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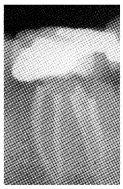

CASE REPORT

One step pulp revascularization treatment of an immature permanent tooth with chronic apical abscess: a case report

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Abstract

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Aim To describe a case in which a mandibular right second premolar with a necrotic pulp, sinus tract, periradicular radiolucency and an immature apex underwent revascularization via a single treatment approach.

Summary Revascularization procedures have the potential to heal a partially necrotic pulp, which can be beneficial for the continued root development of immature teeth. However, it is not clear which revascularization protocols are the most effective. This case report details the outcome of a successful revascularization procedure on tooth 45 (FDI) in a 12-year-old patient, eliminating the associated periapical pathosis within 19 months. The tooth was treated using coronal root irrigation with 6% NaOCl and 2% chlorhexidine without instrumentation in a single visit. The successful outcome of this case report suggests that this conservative revascularization treatment approach can preserve the vitality of the dental pulp stem cells and create a suitable environment for pulp regeneration, resulting in the completion of root maturation.

Key learning points

- The noninstrumentation procedure using 6% NaOCl and 2% chlorhexidine coronal irrigation may help preserve the remaining vital dental pulp stem cells believed to be critical for pulp revascularization.
- A single visit pulp revascularization protocol can be a favourable treatment option for an immature permanent tooth with a partially necrotic pulp.

Keywords: dental pulp stem cells, immature apex, pulp regeneration, revascularization, stem cells of the apical papilla.

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Introduction

Recently there has been evidence indicating that a better alternative to conventional calcium hydroxide apexification exists in immature permanent teeth exhibiting periapical pathology (Shah *et al.* 2008). Procedures attempting to preserve the potentially remaining dental pulp stem cells and mesenchymal stem cells of the apical papilla can result in canal revascularization and the completion of root maturation (Sonoyama *et al.* 2006, Huang *et al.* 2008). Revascularization of a partially necrotic pulp in an immature root is based on the concept that vital stem cells located in the apical papilla can survive pulpal necrosis, even in the presence of a periradicular infection (Huang *et al.* 2008). These stem cells are believed to differentiate into secondary odontoblasts, ultimately allowing for dentinal deposition (Huang *et al.* 2008). Survival of the stem cells is aided by an abundant blood supply to the apical papilla, contributing to pulp revascularization. In addition, it has been speculated that some vital dental pulp stem cells in the apical canal may survive partial pulpal necrosis, even in cases with associated periapical pathology (Lin *et al.* 1984, Iwaya *et al.* 2001, Huang *et al.* 2008). Previous studies involving tooth reimplantation indicate that apically survived pulp tissue can proliferate and replace the remnant coronal necrotic tissue (Ohman 1965, Barrett & Reade 1981, Skoglund & Tronstad 1981). Furthermore, some of these dental pulp stem cells may have the capacity to differentiate into odontoblast-like cells, contributing to root maturation (Yousef 1988, Shah *et al.* 2008). Maintaining the viability of the remaining survived pulp tissue and the stem cells of the apical papilla are considered critical for revascularization to succeed. Therefore, most recent case reports follow a protocol of no canal instrumentation throughout the revascularization procedure in order preserve these essential enduring stem cells (Iwaya *et al.* 2001, Chueh & Huang 2006, Jung *et al.* 2008).

The literature indicates several advantages of promoting apexogenesis in immature teeth with open apices (Murray *et al.* 2007). Contrary to apexification, apexogenesis encourages a longer and thicker dentinal composed root to develop (Rafter 2005). These beneficial anatomic properties may decrease the propensity of long-term root fracture, a significant risk associated with apexification procedures (Andreasen *et al.* 2002, Reynolds *et al.* 2009). Revascularization procedures attempt to obtain a longer and thicker root, whilst restoring vital pulpal conditions. A successfully revascularized tooth would require no additional treatment. Conversely, apexification involves supplementary treatment visits to replenish the calcium hydroxide and ultimately requires an apical plug of mineral trioxide aggregate (MTA) or final Gutta-percha canal filling (Rafter 2005).

