydroxide dressing apically (Fig. 6).

Following anaesthesia and isolation, a horizontal slot was cut on the buccal cervical aspect of the temporary crown and it was levered off along with the post core using a flat plastic instrument. The canal was irrigated with 17% EDTA, which was agitated using the Endo-Activator for one minute to help remove the remaining calcium hydroxide dressing. Then distilled water was used to flush the canal and 2% chlorhexidine was left in the canal for two minutes. Thereafter, the canal was irrigated with distilled water and dried with paper points. A periapical radiograph was taken to determine the placement of the MTA Gun System (DENTSPLY Maillefer) and confirm removal of residual calcium hydroxide (Fig. 7).

White MTA-Angelus (Angelus) was mixed according to the manufacturer's instructions and placed into the canal using the MTA carrier gun. After the placement of three aliquots of MTA, a #5 Dr Machtou Plugger (DENTSPLY Maillefer) was used to condense the MTA, with ultrasonic vibration applied to the plugger for 20 seconds to aid in condensing the MTA mass apically. A further three aliquots of MTA were placed and the condensation procedure repeated. The post was used to condense the final two aliquots of MTA. A periapical radiograph was taken to assess the MTA placement (Fig. 8). A post brush (DiaDent) was used to remove excess MTA in the post space, and a cotton pellet soaked in distilled water was placed in the canal for 15 minutes.


Fig. 8

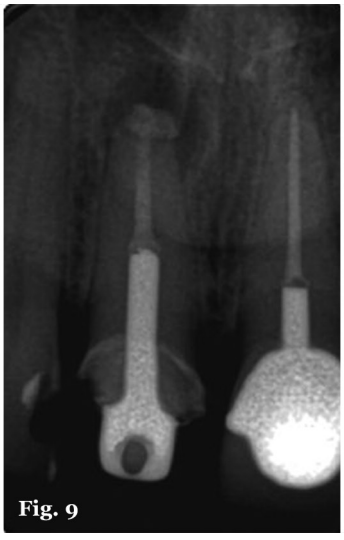
Fig. 9

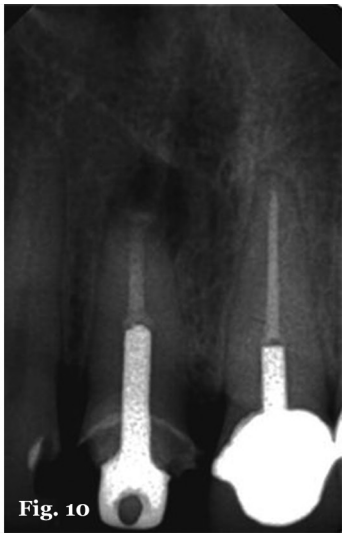
Fig. 10

Fig. 8 Placement of apical MTA barrier and slight apical extrusion of MTA.

Fig. 9 Immediate post-op X-ray.

Fig. 10 Follow-up X-ray at five months showing some dissolution of extruded MTA.


Fig. 11


Fig. 12a


Fig. 12b

Fig. 11 Gingiva is healthy and no further recession at the cervical margin at five months with temporary crown in place. **Fig. 12a** Follow-up X-ray at 18 months showing decrease in size of periapical radiolucency and the permanent crown placed. **Fig. 12b** Patient is happy with the new crown and gingival margin six months after permanent crown placement.

The RONDOflex was used to lightly air abrade the post surface to remove the remnant of the temporary cement, and the post was soaked in 2% chlorhexidine for two minutes. The post was then etched with 37% phosphoric acid for 20 seconds, rinsed and air-dried, and then Monobond Plus was applied and air-dried after 30 seconds. After 30 minutes the initial set of the MTA was confirmed by inserting a #60 K-file (DENTSPLY Maillefer) into the canal against the MTA mass. The post space was dried using paper points. The post-core crown was recemented using the RelyX Unicem resin-modified glass ionomer cement (3M ESPE) and a periapical radiograph was taken (Fig. 9). The preparation of the permanent crown was post-poned to monitor healing and symptoms, to assess the gingival response to the new crown margin and to spread the cost. A five-month post-operative radiograph (Fig. 10) showed some dissolution of the extruded MTA, and the tooth was asymptomatic and the gingiva above tooth #11 showed no further recession (Fig. 11). An 18-month follow-up radio-graph showed a decrease in periapical radiolucency (Fig. 12a) and the patient was happy with the new crown (Fig. 12b).

Discussion

It is important to discuss treatment alternatives, risk factors and costs with patients before proceeding with treatment. The approach to cleaning and shaping in teeth with open apices requires an adaption of strategies and the biological objectives described by Schilder take precedence. Particular attention should be given to working length control to reduce the possibility of extrusion of irrigants. Subsonic agitation was used for the irrigants to minimise extrusion and improve the efficacy of chemical debridement. The combined use of EDTA and sodium hypochlorite has been shown to have better antibacterial efficacy than sodium hypochlorite alone. Chlorhexidine exhibits substantivity and dentine medicated with a 2% solution for ten minutes can exhibit substantivity for up to 12 weeks. Furthermore, chlorhexidine is antifungal, which is beneficial because fungi may be involved in cases with persistent or secondary endodontic infection. Premedication with calcium hydroxide improves the marginal adaptation of the apical MTA plug and it appears to be the only medicament that is effective against endotoxin. White MTA-Angelus was used because of its short setting time. (MTA-Angelus is available in both grey and white forms.) It is composed of 80% Portland cement and 20% bismuth oxide. The absence of calcium sulphate allows a quicker initial setting time of approximately 15 minutes.41 In teeth with open apices, apical control is difficult during obturation, but MTA extrusion is well tolerated.

In the present case, the cast post core was reused because there was no unnecessary mechanical enlargement of the post space, the well-fitting post core was removed largely intact, its reuse minimised the cost to the patient and there was an adequate ferrule around on sound tooth structure.

A second surgery in teeth that have undergone apicoectomy results in further scarring, shortening of the root and decreased localised blood supply. The present case report shows healing in progress and the absence of symptoms 18 months after non-surgical retreatment. Further follow-up is necessary to assess the long-term outcome.

Non-surgical retreatment with an MTA apical barrier after root resection is considered an empirical treatment modality, as no data exists on success rates. This warrants further research of this approach, as it may provide comparable healing and less morbidity compared with conventional retreatment combined with apical surgery.

Editorial note: A complete list of references is available from the publisher.

Acknowledgement: I would like to thank Prof. J. L. Gutmann for his encouragement and help in writing this case report and Dr. K. Serota and the roots community.

Source: First published in www.dentinaltubules.com with permission from the author.

Reattachment of Fractured Tooth Fragment Using the Fiber Post in an Endodontically Treated Tooth – A Case Report

Dr. Arjay Kadam

Case Report

A male patient aged 21yrs reported to clinic of fractured tooth fragment. On examination revealed root-stump with upper left lateral incisor fractured obliquely sub-gingivally palatally.

Fig. 1 Pre-operative

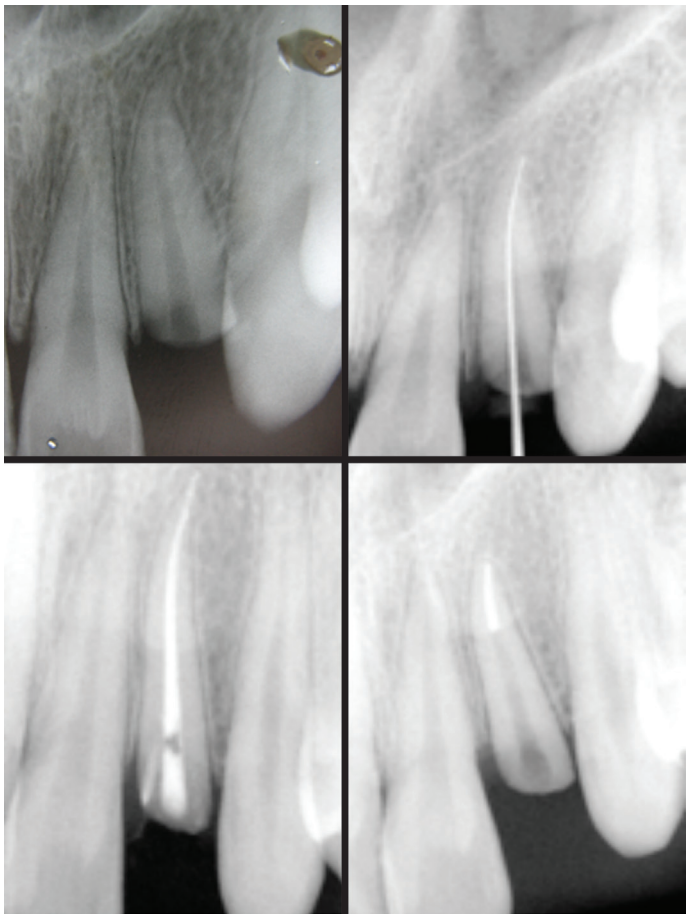

Fig. 2 Root canal treatment: Walking bleach of fragment

Radiographically the level of fracture was 1mm above the bone distally & at the level of bone mesially.

On questioning patient about root fragment, he had removed on self and had preserved without any medium.

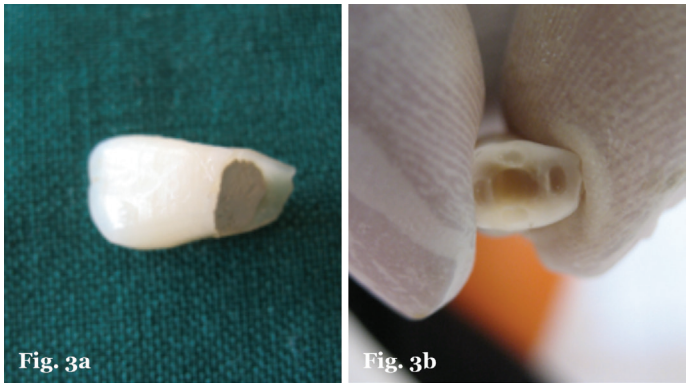

Fig. 3a Dentinal slot prep. **Fig. 3b** Crown lengthening

It was decided for root canal treatment, followed by crown lengthening and reattachment of the same fragment with fiber post (Glassix) & resin luting cement (RelyX unicem).

As the crown fragment was discoloured extroral walking bleach was performed using sodium perborate.

Fig. 4 Reattachment of fragment with fibre post

During reattachment procedures four retention grooves of depth 2mm and width 2mm were prepared on root portion as well as crown fragment. Post was first tried inside the canal with crown fragment in position and length of post adjusted accordingly.

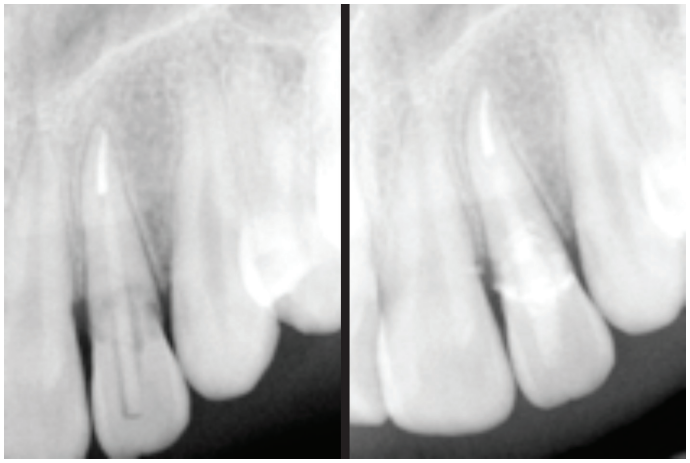

Fig. 5 Post-operative

Fig. 6 Post-operative

Bonding agent was applied to the post space as well as crown fragment. Resin luting was mixed according to manufactures instructions and applied to root canal, crown fragment & fiber post and seated and light cured for 60 sec from all the aspects. Excess flash was trimmed with BP-blade and finished, polished.

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Once Bitten Twice the Root Canal Controversy

Dr. Omar Ikram

Introduction

What started this debate?

Apical periodontitis is caused by microorganisms (Moller et al 1981); elimination of these microorganisms from the root canal is correlated with radiographic healing (Sjogren 1997). On most occasions a community of microorganisms needs to be established for apical periodontitis to occur (Fabricius et al 1982). In order to predictably disinfect a root canal system, physical removal of microorganisms with root canal files and irrigation using sodium hypochlorite should be carried out to the full working length (Byrstom and Sundqvist 1983). The creation of a tapered root canal preparation using files allows our antibacterial irrigants to reach the apical regions of the root canal.

Stainless steel hand files and Gates Glidden drills were traditionally the only instruments available to create this tapered preparation. The greatest disadvantage of stainless steel is that as the thickness of the file increases it loses its flexibility and therefore the ability to negotiate curved canals. Stainless steel files are constructed with only a 2% taper, so in order to create a sufficiently tapered root canal preparation the middle and apical regions of the canal are prepared using hand files and then the coronal preparation is completed using Gates Glidden drills. Creation of a tapered preparation using these instruments can be technique sensitive and time consuming. Therefore to be able to reliably disinfect a root canal in this way often requires a number of appointments. To prevent bacterial growth between these appointments and to aid disinfection of the apical region an antibacterial medicament is used as a dressing.

Nickel titanium is an alloy that has shape memory and super elasticity. Root canal files made from this alloy can be constructed with a greater taper and still negotiate curved root canals. Their use in a rotary handpiece decreases operator fatigue; as well as allowing the creation of a three dimensional and sufficiently tapered preparation much more quickly than was possible, using stainless steel instruments. This means irrigants are able to reach the apical region of the root canal in a single visit. In addition to this the invention of new warm vertical condensation techniques means that obturation can be carried out predictably in a single visit.

Any clinician would admit it has never been possible to sterilise the root canal system and the dentinal tubules of necrotic root canals, even after treating them over multiple visits. But with the efficiency of our modern endodontic armamentarium is it possible to achieve just as good clinical outcomes in a single visit?

The case for root canal treatment over multiple visits

Clinicians who favour multiple visit root canal treatment draw our attention to the decalcified sections of teeth which show that the root canal system is a complex network of fins, webs and lateral canals. They could also quote the study by Peters et al 2001 which shows the surface area instrumented by our root canal files during preparation is minimal. Therefore if we are to have any hope of disinfecting this complex root canal system we must try to make the environment within it as uninhabitable for microorganisms as possible. So in addition to disinfection using antimicrobial irrigants we should use calcium hydroxide as an interappointment medicament which raises the PH of the root canal system, decreasing the viability of microorganisms in the areas which cannot be reached by filing alone. Calcium hydroxide must be present in the root canal for at least 1 week to be an effective antibacterial medicament. Meaning that more than one visit is required if it is used.

