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Feature Article

## Endodontics

# Strategies to Treat Infected Root Canals

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abstract

*Periradicular lesions are diseases either primarily or secondarily caused by microorganisms and therefore they must be prevented or treated accordingly. If the professional is well-versed in both preventing and eliminating the root canal infection, the success rate of endodontic therapy may exceed 90 percent. The present paper discusses theoretical and practical aspects of effective antimicrobial endodontic therapy and delineates strategies to effectively control root canal infections.*

Periradicular lesions are diseases either primarily or secondarily caused by microorganisms.[1-3] Microorganisms of probable pathogenic significance in endodontic infections include *Porphyromonas* species, *Prevotella* species, *Fusobacterium nucleatum*, species of the *Streptococcus anginosus* group, *Bacteroides forsythus*, *Treponema denticola*, *Peptostreptococcus* species, *Eubacterium* species, and *Actinomyces* species.[2,4-6] In addition, enterococci, pseudomonas, yeasts, and some enteric rods may be involved in persistent or secondary root canal infections[7-9] (**Figure 1**).

Because of the critical role played by microorganisms in the pathogenesis of periradicular lesions, endodontic therapy should be considered for the clinical management of a microbial disease. Thus, it is extremely important that clinicians understand the role of microorganisms in the pathogenesis of periradicular lesions and be aware that they are treating and/or preventing an infectious disease. Nonsurgical and surgical endodontic techniques are unique tools to treat and/or prevent root canal infections.

Antimicrobial endodontic therapy is based on the premise that periradicular diseases are infectious disorders. At a minimum, antimicrobial intracanal procedures must be able to eradicate pathogenic microorganisms effectively. As knowledge of the microorganisms implicated in the pathogenesis of periradicular diseases and of the structure of the root canal microbiota increases, clinicians will be able to incorporate more-effective antimicrobial strategies as part of their armamentarium for optimum treatment. To date, from a treatment point of view, root canal infections should be considered polymicrobial and treated accordingly.

This paper outlines basic and current concepts of and practical approaches to antimicrobial root canal therapy and attempts to relate current knowledge to clinical protocol.

## Root Canal Infection

As are all connective tissues, the dental pulp is a sterile tissue. Contact with oral microorganisms is prevented by a barrier that consists of enamel at the crown of the tooth and cementum at the root. In certain conditions, such as caries, the pulp may come into contact with microorganisms from the oral cavity and therefore be injured and become inflamed. If pulp necrosis occurs as a consequence of injury, the pulp then loses its defense capability. As a result, microorganisms colonize the root canal system.

Most pulpal and periradicular pathoses are inflammatory diseases of microbial etiology. Microorganisms and their products play an essential role in the induction, progression, and perpetuation of such diseases.[1-3] More than 150 microbial species have been isolated from infected root canals, usually in mixed infections consisting of four to seven different species and with predominance of obligate anaerobic bacteria.[10]

Whereas most of the endodontic microbiota remains suspended in the fluid phase of the root canal,[11] dense bacterial aggregates also commonly adhere to the root canal walls, sometimes forming multilayered bacterial condensations (**Figure 2**). In addition, particularly in teeth associated with periradicular lesions, infection can propagate to dentinal tubules and anatomic variables, which are more common in the apical third of the root canal.

Given the importance of bacteria in the development of periradicular lesions, the eradication of the root canal infection is paramount in endodontic therapy. Studies have revealed that the success rate of the endodontic treatment is significantly increased when the endodontic infection is effectively eradicated before filling.[12-14] In addition to the eradication of the root canal infection, maintenance of the aseptic chain also assumes special importance in root canal therapy. Treatment must be undertaken in a sterile environment, thereby precluding the possibility of new microorganisms entering the root canal system and establishing a secondary infection. A rubber dam must be used, and it should not leak. Efforts should also be made to effectively remove plaque and all vestiges of caries, to decontaminate the operative field, to avoid touching with fingers the parts of the sterilized endodontic instruments that will enter the root canal, and always to use sterilized or self-sterilizing irrigant solutions.[10]

## Treating Infected Root Canals

Root canal infections possess some peculiarities that differentiate them from infections in other human sites. Once established, a root canal infection cannot be eliminated by the host defense mechanisms nor by systemic antibiotic therapy. This is explained by the fact that microorganisms present in root canal infections are in a privileged sanctuary, where the absence of a blood supply in a necrotic pulp impedes the transport of defense cells and molecules as well as systemically administrated antibiotics to the infected site. On the other hand, although host defense mechanisms and systemic antibiotics are ineffective against microorganisms within the root canal system, if microorganisms gain access to the highly vascularized periradicular tissues, they are usually effectively eliminated and thereby prevented from spreading to other sites. Due to the anatomical localization of the endodontic infection, it only can be treated through professional intervention using both chemical and mechanical procedures. Thus, the endodontic treatment involves three important steps to control of the root canal infection: the chemomechanical preparation; the intracanal medication; and the root canal obturation.[10]