Although it has been demonstrated clinically that revascularization procedures can be successful, it is not completely understood to what extent the preservation of the apical papilla is involved in final root maturation (Huang *et al.* 2008, Shah *et al.* 2008). Continued research is needed to determine if the stem cells of the apical papilla are irrefutably responsible for differentiation into odontoblasts and subsequently accountable for the characteristic dentinal deposition involved in typical root maturation (Chueh *et al.* 2009). Finally, research experiments investigating the outcome of intentionally removing the apical papilla in minipigs has failed to determine whether terminated root maturation is related to the destruction of the apical papilla stem cells or damage to Hertwig's epithelial root sheath (Huang *et al.* 2008).

Drawbacks of the revascularization process include a lack of long term follow up data on root canal morphology and pulpal cellular composition following the procedure on patients. This refers to the possibility of accelerated canal calcification, rendering the tooth more difficult to treat endodontically in the future (Shah *et al.* 2008). Furthermore, it has not been determined the stage and duration of pathosis that will ultimately lead to the complete destruction of the resistant apical mesenchymal cells and surviving dental pulp

stem cells. Under the circumstances of total pulpal and apical papilla necrosis, revascularization treatment may not be possible. As a result, it is difficult to case select appropriate teeth that clinically test nonvital, but maintain vital apical cells believed to be necessary to successfully perform the procedure. Additional complications such as various systemic health conditions and immunologic problems may offer other obstacles in achieving adequate root maturation in the presence of a periradicular infection.

The current case report examines the concept of pulp revascularization of a mandibular right second premolar via a single visit treatment approach. The objective was to determine if the presented protocol would result in the formation of a longer and thicker root in a tooth believed to exhibit a partial loss of vital pulp tissue. The resolution of periradicular pathology and related symptoms was considered essential for a successful outcome. Previous case reports illustrate a multi-visit treatment method to achieve satisfactory revascularization results (Chueh & Huang 2006, Jung *et al.* 2008, Shah *et al.* 2008). Banchs & Trope (2004) reported the successful revascularization of an immature mandibular right second premolar diagnosed with chronic apical abscess. The canal was disinfected with NaOCl and peridex to 1 mm of the apex without mechanical instrumentation. A tri-antibiotic paste, composed of metronidazole, ciprofloxacine and minocycline was placed for 2 weeks. At the second visit, a blood clot was produced to the level of the cementoenamel junction to provide a scaffold for the in-growth of new tissue, subsequently using MTA to provide an effective seal (Hoshino *et al.* 1996, Banchs & Trope 2004). In a similar clinical report, Chueh & Huang (2006) followed a more conservative revascularization technique to achieve analogous results. A periradicularly involved immature tooth was treated without instrumentation and irrigation with NaOCl was confined to the pulp chamber. A calcium hydroxide paste was then placed. Two additional visits were required to replenish the calcium hydroxide at coronal portion of the root to achieve comparable root maturation results (Chueh & Huang 2006). The current case report attempts to provide an utmost conservative single visit, modified technique to revascularize a partially necrotic pulp with associated chronic apical periodontitis.

Case report

A 12-year-old girl of Hispanic descent was referred by her general dentist for evaluation and root canal treatment of the mandibular right second premolar. The medical history was unremarkable. The patient was scheduled as an emergency visit with her general dentist 3 days prior, complaining of pain in the mandibular right premolar region. The dentist prescribed amoxicillin 500 mg PO tid. The intra-oral exam revealed an asymptomatic tooth 45 with an associated draining sinus tract located distal to the root (Fig. 1a). Vitality, percussion and palpation exams were performed on the tooth and adjacent teeth. Tooth 45 exhibited occlusal caries (Fig. 2a) with slight palpation and percussion sensitivity. It did not respond to 1, 1, 1, 2-tetrafluoroethane (Endo-Ice; Hygenic Corp., Akron, OH, USA) or the electric pulp test (Analytic Technology, Redmond, WA, USA). The adjacent teeth were caries free, asymptomatic and tested vital. The periodontal exam presented probings and physiologic mobility within normal limits.

