Root perforations: a review of diagnosis, prognosis and materials

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Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

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https://doi.org/10.1590/1807-3107bor-2018.vol32.0073

Submitted: May 04, 2018
Accepted for publication: May 29, 2018
Last revision: June 06, 2018

Abstract: Root perforation results in the communication between root canal walls and periodontal space (external tooth surface). It is commonly caused by an operative procedural accident or pathological alteration (such as extensive dental caries, and external or internal inflammatory root resorption). Different factors may predispose to this communication, such as the presence of pulp stones, calcification, resorptions, tooth malposition (unusual inclination in the arch, tipping or rotation), an extra-coronal restoration or intracanal posts. The diagnosis of dental pulp and/or periapical tissue previous to root perforation is an important predictor of prognosis (including such issues as clinically healthy pulp, inflamed or infected pulp, primary or secondary infection, and presence or absence of intracanal post). Clinical and imaging exams are necessary to identify root perforation. Cone-beam computed tomography constitutes an important resource for the diagnosis and prognosis of this clinical condition. Clinical factors influencing the prognosis and healing of root perforations include its treatment timeline, extent and location. A small root perforation, sealed immediately and apical to the crest bone and epithelial attachment, presents with a better prognosis. The three most widely recommended materials to seal root perforations have been calcium hydroxide, mineral trioxide aggregate and calcium silicate cements. This review aimed to discuss contemporary therapeutic alternatives to treat root canal perforations. Accordingly, the essential aspects for repairing this deleterious tissue injury will be addressed, including its diagnosis, prognosis, and a discussion about the materials actually suggested to seal root canal perforation.

Keywords: Root Canal Therapy; Calcium Hydroxide.

Introduction

Root perforation is characterized by a communication between the root canal system and the external tooth surface.[1] This issue can be caused by a pathological process (dental caries, root resorption) or an operative procedural accident. Pathological perforations are found in routine clinical exams, whereas iatrogenic root perforations may occur during access cavity opening, root canal preparation or during post preparation.[2,3,4,5,6,7,8,9,10,11] Procedural operative errors may occur at any time in root canal treatment, and may cause the treatment to fail.[12]

Some factors may predispose to operative procedural accident or errors.[12] The presence of pulp stones, calcification, misplaced tooth (incorrect inclination in the arch, tipping or rotation), extensive caries, internal root resorption, misidentification of the root canal, an extra-coronal restoration or intracanal posts are factors that may make root canal access difficult, and predispose to root perforation.[2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17] An insufficient access cavity reduces the quality of root canal debridement and may affect the final root canal preparation shape. An exaggerated or misdirected access cavity is also conducive to root perforation, and makes the tooth susceptible to coronal/radicular fracture. Root perforation, overfilling, endodontic and periodontal lesions, root fracture, periapical biofilm, traumatic dental injury, instrument fracture, apical periodontitis, and root resorption characterize the complex challenge facing the endodontist, and these may contribute (alone or in association) to a doubtful or poor prognosis.[12]

During the operative procedures, the endodontist must avoid and prevent these nocuous events, since intra-operative accidents are risk factors that may result in failure of root canal treatment. Successful root canal treatment entails understanding the risk factors associated with root canal treatment failure.[12] Root perforation may occur in different clinical conditions, which the patient should be immediately informed of, together with the procedures to be followed, the treatment options and the prognosis.[10] Root perforation constitutes a serious complication which needs to be diagnosed early and treated immediately and appropriately.[18-20] The consequences of root perforation may result in an inflammatory response associated with periodontal tissue and alveolar bone destruction. Depending on the severity of the injury, and possible chronic inflammatory reaction, it may cause the development of granulomatous tissue, proliferation of the epithelium, and, eventually, the development of a periodontal pocket.[9,19,21,22] Lack of understanding of root perforations and their consequences, to the extent that could delay diagnosis and treatment, may cause future problems leading to tooth loss.

This review aimed to discuss contemporary therapeutic alternatives to treat root canal perforations. Accordingly, the essential aspects for repairing this nocuous operative accident will be addressed, including its diagnosis, its prognosis, and a discussion about the materials used to seal root canal perforation.