## Role of the Chemomechanical Preparation

The main root canal makes up the largest area of the root canal system. Because most of the intracanal microorganisms and their products are located in the main root canal, the chemomechanical preparation may be considered an essential step in the root canal disinfection, once significant amounts of irritants are removed during this phase.[15-21] The removal of irritants from the root canal is carried out through mechanical action of instruments and the flow and backflow of the irrigant solution.[15-18] In addition, antibacterial irrigants may be of significant help in eliminating bacterial cells from the root canal system.[19-21]

### Mechanical Action

Studies in which no antibacterial irrigants were used have reported that the mechanical action of instrumentation and irrigation was effective in significantly reducing the number of bacterial cells in the root canal.[17,18] However, total elimination of bacteria was not observed in most of the cases. Ingle and Zeldow[22] have observed that immediately after instrumentation, using sterile water as an irrigant, 80 percent of the initially infected root canals yielded positive cultures. At the beginning of the second appointment, 48 hours later, this number increased to 95.4 percent. Byström and Sundqvist,[17] using physiologic saline solution during instrumentation, found that bacteria persisted in about half of the cases despite treatment on five successive occasions. Infection persisted in those teeth with a high number of bacteria in the initial sample. Siqueira et al.[18] evaluated the reduction of the bacterial population within root canals experimentally infected with *E. faecalis* by the mechanical action of instrumentation using hand Nitiflex files in alternate rotary motions, GT files, and Profile 0.06 taper Series 29 rotary instruments. Irrigation was performed using sterile saline solution. All the techniques and instruments tested significantly reduced the number of bacterial cells in the root canal. Instrumentation with a Nitiflex #30 was significantly more effective than GT files. There were no significant differences when comparing the effects of the Profile instrument #5 with either the GT files or the Nitiflex #30. Enlargement to a Nitiflex #40 was significantly more effective in eliminating bacteria when compared with the other techniques and instruments tested. The larger the apical preparation, the higher the percentage of bacteria eliminated from the root canal.

In clinical practice, the extent of instrumentation will depend on the root dimension, the presence of curvatures, and the type of endodontic instruments used. Hand and rotary nickel-titanium instruments can predictably enlarge curved root canals, while maintaining the original path, to sizes not routinely attainable with stainless steel files. Sufficient large preparations can incorporate more anatomic irregularities and allow the removal of a substantial amount of bacterial cells from the root canal. In addition, instrumentation with larger file sizes can also result in better irrigant exchange in the apical third of the root canal. Since larger preparations remove more bacterial cells, a higher rate of treatment success can be expected.

A higher success rate for endodontic treatment has been reported for teeth instrumented with hand NiTi files when compared with teeth prepared with hand stainless steel files.[23] The authors observed that NiTi file utilization was five times more likely to achieve success than utilization of stainless-steel files.[23] This probably occurred because of the greater capability of NiTi files in maintaining the original canal shape during instrumentation.

Thus, it appears that regardless of whether hand or rotary instruments are used, it is more important how much the root canal is enlarged. NiTi instruments allow the attainment of larger preparations in curved root canals with reduced risks of procedural accidents. Because of this, they should be the instruments of choice to prepare curved root canals. One should bear in mind that enlargement must be restricted up to 1 mm short of the root terminus. Although the apical foramen ideally should be cleaned, disinfected, and maintained patent, it must not be enlarged, The clinician should be aware of the risks in using large instruments at the patency length, as this procedure can result in severe periradicular injury, cause lack of an apical stop, and extrude a large amount of infected debris, which can predispose the tooth to postoperative discomfort and/or jeopardize the outcome of the endodontic therapy.[10,13,24,25]

Chemical Action

Although considerable bacterial reduction can be achieved by the mechanical action of instruments and irrigants, microorganisms are rarely completely eliminated from the root canals regardless of the instrumentation technique and file sizes employed. Remaining pathogens may survive in sufficient numbers to jeopardize the outcome of the root canal treatment.[9,14,24,25] Therefore, it becomes evident that antibacterial irrigants must be used to maximize bacterial elimination from the root canal. Stewart[26] and Auerbach,[27] in clinical investigations, reported negative cultures in more than 70 percent of the initially infected root canals after chemomechanical preparation using antibacterial irrigants. Siqueira et al.[21,28] found that irrigation with antibacterial irrigants was significantly more effective than saline solution in rendering canals free of bacteria.

During World War I, Dakin introduced the widespread use of a 0.5 percent to 0.6 percent sodium hypochlorite solution for antisepsis of open and infected wounds.[29] NaOCl was recommended as an endodontic irrigant by Coolidge in 1919;[30] and, in 1936, Walker introduced the use of double-strength chlorinated soda (5 percent NaOCl) solution as a root canal irrigant.[31] NaOCl use as an irrigant in endodontic practice has continued worldwide, and no study has hitherto definitively shown any other substance to be more effective. NaOCl has tissue-dissolving ability and a broad-spectrum antimicrobial activity; it can rapidly kill vegetative bacteria, spore-forming bacteria, fungi, protozoa, viruses, and bacterial spores.[32-35]

Siqueira et al.[35] compared the antibacterial activity of several irrigants against four black-pigmented anaerobic bacteria and four facultative bacteria through the agar diffusion test. The antibacterial effectiveness was ranked as follows, in decreasing order: 4 percent NaOCl; 2.5 percent NaOCl; 2 percent chlorhexidine; 0.2 percent chlorhexidine; EDTA; citric acid; and 0.5 percent NaOCl. These laboratory findings also confirmed that the antimicrobial effectiveness of NaOCl is directly dependent on the concentration of the solution.