Radiographic evaluation showed an immature open apex, measuring 2 mm in diameter with a large periradicular rarefaction approximately 9 × 9 mm in size, extending from the apex of tooth 45 to the distal crestal bone area. The periapical radiograph demonstrated a carious lesion associated with a pre-existing Oehlers type I dens invaginatus, where the developmental anomaly presents an enamel lined invagination terminating in a blind sac located within the crown. There was visible external inflammatory resorption on the mid distal portion of the root. Condensing osteitis was apparent at the periapical area of the tooth (Fig. 3a).

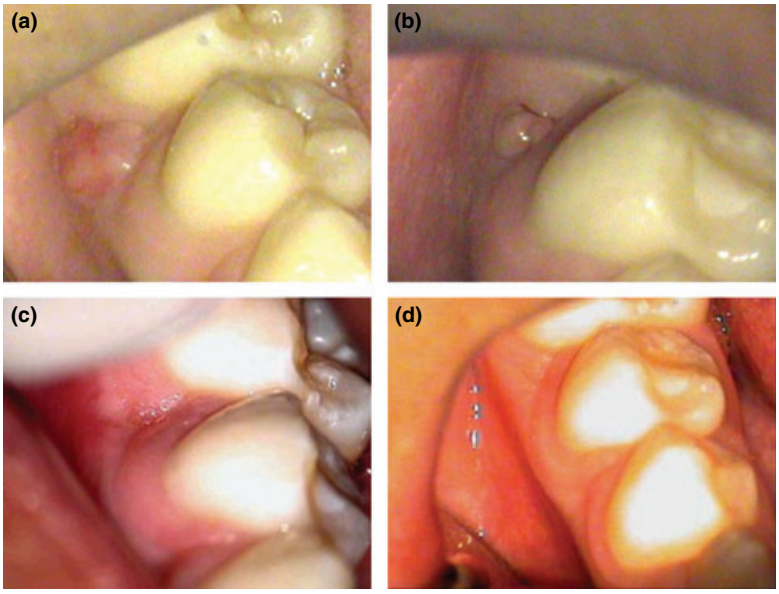

Figure 1 Clinical observations. (a) Pre-op clinical photograph illustrates a draining sinus tract distal to the mandibular right second premolar. Hypomineralized enamel is visible on the distal occlusal pit. (b) Two-week post-op photograph depicts a reduction in size of the sinus tract. (c) Six-week follow-up photograph demonstrates complete healing of the sinus tract. (d) At the seven-month post-op visit, re–establishment of normal gingival contour was observed.

The initial diagnosis of pulpal necrosis with suppurative chronic periapical abscess was determined for tooth 45. Following local anaesthesia administration, rubber dam isolation and occlusal access preparation using the dental operating microscope, all remaining caries and hypomineralized enamel were removed. Upon entering the coronal aspect of

