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Mini Review

Failures of Endodontic Treatment: Pulp Floor and Root Perforations

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Abstract

Endodontic procedures include partial and total pulpotomy, pulpectomy, apexification, and apexogenesis. Failures of endodontic treatment implicate bacterial infection. Regenerative endodontic therapies involve pulp floor and root perforations. Failures occurr after the disinfection and removal of necrotic tissues. Three possible mechanisms include perforations that arise primarily through: 1) procedural errors occurring during root canal treatment, 2) post-space preparation, and 3) resorptive processes. Inadequacy of endodontic treatments involve mostly bacterial infection (or re-contamination). In addition, bur perforation during access opening during the search for canal orifices, excessive removal of dentin, either with hand or rotary instruments, and/or unsuccessful attempts at bypassing separated instruments. Root canal perforations may also result from excessive removal of tooth structure. This is occurring in anatomically vulnerable locations such as the mesial roots of lower molars. Classification of perforation divides the root into the coronal, crestal, and apical portions. They are implicated in root perforation and/or bacterial re-infections. Transportation, ledge and zipped are also important factors implicated in endodontic failures.

Keywords: Endodontic Failures; Pulp Floor; Root Perforation; Apexification; Apexogenesis; Transportation; Ledge; Zipped; Root Perforations

Introduction

The anatomy of the pulp chamber has been revisited [1]. At the end of the crown formation, inter-radicular tiny opening of the floor of the pulp chamber favour such fortuitous incidents.

The aberrant holes are due to localised failures in the formation of Epithelial Hertwigs Root Sheath (HERS), with a consequent lack of odontoblast differentiation and dentin formation in this interradicular area. Between roots, an opercule remains open where the pulp persist and is in contact with the follicule and/or the periodontal tissues. The gap in Hertwigs sheath is produced by the lack of sequestering of abnormal blood vessels. They cross the whole thickness of the dentin layer and expand within the pulp [2].

These epithelial protrusions appear as non-mineralized round or oval parts located in the center of the pulp floor between the roots. The connections may persists between the periodontal ligament and the pulp chamber. Interroot proliferation divides the lower part of the crown in asymetric spaces [3,4] (Figures 1). Epithelial cells proliferate and usually merge in the central part of the interradicular pulp floor. In a few cases, they failed to merge, and a non-mineralized tiny canal persists in the center of the pulp floor. Accessory canals were demonstrated in the "furcation region" in 28.4% of the total samples[In the furcation’s, 25.5% exhibited central canals, while 10.2% canals were registered on the lateral root surface.

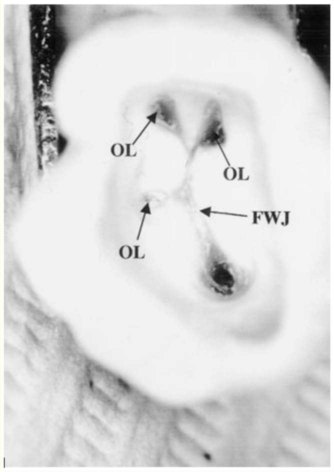

Figure 1: The orifices of root canals may be difficult to find [1].

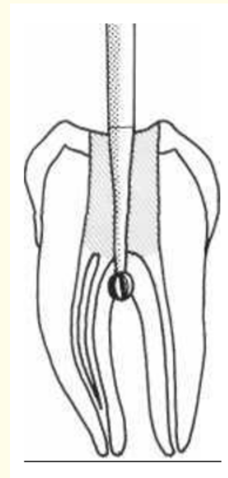

Figure 2: Accidental root floor perforation.

Repair of furcal perforations

Following the diagnosis of furcal perforation, during endodontic treatment accidental perforations may occur in the interradicular pulp chambers (2 - 12% of endodontic treatments). The accident happen 1) when the canal is calcified or curved, 2) when perforation are occurring in the floor of the pulp chamber, or 3) when a non-mineralized channel persists in the furcation of two- or multi-rooted teeth (Figures 1 and 2) [4]. If it is a fresh perforation, treated immediately under aseptic conditions, the prognosis of the treatment is good. If the perforation is old accompanied by bacterial infection, the prognosis is questionable. In contrast, apical perforations have a relatively good prognosis.