Diagnosis and prognosis of root perforation

Several clinical findings may be determinant in diagnosing root perforations. The clinical and radiographical exams constitute the basis of root perforation diagnosis.[5,7,9,10,15,23,24,25,26]

During vital root canal preparation (pulp is emptied), the radicular pulp may be removed by pulpectomy (when the pulp is excised, or when root canals are narrow, removal is by fragmentation). After removal of pulp tissue, persistent bleeding during coronal access or root canal preparation may be a sign of perforation. A paper point with blood may also suggest perforation. Systemic conditions, medications, teeth with an open apex and internal resorption and acute apical periodontitis may be associated excessive bleeding, and be confused with root perforation. Clinically, its diagnosis is a challenge;[10,12,14] however, the apex locator is a technological resource that may help in diagnosing root perforation.[27,28]

Periapical radiography is the imaging method frequently indicated for endodontic diagnosis, treatment plan, and follow-up.[23,24] A radiolucency associated with a communication between the root canal walls and the periodontal space constitutes an important vestige of this procedural accident.

The incorporation of cone-beam computed tomography (CBCT) in endodontic procedures ensures new parameters to aid in the diagnosis and prognosis of these pathologic and iatrogenic conditions.[29,30,31,32,33,34,35,36,37,38,39] Shemesh et al.[38] compared ex vivo the sensitivity and specificity of CBCT scans and digital periapical radiographs (PR) in detecting strip and root perforations in 45 curved mesial roots of mandibular molars. The risk in misdiagnosing strip perforations was high with both methods, but CBCT scans showed a significantly higher sensitivity than PR. There was no significant difference between the methods for detection of root perforations.

An essential factor to consider is whether or not an endodontically treated tooth is associated with a root perforation. The diagnosis of root perforation in endodontically treated teeth may be complex. Diagnostic errors occur and constitute a serious problem; errors are frequently detected in association with a metallic or solid structure of higher density, which produces an image artifact, lacking homogeneity and being defined by image contrasts. Misdiagnosis is a serious problem that has encouraged the search for alternatives to reduce the beam hardening effect during image acquisition and reconstruction.[40,41,42] Metallic artifacts associated with intracanal posts constitute potential risks for misdiagnosis, particularly when root perforation or bone destruction is suspected.[29,38,39] A map-reading strategy to diagnose root perforations near metallic intracanal posts using CBCT images was previously suggested by Bueno et al.[29] The strategy suggested minimizing metallic artifacts associated with intracanal post and endodontic material by making sequential axial slices of each root with an image navigation protocol from the coronal to the apical direction (or apical to coronal), and with axial slices of 0.1 mm/ 0.1 mm. This directional orientation provides precious information concerning the exact localization of vestiges that suggest points of communication between the root canals and the periodontal space, associated with radiolucent areas, suggesting root perforation. The dynamic navigation of CBCT images has made it a distinct tool by revealing what was once static. In the slices located near the post apex, the beam hardening effect is reduced, because CBCT allows us to capture a lesser amount of metal on the images.[29] A new software program able to reduce metallic artifacts in future reconstructions of CBCT images has been tested (*e.g.*, e-Vol DX, CDT, Bauru, SP, Brazil).

The appropriate management of CBCT images could reveal abnormalities that are difficult to detect in conventional periapical radiographies.[35,36,37] The final diagnosis and choice of clinical therapeutics for these root perforations should always be made in conjunction with the clinical findings. The major potential of CBCT examinations is the possibility of viewing the different planes of all the surfaces and the location of the tooth, at the same time.[29]

After a root perforation is diagnosed, root canal treatment can be challenging. Root perforation could affect the prognosis of root canal treatment and retreatment. Three clinical factors have been considered as relevant in the prognosis and healing of root perforations: time (the time between the occurrence of the perforation and the appropriate filling); extent (a small perforation causes less tissue destruction and inflammatory response); location (perforations located apical to the critical zone, involving the level of the crestal bone and the epithelial attachment, are likely to have a good prognosis when the root canal is accessible and the treatment is appropriate).[7] Thus, clinical parameters associated with the timeline (avoiding the onset of infection), with the severity of the tissue injury, and with its location in relation to the crestal bone, are factors essential to treatment prognosis.[7,8,9] It has been suggested that perforations located apical or coronal to the crest bone and epithelial attachment have a good prognosis.[7,43,44]

The therapeutic factors associated with the clinical protocols used during root canal treatment, and the systemic conditions associated with the periapical healing process of endodontically treated teeth, were recently discussed by Holland et al.[45] The repair process of endodontically treated teeth depends not only on the adoption of correct clinical approaches to promote better root canal treatment, but also on patient-related factors (such as chronic disease, hormones and age), and those that can change the host's immune defenses and interfere in the treatment outcomes and healing process.