In another study, Siqueira et al.[28] investigated the ability of a 4 percent NaOCl solution used in different irrigation methods in eliminating *E. faecalis* from the root canal. Regardless of the irrigation method used, more than half of the teeth yielded negative cultures. Conversely, all specimens irrigated with saline solution yielded positive cultures. Although the mechanical effects of irrigation can significantly contribute to the elimination of root canal bacteria, this finding confirmed the need to use antimicrobial substances to maximize the root canal disinfection.

Siqueira et al.[21] evaluated the in vitro intracanal bacterial reduction produced by instrumentation and irrigation with 1 percent, 2.5 percent, or 5.25 percent NaOCl or saline solution. All test solutions significantly reduced the number of bacterial cells in the root canal. There was no significant difference between the three NaOCl solutions tested. Nonetheless, all NaOCl solutions were significantly more effective than saline solution in reducing the number of bacterial cells within the root canal. This emphasized the importance of the chemical effects together with the mechanical effects in eliminating intracanal bacteria. Regular exchange and the use of large amounts of irrigant should maintain the antibacterial effectiveness of the NaOCl solution, compensating for the effects of concentration. The same observation was done by Baumgartner and Cuenin[36] when evaluating the tissue-dissolving ability of NaOCl solutions.

Therefore, the use of an antimicrobial irrigant significantly contributes to the elimination of microorganisms from the root canal. NaOCl remains as the irrigant of choice in root canal therapy. Regardless of the concentration, high volumes and frequent exchange are required for optimum antimicrobial and tissue-dissolving capabilities.

Role of the Intracanal Medication

Although a considerable reduction in bacterial cell numbers within the root canal can be achieved by the chemical and mechanical effects of instrumentation and irrigation, viable bacteria can still be found in at least half of the cases.[17,19-21,28] Whilst minor anatomical irregularities are usually incorporated into preparation, other areas such as isthmuses, culs-de-sac, branches, and dentinal tubules can harbor microorganisms. These areas are not commonly affected by the chemomechanical preparation because of inherent physical limitations of instruments and the short time the irrigants are present within the root canal (**Figure 3**).

In situ investigations have revealed that bacteria can infect dentinal tubules to an extent ranging from 10 to 300 ¼m[37-38] (**Figure 4**). Bacterial cells penetrating up to approximately 200 to 300 ¼m are unlikely to be eliminated by chemomechanical procedures. In such areas of dentin infection, the root canal should be theoretically enlarged to a diameter approximately 0.4 to 0.6 mm larger than the initial diameter of the root canal in order to remove bacteria inside tubules. This is practically impossible to accomplish in most cases, particularly in the apical third of the root canal. In vitro studies have evaluated the capacity of irrigants in eliminating bacterial cells within tubules during varying periods.[39,40] However, depths of disinfected zones in dentin have been rarely reported. It is unknown to what extent irrigants can reach antimicrobial effectiveness within dentin in in vivo conditions.

In most cases, surviving bacteria within tubules are entombed by the root canal filling and may have a drastically reduced substrate. In such anatomical regions, bacteria entombed by the root filling usually die or are prevented from gaining access to the periradicular tissues. Even interred, some bacterial species are likely to survive for relatively long periods, deriving residues of nutrients from tissue remnants and dead cells.[25] If the root canal filling fails in promoting a fluid-tight seal, seepage of tissue fluids into the canal can provide substrate for bacterial growth. If growing bacteria reach a significant number and gain access to the periradicular tissues, they can perpetuate inflammation.[25] Thus, one might assume that persistent dentinal infection has the potential to jeopardize the outcome of the endodontic therapy and ideally should be eradicated before filling.

Histologic studies have shown that some root canal walls remain untouched after chemomechanical preparation, regardless of the instrument type, the instrumentation technique, and the irrigant used.[16,41-43] Untouched areas may contain bacteria and necrotic tissue substrate even though the root canal filling appears to be radiographically adequate. If infected areas are not effectively isolated from the periradicular tissues by a three-dimensional seal provided by the root canal filling, microorganisms may maintain periradicular inflammation. The fact that studies have reported the occurrence of viable microbial cells in treated teeth with a persistent periradicular lesion indicates that microorganisms derive nutrition from tissue fluid, which can seep into the root canal space.[9]

Studies have revealed that the success rate of endodontic treatment is increased if the root canal is free from microorganisms at the time of obturation.[12-14] Since microorganisms are the major etiological agents of periradicular diseases, their presence in the root canal system at the time of root canal filling jeopardizes the outcome of the treatment. Therefore, all efforts should be directed toward the thorough elimination of microorganisms.

Inherent physical limitations impede action of the instruments in areas beyond the main root canal. Irrigants remain for a short time in the root canal to eliminate microorganisms located in such areas, and the faster the instrumentation technique the lesser the time of irrigant presence within the root canal. Thus, the effects of the chemomechanical preparation are restricted to the main root canal. By remaining for a longer time in the canal than irrigants, antimicrobial intracanal medicaments have a higher probability to reach microorganisms located in areas unaffected by the chemomechanical preparation and thereby help in disinfection of the entire root canal system.

