Revascularization: A Treatment for Permanent Teeth with Necrotic Pulp and Incomplete Root Development

Ronald Wigler, DMD, Arieh Y. Kaufman, DMD,* Shaul Lin, DMD,*† Nelly Steinbock, DMD,* Hagai Hazan-Molina, DMD,‡ and Calvin D. Torneck, DDS, MS§*

Abstract

Introduction: Endodontic treatment of immature permanent teeth with necrotic pulp, with or without apical pathosis, poses several clinical challenges. There is a risk of inducing a dentin wall fracture or extending gutta-percha into the periapical tissue during compaction of the root canal filling. Although the use of calcium hydroxide apexification techniques or the placement of mineral trioxide aggregate as an apical stop has the potential to minimize apical extrusion of filling material, they do little in adding strength to the dentin walls. It is a well-established fact that in reimplanted avulsed immature teeth, revascularization of the pulp followed by continued root development can occur under ideal circumstances. At one time it was believed that revascularization was not possible in immature permanent teeth that were infected. **Methods:** An in-depth search of the literature was undertaken to review articles concerned with regenerative procedures and revascularization and to glean recommendations regarding the indications, preferred medications, and methods of treatment currently practiced. **Results:** Disinfection of the root canal and stimulation of residual stem cells can induce formation of new hard tissue on the existing dentin wall and continued root development. **Conclusions:** Although the outcome of revascularization procedures remains somewhat unpredictable and the clinical management of these teeth is challenging, when successful, they are an improvement to treatment protocols that leave the roots short and the walls of the root canal thin and prone to fracture. They also leave the door open to other methods of treatment in addition to extraction, when they fail to achieve the desired result. *(J Endod 2013;39:319–326)*

Key Words

Apexification, apexogenesis, immature permanent tooth, maturogenesis, mineral trioxide aggregate, regeneration, revascularization, revitalization, triple antibiotics

Unlike fully developed teeth, pulp necrosis of an immature permanent tooth with apical inflammation does not preclude the presence of residual pulp progenitor cells in the apical third of the root canal (1–4). It does, however, create a situation where achieving the goals of conventional root canal treatment is not only difficult, but even when these are met, it leaves the root short, weak, and prone to fracture (5). Although some of the technical difficulties associated with conventional root canal treatment can be overcome when a calcium hydroxide [$Ca(OH)_2$] apexification approach (6) or an apical plug of mineral trioxide aggregate (MTA) is used (7), the risk of future root fracture and tooth mobility because of a poor root-crown ratio still remains.

In the retrospective clinical study by Cvek (5), the frequency of cervical root fractures was markedly higher in endodontically treated immature teeth than in mature teeth and ranged in incidence from 28%–77%, in accordance with the stage of root development. This finding emphasized the importance of preserving pulp vitality of the immature teeth involved in dental trauma or deep caries.

Conventional root canal preparation of immature permanent teeth with necrotic pulp and apical pathosis presents several treatment challenges. Mechanical cleaning with instruments that remove dentin is contraindicated, because it may further weaken the already thin root canal walls. Obturation of the root canal without extending the root canal filling into periapical tissues is clinically challenging, even for the experienced clinician; the large apical opening that at times can have a divergent configuration does not provide the mechanical stop necessary to confine the filling material to the root canal. In 1966 Alfred L. Frank (6) published an article describing a clinical technique aimed at inducing apical closure. By using repeated $Ca(OH)_2$ dressings during a 3- to 6-month period, he demonstrated that it was possible not only to induce healing of the apical lesion but also to induce closure of the root apex with calcified tissue (apexification). In some of the teeth in his case series, there was also continued formation of the root. In a subsequent series of articles by Torneck et al (1–4), these events appeared to be related not only to the ingress of a new population of cells but also to the stimulation of residual papilla and root sheath cells that survived the apical infection.