In order to evaluate the differences between a hydroxylapatite-based material, a calcium sulfate (plaster of Paris) and a resin-modified glass-ionomer cement (RM-GIC) to repair perforations, standardized holes were created in the center of the floors of pulp chamber. After 1, 3 and 6 months, success was found to be about 67% for calcium sulfate, 62% for the hydroxylapatite and 59% for the GIC. The results obtained with MTA allowed a more favorable response compared with the other drugs (Figure 2).

The dental pulp is an ecto-mesenchymally derived connective tissue. It is encased in hard tissues. The pulp provides a matrix binding the cells and organizes a tissue network allowing communications between the cells. In addition to immune cells, the dental pulp contains odontoblasts.

The advances and achievements in the field of stem cell regenerative medicine have inspired biological approaches to apexogenesis in young patients suffering from pulpitis or periapical periodontitis. The clinical regeneration of root apex may be mediated by adult stem cells [5,6].

Bone Marrow Mesenchymal Stem Cells (BMMSCs) have the ability to adhere to a plastic surface. They display high proliferative potential. They possess the self-renewal capacity to form colonies in vitro and they may differentiate into multiple cell lineages such as osteoblasts, adipocytes, chondrocytes, muscle cells, tenocytes, and nerve cells. BMMSCs express the Oct-4, Nanog, STRO-1, CD73, CD90, CD105, CD146 and are negative for CD14, CD34, CD45 and human leukocyte antigen-DR. BMMSCs have a great potential for stem cell-based regenerative therapies, established on their multilineage differentiation potential and their high proliferative capacity.

The revascularization method assumes that the root canal space has been disinfected and the formation of blood clot produces a matrix that traps cells capable of initiating new tissue formation. The treatment effect of apexogenesis is different from apexification because not only the apex is closed but the canal walls are thicker. All the studies report the continued thickening of the dentinal walls and the subsequent apical closure. In addition, the root length is increased by the growth of cementum.

The completion of root development and closure of the apex occurs up to 3 years after eruption of the tooth. The inner and outer enamel epithelium are no longer separated by the stratum intermedium and stellate reticulum, but develop as a two layered epithelial wall to form Hertwig's epithelial root sheath [7].

Complete destruction of Hertwig's epithelial root sheath results in cessation of normal root development. This does not mean that there is an end to deposition of hard tissue in the region of the root apex. Once the sheath has been destroyed, there is no further differentiation of odontoblasts. However, hard tissue can be formed by cementoblasts that are normally present in the apical region and by the fibroblasts of the dental follicle and periodontal ligament that undergo differentiation after the injury to become hard tissue producing cells.

The goals of apexogenesis were as follows:

- Allowing a continued development of root length for a more favorable crown-to-root ratio.
- Allowing the remaining odontoblasts to lay down dentin, producing a thicker root and decreasing the risks of root fracture.
- Promoting root end closure, creating a natural apical constriction for root canal filling.
- Generating a dentinal bridge at the site of the pulpotomy. It suggests that the pulp has maintained its vitality.

Apexogenesis is a natural physiologic process of root development. The term is used to describe the endodontic procedure of preservation of pulp vitality. It has also been suggested that maturogenesis is a more appropriate term than apexification, because not only the apex but the entire root is allowed to mature [7,8].

Calcium hydroxide induced the deposition of calcified material. It became the standard treatment protocol for the treatments of non-vital immature tooth. Many other biomaterials have been used to induce apexification, but none has replaced calcium hydroxide. However, calcium hydroxide – induced apexification might require 6 - 24 months for barrier formation. The barrier formed is often porous and discontinuous. Further development of the root does not take place. Intra-canal calcium hydroxide dressing can also make the tooth brittle because of its proteolytic properties. The rationale of revascularization is that if a sterile tissue matrix is provided in which new cells can grow, pulp vitality can be re-established. It provide a matrix into which the cells from the periapical tissues could grow and re-establish pulp vascularity, slowly replacing the necrotic tissue. It is possible that a few vital pulp cells remain at the apical end of the root canal. These cells may proliferate into the newly formed matrix and differentiate into odontoblasts. The newly formed odontoblasts can lay down atubular dentin at the apical end, causing apexogenesis, as well as on lateral aspects of dentinal walls of the root canal, reinforcing and strengthening the root.