## One-Visit Versus Two-Visit Treatment

One-visit endodontic treatment offers some potential advantages to both the dentist and patient. In addition to being faster and well-accepted by patients, it prevents the contamination or recontamination of the root canal system between appointments. In cases of vital pulp, treatment ideally should be finished in one session provided that the time available, operator's skills and anatomical conditions are all favorable. On the other hand, treatment in one session of necrotic pulps whether associated with a periradicular lesion or not is still a controversial issue in endodontics.

Despite anecdotal evidence supporting endodontic therapy in a single visit, two factors must be taken into account before deciding upon a one-visit treatment of teeth with necrotic pulp: the incidence of postoperative pain and the long-term outcome of the treatment. Studies have found no difference in the incidence of postoperative pain between one- and multiple-visit endodontics.[44-46] As consequence, the outcome of the endodontic treatment should be the major factor taken into account when deciding the number of therapy sessions.

There is a paucity of studies comparing the success rate of the endodontic therapy performed in one or more sessions. Most of these few studies have been based on poorly defined criteria of evaluation. The most common flaws include short-term follow-up, no differentiation between pathological conditions (vital or necrotic pulps, presence of periradicular bone destruction, etc.), nonstandardized intracanal procedures, multiple operators with obvious divergent skills, retrospective evaluation, and loose criteria in determining success and failure.

Pekruhn[46] published one of the largest studies on single-visit treatment results. His study used a one-year follow-up period, and the inclusion criteria was undefined. Many cases were treated in two visits. There were significantly fewer failures in the two-visit treatment group than in the one-visit treatment group, regardless of the pretreatment diagnosis.

A few studies have presented clearly defined criteria. In a very well-controlled clinical study, Sjögren et al.[14] investigated the role of infection in the outcome of one-visit treatment after a follow-up period of five years. All followed-up teeth (n = 53) showed infected pulps before treatment. The irrigant solution used was 0.5 percent NaOCl. Although it is considered a weak solution, it has not been demonstrated to be clinically less effective than 5 percent NaOCl in eliminating intracanal microorganisms.[19,20] Forty-four cases were successful (83 percent). Of the nine failed root canals, seven yielded positive culture before filling. Slight overfilling appeared to have no influence on the outcome because all 10 overfilled teeth were successful. The remaining 43 cases were obturated within 2 mm of the apex. These findings can be directly compared to others of the same research group.[13] Success was reported for 94 percent of the infected root canals associated with periradicular lesions treated in multiple visits when the root canals were filled within 2 mm from the root apex (the same conditions of the one-visit study). Thus, a difference of 11 percent could be detected between single- and multivisit treatment.

In another well-controlled clinical study, Trope et al.[47] evaluated radiographic healing of teeth with periradicular lesions treated in one or two visits. All patients were treated by the same operator. Instrumentation was standardized with 2.5 percent NaOCl used as irrigant. All teeth were obturated with lateral condensation of gutta-percha and Roth 801 sealer. In the two-visit group, root canals were medicated with calcium hydroxide for at least one week. After a one-year follow-up evaluation, the additional disinfecting action of calcium hydroxide resulted in a 10 percent increase in healing rates. This difference should be considered clinically important.[47]

Katebzadeh et al.[48,49] radiographically and histologically compared periradicular repair after endodontic treatment of infected root canals of dogs performed in one or two sessions. They reported better results for the two-visit treatment in which calcium hydroxide was used as an intracanal disinfecting medicament for one week.

Microorganisms can survive the effects of chemomechanical preparation in 40 percent to 70 percent of the cases.[17,19-21,28] Most of the surviving microorganisms die either by the antimicrobial action of root canal filling material or by the absence of available nutrients in a filled root canal. Nonetheless, in certain cases, microorganisms can survive even in a well-filled root canal, acquiring nutrients and reaching sufficient numbers to perpetuate a periradicular lesion.

Perpetuation of a periradicular lesion caused by a persistent root canal infection will depend on (a) the access of remaining microorganisms to the periradicular tissues; (b) the ability of residual microorganisms to survive in an environment with low nutrient availability; (c) the virulence; (d) the number of the surviving microorganisms; and e) the host resistance.[10]

Therefore, overwhelming scientific evidence indicates that microorganisms can survive the effects of chemomechanical preparation in at least a half of the cases; and microorganisms are the major causative factors of the endodontic failure, even in well-treated cases. Because remaining microorganisms jeopardize the long-term outcome of the endodontic treatment, additional measures should be taken to predictably eradicate the root canal infection. To date, the support of an interappointment antimicrobial dressing is necessary to accomplish such an objective.

In cases of vital pulp, a single-visit treatment should be used whenever possible. This is based on the fact that the pulp is only superficially infected and the root canal is free of bacteria, provided the aseptic chain is maintained during the intracanal procedures. Therefore, there is no apparent reason not to treat vital pulps in a single visit.