Clinicians who advocate multiple visit root canal treatment can quote the classic studies that give good evidence for the use of calcium hydroxide as an antibacterial medicament (Sjogren et al 1991), (Bystrom et al 1985). They may also quote the famous 'Mexican' histological study (Nair et al 2005) which shows many viable bacteria still present in the canals of lower molars following treatment in a single visit.

The case for single visit root canal treatment

There are a number of systematic reviews which have concluded there are no significant differences in the outcome between single visit and multiple visit root canal treatments (Figni et al 2008, Sathorn et al 2005). Clinicians who advocate single visit treatment often quote these reviews as evidence. They believe that if the tapered preparation can be made quickly and the irrigant solutions can reach the apex then there is no need to get the patient to come back for further appointments. There is also evidence that when treatment is done over multiple visits there is a greater risk of infection with Enterococcus faecalis, due to microleakage of the temporary restoration (Siren et al 1997). Other studies conclude that calcium hydroxide can cause weakening of the dentine (Andreasen et al 2002). Some recent studies have even cast doubt on the antibacterial efficacy of calcium hydroxide. A study by Peters et al 2002 showed that after dressing samples for 4 weeks with calcium hydroxide bacteria were still able to regrow between visits.

Conclusion

My personal view
I am a great believer that research gives us guidelines by which to treat our patient, but our clinical experience helps us refine these guidelines.

The literature only tells us two things:

1. In a tooth with a healthy pulp there are no bacteria present and in a tooth with an acute pulpitis the bacteria causing the disease are mainly in the coronal pulp. This means removal of the inflamed pulp and microorganisms as well as obturation in a single visit is likely to prevent microleakage and therefore contamination of the root canals. The success rate of single visit root canal treatment on teeth with an inflamed vital pulp is well above 90%. In this situation single visit root canal treatment is actually recommended.

2. Calcium hydroxide can be an effective antibacterial medicament if it is placed correctly within the canals for 1 week or more. The classic studies we base so much of our treatment on, show that it has to be considered the 'gold standard' antibacterial medicament for the disinfection of necrotic root canals.

What the literature can never tell us is which necrotic cases would be successful due to the antibacterial action of calcium hydroxide and which cases do not require the dressing. Although many operators would like to think every root canal they treat is the same, they are not. The bacterial count inside the canal and the healing capacity of the patient are often very different between cases. Therefore the decision on whether the treatment is to be carried out in single or multiple visits must be based on both the condition of the tooth being treated, as well as the perceived ability of the patient to heal.

Single Visit Cases

Healthy or inflamed pulps
In inflamed pulps the bacteria are often located in the coronal pulp. Therefore removal of them is much simpler than if they were present in the apical regions. In cases where elective root canal treatment is carried out, such as teeth that are to undergo root amputation then the pulp is sterile and as long as good aseptic techniques are followed then single visit root canal treatment is the gold standard in these cases.

Asymptomatic cases with no periapical disease
In cases where the tooth is asymptomatic and no periapical disease is present then there are little or no microorganisms present. If it is possible then root canal treatment in a single visit treatment can be considered for these cases.

Cases which are now asymptomatic following a previous root canal dressing
If the tooth has had a root canal dressing done by a previous clinician under acceptable aseptic conditions and is now asymptomatic, it is possible to consider a single visit root canal treatment. This is the same as a two visit root canal treatment, albeit the first stage was done by another clinician.

General anaesthetic cases
Because of the risks and costs involved root canal treatment of patients who require a general anaesthetic should be completed in a single visit if possible. The exception to this is where the patient requires multiple general anaesthetics for other treatment which would make multiple visit treatment a possibility.

Patients requiring antibiotic cover
The laws governing the use of antibiotic cover are different all over the world. But as a general rule exposing these patients to the least amount of antibiotics possible is more beneficial. Single visit root canal treatment should be a considered for patients requiring antibiotic cover.

Patient needs
In situations where the patient finds attending the surgery difficult, such as those who are physically disabled or those that travel extremely long distances, single visit root canal treatment should be considered. If the case is technically difficult or it is in the best interest of the patient to return for future visits then the treatment must be undertaken over multiple visits.

Multiple Visit Cases

Systemic health of the patient
Patients who are immunocompromised or are poor healers are perhaps less likely to heal following root canal treatment. Therefore in infected cases it is preferable to treat these patients over more than one visit.

Large lesions
Some studies tell us that in patients with very large lesions the chance of healing is lower than smaller lesions. Often large lesions require both orthograde root canal treatment as well as apical surgery. If cases with large lesions are treated over multiple visits and surgical treatment is still required at a later date then both the operator and the patient know that the best care was provided. However if the patient requires apical surgery after a single visit root canal treatment they could feel that surgery may not have been necessary should a multiple visit approach been taken.

Inability to dry the canal after preparation
An indicator of whether the periapical tissues are still inflamed is the presence of apical exudate. If after preparation and irrigation of the root canals exudate continues to drain from the apex then even after obturation this may continue to drain from the apex back into the canal and feed the proteolytic bacteria inside the root canals. Cases that cannot be dried are best treated in multiple visits.

Retreatment cases
Research suggests that failed root canal treatments contain bacteria which are resistant to our medicaments such as Enterococcus faecalis (Molander et al 1998). These gram positive cocci have a proton pump which makes them resistant to calcium hydroxide (Evans et al 2002). This does not mean that they are immune to our medicaments just that they are simply more difficult to eliminate. There are other irrigants such as Chlorhexdine which have shown to be effective against this organism. For this reason I tend to treat teeth with post treatment disease over multiple visits.

Technical difficulties
In teeth with posts, fractured files, ledges or resorbed apices it is often technically difficult to complete treatment in a single visit, due to time constraints. With the increased difficulty of treatment in these cases I prefer to treat them over multiple visits so that I feel maximum disinfection of the root canals has been attempted.

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Endodontics Case of the Month, HeroDontics on Tooth #25, What Would You Do? Extract-Surgery

Dr. Rico Short

I wanted to share another very interesting case with you. This patient presented with pain and swelling on the lower anterior tooth associated with #25. He had a previous root canal that "did not work", and an apicoectomy that "did not work".

He still wanted to try to save his tooth anyway, so I recommended a retreatment! Yes a retreatment, not a surgery, or implant! However, I did tell him the prognosis was guarded and may still require an extraction and possible implant.

We proceeded with the retreatment in 2 visits using Calcium Hydroxide in a 2 week period. Upon access I noticed an accessory canal. The accessory canal was instrumented as well as the main canal with the amalgam retrofill from the surgery. The case was obturated with MTA by Dentsply/Tulsa.

Patient was recalled in 2 years. The healing on this case was very surprising even though he did not get a permanent restoration like instructed within 30 days of completion!

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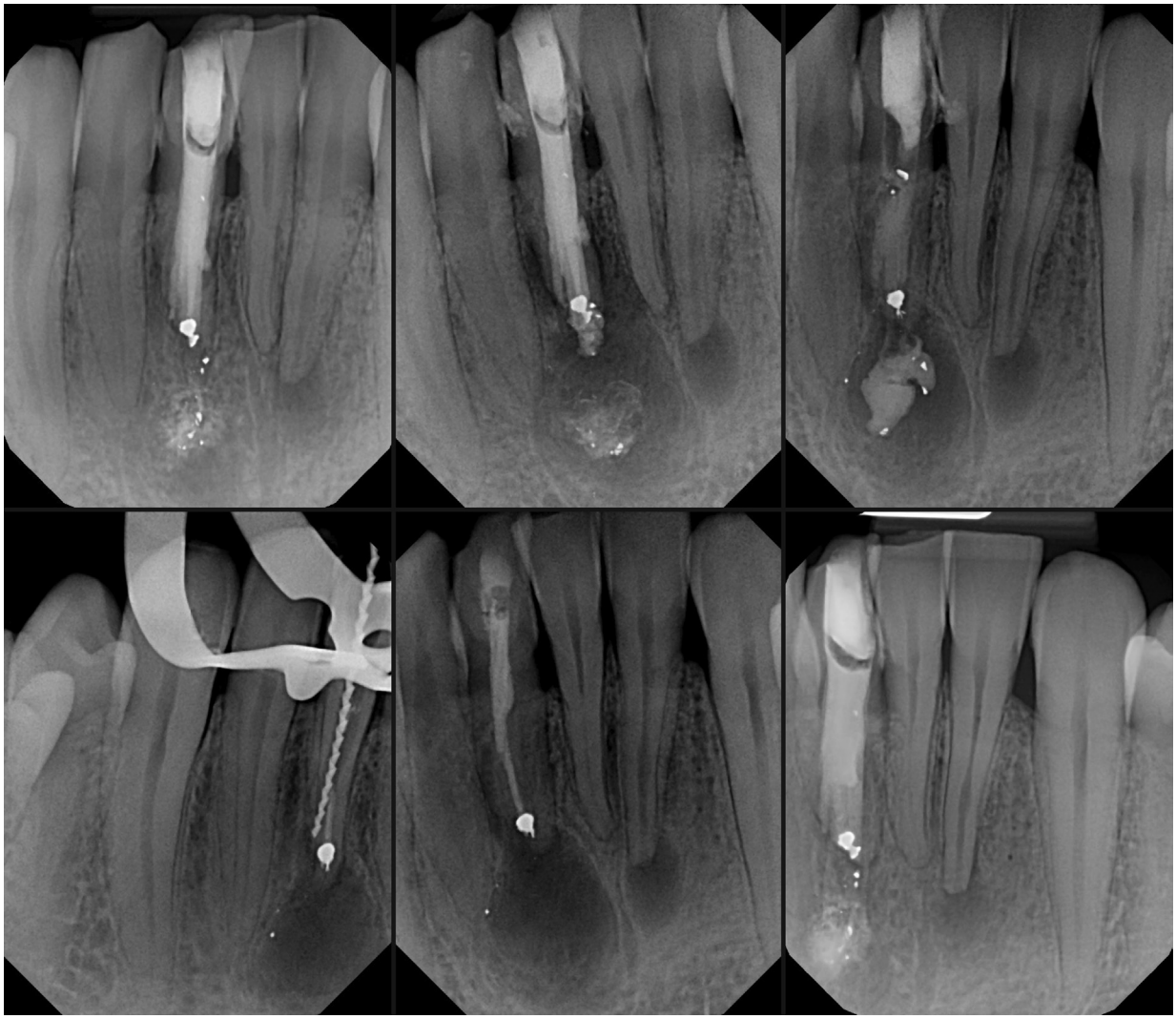

Revascularization of the Non-vital Pulp Space – A Discussion

Dr. Raghav Munjal

It is now possible to revascularise the non-vital pulp space. Describe the scientific concept and the clinical technique that has made this possible and the cases for which it is most appropriate. Indicate where current research in this field may lead in the future.

This essay was an entry into the British Endodontic Society's 2012 essay competition, of which I was highly commended.

Introduction

The concept of "revascularization" was first explored within the field of regenerative dentistry by Nygaard-Østby in 1961(1). By definition, "revascularization" means 'a surgical procedure for the provision of a new, additional, or augmented blood supply to a body part or organ' (2). However, within the field of regenerative endodontics, it extends to tissue formation and regeneration of damaged, diseased or missing structures, including dentine and root structures, to restore the normal physiological functions of the pulp-dentine complex (3).

A 'paradigm shift'

It has long been recognized that following trauma to an immature tooth with an open apex, such as an avulsion injury leading to a necrotic pulp, revascularization is a desirable and achievable outcome, enabling further development of the root (4). In this situation, the pulp is necrotic, but infection is not present. Thus, it can act as a matrix for revascularization to occur and if replantation techniques are performed well, the procedure carried out promptly and a wide open apex present, there is a high chance of success (5).

The 'paradigm shift' is a label that has been coined within the field of regenerative endodontics to describe a new form of management in the treatment of necrotic immature teeth, with infected root canal systems, including sinus tracts, by means of revascularization (6,7). This follows on from numerous case reports and case studies in recent years (8-16), which have effectively demonstrated that revascularization procedures can lead to continued root maturation and positive responses to vitality testing, as well as alleviating symptoms of periapical periodontitis from the necrotic infected tooth.

Apexification to Revascularization

Traditionally, 'apexification' using calcium hydroxide was the clinical protocol for necrotic immature teeth with open apices (17). The idea was to firstly eliminate the intra-radicular infection and then induce an apical hard tissue barrier over time, followed by a root filling. Although predictable and successful outcomes have been achieved (18), this protocol carries numerous disadvantages, namely multiple-appointments, increased potential recontamination of the root canal system and a significant time period before a root filling can be placed (19).

Moving away from apexification is the 'artificial apical barrier technique', which involves the placement of mineral trioxide aggregate (MTA). This material is placed in the apical portion of the canal, on to which a hard tissue barrier forms (20). This procedure has the advantage that it can be done within one or two appointments (21) and successful outcomes have been achieved (22-23). However, both 'apexification' and 'artificial apical barrier technique' fall short in that they do not allow for continued root growth, making the treated tooth susceptible to root fracture. And that is where this fascinating concept of revascularization takes centre stage with its promise of the continuation of root development (24).

The Scientific Concept

In order to understand how the process of tissue regeneration actually occurs; or revascularization as it has been propagated, a sound knowledge of stem cell biology and its application to dentistry is required (25).

In basic terms, stem cells are biological cells that are capable of dividing (via mitosis) and differentiating into diverse specialized cell types and can self-renew to produce more stem cells. Mesenchymal stem cells (MSCs), are multipotent stem cells that can differentiate into a range of cell types and have been found in numerous tissues in the body (26). Bone marrow-derived mesenchymal stem cells (BMMSCs) are the most commonly studied MSCs. However, such cells have not been shown to be able to demonstrate dentinogenic differentiation thus far.

Dental Stem Cells

The first type of human dental stem cells to be isolated were from extracted third molars and their characterization made by their relationship with BMMSCs. Such stem cells were named dental pulp stem cells (DPSCs) for their ability to differentiate into odontoblast-like cells and form dentine/pulp like complex when implanted in immunocompromised mice (27).

Following on from this, other dental MSCs have been isolated showing variable capabilities in generating odontoid structures experimentally. These include stem cells from human exfoliated deciduous teeth (SHED) (28), periodontal ligament stem cells

(PDLSCs) (29) and most recently, stem cells in the apical papilla of incompletely developed teeth (SCAP) (30).

'Hidden treasure in apical papilla'
SCAP, found loosely attached to the apex of the developing root, have been described as "hidden treasure in apical papilla" by Huang et Al (25). Thetreasure refers to stem cells in apical papilla relative to cellular types and their ability to differentiate and express their genetic potential (25). Essentially, they are cells with the phenotypic potential of becoming new or primary odontoblasts, as opposed to DSPCs, which are considered to be the source of replacement odontoblasts (27).

As such it is the SCAP that enables the formation of root dentine and the continued root formation. It is thought that as they have a close proximity to the periodontal blood supply, they can survive pulpal necrosis even in the occurrence of a periradicular infection (25,30).