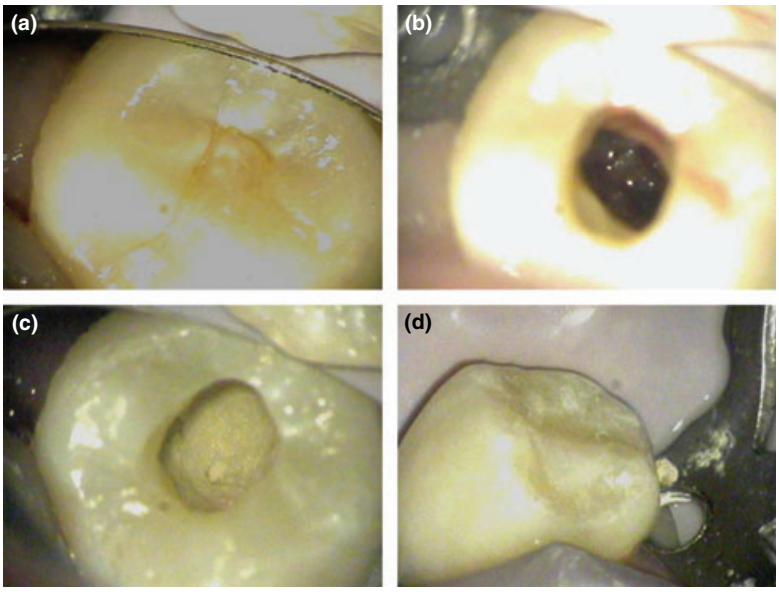

Figure 2 Root canal revascularization procedure. (a) Clinically, the mandibular right second premolar presented with distal pit caries. (b) After controlling the haemorrhage, viable tissue was observed in the canal. (c) The placement of white MTA in the canal. (d) Final composite restoration.

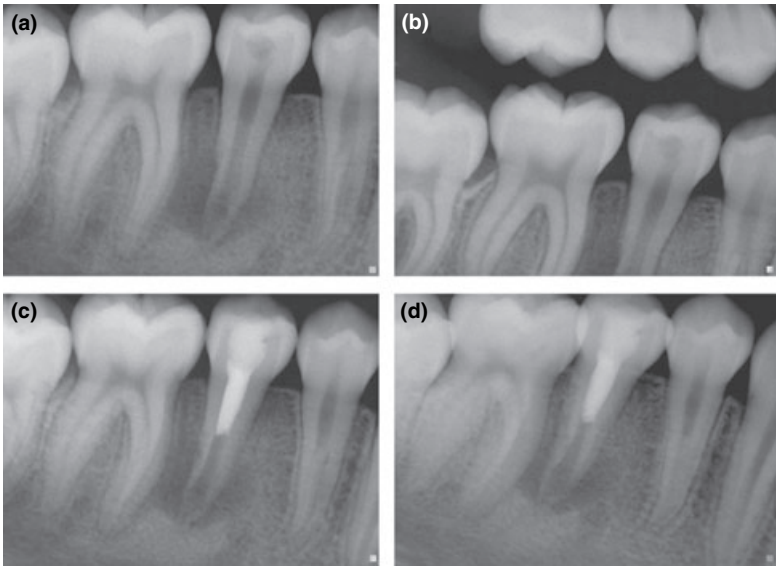

Figure 3 (a, b) Pre-treatment radiographs of tooth 45 (FDI). Radiographic examination demonstrates type I dens invaginatus with associated caries and incomplete root formation with diffuse periapical radiolucency measuring 9 × 9 mm in size. (c) Post-op radiographs show coronal canal MTA placement with a composite restoration. (d) Two-week follow-up radiograph shows a wide open apex.

the root canal, haemorrhage into the pulp chamber was observed (Fig. 2b). A size 10 K-file (Kerr, Romulus, MI, USA) was inserted into the canal and the patient reported discomfort, potentially indicating the survival of residual vital pulp tissue. The clinical diagnosis was revised from total pulpal necrosis to partial necrosis. After evaluating the treatment options, it was established that the patient would benefit greatest from a revascularization procedure. A thorough explanation of the potential risks, complications and benefits of the suggested treatment was carried out. The alternative option of conventional calcium hydroxide apexification was discussed. Based on the increased long-term risk of root fracture attributed to traditional calcium hydroxide apexification and the potential rewards of revascularization, maternal consent was obtained to initiate revascularization treatment. The proposed, most conservative treatment protocol is a modification of the Banchs & Trope (2004) and Chueh *et al. (*2009) clinical case reports. It was explained to the mother that they would be given additional options of the triple antibiotic paste technique or calcium hydroxide apexification if the current revascularization procedure did not succeed. The haemorrhaging coronal portion of the canal was irrigated with 10 mL of 6% NaOCl and then rinsed with sterile saline solution. The coronal canal was then irrigated with 10 mL of 2% chlorhexidine gluconate (Vista Dental, Racine, WI, USA) and left there for 5 min. No instrumentation was performed. The coronal canal was dried with paper points and white MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) was gently packed into the coronal canal (Fig. 2a). A thin layer of thermoplastic Gutta-percha (Calamus system, Dentsply Tulsa Dental, Johnson City, TN, USA) was temporarily placed over the MTA to prevent washing out and the chamber walls were etched with 37% phosphoric acid, rinsed with water and dried. Prior to restoring the access cavity with a final resin-bonded composite (ESPE Filtek, 3M, St Paul, MN, USA) restoration (Fig. 2d), the Gutta-percha was removed from the pulp chamber. The draining sinus tract was rinsed with 3 mL of 0.12% chlorhexidine gluconate (Peridex, Zila Pharmaceuticals, Inc, Cincinnati, OH, USA). The patient was instructed to complete the amoxicillin provided by her dentist and was prescribed ibuprofen 800 mg for pain. The mother was informed to call if there were any complications.