Other possibile mechanisms implicated in apexogenesis are the followings:

- The development of multipotent dental pulp stem cells. They differentiate into odontoblasts and deposit tertiary or atubular dentin.
- Cementum and Sharpey's fibers are at the origin of the newly formed tissues.
- Stem cells from the apical papilla or the bone marrow can form bone or dentin *in vivo.*
- The blood clot itself is a reservoir of growth factors. The advantage is that achieving continued root lengthening and strengthening, result as a reinforcement of lateral dentinal walls with deposition of new dentin/hard tissue.
- Complete root development requires a viable pulp containing cells that can differentiate into dentin-producing odontoblasts. The dental pulp is complex with a variety of cells, nerves, and blood vessels. It is important to keep in mind the required prerequisites, including
- Cells that are capable of differentiating into pulp cells,
- The proper signal that is required for the differentiation,
- An appropriate scaffold that is suitable for guiding regeneration of the tissues [9].

Apexification

Apexification is a method of inducing a calcified apical barrier or continued apical development of an incompletely formed root in which the pulp is necrotic [8,9]. The developing consensus approach to accomplish apexification is to instrument root canals, to remove the necrotic tissue, and to place MTA in the root canal apex, with the remainder of the canal obturated with gutta-percha.

In the absence of a vital pulp, dentin deposition is arrested. When an immature tooth is affected by caries or trauma, the pulp requires proper management according to the degree of inflammation and keeping some vitality.

Artificial apical barriers are formed after implantation of a variety of materials. Apexification was demonstrated in a complete layer of cementum when using MTA as a root-end filling inducing apical hard tissue formation in immature roots.

An alternative treatment of the immature permanent tooth is apexification procedures. The classic apexification method involves long term application of Ca (OH)2. A more recent method of apexification involves the use of MTA as an apical barrier. However, it is important to note that apexification by either Ca (OH)2 or MTA completely prevents any further root development in terms of increased radiographic measures of either root length or width. The immature tooth treated by apexification procedures demonstrates healing of apical periodontitis, but does not achieve the goals of continued root development or restoration of functional pulp tissue [10].

Apexification is defined as ‘a method to induce a calcified barrier in a root with an open apex or the continued apical development of an incomplete root in teeth with necrotic pulp.

Success rates for calcium hydroxide apexification is a method of inducing apical closure through the formation of mineralized tissue in the apical pulp region of a non-vital tooth with an incompletely formed root. It is composed of osteocementum, osteodentin or bone, or by some combination of the three [11].

Apexification may be induced by Ca (OH)2 or MTA. Revascularization of necrotic pulp has been considered possible after traumatic injury to an immature tooth. A unique set of circumstances exist that favor revascularization. The potential for revascularization appears to directly depends on the race between bacterial infection of the necrotic pulp, and revascularization of the canal space using the ischemic pulp as a matrix [12]. Revascularization involves desinfection the root canal. The canals were sampled before and after irrigation with 1.25% NaOCL and after dressing with a triple antibiotic paste, consisting of metronidazole, ciprofloxacin, and minocycline. The access cavity was sealed with a glass ionomer cement (GIC). An increased tooth length was observed. Revascularization procedures conducted to immature non-vital, infected permanent teeth [7].

Maintenance of pulp vitality by using apexogenesis allow continued root development along the entire root length. Depending on the extent of inflammation, pulp capping, or conventional pulpotomy may be indicated. The approach has been to use calcium hydroxide (CH) to induce apexification after disinfection of the root canals.

Metronidazole is a nitroimidazole compound that exhibits a broad spectrum of activity against protozoa and anaerobic bacteria. It has been used both systemically and topically in the treatment of periodontal disease. Metronidazole readily permeates bacterial cell membranes. It binds to the DNA, disrupting its helical structure, and leads to rapid cell death. Completion of endodontic therapy was typically delayed until completion of root-end closure through apexification. Tetracyclines, which include doxycycline and minocycline are effective against most spirochetes, and many anaerobic and facultative bacteria. The tetracyclines gain access to bacterial cells. Then, they inhib protein synthesis on the surfaces of ribosomes. Minocycline is a semi-synthetic derivative of tetracycline. It is available in many topical forms ranging from gel mixtures to release microspheres. Ciprofloxacin, a synthetic floroquinolone, has a bactericidal mode of action. It has very potent activity against gram-negative pathogens but displays limited activity against gram-positive bacteria. Most anaerobic bacteria are resistant to ciprofloxacin, even if side effects have been reported. It was found that the drug is clinically safe when applied in low doses. When applied as an intra-canal medicament in low doses, adverse systemic side effects should be minimized.