On the other hand, if the pulp is necrotic and associated with a periradicular disease, there is ample evidence that the root canal system is infected. In these cases, the root canal ideally should be cleaned and shaped, an intracanal medication placed, and the canal filled in a second appointment. These procedures, as previously mentioned, are based on scientific evidence and not merely suppositions.

It is obvious that in the future, the single-visit treatment will become a suitable choice for treating infected teeth also. Ongoing research has the potential to discover measures that will enable dentists to treat infected root canals in one session predictably. However, the current treatment that offers a significantly higher success rate is accomplished in two or more sessions and, for this reason, should be the only choice for the treatment of infected root canals at this time.

## Intracanal Medicaments

Since its introduction by B.W. Hermann,[50] a German dentist, in 1920, calcium hydroxide has been widely used in endodontics. It is a strong alkaline substance with a pH of approximately

12.5. Currently, this chemical substance is acknowledged as one of the most important antimicrobial dressings used during endodontic therapy.

Most endodontopathogens are unable to survive in a highly alkaline environment such as that of calcium hydroxide, therefore several bacterial species commonly found in infected root canals are eliminated after a short period when in direct contact with this substance.[51]

The antimicrobial activity of calcium hydroxide is related to the release of hydroxyl ions in an aqueous environment. Hydroxyl ions are highly oxidant free radicals that show extreme reactivity, reacting with several biomolecules. This reactivity is high and indiscriminate, so this free radical rarely diffuses away from sites of generation. Their lethal effects on bacterial cells are probably due to the following mechanisms:

**Damage to the bacterial cytoplasmic membrane.** Hydroxyl ions from calcium hydroxide can induce lipid peroxidation, resulting in the destruction of phospholipids, structural components of the cellular membrane. Hydroxyl ions remove hydrogen atoms from unsaturated fatty acids, generating a free lipidic radical. This free lipidic radical reacts with oxygen, resulting in the formation of a lipidic peroxide radical, which removes another hydrogen atom from a second fatty acid, generating another lipidic peroxide. Thus, peroxides themselves act as free radicals, initiating an autocatalytic chain reaction, and resulting in further loss of unsaturated fatty acids and extensive membrane damage.[52]

**Protein denaturation.** Alkalinization provided by calcium hydroxide can induce the breakdown of ionic bonds that maintain the tertiary structure of proteins. As a consequence, the enzyme maintains its covalent structure; but the polypeptide chain is randomly unraveled in variable and irregular spatial conformation. These changes frequently result in the loss of biological activity of the enzyme and disruption of the cellular metabolism. Structural proteins may also be damaged by hydroxyl ions.

**Damage to the DNA.** Hydroxyl ions react with the bacterial DNA and induce the splitting of the strands. Genes are then lost.[53] Consequently, DNA replication is inhibited, and the cellular activity is disarranged. Free radicals may also induce lethal mutations.

Several studies have demonstrated that calcium hydroxide exerts lethal effects on bacterial cells.[51,54,55] Optimum effects were observed when the substance was in direct contact with bacteria in solution. In such conditions, the concentration of hydroxyl ions is very high, reaching incompatible levels to bacterial survival. Clinically, this direct contact is not always possible.

Although hydroxyl ions possess antibacterial effects, rather high pH values are required to destroy microorganisms. Killing of bacteria by calcium hydroxide will depend on the availability of hydroxyl ions in solution, which is higher where the paste is applied (the main root canal). Calcium hydroxide exerts antibacterial effects in the root canal as long as they retain a very high pH. If calcium hydroxide needs to diffuse to tissues and the hydroxyl concentration is decreased as result of the action of buffering systems (bicarbonate and phosphate), acids, proteins, and carbon dioxide, its antibacterial effectiveness may be reduced or impeded.[56]

Bacteria inside dentinal tubules may constitute an important reservoir from which root canal infection or reinfection may occur during and after endodontic treatment. As previously mentioned, remaining microorganisms may cause a persistent infection that puts the outcome of the endodontic therapy at risk. Bacteria inside dentinal tubules are protected from the effects of host defense cells and molecules, systemically administered antibiotics, and chemomechanical preparation. Therefore, treatment strategies that are directed toward the elimination of tubule infection are necessary and must include medicaments that penetrate dentinal tubules and kill microorganisms.

After a short-term intracanal dressing with calcium hydroxide, pH levels reached in dentine may still allow the survival or growth of some microbial strains. Microorganisms vary in their pH tolerance ranges, and most human pathogens grow well within a range of 5 to 9 pH.[57] Some strains of *Escherichia coli*, *Proteus vulgaris*, *Enterobacter aerogenes* and *Pseudomonas aeruginosa* can survive in pH 8 or 9.[58] These bacterial species have occasionally been isolated from infected root canals, usually causing secondary infections.[7] Certain bacteria, such as some enterococci, tolerate very high pH values, varying from 9 to 11. Fungi generally also exhibit a wide pH range, growing within a range of 5 to 9 pH.[58] It has been demonstrated that enterococci and fungi are highly resistant to calcium hydroxide.[51,59] Since these microorganisms are commonly found in cases of endodontic failure, the routine use of calcium hydroxide should be questioned.