Later, Cvek (8) reported on the outcome of 55 nonvital permanent incisors treated by apexification and noted that in 50 incisors there were healing and apical closure but no continued root formation 14–21 months posttreatment. He reported that the healing rate was dependent on the width of the apical foramen and the diameter of the periapical lesion. He concluded that the long-term outcome of apical closure and periapical healing had a high predictability rate.

However, apexification with $Ca(OH)_2$ has several disadvantages. It requires multiple visits during a long period of time (6–24 months; average, 1 year ± 7 months) (9, 10), it depends on the parents' commitment to ensure the child's dental visits are

From the *Endodontics and Dental Traumatology Department, Graduate School of Dentistry, Rambam Health Care Campus, Haifa, Israel; †B. Rappaport-Faculty of Medicine, Technion Israel Institute of Technology, Haifa, Israel; ‡Orthodontic and Craniofacial Department, Graduate School of Dentistry, Rambam Health Care Campus, Haifa, Israel; and §Discipline of Endodontics, University of Toronto, Toronto, Ontario, Canada.

Address request for reprints to Dr Ronald Wigler, Department of Endodontics and Dental Traumatology, School of Graduate Dentistry, Rambam Health Care Campus, P.O.B 9602, Haifa 31096, Israel. E-mail address: dr.wigler@gmail.com

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2012.11.014

kept, and it undermines the mechanical strength of dentin because of a prolonged exposure to $Ca(OH)_2$ (10).

An alternative $Ca(OH)_2$ apexification was suggested by Torabinejad and Chivian (7). They suggested that cleaning the root canal and sealing the open apex with MTA in 1 or 2 visits could minimize the risk of root canal overfilling and promote apical repair. Simon et al (11) assessed the outcome of this technique in only 1 appointment in teeth with open apices and apical lesions and concluded that it was a reasonable and predictable treatment alternative to $Ca(OH)_2$ apexification. Although this procedure offered a favorable healing outcome and required only 1 appointment (12), it still did little to improve on 2 shortcomings of the $Ca(OH)_2$ apexification technique, namely the predisposition to root fracture and the failure to stimulate root development (5). These shortcomings prompted clinicians to continue the search for a procedure that promoted post-treatment pulp regeneration, dentin formation, and root development (13).

Nygard Ostby (14), a pioneer of regenerative endodontic procedures in the early 1960s, showed that new vascularized tissue could be induced in the apical third of the root canal of endodontically treated mature teeth with necrotic pulps and apical lesions. This was accomplished by the creation of a blood clot in the apical third of a cleaned and disinfected root canal by using an apically extended root canal file just before root canal filling. He proposed that through formation of a clot (scaffold), a vasculature could be established to support growth of new tissue into the unfilled portion of the root canal. He provided histologic evidence in support of his concept that was taken surgically from teeth that had been treated in this manner.

Revascularization with continued root development and continued deposition of hard tissue in the root canal has also been shown to occur over time when immature teeth were reimplanted after intentional or traumatically related avulsion (15, 16). Extraoral time and degree of root maturation were shown to be important factors in the clinical success of this procedure (16, 17). It became apparent that the larger the foramen, the greater is the opportunity for ingrowth of a new blood supply and the reestablishment of new tissue. It was also apparent that the shorter the extraoral time, the lesser is the risk of infection and hence the greater the chance for cells to retain their vitality (16, 17). It appeared that the "devascularized" pulp acted as a matrix into which the new blood vessels and tissue could grow (17, 18). Skoglund and Tronstad (17) investigated changes that occurred in the root canal of replanted and autotransplanted immature teeth and reported that during the first 6 months there was an ingrowth of vascularized, cell-rich connective tissue throughout the entire root canal. After 6 months most teeth displayed a marked reduction in the number of cells and blood vessels and a newly formed atubular hard tissue. In some teeth, a pulp with a functioning odontoblastic layer was present (17).