Thus, if a favourable environment can be achieved (as in that of an avulsed tooth undergoing revascularization mentioned earlier), namely eradication of bacteria and their by-products, a protein scaffold and a good coronal seal, then these stem cells will grow and populate the root canal space of necrotic immature teeth (8-16,31).

The Clinical Technique

There is currently no standard protocol for revascularization procedures involving immature necrotic teeth. However, Banch and Trope's technique (9) is the model that most case reports have followed, albeit with slight variations. The first step in the procedureinvolvesdisinfectionoftherootcanal.Thisisdonewithcopius irrigation of sodium hypochlorite, followed by placement of tri-antibiotic paste-a combination of ciprofloxacin, metronidazole and minocycline (32). After successful disinfection, the antibiotic paste is removed and apical bleeding is induced to produce a blood clot. The final step involves sealing the canal orifice with MTA and the placement of a permanent coronal restoration. The procedure is usually carried out within 2-3 visits.

The following paragraphs will now seek to examine each stage in more detail, alongside variations to the technique that have arisen in a range of case reports and illustrate scientific concepts relative to the technique where appropriate.

Disinfection
Following appropriate anaesthesia and rubber dam isolation and access, the treatment begins with chemical disinfection of the root canal(s), with passive and copius irrigation of sodium hypochlorite (NaOCl) without instrumentation (given that instrumentation would make the thin dentinal walls weaker and more susceptible to fracture, plus a smear layer may form occluding the dentinal walls) (10). Other irrigants to be used, have included NaOCl-chlorhexidine (9,13) and NaOCl-hydrogen peroxide 3% (12). Different concentrations of NaOCl have been shown to be effective including 6% (13), 5.25 (9), 2.5% (12) and 1.25% (10).

Next, the canals are dried with paper points and a tri-antibiotic dressing comprising of ciprofloxacin, metronidazole and minocycline, is placed in a creamy consistency, delivered down the canal via a lentulo spiral instrument. This combination of antibiotics has been shown to consistently eliminate bacteria in the infected root dentine, while only a substantial decrease in bacteria was found when used individually (32).

However, the triple antibiotic paste, pioneered by Hoshino et Al, has also been modified or bypassed altogether in some studies, with calcium hydroxide used instead (8,15), or formocresol (12) and even sodium hypochlorite alone deemed suitable for disinfection. Other variations have included replacing minocycline with amoxycillin and cefaclor respectively (14), to prevent discolouration caused by minocycline (33).

Finally, after disinfection procedures have been completed, the access cavity is sealed with Cavit and the patient is discharged for 3-4 weeks (9)-though the required time period of dressing can vary from a few days to a few months, according to different case studies.

Forming a blood clot
Subsequently, if symptoms remain (i.e. sensitivity to percussion, presence of swelling, sinus tract etc), then the canals are redressed with antibiotic paste and the process of disinfection repeated as outlined above. In the absence of any signs/symptoms of periradicular disease, the next stage of treatment can take place.

The tooth is isolated with rubber dam and anaesthesia given without a vasoconstrictor (Mepivacaine 3% plain). It is thought that it is easier to induce bleeding with anaesthetic that did not contain a vasoconstrictor and studies have shown infiltration injections containing epinephrine lead to a reduction in pulpal blood flow (34, 35).

The canal(s) are once again irrigated with copius NaOCl, removing any remnants of antibiotic paste still present. The canals are then dried with paper points. Bleeding is induced into the root canal system by irritating the apical tissues. This has been achieved by different means in various studies, including sterile files, endodontic explorers and needles (10, 9, 12). The bleeding is stopped at a level of 3mm below the cemento-enamel junction (CEJ) and left for a period of approximately 15 minutes to form a clot at this level (9).

The evoking of a blood clot into the disinfected root canal helps to deliver a "protein rich scaffold" as mentioned before. This is a combination of the platelet-derived growth factors in the root canal space and the growth factors originating from the dentinal walls. The scaffold is thought to be crucial in delivering undifferentiated MSCs into the root canal space, whose differentiation and population ultimately leads to root development (31).

Sealing the canals and permanent restoration
After formation of a blood clot, the orifices of the canal(s) are sealed with MTA, which permits regeneration of novel tissue adjacent to it (9). Finally, the crown is permanently restored. Getting a good coronal seal is as important as ever to prevent bacterial leakage.

It is important to use a material like MTA, given its biocompatible sealing properties. Restorative materials such as amalgam, composite resins, or glass ionomers, if placed directly over exposed pulp tissues can result in cell death and pulpitis given their non-biocompatible nature (36). However, to go against these principles, there is one study which has shown the successful use of glass ionomer, instead of MTA, in revascularization procedures (12).

Moreover, a recent study has used Calcium enriched mixture cement (CEM), as opposed to MTA (16). It has the same clinical applications as MTA and is believed to be more conducive to the differentiation of stem cells and the stimulation of a hard tissue barrier. Yet, further research is required to determine its superiority over MTA.

Follow-up
Patients have been followed up at 6 month, 12 month, 18 month and 24 months respectively. The patient should be asymptomatic (no pain, soft tissue swelling). Radiographic examination should reveal progressive regeneration of the development of the root, alongside an increased width of the dentinal walls (9).

Case Selection

As with conventional endodontic procedures, each case must be evaluated on its own merits to determine whether a revascularization procedure is appropriate.

Before any clinical considerations are taken into account, informed consent must be gained. The patient, alongside their parents/guardians, must be made aware that the procedure of revascularization is in its experimental stage and that no standardized guidelines have been formed. Furthermore, significant compliance would be required by both patient and parents, given that the procedure requires multiple-appointments.

The following paragraphs will now proceed to explain the clinical factors that need to be taken into account.

Apex size and stage of tooth maturity
The size of the apical foramen is a decisive factor as to whether revascularization is a suitable procedure. A small apical foramen is thought to restrict blood flow and consequently limit the chances of revascularization. Traumatized immature permanent teeth with an open apex to a diameter of 1.1mm or greater are considered the best candidates for revascularization (37).

Age and health of the patient
Revascularization procedures have generally been consigned to patients nearing adolescence, within the ages of 8-16 years (8-16).

Studies have also been restricted to healthy patients i.e. those with no genetic abnormalities or severe medical diseases that may result in a compromised immune system. One would imagine that a patient with an inhibited capacity to heal would not be a good contender for revascularization, given that the procedure is dependent on the healing of the pulp tissues.

Another health consideration would be to determine any allergy to the intra-canal medicaments (i.e. the tri-antibiotic paste).

Extent of infection/necrosis of the pulp
While it has been purported that revascularization is suitable for necrotic immature teeth in the presence of apical periodontitis, it has been suggested that some vital pulp tissue, or a pulp that is only partially necrotic and infected, is key to promoting revascularization. This theory promotes the idea that for regeneration of the pulp and root development to occur, some stem cells in pulp tissue and in the apical papilla must also survive (25).The evidence base comes from case reports, where patients, undergoing revascularization procedures, felt the access of instruments within the pulp chamber, or vital pulp tissue and haemorrhage was observed (6).

Thus cases with prolonged infection would not be suitable for revascularization, given that under these conditions, total necrosis of the pulp and apical papilla is likely to occur.

Research and Future Developments

There is a major research initiative into "the hidden treasure in apical papilla" (25), a model that has developed some of its own nomenclature in its claims, such as bioroot engineering, pulp revascularization or regenerative endodontic treatment.

The following paragraphs seek to elucidate the need for guidelines, potential future changes and developments in the clinical technique of revascularization and regenerative endodontic therapies as a whole, as well as raise issues that need further clarification before the procedure can be universally accepted by clinicians.

Guidelines
If not used appropriately, regenerative endodontic procedures can inextricably cause harm to patients, by failing to disinfect or remove necrotic tooth tissue. Currently, data has only arisen from successful case reports making it impossible to determine a failure rate. There is obviously a need for randomised control trials and further studies, in order to formulate a standardized approach, ensuring the procedures are carried out correctly and safely.

As such, new guidelines, incorporating revascularization procedures are eagerly awaited from the International Association of Dental Traumatology and other respected bodies. Indeed, the American Association of Endodontists has started a database enabling clinicians to supply details of their regenerative endondontic cases, thus enabling the evaluation of different approaches, so that guidelines with optimal outcomes can be formed in the future. (38).

What tissue forms?
The nature of tissue that is said to grow into the root during revascularization is yet to be identified. Recent animal studies have suggested that the vital tissue formed in the canal space was a connective tissue similar to periodontal ligament and the thickening of the dentinal walls was attributed to newly formed cementum-like tissue (39). Further research is required to provide definitive answers and so enable clinicians to reassure their patients that appropriate root development is occurring.

Antibiotics: Yes or No?
The tri-antibiotic paste, as explained previously, is a step within the procedure of revascularization that has been modified or avoided altogether in some case studies and further research is necessary to determine the most favourable antibiotic dressing, or indeed whether it is necessary at all.

The fact that the triple antibiotic paste has to be mixed by a compounding pharmacist (32) isn't helpful in terms of accessibility of the product, meaning it is predominantly only at the disposal of dental schools involved in regenerative endodontic research.

Furthermore, aside from the discolouration issues associated with minocycline (35), there are still bigger question marks surrounding the use of antibiotics in the procedure. Studies have yet to assess whether these antibiotics administered in the pulp canal have a systemic impact on the patient over time. Additionally, it remains unknown if the bacterial species present in pulp canal with adapt to the antibiotic mixtures and reengineer themselves over time.

Future regenerative endodontic therapies
Currently, most therapies use the host's own pulp cells for regeneration, but there are now different types of therapy under

development. Due to the increasing emergence of dental stem cell banks, it is likely that stem cells from deciduous teeth will be implanted into mature teeth to achieve regeneration in the future (40).

In addition, there is extensive research going on into the use of scaffolds for dental pulp tissue engineering purposes. Ultimately, the goal of these injectable scaffolds is to allow for stem cell transplantation throughout the full extent of the root canal and pulp chamber (41). Closely linked to scaffolds is the use of growth factors such as Vascular endothelial Growth factor (VEGF), which can be incorporated into the scaffold and have been found to promote stem cell-mediated regeneration of dentine and pulp (42).

Early studies have showed scaffolds to improve the effectiveness of the revascularization procedures (43) and surely their translation from laboratory to dental clinic will happen in due course, alongside the use of growth factors.

Conclusion

In conclusion, stem-cell based dental tissue regeneration is a fast emerging field with the potential of transforming the practice of dentistry as we see it today; as well as redefining the speciality of endodontics in the process.

The field of stem-cell based regenerative dentistry requires a multidisciplinary approach (e.g. biomaterials, stem cell biology, endodontics). As such, future progress will continue to depend on the partnership of clinicians and researchers, with the common goal of regenerating dental tissues and saving teeth that might otherwise have a poor or hopeless prognosis.

Revascularization treatment of necrotic immature teeth is an exciting concept, which has the potential to consign the traditional means of apexification and apical barrier technique to history. However, the current evidence base consists largely of case reports, and further studies, alongside the formation of standardized protocols are required, before the technique can be widely accepted and sought after by the clinician. Undoubtedly, it won't be too long and 'a paradigm shift' has certainly materialized.

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Diagnosis in Endodontics 1 – Getting to the Root of the Problem

Dr. Bhavin Bhuva

"It's killing me doc!" - I just can't tell whether it's top or bottom! Fifteen minutes later you are still bashing a long line of heavily filled teeth with the end of your mirror head to try and find the culprit!

Although tedious, a good history combined with a patient and thorough examination will almost always help you to reach the correct diagnosis.

The Basics - Inflamed vs. Infected Pulps

In endodontics, simplistically, we treat two types of pulpal states - inflamed and infected:

Inflamed
This is where the pulp tissue is alive (at least in part). The symptoms are due to inflammation (caused by bacteria – generally only coronally) within the pulp, resulting in a lowering of the threshold for triggering of pain, and/or a heightening of the response of the pulp tissue to thermal and electrical stimuli. Here, changes in blood flow (for example, lying down) may be sufficient to induce pain.

Typically, when acute, the patient has been experiencing acute throbbing radiating pain. The pain comes and goes in waves and is classically pulsatile in nature. The pain may be poorly localised. Pulpal pain often refers between top and bottom but never crosses the midline.

Classically, cold tends to be the first trigger, and then, hot and sweet foods/drinks may initiate the pain. At a later stage, cold may reduce the pain. The length and severity of the pain may increase with time.

Spontaneous pain of increased duration may develop, and at this stage, pain relief may become relatively ineffective.

As the inflammation becomes more established bacterial byproducts will initiate inflammation in the surrounding tissues. Tenderness to biting is a very late sign of pulpal inflammation, but is not evident in all cases.

Infected
In most instances the source of pain is easily identifiable. This is because the inflammation (again caused by bacteria – this time in the entire root canal space) is in the tissues surrounding the tooth (periapical alveolar bone). The periapical region becomes infiltrated with inflammatory cells which resorb bone to make space for themselves. These inflammatory processes may manifest as tenderness of the tooth to pressure/percussion and/or there may be tenderness of the tissues overlying the apices of the affected tooth. More obviously, there may be swelling or sinus formation.

Again, the pain may be acute. The nature of the pain may be more of a dull ache. The effects of infection may lead to localised, swelling, tenderness and pain to pressure or biting. Systemic involvement is uncommon but serious!

History

History - is the key to accurate diagnosis. When taking a history, you are trying to develop a picture that broadly fits either the inflamed or infected pulpal state.

With inflamed teeth you are trying to assess whether the inflammation is reversible (for example, a few seconds in duration) or irreversible (for example, spontaneous or prolonged pain). Obviously, these terms are crude and strictly speaking can only be determined by assessing the histological state of the pulp.

When it is not obvious, determining any exacerbating or relieving factors is pivotal to making a diagnosis. These factors can be reproduced during the examination (see below) to try and locate the causative tooth.

Examples of exacerbating/relieving factors:
Pressure - the type of pressure may be important - pain on prolonged axial pressure (apical periodontitis) or on hard foods/release of clenched teeth (cracked tooth).
Temperature - may trigger or alleviate pain.
Posture change - (bilateral) think sinusitis.

Obviously, there will be situations where the patient has 'swallowed' a number of painkillers before the appointment. This could potentially make diagnosis even more challenging. However, it may still be possible to reproduce the patient's symptoms sufficiently to make a diagnosis (together with the clinical and radiographic findings), but sometimes it may be necessary to ask the patient to return at a later stage (however reluctant they may be to leave without treatment).

Look out for cases where the history does not fit. Non-odontogenic causes of pain should always be in the back of your mind!

Examination

Soft tissues

Following extra-oral examination, the soft tissues should be examined for any obvious signs of infection/inflammation; swelling (diffuse or fluctuant), erythema or sinus tracts.

Furthermore, signs of current parafunction may be apparent in the soft tissues. For example, cheek biting or ridging on the lateral aspects of the tongue may be apparent.