Thus, the risk factors of root canal treatment failures (such as systemic disease and periodontal status) must be addressed correctly during the treatment plan. Treatment success is influenced by the preoperative status of the dental pulp, associated with the presence or absence of a preoperative periapical lesion. The diagnosis of dental pulp and/ or periapical tissue previous to root perforation is an important predictor of prognosis (including such issues as clinically healthy pulp, inflamed or infected pulp, and primary or secondary infection).[25] Each clinical case must be analyzed carefully and individually, in order to determine the presence or absence of infection, the extent of perforation, the time elapsed before sealing, and the periodontal risk to the patient, to see whether or not the disease could interfere directly in the prognosis.

The ability to access the perforation area and promote an appropriate sealing, and the pathological conditions, are clinical determinants of success or failure.

In root perforation due to over-instrumentation, resulting in over-enlargement of the apical foramen, the treatment consists of determining a new working length, 1-2 mm short of the root apex, in which the main cone will fit tightly. An apical plug with calcium hydroxide should be maintained in the apex, and the remainder of the root canal should be filled. Clinical and radiographic follow-up should be conducted to determine success or failure. A surgical procedure (periapical surgery) is still an option if failure occurs. Root perforation near the apex presents a good prognosis, and those that are smaller in extent are easier to seal. The survival of an endodontically treated tooth, especially one with a history of root perforation, depends on understanding the biological and mechanical outcomes as multifactorial events over the individual's life span.[10,12,25]

Tooth type, strategic position of the tooth (or surface of the tooth) and the level of the perforation influence the complexity of treatment. In lateral perforations, the relation of the crestal bone to the perforation may favor a good prognosis and sealing. In furcal perforations in molars, the major issue is the degree of tissue damage and the possibility of communication with the gingival sulcus. The probable extrusion of adhesive materials to seal large perforations constitutes a common occurrence. In small furcal perforations, the prognosis is favorable.[7,9,11,20] An important clinical feature is the thickness of the gingival and bone tissue, since a better prognosis occurs in patients with thick gingival and bone tissues.[46] Overall, the sealing of a root perforation has shown a high level of success; however, the impact of new therapeutic procedures on the prognosis of endodontic therapy should be carefully considered.

Materials used to seal root perforations

The endodontic literature published over the years presents reports on several intracanal medicaments that have been studied to treat infected root canals. Calcium hydroxide has been extensively evaluated, and shows well-documented results.[47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62, 63, 64,65,66,67,68,69,70,71,72,73, 74,75,76,77,78,79,80] However, new materials for sealing root perforations of iatrogenic and pathological origin have been made available for endodontics.[81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100, 101,102,103,104,105,106,107,108,109,110,11,112,113,114,115,116,117,118, 119,120,121,122,123,124,125,126,127,128,129,130, 131,132,133,134,135,136,137,138,139,140,141] Nowadays, the materials demonstrating antibacterial potential for infection control of the root canal system promote healing by mineralized tissue deposition and sealing ability. As such, they were selected to be the focus of attention of this review.[47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63, 64,65,66,67,68,69,70,71,72,73,74,75,76,77, 78,79,80, 81,82,83,84,85,86,87, 88,89,90,91,92,93,94,95,96,97,98,99,100, 101,102,103,104,105,106,107,108,109,110,11,112,113, 114,115,116,117,118,119,120,121,122,123,124,125, 126,127,128,129,130,131,132,133,134,135,136, 137,138,139,140,141,142,143,144,145,146,147] Accordingly, three materials to seal root perforations were analyzed retrospectively, based on their biological, antimicrobial and physicochemical characteristics, namely calcium hydroxide, mineral trioxide aggregate and calcium silicate cements (bioceramics).