In 2001, Iwaya et al (19) described a procedure, which they termed *revascularization*, that was undertaken on a necrotic immature mandibular second premolar with a chronic apical abscess. After 30 months they noted thickening of the root canal walls by mineralized tissue and continued root development.

Subsequent to this case report, Banchs and Trope (18) described a revascularization procedure for the treatment of a necrotic immature mandibular second premolar with an open apex and a large apical lesion. They stated that many thought that regeneration of pulp tissue in a necrotic infected tooth with apical periodontitis was impossible. Nonetheless, because it had been radiographically proven that regeneration was possible in a re-implanted tooth, the same could be accomplished in an infected tooth if a favorable environment was established. After accessing the root canal, they irrigated it with sodium hypochlorite (NaOCl) and chlorhexidine gluconate (CHX) and sealed in a combination of 3 antibiotics in an attempt to disinfect it and stimulate periapical repair. After 24 months, they found that the root development in the treated tooth was progressing in a manner similar to that of adjacent and contralateral teeth. On the basis of these findings, they proposed a clinical protocol for revascularization of infected immature teeth that they believed would stimulate pulp regeneration and promote apical closure (18). Although the predictability of this procedure and the true nature of the tissue that developed in the root canal posttreatment were unknown, they believed that the benefits of the procedure, when successful, made it one worth the attempt. These sentiments were supported by Murray et al (20), who also added that the procedure was technically simple, inexpensive, and adapted to currently available instruments and medicaments.

The drugs required for root canal disinfection can be obtained from any pharmacy and can be easily introduced into the root canal by using readily available instruments (21). Furthermore, if the revascularization fails, other more traditional treatment options remain available (21). Whether the newly regenerated tissue is truly pulp or only pulp-like is of little consequence, as long as the root is strengthened by the deposition of new mineralized tissue in the root canal and continued development of the root occurs (18).

At present, the use of the term *revascularization* is debatable. Trope (22) claimed that the term *revascularization* was chosen because the nature of the tissue formed posttreatment was unpredictable, and the only certainty was the presence of a blood supply; hence it was "revascularized." Huang and Lin (23) challenged the term *revascularization* as applied to endodontic procedures and believed it was more applicable to events that followed dental trauma. They gave 7 reasons why this term was inappropriate for procedures designed to stimulate tooth maturation and suggested the term *induced or guided tissue generation and regeneration*. More recently, Lenzi and Trope (24) suggested the term *revitalization* as being more appropriate because it is descriptive of the nonspecific vital tissue that forms in the root canal. In 2003, Weisleder and Benitez (25) suggested the term *maturogenesis* for a direct pulp-capping procedure of a tooth with deep caries that resulted in the complete development of the tooth. They claimed maturogenesis best describes the physiologic development of the root that occurs rather than development restricted to the apical segment. Patel and Cohenca (26) also agreed that the term *maturogenesis* was equated with physiological root development and not simply apical development.

In 2008, Hargreaves et al (27) used the term *maturogenesis* to describe "continued root development" in contrast to apexogenesis, which they describe as "apical closure." They too challenged the use of the term *revascularization* for regenerative endodontic procedures, claiming that the goal of treatment was to regenerate a pulp-dentin complex with functional properties that are capable of supporting continued root development, while resolving apical periodontitis. Huang and Lin (23) also have suggested the use of this term when a nontraditional approach is used in the treatment of nonvital immature permanent teeth with apical pathosis. Because this new approach in the management of immature teeth with apical lesions has been described in different terms by different investigators, it has caused confusion among clinicians. We suggest that the term *apexogenesis* be used for procedures designed to encourage continued apical development in teeth with some vital tissue in the root canal, and the term *maturogenesis* be used for procedures that promote continued root development in infected immature permanent teeth, rather than revascularization or revitalization. Hopefully, universally accepted terms for these procedures will eventually be considered and resolved by the American Association of Endodontists.

Regenerative endodontic procedures are biologically based procedures designed to restore function to a damaged and nonfunctioning