Tenderness to palpation

There may be tenderness in the sulcus overlying the apices of teeth with apical periodontitis. This tends to be more common in teeth where the root apices are in close proximity to the buccal cortical plate. Don't forget to examine the lingual/palatal tissues.

Make sure you differentiate tenderness over the root apices with that located at the insertion of the muscles of mastication. Tenderness at the insertion point of the muscle fibres may indicate a myofacial component to the pain.

Sinus tracts

Sinus tracts can be traced by inserting a gutta percha point (at least a size 30) into the sinus. You may have to tease the point in different directions to 'feel' the path it wants to take. The eventual direction may 'point' to the tooth where the causative infection is, as well as the region of the tooth (apical or elsewhere).

A radiograph will often give further clarification of the origin of the sinus tract; however, the angulation of the radiograph can sometimes be misleading.

Probing depths

A careful periodontal examination with a periodontal or CPITN/BPE probe is very important especially in teeth with cracks.

A sinus tract may occasionally drain up the root surface and through the gingival sulcus to form a pocket. Generally, this will be easily distinguishable from a periodontal pocket as it will be localised, very deep and not found on the opposing or contralateral tooth.

Deep probing depths may also be associated with vertical root fractures and of course, periodontal disease!!

Periodontal diseases do not generally cause significant pain. However, food packing is an important cause of discomfort and should always be eliminated as a potential cause. It can make individual, or more commonly, neighbouring teeth tender to pressure.

The crude test of tapping the teeth with the back of a mirror handle can be useful when there is obvious inflammation in the periodontal tissues below a tooth. However, it may elicit discomfort in the healthy teeth of some individuals, particularly patients who grind or clench. Furthermore, percussion may not elicit pain in teeth with cracked cusps. A more suitable test may be to use a Tooth Sleuth or cotton wool roll (see below).

Teeth

Teeth must be examined after being dried adequately. The teeth should then be observed under magnification, preferably with additional illumination. An operating microscope or loupes with a good light source are ideal for this purpose.

Restorations/caries

Look at the size and quality of the restorations. Check carefully for the presence of secondary caries and cracks.

Cracked teeth

Cracked teeth can be either inflamed or infected. With inflamed teeth the patient's tend to have quite vague and poorly localised symptoms. These may include pain on biting particularly with hard foods.

Cracked teeth generally occur as a result of fatigue through repeated clenching and/or grinding. Patient's who parafunction tend to present with cracked teeth in the 4th or 5th decade. Cracked teeth may be restored or even unrestored.

Diagnosis can be challenging when there are large approximal restorations which prevent the visualisation of the cracks. Again, the history may be very important in identifying previously cracked teeth - look at the contralateral tooth, for example.

A cotton wool roll can be used as a useful aid in the diagnosis of cracked teeth. The patient is asked to clench firmly on the roll. After several seconds of clenching the patient can release the pressure. With a cracked tooth the pain is most usually elicited on release. This test can also be used instead of tapping the teeth when diagnosing apical periodontitis. Here, there will be tenderness on application of the pressure.

The Tooth Sleuth is a rubber instrument that can be used as an alternative to the cotton wool roll. It is used in the same way as a cotton wool roll but has the advantage that individual cusps can be tested. However, there is a higher risk of cusp fracture when using the Tooth Sleuth and so caution should be exercised.

Transillumination is the technique of using light to pass through the fracture line. The altered diffraction of light through the fracture line allows detection of cracks that cannot be seen visually. The composite curing light is suitable for this purpose. Obviously, a lamp shield should be used to protect the eyes.

Diagnosis or confirmation of the crack may on occasion be possible following removal of the restoration. If the crack has been there for some time, there may be staining of the fracture line. However, fresh cracks may be more difficult to visualise, and here, the use of transillumination or a dye (for example, methylene blue) may be useful.

Critically, if cracks enter into the root canal proper or involve the floor of the pulp chamber, the prognosis of the tooth may be severely affected. An increased probing depth associated with a crack is a further indication of a reduced prognosis.

Vitality Testing

Vitality testing is undervalued and underused. Testing can be surprisingly reliable when conducted correctly.

Strictly speaking the vitality test does not assess the vitality (i.e. the blood supply) of the tooth, and so some have questioned this term and suggested alternatives such as sensibility or sensitivity testing.

However, this is semantics and I will continue to use the term vitality! Vitality tests assess the response of the pulp-dentine nerve fibre complex.

The most commonly employed tests are thermal and electric. Again, it is important to try and reproduce the patient's symptoms. When conducting any vitality test it is imperative to isolate and dry each tooth prior to testing. This is particularly important when the tested teeth have large metallic restorations that are in contact with the neighbouring teeth or periodontal tissues.

Strips of rubber dam or cellulose may be used to isolate individual teeth. It is important to try and use the same point on each tooth when testing and it has been suggested that the incisal third of incisor or canine teeth should be tested. When testing premolar/molar teeth, the middle third has been suggested.

Vitality testing is subjective, so readings must be calibrated for each individual. It is very important to test and compare the opposing and contralateral teeth. In some individuals, no teeth will elicit a response. In others, every tooth may elicit an uncomfortable response.

Thermal

Cold

Normally, a relatively increased or prolonged response (for example, greater than 30 seconds) indicates irreversible pulpal inflammation. Occasionally, with more advanced inflammation, cold testing may relieve the symptoms. Ethyl chloride is not very reliable for cold testing as it is only -4 C. Endofrost (-50 C) is far more reliable. It is available as an aerosol refrigerant and is easy to use. Even more reliable is the use of CO2 snow (-78 C), however, this is stored in a large pressure filled canister. Both Endofrost and CO2 snow can be used effectively on teeth restored with metallic crowns. Despite the very low temperatures, these tests cause no damage to the pulp.

The cold tests are far more accurate than electrical testing in immature teeth, due to the incomplete neural maturation of the pulp.

Warm

The use of warm gutta percha points has been suggested as a good way to test vitality. If using this test, petroleum jelly should be applied to the tooth to prevent the gutta percha from sticking to it. A far more reliable test is to isolate each tooth individually with rubber dam (without local), after which it can be bathed with hot (not boiling) water delivered through a syringe.

Electric pulp testing

Again, it is very important to have dry, well isolated teeth. This will prevent conduction to the neighbouring teeth or periodontium. When electric pulp testing is performed it is imperative that direct contact with natural tooth substance is obtained. This may be a problem with heavily filled teeth, in which case thermal testing may be more appropriate. To facilitate the testing of crowned teeth a small electrode tip can be used to contact any exposed dentine that may be accessible below the crown margins. A conducting medium such as prophy paste or topical anaesthetic gel must be used when carrying out this form of testing.

Multi-rooted teeth may be confounders to vitality testing as they may have both infected (non-vital) and vital roots.

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Diagnosis in Endodontics 2 – Getting to the Root of the Problem

Dr. Bhavin Bhuva

So you've carried out a thorough clinical examination and have managed to narrow down the offending tooth to one of two! However, you are hoping that your radiograph will reveal all and clearly demonstrate the causative tooth!! Unfortunately, when you study the radiograph you are none the wiser!!

Conventional Radiographs

Radiographs are, of course, an essential diagnostic aid in endodontics. In general, teeth with established apical periodontitis are usually fairly easy to diagnose using conventional radiography *(see Fig. 1)*.

Fig. 1

Teeth with inflamed pulps (pulpitis) do not usually initiate sufficient inflammation in the periapical tissues to cause bone resorption that can be detected radiographically. Occasionally, you may see some minor radiographic changes *(such as the widening of the periodontal ligament space that can be seen around the apices of the lower left first molar, see Fig. 2)*.

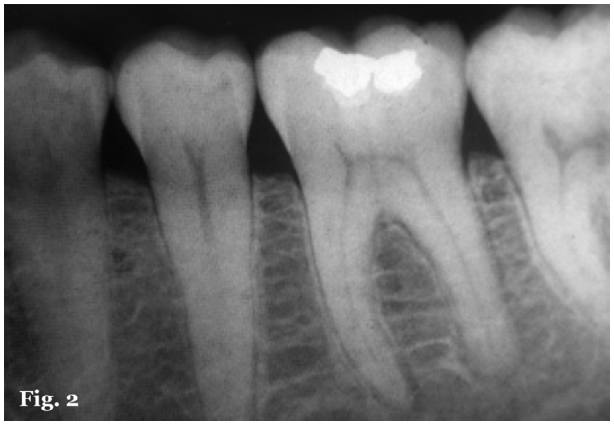

Fig. 2

That said, even with inflamed teeth, other important information can be obtained from periapical radiographs (and for that matter bitewing radiographs).

Firstly, the depth of the existing restorations can be evaluated. In particular, the proximity of the restoration to the pulp may give an indication of the problem tooth. In addition, previous pulp capping treatments may be evident radiographically under a restoration.

Calcification or shrinkage of the pulp chamber may be apparent when compared with the neighbouring teeth. Loss of the pulp horns and loss of height of the pulp chamber are typical signs of past or present pulpal inflammation within the root canal space.

A tooth with what appears to be a very shallow restoration may sometimes demonstrate periapical disease. This appearance may be somewhat confusing but may signify a crack or fracture.

Limitations of conventional radiographs

Aside from the potential problems of diagnosing teeth with inflamed pulpal states, there are several more fundamental limitations of the conventional radiographic technique.

Radiographs are essentially compressed two dimensional images of three dimensional structures (sometimes called shadowgraphs), and as such can only provide limited information.

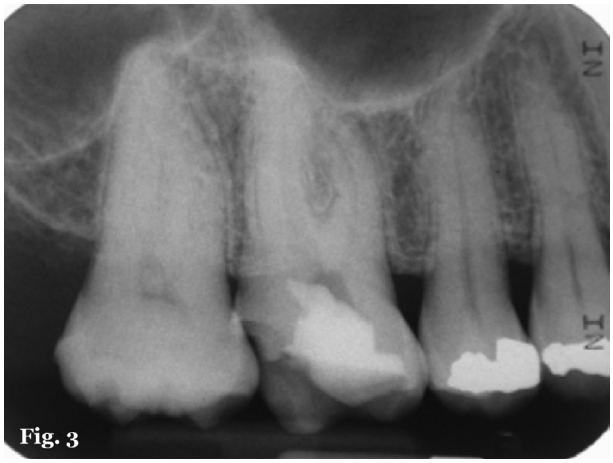

Fig. 3

Furthermore, superimposition of various anatomical structures and image distortion are further limitations, which result in limited diagnostic yield. An example of this is the problem of diagnosing

periapical disease reliably in upper molar teeth when the apices are in close proximity to the floor of the maxillary sinus *(in the radiograph, Fig.3 the periapical region of 16 has been obscured by the floor of the maxillary sinus)*.

This periapical region of the upper molar teeth may also be obscured by the zygomatic buttress.

Even with the use of a beam aiming device and paralleling technique, conventional periapical radiography has poor geometric reliability and is susceptible to image distortion.

Diagnosis of periapical disease

It has been demonstrated that conventional radiography only has limited ability in detecting periapical bone destruction.

Numerous studies have shown conventional radiographic techniques are unable to reliably disclose histological bone loss. For bone loss to be determined radiographically, a certain amount of mineral loss is necessary, and therefore, bone loss below this threshold will not be detected by conventional techniques. This has been demonstrated in studies where periapical lesions have been created in the mandibles of cadavers and then radiographs taken. Broadly speaking, the conclusion of these studies is that periapical lesions may only be reliably detected when the cortical plate has been perforated by the periapical lesion, and not when it is confined to the cancellous bone. This effect is more evident in certain regions of the dentition (for example, the lower premolar and molar region).

Cone Beam Computed Tomography (CBCT)

Recently, the innovation of cone beam computed tomography (CBCT) in dentistry offers an imaging modality capable of three dimensional analysis of the dentoalveolar anatomy. Aside from providing a three-dimensional unobscured view of the anatomical structures, CBCT has been shown to provide geometrically reliable images when compared to traditional radiographic techniques.

Cone beam tomographic scanners (see below) have been developed from medical CT scanners for specific maxillofacial and dental use. The three-dimensional volumetric data is acquired using an extra-oral scanner which rotates through 180-360 degrees with an average scan time of between 10 and 40 seconds.

CBCT acquires all image data with a single sweep of the scanner, as opposed to medical CT imaging which uses multiple slices in order to compose a three-dimensional image. Dental CBCT scanners are capable of imaging areas which are much smaller than medical CT. The field of view (area of scan) for one such limited cone beam CT is only 30 mm by 40 mm which is equivalent to the size of a periapical radiograph.

These differences result in a significantly lower effective dose with CBCT than with conventional CT. In fact, the effective dose for a limited CBCT scan may be equivocal to that of only 2-3 plain film periapical radiographs. Modern scanners are able to provide high resolution, small volume (and therefore small dose) reconstructions of regions equivalent to a periapical radiograph.

The resolution of CBCT approaches that of conventional radiography and so is vastly superior to that obtained with medical CT imaging.

Potential uses of CBCT in Endodontics

1. Diagnosis of apical periodontitis/radicular cysts
2. Assessment of root canal anatomy/missed canals
3. Assessment of root canal calcification

The radiograph below (left) demonstrates a fractured instrument in what appears to be a calcified root canal (tooth 21). The CBCT image (below right) clearly demonstrates the calcification, and the instrument 'bound' between the calcification and root canal wall. The canal beyond the calcification is patent. The additional information obtained from the CBCT scan greatly facilitates non-surgical management of the case. With the judicious use of ultrasonics it was possible to remove the calcified tissue and complete orthograde root canal treatment.

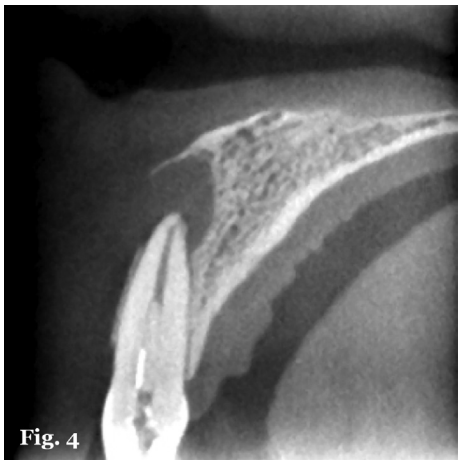

Fig. 4

4. Diagnosis of resorption (for example external or internal)
5. Assessment of extent of resorption

In the example below, what appears to be almost classical internal resorption (tooth 12) in the radiograph (below left) can be seen to be perforating the root palatally in the CBCT image (below right). This may affect treatment planning as the perforation has implications on the ability to clean and fill the root canal system optimally. Furthermore, prior knowledge of the perforation may help to prevent a hypochlorite accident.

The information is useful in advising the patient of the increased possibility of requiring apical surgery and in the planning of the procedure itself.