Calcium hydroxide

In 1920, Bernhard W. Hermann suggested the use of calcium hydroxide (Calxyl-Otto & CO; Frankfurt, Germany) for dental pulp treatment.[47] This material has been studied for many years, and has several potentials, among which of favoring the healing process of the pulp and periapical tissues.[47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74] Stanley, in 1997,[59] reported that a new era had begun.

Calcium hydroxide is obtained by the calcination of calcium carbonate, which is transformed into calcium oxide, and then hydrated to form calcium hydroxide. The reaction between calcium hydroxide and carbon dioxide forms calcium carbonate.[51,63,75] The ionic dissociation of calcium hydroxide into calcium and hydroxyl ions, and the action of these ions on tissues and bacteria explains its biological and antimicrobial properties.[63]

The biological action of calcium hydroxide on connective tissues of the pulp, periapical or periodontal regions occurs in a similar manner.[22,45,51,54,55,56,57,58,61,64,68,70,71,72,73] Holland[51] attributed the post-pulpotomy healing process and pulp protection with calcium hydroxide to following zones: necrotic zone – located under the calcium hydroxide; outer granular zone - located immediately underneath the necrotic zone, and formed by 2 fractions, a mineral fraction, positive to the calcium reaction, which contained glycoprotein complexes, and metachromatic stainable material; inner granular zone - located under the outer granular zone; cellular proliferation zone - located under the inner granular zone and presenting connective cell proliferation, considering that the cytoplasm of these cells had great amounts of RNA and glycoprotein complexes, and a small number of granulations containing glycogen. During the healing process, some alterations could be found, mainly in the granular and cellular proliferation zones. In the inner granular zone, there was a progressive increase in deposition of calcium compounds. In the cell proliferation zone, young odontoblasts determined dentin formation. Thus, calcium hydroxide in direct contact with conjunctive tissue gives origin to a zone of necrosis, altering the physicochemical state of the intercellular substance, which seems to determine protein denaturation by the rupture of glycoproteins. Studies have reported the formation of mineralized tissue after contact of calcium hydroxide with conjunctive tissue from the 7th to the 10th day. Seux et al.[69] confirmed this result studying odontoblast-like cytodifferentiation of human dental pulp cells in vitro, in the presence of a calcium hydroxide-containing cement. Mizuno & Banzai[74] studied the effect of calcium ions on the dental pulp cells and the mechanism of dentin bridge formation by calcium hydroxide. Calcium ion release from calcium hydroxide stimulates fibronectin synthesis in dental pulp cells. Fibronectin could induce the differentiation of dental pulp cells into mineralized tissue-forming cells, which are the main cells forming dentin bridges by direct contact.

The active participation of calcium ions from calcium hydroxide in the mineralization of dentinal tubules (mineralization barrier on dental pulp, in apical biological sealing), and other areas involved in mineralization has been demonstrated in various studies.[22,45,51,54,55,56,57,58,61,64,68,70,71,72,73]

Calcium hydroxide has an antibacterial effect on the cytoplasmic membrane. The release of hydroxyl ions and inactivation of enzymes chemically alters the organic components and transport of nutrients, and causes toxic effects on cells. The effectiveness of certain vehicles derives from their chemical characteristics (dissociation and diffusion). Chemically speaking, hydrosoluble vehicles induce a higher speed of ionic dissociation than viscous and oily vehicles. The chemical dynamics of calcium hydroxide develops by ionic dissociation. Two enzymatic properties of calcium hydroxide are verified, namely, the activation of tissue enzymes, such as alkaline phosphatase, which causes a mineralizing effect, and the inhibition of bacterial enzymes, which leads to its antibacterial action, characterizing the biological dynamics of hydroxyl and calcium ions relative to both tissue and bacteria.[63,65,66,67]

Several etiological agents may be responsible for pulp and periapical injury. Knowledge of the conditions of pulp, periodontal or periapical tissues prior to root perforation is important to structure a treatment plan. A greater challenge is the treatment of infected root perforations. Previous studies[89,108] have shown that the repair process during treatment is more successful when perforation is noncontaminated rather than contaminated.