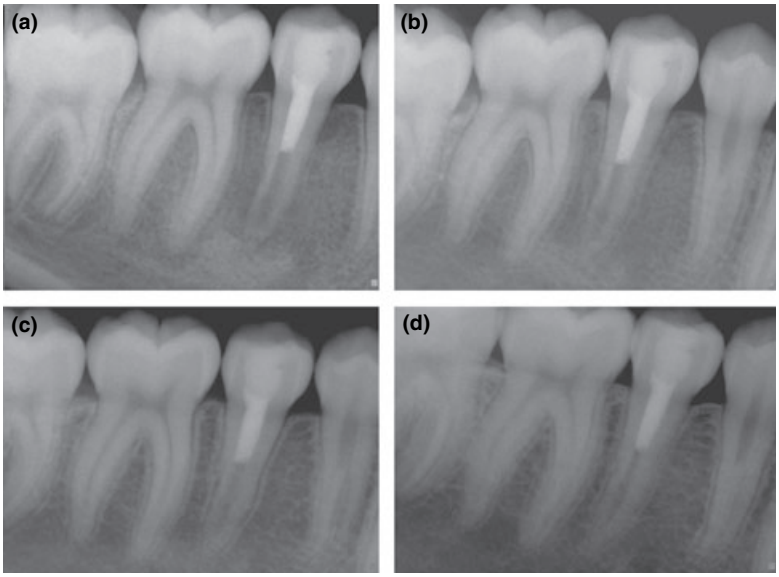

Figure 4 Post-treatment radiographs of tooth 45. (a) Six-week post-op radiograph shows thickening of dentinal walls with no evidence of the lamina dura apically. (b) At the seven-month recall, a re-establishment of the periodontal ligament space and lamina dura was observed. Root maturation is visible. (c) Thirteen-month follow-up radiograph shows further thickening of the lamina dura and maturation of the root. (d) At the 19-month post-op visit, a complete maturation of the apex and resolution of condensing osteitis are evident.

The patient returned for the 2-week follow-up visit, asymptomatic with no sensitivity to palpation or biting. The tooth exhibited minimal sensitivity to percussion. No significant radiographic changes were noted. (Fig. 3d) The smaller sinus tract (Fig. 1b) was irrigated with 3 mL of 0.12% chlorhexidine gluconate.

At the 6-week recall appointment, the patient returned asymptomatic. Tests for percussion, mobility, palpation and biting sensitivity were all within normal limits. The sinus tract had completely healed (Fig. 1c) and the periapical radiolucency became less radiolucent. The diameter of the open apex had decreased and thickening of the radicular walls were evident. Periodontal probing depths were normal. No additional treatment was administered.

The patient returned for the 7-month post-op visit completely asymptomatic. Radiographically, the lamina dura could be traced around the entire root surface and the periodontal ligament space was re-established. The alveolar crestal bone around the tooth had healed and condensing osteitis became less radiopaque (Fig. 4b). Clinically, there was a complete re-establishment of gingival contour (Fig. 1d). The Endo Ice test and electric pulp test did not elicit a response.