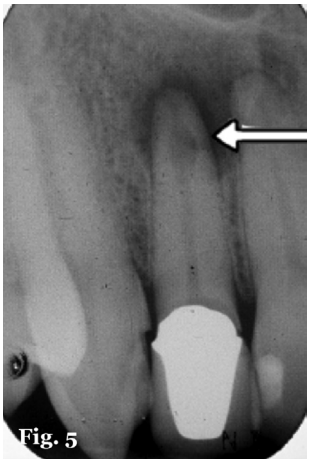

Fig. 5

6. Root fractures
7. Pre-surgical assessment and planning
8. Evaluation of healing

The endodontic applications of CBCT will be discussed in more detail in a future article.

New applications for the use of CBCT are constantly being evaluated, and as the evidence gathers, it is likely that the technique will become the gold standard for diagnostic and follow-up imaging in endodontics (and most likely other disciplines).

Recent studies have already demonstrated the high level of diagnostic accuracy of limited CBCT over conventional radiography in diagnosing apical periodontitis, resorption and the assessment of the geometric relationship and proximity of neighbouring anatomical structures (for example, the inferior alveolar nerve to the apices of a lower molar tooth).

The information from a CBCT scan can be viewed in a variety of ways. The 'traditional' observation of image slices is one such way. However, the data may be made even more useful by converting the scan information into volume rendered images or three dimensional reconstructions.

The example below demonstrates a reconstruction which was used to plan apical surgery on the lower left first molar. The perforation in the buccal cortical plate can be seen near the distal root of 36. The image also shows the exact proximity of the inferior alveolar neurovascular bundle to the root apices of the tooth to be treated. This information can be invaluable in pre-surgical planning.

Hopefully this article has given you a brief introduction into the potential uses of CBCT in endodontics. As mentioned previously, we will look more closely at exactly how the technique is used, with some examples, in a future article.

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The Endodontic Management of Traumatized Permanent Anterior Teeth – A Review

Dr. Alexander Moule

Abstract

Despite the many journal articles and reviews that have been published regarding the treatment of trauma to teeth, the endodontic management of these injuries is often still not fully understood. The purpose of this review is to establish clear and up-to-date guidelines for practitioners who are faced with treating dental injuries on a day-to-day basis, based on an assessment of current available scientific information relating to the endodontic management of these injuries.

Treatment is discussed under the headings: infractions, uncomplicated crown fractures, complicated crown fractures, crown-root fractures, root fractures, luxation injuries, avulsion, root resorption, pulp canal obliteration and open-apex teeth. Emphasis is placed on the treatment of traumatized immature teeth where maintenance of pulp blood supply is important to encourage continued development of the root system. Only the treatment of traumatized permanent anterior teeth is reviewed.

Information contained in this article is based on a review of the literature on dental trauma which involved a MEDLINE search using the key words "dental trauma" and the individual topics listed above. The guidelines produced by the International Association of Dental Traumatology, the American Academy of Pediatric Dentistry and the American Association of Endodontists were also reviewed and the recommendations contained in this paper are in concert with the major recommendations of these bodies.

Key words: Dental trauma, review.
Abbreviation: MTA = mineral trioxide aggregate.

Introduction

The management of patients who have suffered traumatic injuries to their dentition is an integral part of general dental practice. This will continue to be the case given the ever-increasing incidence of dental trauma as a result of traffic accidents, sporting injuries, risk-taking physical activities, violence and child physical abuse in modern society.1-3 There are already numerous texts and articles which discuss the causes and incidence of dental trauma.4-8 It is not the purpose of this review to consider these aspects of dental trauma; instead, the immediate and long-term endodontic management of traumatized teeth is the focus of this review. It would be remiss not to state, however, that all clinicians must be cognizant of the fact that some dental injuries to children may be a result of child abuse, and there is a need to be vigilant in assessing an injured child and the circumstances of an injury to distinguish, where possible, between accidental injuries and injuries from abuse.1-3

Dental injuries often involve damage not only to the tooth, but also to the supporting tissues. If treatment is to be completely successful, an examination of a patient with dental injuries must pay attention to both components jointly. Soft tissue injuries should be assessed; displaced or lacerated tissues should be immediately repositioned and where necessary sutured into place.4 Where soft tissue injuries occur concomitantly with tooth fractures, the soft tissues should be examined for the presence of embedded tooth fragments.

A number of studies have confirmed that fracture of the tooth results in disruption of the energy of the blow and minimizes damage to the periapical region.9 Tooth mobility is more often associated with teeth without hard tissue damage than with teeth that are fractured.9 Prognosis is better in teeth with hard tissue damage than in teeth that are luxa ed.4,10 Where the supporting tissues are concurrently damaged, the prognosis for the tooth, particularly with respect to the vitality of the pulp, is poorer.11 Thus, teeth that are not obviously traumatized may be the ones that could present longterm management problems.

No review on the management of dental traumatic injuries would be complete without a discussion of the need to fully assess a patient with dental injuries: assessing the injured dental hard and soft tissues, injuries to supporting tissues and to the patient as a whole. The systematic assessment of a patient with traumatic dental injuries is well covered in the literature.4,8,12 Many strategies have been suggested for the prevention of traumatic dental injury and there is considerable evidence to support the efficacy of these preventive aspects pertaining to dental injuries.4,12,13

Splinting of teeth with luxation injuries, avulsions and root fractures is often necessary to stabilize a tooth in position, and to assist in periodontal and pulpal healing. A flexible splint has been shown to be the most desirable.4,14-16 The American Academy of Pediatric Dentistry suggests that an ideal splint should amongst other things: be easily fabricated in the mouth without additional trauma; be passive, unless orthodontic forces are intended; allow physiological mobility; be nonirritating to soft tissues; not interfere with the occlusion; allow endodontic access; be easily cleaned and easily removed.17 Recommended splinting times are up to two weeks for most avulsion and luxation injuries unless they occur in association with alveolar fractures, up to four weeks for lateral luxation injuries, alveolar fractures and root fractures, and up to four months for cervical-third root fractures.18 Many dental injuries do not occur singly. Thus, these splinting times cannot be rigorously applied. In general, splinting times have to be adjusted to accommodate the more major injuries.

All traumatic dental injuries need to be followed up over time. Follow-up procedures include a clinical examination, a radio-graphic assessment and pulp sensibility testing. Recommendations for follow-up examinations for injuries proposed in this study are in accord with those recommended by the International Association of Dental Traumatology.18

While continued negative responses to pulp testing procedures imply that a pulp has become necrotic, pulp sensibility testing procedures test only a neural response. Blood vessels and nerves differ in their elasticity. Thus, it is possible to disrupt the nerve supply to a tooth without disrupting blood supply. Also, it is possible for a pulp to revascularize without there being a concomitant neural regeneration. Hence, the absence of a positive result to pulp sensibility testing does not automatically imply loss of vitality of pulpal tissues. Careful attention must be placed on clinical assessment and an examination of changes that occur both within the pulp canal and at the apex. If calcification continues to occur, the pulp must be regarded as vital even if the response to pulp sensibility testing is negative or ambiguous.

Recommendations for the overall management of dental trauma have been produced by the International Association of Dental Traumatology and the American Academy of Pediatric Dentistry, 17 and in a number of texts2,4,8,12 and articles.19-23 This paper specifically reviews only the endodontic management of traumatized permanent anterior teeth. The role of endodontic treatment following trauma to these teeth has been reviewed in the past.24-27 In this study, the endodontic management of teeth that have been traumatized is discussed in light of recent developments and guidelines for their endodontic management are described. In the past, variations in classification techniques, clinical assessment procedures, observation times, and shortcomings in the statistical assessment of data have all clouded the issue. More recently, however, thanks to the rigid methodology proposed by Andreasen and his many co-workers,4 many of these variations have been eliminated from the literature. The classification of dental injuries described by Andreasen4 is, in general, followed.

Infraction

Infraction injuries involve damage or cracking of the enamel without any loss of tooth structure. Only a few studies have investigated pulpal complications following this type of injury. Pulpal complications are considered to be rare (0–3.5 per cent) unless there is an associated luxation injury.4,28,29 Pulp treatment should only be carried out in the presence of signs and symptoms of irreversible pulpitis or pulp necrosis with infection. In assessing pulpal damage, clinicians must remain cognizant of the fact that reactions to pulp sensibility testing in traumatized teeth are lowered immediately following trauma and longer observation times (up to at least eight weeks initially) may be required before a definitive decision can be made regarding the state of the pulp.30,31 As with all traumatic injuries, further follow-up after 12 months is advised.

Uncomplicated crown fractures

In uncomplicated crown fractures there is loss of tooth structure without an exposure of the pulp. These injuries can involve the loss of enamel only or loss of enamel and dentine. Pulpal complications rarely occur in teeth with enamel fractures only (0–1 per cent),29,32,33 unless there is an associated luxation injury (8.5 per cent).32 In the absence of concomitant luxation injury, complications resulting from injuries involving both the enamel and the dentine are also infrequent (0–6 per cent).10,34,35 An increased incidence of pulpal necrosis in teeth with combined fracture and luxation injuries has been clearly established (25 per cent).10,34 In the absence of simultaneous luxation injuries, complications are also believed to develop from bacterial penetration into open dentinal tubules. Dentine coverage is indicated for all these fractured teeth. Relevant determinants of prognosis are: the type and site of fracture; the presence of luxation injury; the type of treatment undertaken and the timing of treatment. Pulp necrosis occurs more often in deep angular fractures and in deep fractures that are left untreated for more than 24 hours. Lost tooth structure can be restored by restorative materials4,23,36 or by re-attachment of the fragment.4,23,37-39

The prognosis for re-attached crown fragments is good and continues to improve with the increasing bond strengths achievable with dentine bonding agents.40 Thus, patients should be advised to search for and bring any tooth fragments with them when presenting for treatment. Reinforcing the fragment margins with composite resin does not appear to have any significant effect on the retention rate of the fragment.40 Placement of an internal groove within the dentine of the fragment to improve retention by increasing the surface area available for bonding has been suggested.37 Composite restoration with fibre reinforcement has a higher load-bearing capacity than conventional composite restoration.41 Porcelain laminate veneers are a predictable, effective and relatively conservative way of reinforcing the strength of a re-attached fragment.42,43

Follow-up and treatment of uncomplicated crown fractures

Endodontic treatment of teeth with uncomplicated crown fractures is usually unnecessary unless pulp necrosis and infection

develop subsequent to the injury. With minor injuries, treatment can be restricted to smoothing of rough edges and review. As prognosis is related to time before treatment, dentine-covering procedures should be urgently instituted as soon as possible for fractures involving the dentine, particularly for deep and angular fractures, and when there has been an associated luxation injury. This typically involves re-attachment of the fractured segment or restoration of lost tooth structure with composite resin.

As reactions to pulp sensibility testing procedures are often lowered immediately after injury, sensibility testing of teeth with uncomplicated crown fractures can, in general, be delayed for a short time after injury, particularly in the presence of haemorrhage and associated soft tissue injuries, or where sensitivity to thermal stimulation or to touching the exposed surface clearly indicates that the pulp is responsive. Reversal of negative sensibility testing results can occur, particularly in immature teeth and in teeth with open apices. If pulp problems are to arise, they will generally occur within the first six months after injury. In view of the fact that the pulps in traumatized teeth can become necrotic and infected even a number of years subsequent to injury, routine sensibility testing at six to eight weeks and then at yearly intervals should be included in the treatment regime.18 Sensibility testing and assessment of adjacent teeth should also be routinely undertaken at regular intervals.

Complicated crown fractures

Complicated crown fractures are those in which fracture of the crown involves the pulp. Where exposure of the pulp occurs, some urgent form of treatment is necessary if the health of the pulp is to be maintained. Except in immature teeth,44,45 most traumatically exposed pulps in anterior teeth will become necrotic and infected if left untreated for one month.46 A number of procedures have been recommended for the treatment of exposed pulps. These include pulp capping, partial pulpotomy, pulpotomy and pulpectomy procedures.

In the absence of luxation injury, necrosis of an exposed pulp does not usually occur immediately, although this is the inevitable response if an exposed pulp is left untreated. Inflammatory responses and bacterial contamination, which are responsible for necrosis in exposed pulps, are confined to the site of the exposure for some time.47,48 Accordingly, in traumatically exposed teeth, both pulp capping procedures and partial pulpotomy procedures have been shown to be successful, particularly in younger patients. Pulpotomy procedures appear to be superior to pulp capping8 and involve removal of the "injured" coronal pulp usually at the level of, or near to, the coronal opening of the root canal and the placing of medicament (usually calcium hydroxide) against the remaining vital tissue. Treatment seems to be more successful if the medicament is placed directly onto the exposed pulp without an intervening layer of haemorrhage.48 Cvek has reported that 96 per cent of exposed pulps, which were amputated about 2mm below the exposure site with a high speed diamond bur and then covered with calcium hydroxide after removal of the blood clot, survived and developed calcific bridges at the fracture site.48 The success rate did not appear to be related to the size of the exposure, the location of the exposure, or to the time interval between trauma and treatment. Recent studies have confirmed the success of Cvek's original procedure and suggested the criteria for the use of this technique be expanded to include all traumatically fractured teeth regardless of the patient's age and degree of apical closure of the teeth, and that the restoration placed at this time could be considered a definitive one rather than a temporary measure.49 The advantage of both pulp capping and partial pulpotomy procedures in young teeth, if they prove successful, is that a healthy pulp is maintained throughout the root canal system. This is an especially important consideration in the treatment of young and immature teeth as, in these teeth, measures should be taken to maintain a healthy pulp, not only to ensure apical maturation, but also to promote the development of lateral root dentine to improve root strength. These procedures should only be carried out on vascular pulps. Recently, partial pulpotomy procedures involving the use of mineral trioxide aggregate (MTA) have been described and have been shown to be effective. Proponents of the use of MTA suggest that it helps to protect the pulps from the effects of bacterial penetration and that its use precludes the need to re-enter the exposure site to place a more definitive restorative material over the exposure at later date.50

Endodontic treatment of complicated crown fractures

In young patients, the aim of treatment should be to maintain a healthy pulp to permit closure of the root apex and to encourage development of lateral root dentine. Partial pulpotomy or pulp-capping procedures are indicated for complicated crown fractures in these teeth. The partial pulpotomy procedure described by Cvek48 (i.e., removal of a portion of the pulp using a "gentle technique" (high speed diamond bur with copious water spray), elimination of the blood clot (by irrigation) and capping with calcium hydroxide or MTA followed by regular recall), has been regarded as the treatment of choice.50-52 Since resin-based quicksetting calcium hydroxide preparations inhibit polymerization of composite resin materials, their use in these circumstances should probably be avoided.53 Should deep pulpotomy (rather than partial pulpotomy) procedures be necessary due to major crown loss in immature teeth, the problem of calcific bridge formation at the pulpotomy site, which may obstruct pulpectomy procedures at a later date, can be overcome by the use of a corticosteroid/antibiotic combination (e.g., Ledermix® Paste or Endopaste®) rather than a calcium hydroxide material.54 As with any conservative pulp therapy procedure, it is important that the medicament is placed directly onto healthy noninflamed tissue and that the exposure site is protected against bacteria. In older patients, where the success rate for conservative pulp therapy on mature traumatized teeth is less predictable and tooth formation is complete, routine endodontic therapy is more likely the treatment of choice. Nevertheless, since it has been shown that partial pulpotomy procedures can still be successful in older patients, the decision whether or not to retain the pulp is more often governed by the amount of remaining root dentine and the requirements for crown retention rather than whether the pulp is exposed or not. Although the outcome may not be as predictable in the long term, partial pulpotomy procedures can provide an expedient and much cheaper treatment option for some patients, particularly if there is sufficient tooth structure remaining for the crown to be restored with a composite resin material or by re-cementation of the fractured segment.