The first therapeutic option after detecting root perforation in a tooth with healthy or inflamed dental pulp is root canal treatment followed immediately by sealing of the root perforation. The irrigant solution used during root canal preparation must not be aggressive to periodontal tissues. In other conditions, like root perforation detected in teeth with infected root canals, calcium hydroxide is the first antibacterial option for intracanal dressing. The sanitization process (emptying, irrigation, enlargement, intracanal medication) has led to significant reduction of microorganisms in contaminated root canals. Calcium hydroxide paste may be prepared with a saline solution vehicle (water-soluble in nature). Its placement should be very well condensed within the root canal to avoid empty spaces when filling the root perforation. Its consistency must be thicker than toothpaste. Proper management and placement of calcium hydroxide paste into the root perforation are necessary for better performance of this intracanal dressing. In the second appointment, the calcium hydroxide is removed from the root canal and from the site of root perforation – with the residual paste acting as a matrix – taking care to avoid overfilling. The root perforation is then sealed with mineral trioxide agregate.[10,12,14,22,25,45,63,65,66,67,73,78,79]

Mineral trioxide aggregate

Mineral Trioxide Aggregate (MTA) was introduced in endodontics in 1990 as a new material with the ability to seal communication between the tooth and the external surfaces.[82,83] This material was extensively assessed (physically, chemically and biologically) by several methodologies, and showed good potential to substitute several materials that were used to seal root perforations.[22,68,80, 82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,11,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128,129,130,131,132,133,134,135,136,137,138,139,140,141,142,143,144] In 1993, Lee et al.[81] compared in vitro the sealing potential of an MTA, intermediate restorative material and silver amalgam for the repair of lateral root perforations. MTA presented the lowest rates of marginal leakage, and was statistically superior to the other materials. Torabinejad et al.[82] evaluated in vitro the sealing ability of MTA used as a root end filling material. MTA also demonstrated better sealing ability than other materials.

Thus, a new direction was set for the sealing of root perforations and retrocavities in periapical surgery. Initial evaluations of MTA indicated that it had good performance in sealing lateral root perforations, and in root-end fillings, owing to its ability to improve the mineralization process.[82-121] The biological response of MTA in the repair process after sealing of lateral and furcal perforations, in root-end fillings, pulp capping, pulpotomy, apexification and revascularization, demonstrated that this material presents good tissue behavior.[89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,11,112,113,114,115,116,117,118,119,120,121] A series of studies[22,89,90,108,111,112] reported on the repair of root perforations using MTA, and the results consolidated the indication of this material for this deleterious clinical condition.

The main components of the chemical composition of MTA, according to Torabinejad et al.,[85] include tricalcium silicate, tricalcium aluminate, tricalcium oxide and silicate oxide. Small amounts of a few other mineral oxides are also present in this aggregate. Bismuth oxide powder was also added to make the aggregate radiopaque. The powder consists of fine hydrophilic particles that harden in the presence of water. Hydration of the powder leads to the formation of a colloidal gel, which solidifies into a hard structure in approximately 4 hours. The characteristics of the aggregate depend on the size of the particles, the powder to water ratio, the setting temperature, the presence of water during setting, and the presence of entrapped air.[81,104] A recent systematic review[105] on marginal adaptation of MTA compared with other filling materials in root-end cavities showed that MTA adapted well to dentin walls in most studies. However, there is no standardization of the design of these studies. The literature is also sparse on the clinical relevance of root-end filling material adaptation, but does imply the existence of other yet unidentified factors that affect biological outcome.

Dentin tubes were filled with calcium hydroxide or MTA and implanted in the subcutaneous tissue of rats, during 7 or 30 days.[68] The formation of calcite granulations and a subjacent hard tissue bridge were verified in both materials. The biological mechanism of action of the studied materials showed some similarities. Calcium oxide presents substantial importance in the mineralization process of this materials.