Materials for the repair of furcal perforations.

Hydroxyapatite–based material and calcium sulfate were used to repair furcal perforations. The success rate was found to be 67% for calcium sulfate, 62% for HAP and 59% for the glass ionomer [13]. Experimental calcium phosphate cement (TCP) and MTA were used as repair materials for furcation perforation. MTA exhibited significantly better results than TCP. MTA is a suitable material to close the communication between the pulp chamber and the underlying periodontal tissues [14].

Glass ionomer cement (Chelon Silver) was compared with amalgam [15]. The coronal orifices of the root canals were sealed with amalgam and varnish. No significant difference was found between the mean leakage of the intact pulp chamber floors of the two groups (Chelon Silver or Amalgam). It was concluded that Chelon Silver was an adequate sealer for furcation perforations. MTA is an alternative root canal obturation material for the treatment of stripping perforation in a C-shaped root canal and for the repair of pulp floor perforation.

MTA materials demonstrate acceptable biocompatible behaviour but also exhibits acceptable *in vivo* biologic performance when used for root-end fillings, perforation repairs, pulp-capping and pulpotomy, and apexification treatment [16]. It may be concluded that MTA is the most suitable material, more than amalgam for perforation repair, especially when it is used immediately after perforation.

Iatrogenic perforation of pulpal floor in the furcation of mandibular first molar was treated by using MTA and platelet rich fibrin (PRF). The repair of perforation defect and regeneration in the furcation area seems to be beneficial for the long term clinical results [17]. Resorption and caries are among the major complications of endodontic and restorative treatments.

Tooth (root) perforations

Perforations result in the destruction of the dentin root wall or floor [18]. Perforations occur primarily through three possible mechanisms:

- Procedural errors occurring during root canal treatment
- Post-space preparation,
- Resorptive processes and caries.

Most perforations result from procedural errors. Errors leading to these defects include:

- Bur perforation during access opening
- During the search for canal orifices, excessive removal of dentin
- Either with hand or rotary instruments,
- Misdirected files during canal negotiation,
- Unsuccessful attempts at bypassing separated instruments,
- Misaligned instruments during post-space preparation.

Iatrogenic perforation of the tooth may occur during access preparation, canal instrumentation or during the creation of post-space prior to definitive restoration of the tooth. Perforations may also result from excessive removal of tooth structure during instrumentation of the canal system and this tends to occur in anatomically vulnerable locations such as the mesial roots of lower molars.

Classification of root perforation divides the root into coronal, crestal and apical portions:

- Coronal being defined as 'coronal to the crestal bone and epithelial attachment';
- Apical being defined as 'apical to the crestal bone and epithelial attachment.'

In addition, the position of the perforation in relation to the 'critical crestal zone,' its position in the mesial distal and facial lingual planes must also be taken into account.

With age

- The apical foramen decreases in diameter, and its deviation from the root long axis is increased because of cementum apposition,
- The accessory canals gradually decrease in number,
- The radicular dentine becomes less permeable because of the formation of sclerotic dentine, which leads to the gradual occlusion of the dentinal tubules, especially in the apical third of the root. This might explain why bacterial penetration into the dentinal tubules of older patients' teeth occurs to a lesser extent than in younger patients,
- Additionally, the cementum is supposed to become less permeable with age.
- With age, the apical foramen decreases in diameter, and its deviation from the root long axis is increased because of cementum apposition.

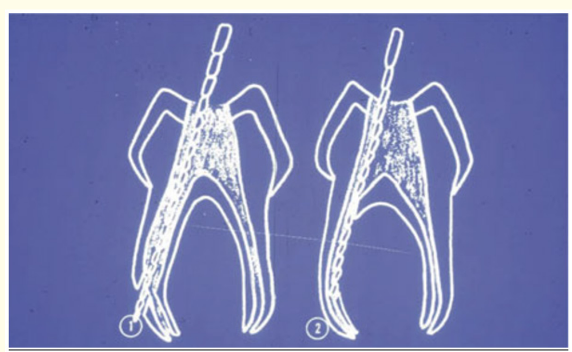

Figure 3: Perforations on the convex and concave aspects of a root due to the use of root canal instruments.