The ability of a medicament to dissolve and diffuse in the root canal system would seem essential for its successful action. A saturated aqueous suspension of calcium hydroxide possesses a high pH, which has a great cytotoxic potential. Nevertheless, this substance owes its biocompatibility to its low water solubility and diffusibility. Because of these properties, cytotoxicity is limited to the tissue area in direct contact with calcium hydroxide. On the other hand, the low solubility and diffusibility of calcium hydroxide may make it difficult to reach a rapid and significant increase in the pH to eliminate bacteria within dentinal tubules and enclosed in anatomical variations. Likewise, the tissue buffering ability controls pH changes. Because of these factors, calcium hydroxide is a slowly working antiseptic. Prolonged exposure may allow for saturation of the dentine and tissue remnants. The long-term use of calcium hydroxide may be necessary to obtain a bacteria-free root canal system.[56] However, in most instances, the routine use of an intracanal medication for a long period does not seem to be an acceptable practice in modern endodontics.

Although clinical studies have revealed that the treatment using calcium hydroxide as intracanal dressing showed higher success rates when compared with single-visit treatment, the search for more-effective medicaments or combinations should not necessarily stop. This statement is based on the following facts: Living microorganisms still remain in approximately 20 percent of the previously infected canals after one week of medication with calcium hydroxide;[60-62] and some microorganisms associated with endodontic failures are intrinsically resistant to calcium hydroxide. Endodontic infections are polymicrobial, and no known medicament is effective against all the bacteria found in infected root canals. In addition, the medicament should ideally reach microorganisms located in distant areas of the root canal system in lethal concentrations. Combination of two medicaments may produce additive or synergistic effects. Recently, renewed interest has been generated regarding the association of calcium hydroxide with other antimicrobial substances, such as camphorated paramonochlorophenol (CPMC), chlorhexidine, or iodine potassium iodide (IPI). Laboratory studies have shown that these substances significantly increase the antimicrobial spectrum of calcium hydroxide.[63-66]

Evidence suggests that the association of calcium hydroxide with CPMC has a broader antibacterial spectrum, has a higher radius of antibacterial action, and kill bacteria faster than mixtures of calcium hydroxide with inert vehicles (water, saline, glycerin).[56,63-65,67] Although CPMC has strong cytotoxic activities,[68] studies have reported a favorable tissue response to calcium hydroxide/CPMC mixture.[69,70] This association probably owes its biocompatibility to:

* The small concentration of released paramonochlorophenol (PMC). Calcium hydroxide plus CPMC yields calcium paramonochlorophenolate, which is a weak salt that progressively releases PMC and hydroxyl ions to the surrounding medium.[71] It is well-known that a substance may have either beneficial or deleterious effects, depending on its concentration. The low release of PMC from the paste might not be sufficient to have cytotoxic effects;

* The denaturing effect of calcium hydroxide on connective tissue, which may prevent the tissue penetration of PMC, reducing its toxicity;[56]

* The fact that the effect on periradicular tissues is probably associated with the antimicrobial effect of the paste, which allows natural healing to occur without persistent infectious irritation. If the wound area is free of bacteria when the transitory chemical irritation occurs, there is no reason to believe that tissue repair would not take place as the initial chemical irritant decreases in intensity.[56]

Therefore, the use of an antimicrobial intracanal dressing can significantly contribute to the eradication of the root canal infection. Logically, not all antimicrobial substances used as intracanal medication exert such desirable effects. Calcium hydroxide has yet to be tried by time and scientific assessment. It is not a panacea. Besides not being effective against all microorganisms present in the root canal infection, after a short exposure calcium hydroxide may not reach microorganisms located beyond the main root canal in lethal concentrations. Association of calcium hydroxide with other antimicrobial substances, such as CPMC, IPI, and chlorhexidine, has the potential to optimize the antimicrobial effectiveness of the intracanal medication.

Role of the Root Canal Obturation

Most endodontic sealers show antimicrobial activity before setting, but most of them also lose this ability after setting. Because antimicrobial activity of most sealers is not pronounced and is usually ephemeral,[72-74] it is highly unlikely that sealers will be of significant assistance in killing microorganisms that survived the effects of the chemomechanical preparation and the intracanal medicament (if used).

In reality, cleaned and shaped root canals must be three-dimensionally filled, eliminating the empty space, which has the potential to be infected or reinfected. In addition, by creating a fluid-tight apical, lateral, and coronal seal, root canal fillings may confine residual irritants within the root canal system, impeding their egress to the periradicular tissues. A fluid-tight seal of the root canal system also prevents both the coronal recontamination by saliva and the seeping of periradicular tissue fluids into the root canal, denying nutrient supply to remaining microorganisms. Therefore, the critical function of the root canal obturation is preventive, essentially acting as a barrier to infection or reinfection of both the root canal system and the periradicular tissues.

The root canal system often possesses a complex anatomy, including fins, culs-de-sac, isthmi, ramifications, and other irregularities. It has been claimed that many of these areas are difficult to fill using conventional techniques, such as the lateral condensation technique. Thermoplasticized gutta-percha techniques have been advocated for root canal obturation as they can provide a more homogenous mass of obturation and a better filling of root canal intricacies when compared with the traditional lateral condensation technique.[75,76] Theoretically, such properties might favor the attainment of an impervious coronal and apical seal of the root canal system.