At the 13- and 19-month follow-up appointments, the patient remained asymptomatic. No tenderness to percussion or palpation was noted. Periodontal pocket depths and physiologic mobility were within normal limits. The Endo ice test and electric pulp test were negative. The radiographs demonstrated evidence of complete periradicular bone healing and root maturation (Fig. 4c,d). The 19-month follow-up radiograph showed complete resolution of condensing osteitis (Fig. 4d).

Discussion

The conventional calcium hydroxide apexification procedure has been extensively studied and appears to be a reliable treatment option. However, the technique has several disadvantages. These include a lengthy treatment period, complications relating to poor

patient compliance and resulting thin dentinal walls with a high risk of long-term root fracture (Cvek & Sundstrom 1974, Andreasen *et al.* 2002). Contemporary research articles examine alternative treatment options to encourage a root maturation process emulating natural root formation, even in the presence of extensive periapical pathology (Banchs & Trope 2004, Chueh & Huang 2006, Jung *et al.* 2008). Revascularization treatment has been suggested to be a favourable alternative, yielding the development of a longer and thicker root, less susceptible to fracture. Using a modified technique, originally outlined by Banchs & Trope (2004), the current investigation offers a more conservative single visit approach, avoiding apical irritation and focuses on preserving the remaining vital pulp tissue and mesenchymal stem cells of the apical papilla. Preservation of these cells is believed to be critical for successful revascularization (Huang *et al.* 2008).

An Oehlers type I dens invaginatus is a developmental anomaly characterized by a hypomineralized, enamel-lined invagination appearing as a radiolucent blind sac in the crown (Canger *et al.* 2009). The deep invagination is susceptible to carious progression because of the hypomineralized quality of the enamel and the exposure of the invagination to the oral environment (Canger *et al.* 2009). If left untreated it often results in necrosis of the pulp and periradicular infection (Cengiz *et al.* 2006, Canger *et al.* 2009). Depending on the stage of pathogenesis, treatment options can vary from preventive and restorative options to nonsurgical root canal treatment (Er *et al.* 2007). When conventional root canal treatment fails, surgical treatment may be necessary (Canger *et al.* 2009). In the present case, tooth 45 appeared radiographically as an Oehlers type I dens invaginatus, with the formation of an associated carious lesion and periapical abscess. The developmental anomaly and pathology was successfully treated through the revascularization procedure and final composite restoration.

The presented case report used NaOCl and chlorhexidine irrigation of the coronal necrotic tissue and systemic antibiotics to provide a favourable environment for pulpal revascularization to proceed. The amoxicillin, prescribed by the general dentist, may have aided the bactericidal activity in the periapical area. The irrigant, 2% chlorhexidine was selected based on its extended residual anti-microbial properties and a relative absence of toxicity (Greenstein *et al.* 1986, Jeansonne & White 1994). An *in vitro* study has reported that root canals treated with 2% chlorhexidine had 72 h of residual antimicrobial activity against *Streptococcus mutans* (White *et al.* 1997). Recent questions concerning the use of 2% chlorhexidine relates to the potential cytotoxicity on cultured dental pulp stem cells. In addition, it has been reported that interactions between NaOCl and chlorhexidine forms *para*-chloroaniline, which is known to be a carcinogen (Basrani *et al.* 2007). Basrani *et al.* (2007) suggested that prior to irrigating with chlorhexidine, it is recommended to wash away the existing NaOCl to diminish the formation of *para*-chloroaniline. The current report used copious irrigation of saline solution to reduce the interaction between NaOCl and chlorhexidine. Further research is needed to weigh the benefits of the residual antimicrobial activity of chlorhexidine versus the cytotoxicity and carcinogenicity of para-chloroaniline.

Mineral trioxide aggregate was used in the study to provide an effective pulpal seal. Contrary to calcium hydroxide, MTA exhibits biocompatibility with adjacent pulp tissue, even capable of inducing pulpal cell proliferation (Kettering & Torabinejad 1995, Fridland & Rosado 2005). In addition, MTA sustains a high pH for extended periods of time and has exceptional marginal adaptation (Torabinejad *et al.* 1995, Moghaddame-Jafari *et al.* 2005). MTA was used as a coronal plug based on its known beneficial properties demonstrated during vital pulp therapy (Torabinejad & Chivian 1999).