Crown-root fractures

Crown-root fractures involve the enamel, dentine and part of the root (cementum) surface of the tooth. The fracture line invariably passes subgingivally. The pulp is often exposed and endodontic therapy is generally necessary if the tooth is to be retained. A number

of treatment alternatives are available depending on the position and circumferential extent of the fracture, and the severity of the fracture in a subgingival direction. Treatment options were reviewed by Moule and Heithersay54 and they include: periodontal surgery to expose crown margins, restorative management only with extension of the margins of the restoration below the level of the gingival margin, orthodontic extrusion, intentional replantation (surgical repositioning), autotransplantation, root submergence (decoronation), extraction and replacement, or orthodontic space closure. Treatment of crown-root fractures can be complex and time consuming. However, most teeth with these types of fractures can be saved.17 In an adult patient, implant replacement is sometimes a viable alternative. In the case of a growing patient with a tooth that is not restorable, root submergence (decoronation) may be indicated to preserve bone and allow for normal alveolar development prior to implant placement when growth is complete.55,56

Endodontic treatment of teeth with crown-root fractures

If a decision is made to retain the tooth, either permanently or as a short to medium-term measure until the patient is practically able to have the tooth replaced, endodontic therapy is usually necessary. This can be complicated by difficulties in isolation and the maintenance of a dry field due to the subgingival position of the fracture line. If the crown fragment is lost, isolation for endodontics is best achieved by using a rubber dam cuff supplemented by cotton rolls in the labial sulcus and the use of haemostatic agents, Cavit® or a cyanoacrylate adhesive. A single step endodontic procedure can be carried out as a definitive treatment, or as a temporary measure to be redone at a later date when the situation is more under control. If the fragment is available, it can be re-attached as an interim measure to the remaining tooth structure using a dentine bonding agent and composite resin. Endodontic therapy can then be carried out in the standard manner using rubber dam before proceeding to the next stage in managing the fractured tooth. Failing this, a temporary composite restoration may be placed through which endodontic therapy can be performed.

In the young patient, the procedures may be complicated by lack of root development. The priority in treatment should then be development of root maturity rather than restoration of aesthetics and function. If root development is incomplete, and if the fracture passes deeply subgingivally and involves most of the crown, conservative pulp treatment should be initiated to maintain the health of the radicular pulp while normal root development proceeds. The canal orifice can be temporarily sealed and a temporary denture inserted until further root development occurs. Subsequently, when the root is mature, standard endodontic management can be carried out and routine restoration undertaken. Root submergence (decoronation) is sometimes an option in these cases.56 In assessing crown-root fractures in young patients, consideration must also be given to the fact that continued eruption of the tooth may bring a subgingival margin into more favourable position without the need for restorative, orthodontic or surgical intervention.

Root fractures

Root fractures pass across the root and involve the cementum, dentine and the pulp. They can present with or without clinical signs of luxation of the coronal fragment, and they are an indication for routine radiographic examination of all traumatized teeth. The clinical sign is commonly an extruded and lingually displaced crown. The fracture can appear radiographically as a single line or multiple lines across the root.57 The image of the fracture is dependent on the angle of the fracture and the angle at which the film is taken. It is usually clearly evident on radiographic examination, although multiple radiographic views at different vertical angles may be necessary to obtain a clear image. Flores et al.23 suggest occlusal and tubeshift radiographs, in addition to a parallel periapical radiograph, are useful to identify and investigate rootfractured teeth. Radiographs taken immediately following trauma may not show the fracture line clearly.

Many root fractures heal without intervention in one of three modalities: hard tissue interposition, interposition of bone and periodontal ligament or interposition of periodontal ligament alone.58 A nonhealing inflammatory process associated with pulp necrosis and infection of the coronal fragment can also occur. Factors that have an effect on healing include age, stage of root development, mobility, fragment dislocation and the separation between the fragments. Pulp tissues are not essential to the healing of a root fracture.59 Healing is more favourable in incompletelyformed teeth and where displacement of the coronal fragment is minimal.58,60 Pulp canal calcification is a common feature that may develop in root-fractured teeth, but this rarely poses a problem in the long term. Canal calcification can only occur if the pulp tissues remain vital.

Pulp survival rates are higher in root-fractured teeth than in traumatized teeth without fracture. Pulp necrosis has been reported to range from 20 per cent to 44 per cent.58 In most instances, if pulp necrosis develops, it will do so within two to five months after the trauma. Maintenance of pulp vitality is affected by the extent of apical maturation, the location of the fracture site, the extent of dislocation and the separation between the fragments. If separation is greater than 1mm the incidence of pulpal necrosis in the coronal fragment increases substantially, suggesting that this is the limit to which the pulp tissue can be stretched before first the neural and then the vascular components are compromised.58 Should the fracture communicate with the gingival tissues, pulp necrosis inevitably occurs and the prognosis for the coronal fragment is extremely poor.

Pulp sensibility testing immediately after trauma is an unreliable means of predicting the final status of the pulp.61 Sensibility testing involving thermal and electrical stimuli is nevertheless an important feature of the initial examination of a root-fractured tooth.62 A negative response is a common finding immediately and for some time after the root is fractured and is an indication that the pulp has suffered some trauma. Teeth that initially give a negative response can respond after periods ranging from one month to one year. Responses to sensibility testing need to be followed up over time before a diagnosis is made of pulp necrosis. Endodontic treatment is only indicated for those teeth in which pulp necrosis has occurred.59 In a rootfractured tooth, this diagnosis is usually based on the development of radiographic changes, often a widening of the space between the two segments and of the periodontal ligament space adjacent to the fracture site, and the development of tooth discolouration or a sinus tract. Localized root resorption may at times occur in the area of the fracture. This should not be taken as a sign of pulp necrosis without other corroborating evidence.

As the blood supply to the apical fragment is usually not disturbed, if pulp necrosis occurs, it is invariably restricted to the coronal

fragment only.59 Thus, the endodontic management of root-fractured teeth can be restricted to the coronal fragment. It has been clearly established that the insertion of calcium hydroxide in the root canal to the level of the coronal fracture leads to the production of a barrier at the level of the fracture site, permitting root filling to this level without over extension.59 More recently, the use of MTA has been recommended in some cases.8,63 Early and accurate repositioning of the coronal fragment has been shown to reduce the likelihood of pulp necrosis.64 Optimum repositioning should be verified radiographically.

Traditionally, long-term rigid splints have been used in an attempt to promote hard tissue healing of rootfractured teeth. A recent review,64 however, found no real difference between teeth that were splinted in this manner when compared to non-splinted teeth. Where excessive mobility dictates the need for a splint, it should be non-rigid, atraumatically placed and removed after a maximum of four weeks, except in teeth where the fracture occurs in the coronal third where the tooth may need splinting for up to four months.18,64 As a general rule, the location of the fracture has not been shown to influence the survival of the pulp; except that in permanent teeth, pulp necrosis is less likely in teeth fractured in the coronal one-third of the root.58 The long-term prognosis of these teeth is poorer, however, principally due to an increased susceptibility to new luxation injury or increased mobility of the coronal fragment.58,65

Root fractures are rare in immature teeth as these teeth are more likely to be avulsed or luxated than to be fractured. However, where root fractures occur, the possibility of calcific repair is quite high.58 Endodontic treatment is generally unnecessary in root-fractured immature teeth.

Endodontic treatment of root-fractured teeth

The initial treatment of teeth with root fractures is a relatively simple matter provided attention is paid to a few principles. An initial assessment must be made as to whether the fracture line is communicating with the oral cavity, or that it could potentially communicate with it due to tooth movement and gingival recession. Should this be the case, the coronal fragment will generally need to be removed, and the remaining root structure assessed on its merits. If the tooth is to be retained, the tooth should be treated as a deep crown-root fracture and the remaining root can be endodontically treated if the root is to be retained.

If the fracture line is not communicating with the oral cavity, an assessment can then be made of tooth position and tooth mobility. If the coronal fragment is displaced, it should be repositioned and splinted. If the fragment is mobile, it should be splinted. In both scenarios, the teeth should be relieved from occlusion. Non-rigid splinting for less than four weeks is now recommended for most root fractured teeth,64 although when excessive mobility of the fragment is encountered, more prolonged splinting may be required. Fractures that occur between the alveolar crest to a distance of 5mm below are the most difficult to manage and have the poorest long-term prognosis.65 However, nothing is lost by splinting these teeth and assessing their prognosis over time. Longer splinting times of up to four months are recommended in these circumstances.18

All root fractures that do not communicate with the oral cavity should be treated as if the pulp is not irreversibly damaged. Endodontic treatment should not be initially undertaken for a tooth with a root fracture, even in the absence of positive pulp sensibility testing, which is a common finding immediately and for some time after a root is fractured.

If the root-fractured tooth is neither displaced nor mobile, then no treatment is necessary in the initial stage, apart from ensuring that the tooth is free from the occlusion in all movements. In the absence of symptoms, follow-up radiographs should be taken at one month, two months and six months following trauma, and then at yearly intervals.18

Two factors need to be assessed at follow-up examination: pulp sensibility and tooth mobility. In general, if pulp necrosis occurs, it will be confined to the coronal fragment. Should pulp necrosis develop, temporary filling of the root canal with calcium hydroxide for four to six months to the level of the fracture followed by root filling with gutta-percha or MTA8,63 to that level is the treatment of choice. Under no circumstances should the pulp be removed beyond the level of the fracture in the first instance as doing so will compromise the long-term success of treatment. As a general rule, the closer the root fracture is to the cervical level the longer the treatment time required. In those rare cases where the apical fragment also becomes necrotic, as would be evident radiographically by the development of a periapical radiolucency as well as a mid-root radiolucency, a decision must be made whether to root fill to the fracture site and to remove the apical fragment, or to include the apical fragment in the root filling. It has been claimed that prognosis is poor if the apical fragment has to be removed, although not all authors agree with this.59

If the tooth continues to be mobile after an initial splinting procedure, consideration can be given to either prolonging the splinting time or splinting the crown of the tooth to adjacent teeth in a more permanent manner. Some long-term discomfort to biting on a root-fractured tooth is not unusual. Treatment of root-fractured teeth by the use of endodontic implants has been recommended in the past as a means to reduce mobility. However, the long-term prognosis for these implants is doubtful and their placement is not recommended.4

Luxation injuries

Andreasen4 describes five types of luxation injury and a number of studies have investigated the prognosis for luxated teeth.66-69 From an endodontic point of view, the main complicating factors of luxation injuries are pulp necrosis with infection, pulp canal calcification, ankylosis and root resorption. Factors that affect the prognosis of luxated teeth are the degree of displacement, treatment time delay, root maturation and concomitant crown fractures. Most cases of pulp necrosis in luxated teeth become evident within four months. Root resorption often occurs within the first five months after injury and can develop quite rapidly, particularly in immature teeth. Hence, frequent follow-up examination is recommended. In some cases pulp necrosis may appear at a much later date and therefore long-term follow-up is essential.70

Concussion

This injury to the supporting structures is characterized by marked tenderness to percussion, but no abnormal loosening or displacement of the traumatized tooth. Only a small percentage of these teeth undergo pulp necrosis (3 per cent) or pulp canal calcification (2–7 per cent).12,71 Root resorption is not a feature of concussed teeth.

Subluxation

This injury is characterized by abnormal loosening of the tooth but without displacement. Teeth are tender to percussion and there may be some bleeding in the gingival crevice. Prognosis for subluxation injuries is good. Endodontic management is, however, sometimes necessary.71 Reported frequency of pulp necrosis ranges from 6 to 17 per cent. Pulp canal calcification has been reported to occur in 9 to 12 per cent of the cases and progressive root resorption in less than 2 per cent.12,71

Extrusive luxation

In this type of luxation, the tooth is extruded from its socket. As such, minimal damage to the socket wall occurs. A recent study involving a paediatric population found that extrusive luxation led to pulp necrosis in 43 per cent of teeth, usually within one year.68 Pulp canal calcification was observed in 35 per cent and progressive root resorption in 5.5 per cent of cases.68 A direct correlation has been established between the degree of extrusion and the incidence of pulp canal obliteration but not necrosis in a recent study in children.68 The incidence of complications with severely extruded teeth was very similar to those of avulsed teeth where the teeth were stored in a suitable physiological medium.68

Lateral luxation

Lateral luxation represents eccentric displacement of the tooth in its socket. This type of luxation is accompanied by fracture or comminution of the socket wall and the tooth is usually locked into the new position. The incidence of pulp necrosis in laterally luxated teeth in a paediatric population was found to be 40 per cent, with an additional 40 per cent of teeth demonstrating pulp canal calcification.69 Fifty-eight per cent of mature teeth exhibited pulp necrosis and infection following lateral luxation in adults.71 The incidence of root resorption following lateral luxation has been reported to be 26 per cent.71

Intrusive luxation

In intrusive luxation the teeth are forcefully intruded into the bone. Because of the direction of displacement, a comminuting fracture of the socket also occurs. The frequency of pulp necrosis is very high. At least 85–95 per cent of mature intruded teeth become necrotic.24,67,72 Pulp canal calcification and progressive root resorption are expected to occur in 4 and 48 per cent of cases, respectively.