Nonetheless, numerous studies have shown that neither contemporary root canal obturation techniques nor available filling materials can provide an impervious seal to leakage.[77-80] To date, no well-controlled clinical study has demonstrated that thermoplasticized gutta-percha techniques provide more favorable treatment outcomes than traditional lateral condensation technique. Further, one should bear in mind that apparently moving gutta-percha or sealer or both into all anatomic variations does not necessarily mean that the root canal system was appropriately cleaned, disinfected, and sealed.

Antibiotics

The purpose of antibiotic therapy is to aid the host defenses in controlling and eliminating microorganisms that have temporarily overwhelmed the host defense mechanisms.[81] The most important decision in antibiotic therapy is not so much which antibiotic should be employed but whether antibiotics should be used at all.

The vast majority of infections of endodontic origin can be treated without antibiotics. Due to the absence of blood circulation within a necrotic and infected pulp, antibiotics cannot reach and eliminate microorganisms present in the root canal system. Thus, the source of infection is unaffected by systemic antibiotic therapy. On the other hand, antibiotics can help impede the spread of the infection and the development of secondary infections in compromised patients. Therefore, antibiotic therapy can be a valuable adjunct for the management of some cases of endodontic infection. The rare occasions in which antibiotics are indicated in endodontics include:

* Acute periradicular abscesses associated with systemic involvement, such as fever, malaise, and lymphadenopathy;

* Spreading infections resulting in cellulitis, progressive diffuse swelling and/or unexplained trismus (**Figure 5**);

* Acute periradicular abscesses (even with localized swelling) in medically compromised patients who are at increased risk of a secondary infection at a distant site following a bacteremia;

* Prophylaxis for medically compromised patients during routine endodontic therapy;

* Some cases of persistent exudation not resolved after revision of intracanal procedures; and

* Replantation of avulsed teeth.

Acute periradicular abscesses in healthy patients without systemic involvement and characterized by localized swelling do not require antibiotic therapy.

Patients under antibiotic therapy must be monitored daily. The best practical guide for determining the duration of antibiotic therapy is clinical improvement of the patient. When clinical evidence indicates that the infection is certain to resolve or is resolved, antibiotics should be administrated for no longer than one or two additional days.

Antibiotic treatment of infections of endodontic origins is initiated based on the knowledge of the most likely pathogens. Amoxicillin, a broad-spectrum semisynthetic penicillin, is the antibiotic of first choice for such infections. Most of the root canal microbiota is susceptible to amoxicillin.[82] In patients allergic to penicillins or in cases resistant to amoxicillin therapy, clindamycin is indicated. The risk/benefit ratio should be always considered before administration of systemic antibiotic therapy.

Laser Irradiation of Infected Root Canals

A laser that transforms light of various frequencies into a chromatic radiation in the visible, infrared, and ultraviolet regions with all the waves in phase capable of mobilizing immense heat and power when focused at close range.[83] Many kinds of laser devices have been used in dentistry. Among potential applications in endodontics, lasers have been tested for efficacy in disinfecting root canals. All lasers have an antimicrobial effect at high power that varies with the type of laser. The Nd-YAG laser has been studied the most because its laser energy and laser fiber can be easily controlled. Although promising results have been reported in vitro,[84,85] root canal disinfection can be problematical in narrow curved canals and because of the possible thermal injury to periodontal tissues. In addition, laser devices are still relatively costly. Future research will help to define optimal laser parameters for safe and effective disinfection of root canals.

Clinical Protocol Based on an Antimicrobial Strategy

Diligent antimicrobial therapy should focus upon employing well-tolerated antimicrobial agents exhibiting effectiveness against the most prevalent microorganisms involved in primary and persistent root canal infections. Moreover, the antimicrobial endodontic therapy should be able to eliminate microorganisms present not only in the main root canal, but also in all variations of the root canal system. The following protocol to routinely treat infected root canals is based on both scientific evidence and clinical experience (**Figures 6 and 7**):

1. The tooth to be treated must be free of plaque and calculus.

2. Preparation of the access cavity can be initiated before the application of a rubber dam but cannot be concluded until after its placement. All carious tissue must be removed.

3. After rubber dam placement, the operative field must be cleaned with hydrogen peroxide and disinfected with iodine solution, chlorhexidine, or sodium hypochlorite solution.

4. After completion of access preparations, the pulp chamber must be copiously irrigated with a 2.5 percent NaOCl solution.

5. Chemomechanical preparation should be performed using a crown-down technique, with hand and/or rotary instruments and at least 1 to 2 ml of 2.5 percent NaOCl after each file size. NiTi instruments should be used in curved root canals. The root canal should be enlarged to 1 mm short of the apex. Overinstrumentation is undesirable as it can predispose the tooth to both postoperative symptomatology and treatment failure. However, the 1 mm apical segment ideally should be cleaned and maintained free of debris by using small size patency files.

6. After smear layer removal, the root canal is medicated with a calcium hydroxide/CPMC/glycerin paste. The paste is prepared on a glass slab, using equal proportions of CPMC and glycerin (1:1, v:v). The two liquids are mixed and then calcium hydroxide is slowly added until a creamy consistency is reached. The paste ideally is applied in the canal using lentulo spirals.