There are several advantages of the single visit revascularization protocol. Eliminating subsequent access appointments to the root canal environment may reduce the possibility of further bacterial contamination of the canal. Single visit procedures also

act to diminish the detrimental consequences of poor patient compliance for regular follow-up evaluation. Decreased successive trauma to the tooth and increased patient comfort are other potential benefits of completing the treatment in one visit.

A variety of revascularization techniques have demonstrated that periapically involved immature teeth that initially appear to have necrotic pulps can undergo the procedure and respond positive to vitality testing over extended periods of evaluation (Iwaya *et al.* 2001, Banchs & Trope 2004, Reynolds *et al.* 2009). These reports indicate that the revascularized teeth regained vitality between 15 months to 2 years. The current case did not achieve a conclusive positive vitality response at the 19-month follow-up appointment. It is possible that over longer periods of evaluation, the tooth may generate a positive response.

In conclusion, the presented case report demonstrates a conservative, single visit revascularization approach, resulting in the elimination of periapical pathology and a stronger mature root. Whilst the discussion advocates following a more conservative technique, it is possible that this single visit approach may not be applicable to all revascularization cases. It is believed that with teeth exhibiting complete pulpal necrosis, the presented protocol would not have succeeded. A more aggressive technique may be required to eradicate the bacteria in the canal system and periapical tissues. A multi-visit, tri-antibiotic paste sequence could be a better treatment choice for teeth potentially presenting with total pulpal necrosis. As a result, case selection is critical when deciding which revascularization protocol is ideal for a particular pulpal condition. Patients that report discomfort to an advancing file within the canal may indicate the presence of viable canal tissue. It is suggested that in these cases, the current technique can be beneficial prior to attempting the less conservative tri-antibiotic sequence or calcium hydroxide apexification. Further investigation is needed to properly diagnose the correct pulpal status of a tooth and design treatment guidelines depending on the stage of pulpal necrosis to obtain a predictable outcome.

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References

Andreasen JO, Farik B, Munksgaard EC (2002) Long-term calcium hydroxide as a root canal dressing may increase the risk of root fracture. *Dental Traumatology* **18**, 134–7.

Banchs F, Trope M (2004) Revascularization of immature permanent teeth with apical periodontitis: new treatment protocol? *Journal of Endodontics* **30**, 196–200.

Barrett AP, Reade PC (1981) Revascularization of mouse tooth isografts and allografts using autoradiography and carbon-profusion. *Archives in Oral Biology* **26**, 541–5.

Basrani B, Manek S, Sodhi R, Fillery E, Manzur A (2007) Interaction between sodium hypochlorite and chlorhexidine gluconate. *Journal of Endodontics* **33**, 966–9.

Canger EM, Kayipmaz S, Celenk P (2009) Bilateral dens invaginatus in the mandibular premolar region. *Indian Journal of Dental Research* **20**, 238–40.

Cengiz SB, Korasli D, Ziraman F, Orhan K (2006) Non-surgical root canal treatment of dens invaginatus: reports of three cases. *International Dental Journal* **56**, 17–21.

Chueh LH, Huang GT (2006) Immature teeth with periradicular periodontitis or abscess undergoing apexogenesis: a paradigm shift. *Journal of Endodontics* **32**, 1205–13.

Chueh LH, Ho YC, Kuo TC, Lai WH, Chen YH, Chiang CP (2009) Regenerative endodontic treatment for necrotic immature permanent teeth. *Journal of Endodontics* **35**, 160–4.

Cvek M, Sundstrom B (1974) Treatment of non-vital permanent incisors with calcium hydroxide, V. Histologic appearance of roentgenologically demonstrable apical closure of immature roots. *Odontologisk Revy* **25**, 379–92.

Er K, Kustraci A, Ozan U, Tasdemir T (2007) Nonsurgical endodontic treatment of dens invaginatus in a mandibular premolar with large periradicular lesion: a case report. *Journal of Endodontics* **33**, 322–4.