Treatment of intruded teeth can be complicated by the fact that most intruded teeth are also associated with crown fractures.73 Delayed repositioning leaves roots in intimate contact with bone and this influences the onset of replacement resorption. Thus, mature teeth should be repositioned as soon as possible and the pulps removed immediately or as soon as possible once the soft tissues have healed sufficiently to do so, in order to help prevent the onset of inflammatory root resorption.22,74 Although immediate (i.e., surgical) repositioning is the treatment of choice for mature teeth in adults (>17 years of age), orthodontic repositioning is another option for managing such injuries.75

Intruded immature teeth behave somewhat differently and more treatment options are available. The apex is open and the bone in children is softer and more malleable. In these teeth, the extent of the intrusion and the presence of associated crown fractures are important prognostic considerations. All intruded teeth in a paediatric population survived for five years if the intrusion was less than 3mm, 90 per cent if the intrusion was between 3mm and 6mm, and only 45 per cent if the intrusion was greater than 6mm.67 Almost all surviving intruded immature teeth undergo pulp canal calcification. Pulp necrosis is usually diagnosed within six months but may develop up to two years later in open-apex teeth.67,72 In open-apex teeth, awaiting spontaneous eruption has been reported to lead to the best outcomes.75 However, careful monitoring must be carried out to ensure that resorptive defects are detected and treated early. Root resorption has been reported to occur in a large number of cases.67,72

It can be seen from the above that luxation injuries result in a much higher incidence of pulp necrosis than do injuries involving fracture of the teeth. As would be expected, the risk of pulp necrosis increased with the extent of the injury; concussion and subluxation represent the least risk, followed in ascending order by extrusive, lateral and intrusive luxation. Intrusive luxation appears to be the most serious type of injury with regard to the development of pulp necrosis and the development of root resorption. Teeth that have been luxated should be identified and observed over a long period. Teeth with completed root formation demonstrate a greater risk of pulp necrosis than teeth with incomplete root formation. In particular, development of pulp necrosis after injury has been shown to be significantly related to the diameter of the apical foramen.76 For extruded and laterally luxated teeth, the smaller the diameter, the greater the probability of pulp necrosis. Intruded teeth with incomplete root development are associated with a much higher probability of pulp survival than teeth with complete root development.

The diagnosis of pulp necrosis following luxation injury needs careful attention. The initial condition of the pulp may be one in which only the nerve supply has been damaged and the potential for revascularization without concomitant neuron-regeneration cannot be dismissed. The extent of apical displacement has been found to be significantly related to the incidence of pulp necrosis for intrusive luxations but not extrusive and lateral luxations.67-69 Sensibility tests, though useful, may be unreliable in luxated teeth. Discolouration and periapical radiolucent lesions are the most important diagnostic features to be noted for subluxation, extrusive luxation and lateral luxation. The presence of inflammatory root resorption is an important factor in establishing the diagnosis of pulp necrosis and infection in replanted and intruded teeth,4 and pulp extirpation must be carried out at the earliest radiographic sign of this process occurring.

There is one factor that should not be overlooked when assessing radiographic changes in luxated teeth. While a rare occurrence, transient apical breakdown is believed to be a non-infected apical remodeling process, which can mimic pulp necrosis radiographically and in clinical tests and observations. Andreason77 examined 637 cases of luxated teeth and identified this process in 4.2 per cent of teeth. The majority of these teeth demonstrated a periapical radiolucency, as well as colour and/or electrometric sensibility changes. All teeth showed resorptive widening of the apical foramen. All signs and symptoms later returned to normal. Recognition of transient apical breakdown is important if unnecessary endodontic treatment is to be prevented. Transient apical breakdown is more common in mild luxation injuries in fully formed or almost fully formed teeth. A case can be made for

observing asymptomatic teeth with early signs of pulp necrosis in selected cases, but only where the clinician is absolutely confident that the patient is likely to comply with frequent recall investigations. Continued root development and calcification within the canal must be regarded as a positive indication of a vital pulp even in the absence of a positive response to pulp sensibility testing. Regular radiographic examination is necessary. Endodontic therapy must be commenced at the first radiographic evidence of inflammatory root resorption.

Endodontic treatment of luxation injuries

It is generally agreed that for most luxation injuries, with the exception of intrusive injuries in mature teeth, endodontic therapy should be postponed until additional signs of necrosis appear such as colour change and radiographic changes, both in the tooth and the surrounding bone.4,17,27 Should the pulp become necrotic and infected, treatment is dependent upon the state of closure of the apex. If apical maturation is complete, standard endodontic treatment is indicated. Should apical development be incomplete, apexification procedures utilizing calcium hydroxide25 and/or MTA27 are indicated.

The first concern in the treatment of luxation injuries should be the repair of the periodontium. Soft tissue injuries and repositioning should be treated before endodontic procedures are contemplated.

Endodontic treatment need not be considered for concussion and subluxation injuries until there are signs of pulp necrosis. However, judicious grinding may be necessary to free the tooth from occlusion. Frequent radiographic examinations and pulp sensibility testing are needed during the follow-up period.

If the root is extruded, careful monitoring of the tooth must be undertaken after repositioning and a period of splinting of two weeks duration. In the event that there has been a delay in repositioning the teeth, gentle orthodontic treatment may be needed to reposition them. Radiographic examination and pulp sensibility testing should be carried out at regular intervals such as: two weeks, one month, two months, six months, 12 months and then on a yearly basis for a number of years.18 Endodontic therapy should be commenced immediately there is evidence of pulp necrosis or root resorption. While immature teeth can revascularize and can continue root development, which can be seen radiographically, it is not prudent to delay treatment in immature teeth that show any sign of root resorption, as inflammatory root resorption can occur very rapidly. A delay in treatment even for one week can result in loss of substantial tooth structure. In these teeth, pulp extirpation and root filling after calcium hydroxide or corticosteroid/antibiotic therapy is the treatment of choice. In mature teeth, endodontic therapy should be undertaken where there is clinical and/or radiographic evidence of pulp necrosis and infection, or root resorption. Continued lack of reaction to pulp sensibility testing is usually indicative of pulp necrosis, unless there is radiographic evidence of ongoing calcific changes in the root canal system.

Where a tooth has been laterally luxated, it should be repositioned without delay. Again, endodontic therapy is carried out only when there are signs of pulp necrosis or root resorption. Lateral luxation does not occur without fracture of the alveolar socket. Immediate repositioning, with forceps if necessary, and splinting is therefore recommended. Splinting should be of four weeks duration to allow the fractured bone to heal.18

Treatment of intruded teeth can be a challenge. Pulp necrosis almost invariably occurs in intruded mature teeth11,71,72 and treatment can complicated by the fact that most intruded teeth are also associated with crown fractures.73 Subsequent re-eruption, if it occurs, may be very slow during which time root resorption may become advanced. Delayed repositioning leaves roots in intimate contact with bone and this influences the onset of replacement resorption. Thus, mature teeth should be repositioned as soon as possible and the pulps removed immediately, or as soon as possible once the soft tissues have healed sufficiently to do so, to help prevent the onset of inflammatory root resorption.22,74

Repositioning intruded teeth is a priority and can occur through spontaneous re-eruption or it may require surgical or orthodontic repositioning. Surgical repositioning or orthodontic repositioning is the treatment of choice for mature teeth in adults (>17 years of age).75 A recent review found no significant difference in healing between surgical or orthodontic repositioning of permanent intruded teeth.75 Surgical repositioning is preferred where there is complete intrusion and gingival healing may prevent re-eruption or complicate orthodontic repositioning. A surgical technique may be more practical for multiple intrusions where orthodontic anchorage may be an issue. Care must be taken in repositioning these teeth to ensure that the hard tissues are brought down with the tooth and that the soft tissues are sutured into place if necessary.

While orthodontic extrusion has been advocated, it is not always possible as the teeth are often wedged firmly into the bone and attempts to extrude the tooth can lead to intrusion of adjacent teeth. Each situation has to be assessed on its merits and on the state of development of the tooth. Mature teeth that are firmly wedged into the alveolus should be immediately repositioned surgically. In mature teeth, urgent endodontic management should be commenced as soon as practical following repositioning.

Intruded teeth with open apices are more likely to erupt spontaneously and less likely to develop problems of an endodontic origin. As immature intruded teeth can spontaneously reposition themselves in the arch and significantly better healing occurs when this happens, it has been suggested that treatment be delayed for these teeth.75 However, if spontaneous repositioning does not appear to be occurring quickly, immature teeth can be brought down by orthodontic or surgical means as soon as possible after trauma. There is an argument for surgically disimpacting these intruded immature teeth from the alveolus to assist with re-eruption. Regular radiographic follow-up at two weeks, one month, two months, six months and yearly is essential for these teeth as root resorption can occur rapidly in immature teeth.18 Should any resorption be detected, pulpectomy and treatment with calcium hydroxide or a corticosteroid/antibiotic paste prior to root filling procedures should be urgently carried out. Surgical exposure of the intruded immature teeth to permit endodontic therapy has been proposed to avoid delay in endodontic treatment and the development of inflammatory root resorption.25

Avulsion

Avulsion or exarticulation occurs when a traumatic injury totally displaces a tooth from the socket. Treatment of the avulsed tooth is one area in dentistry where recent research has been applied to greatly improve the prognosis for the long-term retention of these teeth. Andreasen recently reviewed tooth avulsion and replantation.78-81 Although the prognosis for an avulsed tooth must always be guarded,

replantation as soon as possible followed by a brief period of flexible splinting and endodontic therapy has been shown to be the most effective method of treatment. The shortest extra-oral period (less than 15 minutes), minimum manipulation of the tooth surface and the socket, and the use of an appropriate storage medium have been identified as factors that minimized subsequent root resorption.

The most common reason for unfavourable longterm survival of avulsed teeth is root resorption. A number of factors have been identified as being important in the prevention and management of root resorption associated with avulsed teeth.

Vitality of the periodontal ligament and tooth socket
Vitality of the periodontal ligament cells is a factor that greatly affects the healing of replanted teeth. When the vitality of the periodontal ligament cells is lost, replacement resorption usually occurs. There is a relationship between the total area of root surface where the cells have become necrotic and the amount of replacement resorption generated.82

Extra-oral time
It has been clearly established that the length of extra-oral dry time and the stage of root development are the most critical factors associated with root resorption.78 The critical dry time where a statistically significant increase in root resorption was observed was 15 minutes in one study although just five minutes of dry time was sufficient to increase the incidence of resorption in another study.83 Teeth that are replanted immediately have the best long-term prognosis and the least incidence of root resorption.

One animal study84 has suggested that removal of a non-vital periodontal membrane with solutions such as sodium hypochlorite may slow the rate of resorption in teeth for which replantation has been delayed (e.g., more than 60 minutes), but the findings of this study have not been corroborated in human material. The International Association for Dental Traumatology18 does not recommend pre-soaking in sodium hypochlorite but it does suggest that the roots of avulsed teeth with delayed replantation times (more than 60 minutes) should be scrubbed clean with gauze to remove necrotic material and that the teeth should then be soaked in a 2% sodium fluoride solution for 20 minutes before replantation in order to help delay the inevitable onset of replacement resorption and ankylosis.

If replantation has been delayed, endodontic therapy can be commenced after replantation in mature teeth but, for technical reasons, there may be an advantage in carrying out the endodontic therapy prior to replantation in teeth with open apices and which have experienced long delays (greater than 60 minutes) before replantation.18

Storage medium
As most avulsed teeth are not replanted at the site of the injury and few patients can receive treatment within 15 minutes, a suitable storage medium to maintain the health of the periodontal ligament cells is critical. In studying periodontal ligament healing associated with replanted teeth in monkeys, Andreasen85 varied the extra-alveolar time periods and the storage media. He established that if the teeth cannot be replanted immediately, then storage in saliva or saline solutions significantly reduced the amount of root resorption. Storage in tap water should be avoided as this causes the cells to swell and become necrotic. Acceptable solutions appear to be milk, contact lens solution,86 Hanks Balanced Salt Solution and saliva.87 Wrapping the tooth in polyethylene film (e.g., Glad Wrap) has been suggested where teeth cannot be replaced immediately and if storage solutions are unavailable.

Splinting
Splinting procedures do not significantly improve periodontal healing. Longer splinting times (greater than 10 days) tend to hasten the resorption process, particularly if inflexible splints are used. It is probable that functional stimulation plays a role in repair.14,88

Socket preparation
Transplantation experiments indicate that the vitality and integrity of the tooth socket is a factor to be noted in the development of root resorption, although the length of time out of the socket appears to be more critical. Curettage of the socket is not necessary, although doing so has no major effect on the replanted tooth. However, gentle irrigation of the socket to remove any blood clots prior to replantation is thought to be better than curettage and may be necessary if there has been a time delay in replanting the tooth.21

Antibiotic therapy
Systemic administration of antibiotics is generally recommended in order to prevent the harmful effects of bacterial contamination,4 although the evidence to support this is limited. Experimental animal studies have reported that systemic antibiotics decrease the incidence of inflammatory root resorption but have a limited, or no, effect on the pulp.89 Recent research has focused on the effect of topical antibiotic therapy with promising results in animal models. Topical doxycyline and minocyline applied to the root surface before replantation have been found to increase the chance of pulp revascularization in dogs90 and to decrease the chance of inflammatory root resorption and ankylosis in monkeys.91 The use of intracanal antibiotics and corticosteroids immediately after replantation appears to halt the progression of inflammatory root resorption, although replacement resorption still occurs to some extent.74

Effect of endodontic therapy
Endodontic therapy involving obturation with guttapercha or the placement of calcium hydroxide dressings at the time of replantation delays periodontal healing and hastens replacement resorption in mature teeth. Endodontic therapy should be delayed until the initial period of soft tissue healing takes place.4 However, since revascularization rarely occurs in mature teeth, and as pulp necrosis contributes to inflammatory root resorption, it has been recommended that in mature teeth pulps should be extirpated as soon as possible74 or after initial periodontal healing has occurred (seven to 10 days).18,21,92 Recently, Bryson et al.74 have suggested that pulps in avulsed, mature teeth should be removed immediately after the teeth are repositioned and that an intracanal dressing with a corticosteroid/antibiotic paste should be placed in order to prevent the initiation of inflammatory root resorption.

Contamination of the root surface
Contamination of the root surface has been found to be a prognostic indicator for root resorption. The prevalence of resorption in teeth replanted without visible contamination has been reported to be 57 per cent, whereas 75 per cent of teeth that were washed and 87 per cent of those that were rubbed clean underwent resorption. When teeth were replanted with visible contamination still present, 100 per cent exhibited resorption.83

Stage of root development

The replantation of avulsed teeth with immature root development has been the subject of review.93 As the pulps in a small percentage of replanted immature teeth may survive, it is recommended that endodontic treatment should be delayed in these teeth to establish whether root formation continues. Revascularization appears inversely proportional to root length. However, external inflammatory resorption progresses very rapidly in immature tooth roots. Thus, regular clinical and radiographic examinations at short intervals are recommended to establish whether resorptive processes have been initiated. Great care should be taken in delaying treatment if patient compliance to attend recall examinations cannot be assured. Calcific changes within the pulp canal imply that the pulp has remained viable at least for some time following the injury.

Endodontic treatment of avulsed teeth

It has been previously recommended that in mature teeth, endodontic therapy should be commenced seven to 10 days following replantation.18,21,92 However, it would now seem that pulp extirpation should be carried out as soon as possible to prevent the initiation of inflammatory root resorption.74 The canal should be debrided, dressed with a corticosteroid/antibiotic74 or calcium hydroxide paste preparation for one to three months, after which time the canal can be obturated and the access cavity sealed. Follow-up radiographs should be taken at regular intervals of one, three, six and 12 months.18 Longer-term follow-up radiographs are desirable, as a number of authors have reported that resorption may occur up to 10 years after avulsion.