7. The tooth is radiographed to check the proper placement of the intracanal medication, and a temporarily coronal material is applied.

8. In the second appointment, three to seven days later, the paste is removed using files under copious irrigation with 2.5 percent NaOCl and the root canal obturated.

Outline of Strategies to Treat Root Canal Infections

1. Periradicular lesions are diseases of infectious origin and therefore must be prevented or treated accordingly;

2. Maintenance of the aseptic chain is as important as disinfection of the root canal for the outcome of root canal therapy. In other words, from a microbiological point of view, what one removes from the root canal is as important as what one places into it.

3. Root canal therapy in vital pulp cases ideally should be concluded in a single visit.

4. It is essential to disrupt the microbial communities within root canals by mechanical means (root canal instrumentation) with sodium hypochlorite irrigation.

5. Antimicrobial dressings are valuable adjuncts to predictably eliminate microorganisms from the root canal system. The smear layer should be removed to facilitate diffusion of the medicaments into dentinal tubules.

6. Two-visit endodontic treatment using calcium hydroxide dressing results in a higher success rate than a single-visit treatment. The success rate of treatment may even be increased if an intracanal medicament or a combination of medicaments (such as calcium hydroxide plus CPMC) with a broader antimicrobial spectrum and a higher radius of action is used.

7. Root canal obturation assumes a special relevance in perpetuating the status of root canal disinfection obtained after both chemomechanical preparation and intracanal medication.

8. Antibiotics are never a substitute for either drainage procedures or proper endodontic

therapy. Thus, antibiotics are not used to treat root canal infections, but mainly to prevent their spreading. Clinicians should be aware of the risk/benefit ratio before indicating systemic antibiotic therapy.

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## Legends

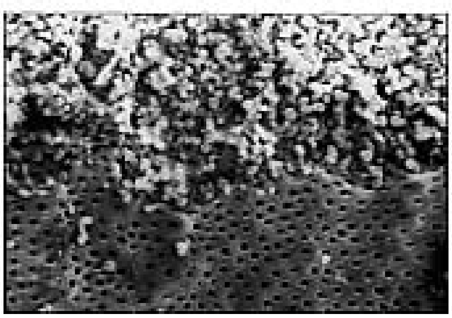

Figure 1

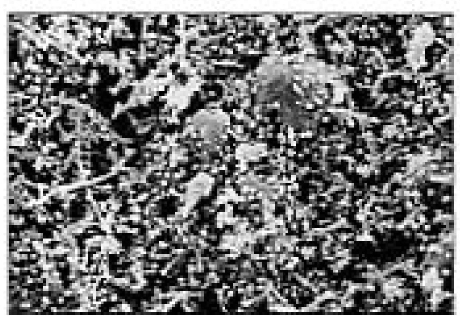

Figure 2

**Figure 1.** Fungi cells colonizing the dentinal walls in the middle third of the root canal (original magnification 2,100x). Although fungi are occasionally found in primary root canal infections, they have been associated with several cases of persistent infections.

**Figure 2.** Dense mixed bacterial population colonizing the root canal walls (original magnification 3,300x).

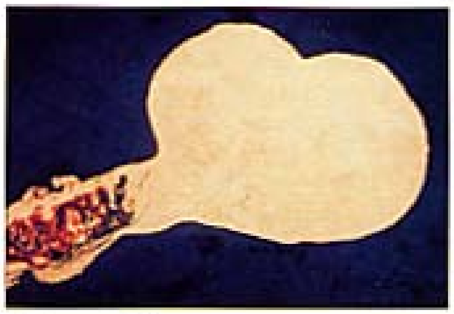

Figure 3

Figure 4

**Figure 3.** Tissue remnants in root canal irregularities after chemomechanical preparation using 5.25 percent NaOCl as irrigant.

**Figure 4.** Bacterial cells invading dentinal tubules (original magnification 1,900x). Efforts should be also directed toward their elimination.

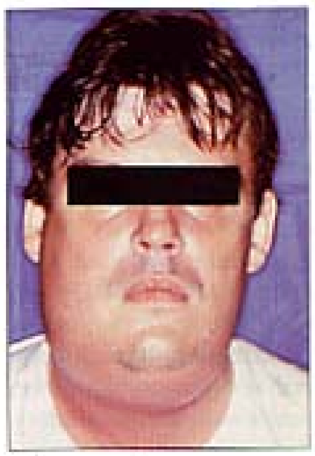

Figure 5

Figure 6a

Figure 6b

Figure 7a

Figure 7b

**Figure 5.** Spreading root canal infection resulting in cellulitis. Systemic antibiotic therapy is indicated in cases such as this (courtesy of Dr. Henrique Martins).

**Figure 6.** Treatment in two sessions of a tooth associated with periradicular lesion and showing apical root resorption. **A.** Preoperative, and **B.** follow-up radiograph after seven

months showing repair of the lesion and stopping of the root resorption process.

**Figure 7.** Treatment in two sessions of a tooth associated with extensive periradicular bone destruction. **A.** Preoperative, and **B.** follow-up radiograph showing bone repair of the lesion (courtesy of Dr. Luis Paulo Mussi).

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