In 1999, Wucherpfenning and Green[78] reported that both MTA and Portland cement seemed almost identical macroscopically and microscopically. Both substances supported matrix formation in a similar fashion in cultures of osteoblast-like cells, and also in the apposition of reparative dentin, when used as direct pulp capping material in rat teeth. The antimicrobial and chemical properties of MTA and Portland cement showed similarity.[79] Portland cement presents the same main chemical elements as MTA, except that MTA also contains bismuth. In chemical assays of a Portland cement, the components were present according to the following average percentages: CaO (58.5%), SiO_2 (17.7%), Al_2O_3 (4.5%), MgO (3.3%), SO_3 (3.0%), Fe_2O_3 (2.9%), K_2O (0.9%), Na_2O (0.2%).

Holland et al.[70] observed the reaction of subcutaneous tissue of rats to dentin tubes filled with MTA, Portland cement or calcium hydroxide. Some similarity has been seen between the mechanisms of action of the materials studied. In another study, Holland et al.[71] observed several reports on the similarity between the chemical compositions of MTA and Portland cement, and analyzed the behavior of dog dental pulp after pulpotomy and direct pulp protection with these materials. After pulpotomy, the pulp stumps of 26 roots of dog teeth were protected with MTA or Portland cement. Sixty days after treatment, the histomorphological analysis showed a complete tubular hard tissue bridge in almost all the specimens. MTA and Portland cement showed similar results when used for direct pulp protection after pulpotomy.

Several studies[120,121,122,123,124,125,126] have carefully analyzed the chemical constitution of MTA and its implications in clinical practice, such as dental discoloration, radiopacity, and clinical management. It is important to use MTA with caution in regard to esthetics, because it may change the coronal natural color. [120,121,122,123,124,125,126] Marciano et al.[124] reported that the color of white MTA Angelus is altered in contact with dental structures. Collagen, which is present in the dentin matrix, reacts with bismuth oxide, resulting in a grayish discoloration. Because of this, the use of an alternative radiopacifier is indicated to replace bismuth in white MTA. In another study,[126] the addition of zinc oxide in the MTA formulation was able to prevent a color alteration without significant interference in its physical, chemical, and biological properties. Thus, stable color formulation with zinc oxide allows the use of MTA with no restrictions in terms of esthetics. Camilleri[125] investigated the color stability of white MTA in contact with various solutions used in endodontics. The author observed that any contact between white MTA or other bismuth-containing materials and sodium hypochlorite solution should be avoided.

Thus, dental professionals must be careful to avoid color changes when using MTA in root perforations considering esthetics.

Calcium silicate cements / Bioceramics

MTA is a calcium silicate cement introduced in endodontics in the 1990s.[82-84] Since then, new materials with similar composition to MTA, but distinct properties, have been introduced into the market on account of properties that facilitate handling and manipulation. New cements such as bioceramics are composed mainly of dicalcium silicate and tricalcium silicate. These materials form a colloidal structure after hydration, and develop sequentially into a hard structure.[129] Numerous bioceramics materials have been developed by the dental cement industry, such as: Biodentine, BioAggregate, EndoSequence, iRoot, and calcium-enriched mixture (CEM) cement, among others.

There are several indications for these materials in endodontics, including such procedures as pulp capping, pulpotomy, root canal filling, perforation treatment, apexification and root-end filling.[103,132] The major advantages of bioceramic cements are related to their physicochemical and biological properties. They present excellent sealing ability, because of their physicochemical interaction with the local environment, and high biocompatibility.[140].

These materials have high compressive strength and physical characteristics similar to dentin.[134,140] Their sealing ability results from their interaction with dentin, and the forming of a mineralized intermediate zone, with tag-like structures that extend into the dentinal tubules, and thus act as a micromechanical anchor to dentin.[127,136] Another characteristic responsible for the good sealability of bioceramic cerments refers to their expansion after hydration and setting.[132]

The antimicrobial activity of these materials has also been demonstrated in the literature. In vitro studies have revealed the microbial control ability of bioceramics, a property related to the alkalization of the medium due to the release of hydroxyl ions and their diffusion through the dentin.[137,141]

In relation to cytotoxicity, calcium silicate cements present good results. Damas et al.[131] evaluated the cytotoxic effects of MTA Angelus, ProRoot MTA, EndoSequence Root Repair Material, and EndoSequence Root Repair Putty on human fibroblasts, and observed a cell viability > 91% in all materials tested. De Deus et al.[133] also evaluated the cytocompatibility of IRoot BP Plus and White ProRoot MTA in human osteoblasts, and observed a higher cellular viability of MTA group, compared with IRoot. However, IRoot group did not present critical cytotoxicity, since cell viability remained above 70%.