In immature teeth, when the time out of the mouth is short and the apex is open, revascularization of the pulp may occur. Endodontic therapy can be delayed to establish whether revascularization will occur but only if patient compliance for follow-up treatment is assured. Regular follow-up is essential and apexification procedures should be carried out at the first sign of resorption, discolouration, the presence of a draining sinus or periapical bone loss. The root canal should be accessed so the infected tissue and debris can be removed and the canal can then be filled with calcium hydroxide. Root filling procedures involving guttapercha and/or MTA can be carried out at a later date.

Root resorption

Resorption is a common sequel to dental trauma and may be caused directly by the traumatic incident or indirectly through subsequent infection. Andreasen has described three types of resorption following trauma: surface resorption, replacement root resorption and inflammatory root resorption.4 Root resorption has also been described as being as ankylosis-related and infection related.18 Heithersay has extensively reviewed root resorption and proposed a new system of classification of these defects, as well as describing a range of treatment options for these lesions.94-96

The three most common resorptive patterns seen in traumatized teeth are surface, replacement and inflammatory resorption. Surface and replacement resorption are trauma induced, whereas inflammatory root resorption is caused by the combination of traumatic injury and infection of the necrotic root canal system.

Surface resorption is believed to be a self-limiting response to a localized injury to the periodontal ligament or cementum. In traumatized teeth this type of resorption occurs more commonly in the apical portion of the root and may be seen as a shallow rounding of the tooth shape.

Replacement root resorption results in the replacement of tooth structure by bone and can be recognized radiographically by the diffuse nature of the resorptive defect, the disappearance of the periodontal space adjacent to the area of the resorption and the lack of a bony defect adjacent to the resorptive defect. Replacement resorption is generally associated with replanted or luxated teeth. It is a progressive type of resorption and the prognosis is very poor. It is thought to be initiated by damage to the periodontal ligament leading to a fusion between dentine and bone with progressive replacement of the dentine by bone.97 In most instances the majority of the root becomes involved over time and, in these cases, the clinician may elect to allow the process to continue to its inevitable end result – i.e., total destruction of the root. This process usually takes about five years but may take much longer, especially in older patients.

Inflammatory root resorption occurs entirely as a result of a necrotic and infected pulp. It can be recognized radiographically by the development of a radiolucency in the bone adjacent to the resorptive defect. Removal of the infected pulp tissue, dressing with an anti-clastic medicament (such as Ledermix® paste) and subsequent filling of the root canal with gutta-percha will usually halt the resorptive process.

Inflammatory and replacement resorption may occur together in the one traumatized tooth. Endodontic treatment may halt the inflammatory resorption but the replacement resorption, once initiated, is generally progressive.

Less commonly, traumatic injury may cause other hyperplastic forms of tooth resorption. Heithersay describes these as internal replacement resorption and invasive coronal, cervical or radicular root resorption. Treatment options for these types of resorptive effects have been extensively described.96

Recently, the desirability of replanting avulsed teeth with long dry times in young patients has been brought into question due to the inevitable complication of ankylosis, infra-occlusion of the tooth and disturbances in alveolar growth.98 Additionally, since removal of mature ankylosed anterior teeth is sometimes difficult and destructive to the supporting bone, early removal of ankylosed and resorbing mature teeth may be warranted if implant replacement is to be carried out at a later date. Alternatively, root submergence (decoronation) in the growing patient allows continued alveolar development and maintains bone for subsequent implant placement when growth is complete.

Endodontic treatment of teeth with resorptive defects

Surface resorption is self-limiting and does not generally require treatment. Frequent clinical and radiographic review is necessary, however, to confirm that inflammatory and replacement resorption are not occurring in these teeth.

Where resorption has been initiated in traumatized teeth, replacement resorption cannot be treated effectively. Nevertheless, as replacement and inflammatory root resorption can occur together, endodontic therapy to remove necrotic and infected pulps

from resorbing teeth is warranted. As an interim measure the teeth can be dressed with a corticosteroid/antibiotic paste or calcium hydroxide, or it can be root filled. Each case has to be treated on its merits. Treatment of resorbing traumatized ankylosed anterior teeth often requires multi-specialty treatment planning. Before extensive endodontic management is contemplated, the options of extraction, prosthetic replacement, maintenance of the space for future prosthetic replacement, orthodontic space closure, autotransplantation and surgical root submergence must be contemplated. In younger patients, where retention of a submerging ankylosed tooth can retard alveolar growth, root submergence (decoronation) should be contemplated once evidence of submergence is noted.18 In contrast, in older patients, extraction and replacement with an osseointegrated implant is an option.

Inflammatory resorptive defects are treated by immediate pulp extirpation and the use of corticosteroid/antibiotic or calcium hydroxide intracanal dressings until there is evidence of bone healing. Since any delay in treatment increases the surface area of the root that needs repair, urgent and early treatment is recommended. Root canal disinfection and medication removes the cause of the resorption. Provided endodontic treatment is initiated early enough, most inflammatory resorptive defects can be treated conservatively.

Treatment of external invasive root resorption is dependent upon the position and extent of the resorptive defect. Heithersay94-96 has recently described treatment options involving the careful application of trichloracetic acid BP (90% solution) from either an internal or external approach as a means of managing some invasive resorptive defects.

Pulp canal calcification

Calcification of the root canal (commonly referred to as pulp canal obliteration, or PCO) is a common sequel following luxation injuries to permanent teeth, particularly teeth that have been injured before their root formation has been completed.99 Abbott and Yu100 have discussed the terminology regarding this condition and they have recommended the use of the term "calcification" (rather than "obliteration") as it more accurately describes what is happening, or what has happened, wit in the root canal. Obliteration implies complete blocking or elimination of the canal which is unlikely, even in a tooth that radiographically appears to have no root canal present.

Clinically, a yellowish discolouration of the crown may be observed. Pulp canal calcification is also a common occurrence in root-fractured teeth occurring principally in the region of the fracture, and in the apical fragment. It may also occur in teeth associated with alveolar and jaw fractures.

In most traumatized teeth that have pulps undergoing calcification, the hard tissue is deposited longitudinally along the dentinal walls of the pulp canal, which gradually diminishes in size until it can barely be observed radiographically. In view of the manner of calcification, there is always a canal present and endodontic management is usually able to be performed, if it becomes necessary, by an experienced clinician. On the other hand, however, pulp canal calcification that occurs in traumatized, root-fractured, open-apex teeth and in immature canine teeth that have had prolonged orthodontic treatment is often irregular and these teeth are difficult to manage endodontically if such treatment becomes necessary.

Fortunately, only a small percentage of teeth with pulp canal calcification develop pulp necrosis and become infected.101 Pulp necrosis and infection is more likely to occur in teeth in which the pulp appears almost totally calcified, in teeth with completed root formation that have had severe periodontal injury at the time of trauma, and in teeth that have shown "rapid" calcification of the canal after injury. Pulp necrosis and infection may occur up to 20 years following injury. However, the pulps in most teeth with pulp canal calcification remain healthy and do not require endodontic treatment. Assessment of the status of the pulp is difficult since these teeth do not usually respond to thermal pulp sensibility testing. Most, however, do respond to electrical stimulus, and therefore electric pulp sensibility testing is the desirable method for assessing the status of the pulp in calcified teeth.

Endodontic treatment of teeth with pulp canal calcification

Treatment of teeth with pulp canal calcification presents a dilemma. A number of authors have proposed that for endodontic technical reasons and for prevention of tooth discolouration, these teeth should be root filled once the calcification process is detected. Endodontic procedures are certainly easier if undertaken at this stage. However, most of the recent literature indicates that endodontic treatment is unnecessary unless the tooth is symptomatic or there is radiographic evidence of pulp necrosis and infection3 – i.e., a periapical radiolucency. Proponents of the latter course of action base their opinions on histological studies which indicate that the calcific changes do not warrant pulp extirpation and that a remnant of the canal is always present.

The presence of a periapical radiolucency implies that a canal is present. Although the location and negotiation of the canal may be difficult, it is invariably present and is negotiable in almost all cases. With care, the orifice to a trauma-induced calcified canal can invariably be located in the crown of the tooth, above the cervical margin. A "catch" on the floor of the pulp chamber, felt with an endodontic explorer or file, will generally indicate the position of the canal, as will a colour change in the middle of the root. As the calcific material is generally softer than regular dentine, carefully "picking away" at this softened material with a suitable explorer and/or the use of rotary nickel titanium instruments will often remove sufficient material to reveal the opening of the root canal system. Negotiation of the canal requires patient exploration of the floor of the pulp chamber with a bright light and radiographic assessment. Transillumination using a light source placed on the cervical area of the tooth under the ruber dam is invaluable. Pre-operative radiographs can assist in determining the level at which the canal is to be found. Increasing the exposure of the pre-operative radiograph may reveal the canal outline more clearly.

Where difficulty is experienced in locating a calcified canal in a traumatized tooth, it is usually because the canal has been bypassed rather than that the canal is not present at the level of the search. If an undetected canal is visible radiographically at the level of exploration, it must be assumed that the canal has been bypassed and exploration deeper in the root is not advisable. As lingual access to a root canal often directs instrumentation in a labial direction, a more lingual approach may assist in locating the canal. Dentine softening agents have been proven to be ineffective as aids for the

location of calcified canals. Early referral to a specialist endodontist is recommended if difficulties are experienced in locating canals in calcified teeth. A surgical approach to the management of these cases has also been advocated but this should only be considered when conservative attempts to locate and negotiate the canal have been unsuccessful, and such surgery should only be carried out by practitioners with appropriate training, such as a specialist endodontist.

The immature tooth with pulp necrosis and infection

A large number of different apical configurations can result if an immature tooth with an open apex is traumatized. Continued root development, apical doming, in-growth of bone, and aberrant root formation have all been reported. Repair appears to be more related to the creation of an environment conducive to repair rather than the type of medicament used.

The diagnosis of pulp necrosis and infection in an immature tooth is often difficult. Radiographic changes may be difficult to see. The clinician often has to rely on an assessment of other signs and symptoms, such as the presence of acute or chronic pain, tenderness to percussion, increased mobility, discolouration of the crown, or the presence of a draining sinus tract. Radiographic comparison of the root formation of the tooth in question with its contra-lateral tooth is helpful to establish if root development is continuing at the normal rate for that patient. Calcific changes indicate that the pulp is vital, or at least it maintained vitality for some time after the injury. External inflammatory resorption indicates that the pulp is necrotic and infected, and in need of urgent treatment. Apical remodeling after luxation injuries may indicate that revascularization of the pulp is occurring, or that it has occurred. In general, erring on the side of caution through observation and review is desirable, but great care should be taken when doing this if the tooth was avulsed or intruded, and also when patient compliance with recall examinations is questionable.

A number of studies have suggested that long-term dressing of root canals with calcium hydroxide may weaken the dentine,101 thus early restoration of immature non-vital teeth with MTA has been suggested as an alternative treatment protocol.103,104

Endodontic treatment of immature teeth with pulp necrosis and infection

Once pulp necrosis and infection has been established, apexification procedures need to be initiated. The access cavity preparation should be made large enough to encompass the larger than normal underlying pulp and to allow access of endodontic instruments to the divergent walls. Cleaning should be carried out with great care using copious amounts of irrigant, such as sodium hypochlorite. Reliance on irrigation to remove debris rather than filing is important, as the canal walls in the apical region are thin and fragile. Over-zealous use of files may damage the walls. An endodontic ultrasonic device operated in a canal full of sodium hypochlorite can help remove debris, but care should be taken to ensure that the ultrasonic instrument does not compromise the walls of the canal.

Teeth with infected root canals and open apices are now routinely treated with calcium hydroxide root induction techniques followed by orthograde guttapercha or MTA root filling techniques. The use of propriety corticosteroid/antibiotic pastes can have a role in initial management to control the apical periodontitis and then once the canal has been fully debrided and the tooth is symptom-free, calcium hydroxide can be placed into the canal using a spiral filler or a proprietary injection syringe. It is imperative that the access cavity then be sealed adequately while apexification takes place. A "double seal" with Cavit® and a stronger restorative dental material is recommended in order to prevent breakdown of the temporary restoration which can lead to re-infection of the canal and subsequently to further apical periodontitis.

Apexification can take from six to 24 months. The role of the medicament is uncertain and apexification has been reported to occur with a number of different paste formulations including tricalcium phosphate, zinc oxide and antibiotic pastes. Continued root development and apical doming can also occur when the canal has been instrumented and left empty or, occasionally, if no treatment at all has been performed.

Regular radiographic assessment is necessary to monitor progress of apexification. The calcium hydroxide should be replaced if apexification is not proceeding, or if the material has resorbed more than one-quarter of the way into the canal space. If the calcium hydroxide is left in the canal for too long without replacement, then apexification may not occur.

As the apical portion of the canal is often larger than the coronal portion and since the cross-section of the canal is much wider in the labio-lingual (or labiopalatal) direction than mesio-distally, a softened gutta percha root filling technique should be used to fill the canal. Care should be taken not to apply too much pressure during root filling since this may dislodge the apical dome. In addition, the amount of heat used should be limited since the root walls are thin and the heat may be transmitted to the periodontal ligament with potential for adverse effects.

Restoration of an immature tooth that has undergone apexification is difficult as the pulp space is large and divergent, and the remaining root structure will be weak. Subsequent fracture of the root is a possible sequel to apexification procedures,104 especially if there is any further trauma to the tooth although it can also occur during normal function. The patient, and his/her parents, should be warned of this possibility before treatment is commenced. It has been recommended that these teeth should be strengthened by the use of an intracanal acid-etched composite resin restoration.106,107

Conclusion

The endodontic management of traumatized permanent anterior teeth has been reviewed and recommendations have been presented for each type of injury. The management of dental injuries is an evolving science. Some traditional treatment options have stood the test of time and are still valid to this day. Others have been reviewed and modified with the passage of time, as new science and new materials evolve to prove, disprove or facilitate approaches to the management of these injuries. Practitioners need to always be aware of changes that occur from time to time with respect to the recommendations for treatment, and of scientific studies that support or disprove treatment rationales. Regrettably, the amount of good evidence based research data on which to base treatment decisions is still lacking for most injuries to the teeth. Thus, while this paper has reviewed the endodontic management of traumatized anterior teeth in the light of past and present scientific studies,

it is inevitable that some of the proposed recommendations will themselves be modified as new science reviews the effectiveness of treatment methods, and new materials and techniques develop to facilitate treatment.

Dental trauma rarely involves just a single tooth. A typical injury may involve multiple injuries to both the teeth and the supporting tissues. Recommendations for single tooth treatment may not always be appropriate for multiple adjacent injuries. Treatment decisions still need to be based on practicality and experience, as well as an understanding of the literature.

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