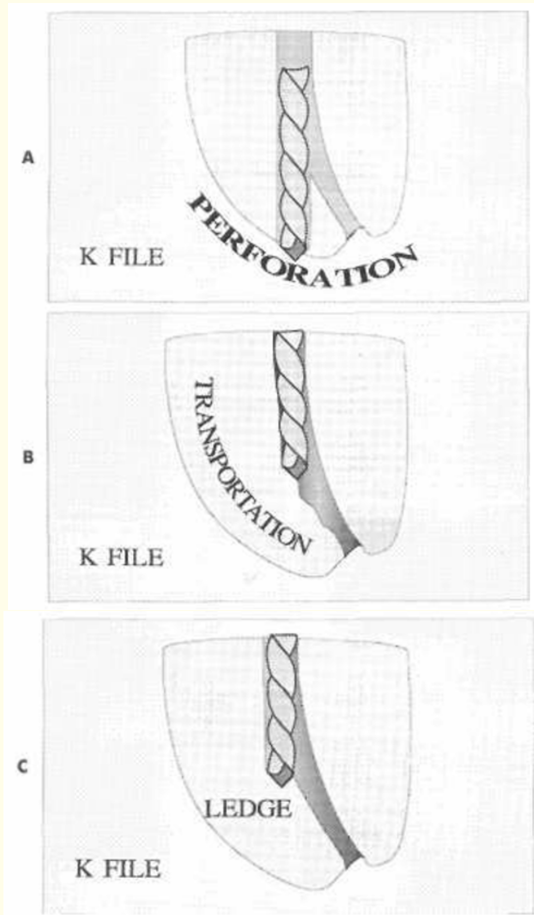

Figure 4: Perforation, transportation, ledge and zipped. Pathologic actions of files in the apical third of roots. Failures, errors, accidents and incidents in pediatric endodonty.

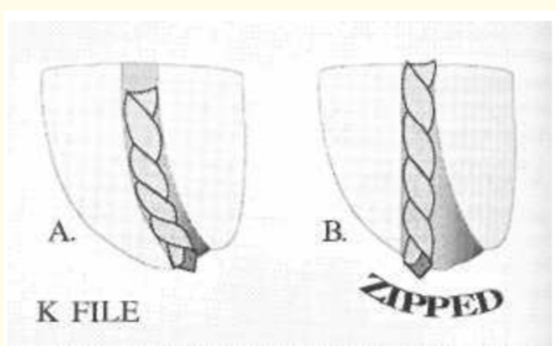

Figure 5: Pulp floor and root perforation account for failures during endodontic treatment.

Conclusions

The related literature shows some controversy on the terminology of 'endodontic-periodontal lesions' or 'perio-endo lesions'. Many authors defined those lesions as primary endodontic or periodontal lesions, causing secondary periodontal or endodontic involvement.

Perforations arise from caries and/or resorptive defects. They are also occurring during root canal therapy and account for 10% of the endodontic failures.

Perforations may result from:

- Iatrogenic perforations occurring in the coronal third, after excessive removal of coronal dentin. These perforations results from drilling in the coronal and furcation regions.
- In the middle third occurring in curved molars' roots and the use by the practitioner of rotary or ultrasonic instruments.
- In the apical third, namely in curved canals, the instruments deviate until perforation occurs. Post-space preparation : constitute a permanent risk.

Pathological perforations may result from root resorption or caries. The frequency of root perforations range from 3% to 10% [19].

Endodontic procedures include partial pulpotomy, pulp revascularization apexification, and apexogenesis. Care is needed to deliver regenerative endodontic methods that maintain or restore the vitality of teeth, but are also acting after the disinfection and removal of necrotic tissues. Furcal perforations, due to the uncomplete closure and lack of merging of buds issued from the basal part of the Hertwig's epithelial root sheath. Root canal perforation, transportation, ledge are the main sources for endodontic failures.

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