Odontoblastic differentiation was induced after the application of Biodentine on exposed rat pulps, and resulted in a dentin bridge formation adjacent to Biodentine, similar to MTA after 14 days and 30 days.[139]. Silva et al.[147] evaluated the response of periradicular tissues of dog teeth to the materials used for sealing furcation perforations (Biodentine, MTA and gutta-percha). The authors observed that Biodentine and MTA exhibited no bone resorption in the furcation region, fewer inflammatory cells, and greater RUNX2 immunostaining intensity than gutta-percha. However, MTA presented a higher frequency of complete sealing, with the formation of thicker mineralized tissue in a larger area. The effect of Biodentine (BD), Endosequence BC Root Repair Material-Putty (ES), Endosequence BC Root Repair Material-Fast Set Putty (ES-Fast), and Pro-Root (MTA) was assessed on the viability and differentiation of stem cells of the apical papilla (SCAP), using an ex vivo dentin disk model.[145] BD and ES promoted greater survival and differentiation of SCAP and an increase in the DSPP odontoblastic marker, whereas MTA appeared to promote greater osteoblastic differentiation. Thus, BD and ES can be considered for regenerative and vital pulp therapies.

Studies with a high level of scientific evidence conducted on these materials are limited. Bioceramics show promising in vitro results, following several in vivo studies, but without a high level of evidence. Studies with an adequate sample size, methodological rigor, standardization of procedures, randomization of individuals, comparative groups and other factors are not yet found in the literature.

Clinical overview

The life of an endodontically treated tooth is associated with correct diagnosis and treatment planning, root canal shaping, sanitization, sealing, and, lastly, tooth rehabilitation.[25] The successful treatment of a root perforation depends on certain factors, like sealing material, perforation extent and location, time between diagnosis and treatment, presence of contamination and related operator experience, presence of preoperative lesions, communication of the perforation with the oral environment, and type and quality of the final restoration.[7,130,138]

The material recommended for treatment of root canal perforations should have good physicochemical and biological properties, proper sealing capacity, antimicrobial activity and osteogenic potential.[45] MTA has been the most widely indicated material to seal root perforations.[9,10,11,22,45,70,71,72,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104] Histological studies have shown lateral and furcal perforations that have been repaired with MTA, and that have been found to have mineralized tissue over the material.[22,89] Clinical studies have shown that MTA appears to provide a biocompatible and long-term effective seal for root perforation, with a higher success rate.[111,112,138,146] Pontius et al.[146] analyzed retrospectively the clinical outcome of 70 perforation repairs performed by 6 endodontic specialists, using a nonsurgical or combined nonsurgical/surgical approach. The success rate for repair of the root perforation was 90%. Siew et al.[138], based on a systematic review using clinical studies published from 1950 to mid-2014, evaluated the treatment outcome of repaired root perforations and identified any preoperative factors that could influence the outcome of the repair. Seventeen studies were included for systematic review and 12 qualified for meta-analysis. An overall pooled success rate of 72.5% (CI, 61.9%–81.0%) was estimated for nonsurgical repair of root perforations. The use of MTA appeared to enhance the success rate to 80.9% (CI, 67.1%–89.8%). The presence of a preexisting radiolucency adjacent to the perforation site fared a lower chance of success after repair. The authors concluded that nonsurgical repair of root perforation results in a success rate of over 70%. Teeth in the maxillary arch and absence of preoperative radiolucency adjacent to the perforation are favorable preoperative factors for healing after perforation repair.

Conclusions

Root perforation during operative procedures should be prevented. Diagnosis and immediate sealing, intensity of aggression, control of contamination, relationship to crestal bone and epithelial attachment are factors that have an impact on the prognosis. Physicochemical, histological and clinical studies have indicated MTA as a good sealer for these situations, but one which lacks a good esthetic outcome.

Acknowledgements

The authors deny any conflicts of interest related to this study. This study was supported in part by grants from the National Council for Scientific and Technological Development (CNPq grants 306682/2017-6 to C.E.).

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