Fridland M, Rosado R (2005) MTA solubility (a long term study). *Journal of Endodontics* **31**, 376–9.

Greenstein G, Berman C, Jaffin R (1986) Chlorhexidine: an adjunct to periodontal therapy. *Journal of Periodontology* **57**, 370–6.

Hoshino E, Kurihara-Ando N, Sato I *et al.* (1996) In-vitro antibacterial susceptibility of bacteria taken from infected root dentine to a mixture of ciprofloxacin, metronidazole and minocycline. *International Endodontic Journal* **29**, 125–30.

Huang G, Sonoyama W, Liu Y (2008) The hidden treasure in apical papilla: the potential role in pulp/dentin regeneration and bioroot engineering. *Journal of Endodontics* **34**, 645–51.

Iwaya S, Ikawa M, Kubota M (2001) Revascularization of an immature permanent tooth with apical periodontitis and sinus tract. *Dental Traumatology* **17**, 185–7.

Jeansonne JJ, White R (1994) A comparison of 2.0% chlorhexidine gluconate and 5.25% sodium hypochlorite as antimicrobial endodontic irrigants. *Journal of Endodontics* **20**, 276–8.

Jung IY, Lee SJ, Hargreaves KM (2008) Biologically based treatment of immature permanent teeth with pulpal necrosis: a case series. *Journal of Endodontics* **34**, 876–87.

Kettering JD, Torabinejad M (1995) Investigation of mutagenicity of mineral trioxide aggregate and other commonly used root end filling materials. *Journal of Endodontics* **21**, 537–9.

Lin L, Shovlin F, Skribner J, Langeland K (1984) Pulp biopsies from the teeth associated with periapical radiolucency. *Journal of Endodontics* **10**, 436–48.

Moghaddame-Jafari S, Mantellini MG, Botero TM, McDonald NJ, Nor JE (2005) Effect of proroot MTA on pulp cell apoptosis and proliferation in vitro. *Journal of Endodontics* **31**, 387–91.

Murray PE, Garcia-Godoy F, Hargreaves KM (2007) Regenerative endodontics: a review of current status and a call for action. *Journal of Endodontics* **33**, 377–90.

Ohman A (1965) Healing and sensitivity to pain in young replanted human teeth: an experimental, clinical and histological study. *Odontologisk Tidskrift* **73**, 168–227.

Rafter M (2005) Apexification: a review. *Dental Traumatology* **21**, 1–8.

Reynolds K, Johnson D, Cohenca N (2009) Pulp revascularization of necrotic bilateral bicuspids using a modified novel technique to eliminate potential coronal discolouration: a case report. *International Endodontic Journal* **42**, 84–92.

Shah N, Logani A, Bhaskar U (2008) Efficacy of revascularization to induce apexification/apexogenesis in infected, nonvital, immature teeth: a pilot clinical study. *Journal of Endodontics* **34**, 919–25.

Skoglund A, Tronstad L (1981) Pulpal changes in replanted and autotransplanted immature teeth of dogs. *Journal of Endodontics* **7**, 309–16.

Sonoyama W, Lin Y, Fang D *et al.* (2006) Mesenchymal stem cell-mediated functional tooth regeneration in swine. *PLoS ONE* **1**, e79.

Torabinejad M, Chivian N (1999) Clinical applications of mineral trioxide aggregate. *Journal of Endodontics* **25**, 197–205.

Torabinejad M, Wilder Smith P, Pitt Ford TR (1995) Comparative investigation of marginal adaptation of mineral trioxide aggregate and other commonly used root-end filling materials. *Journal of Endodontics* **21**, 295–9.

White R, Hays G, Janer L (1997) Residual antimicrobial activity after canal irrigation with chlorhexidine. *Journal of Endodontics* **23**, 229–31.

Yousef SaadA (1988) Calcium hydroxide and apexogenesis. *Oral Surgery, Oral Medicine & Oral Pathology* **66**, 499–501.

