

# Rationale and efficacy of root canal medicaments and root filling materials with emphasis on treatment outcome

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## The biological basis for endodontic disease

There is overwhelming evidence that endodontic diseases can be characterized as infectious diseases. There is no longer any question that microorganisms are at the center of the etiological causes of pulpal and periradicular pathological processes (1, 2). There are many secondary reasons contributing to tissue breakdown and endodontic failures, such as root perforations, instrument fractures, excess of root canal filling materials and poor technical quality of obturations (3–6). However, none of these seemingly important complications to the treatment will result in failure unless microorganisms infect the damaged area and establish a progressive tissue breakdown. Microbial agents are needed for the expansion of periradicular disease.

As there is a microbial cause of progressive periradicular tissue disease, the elimination or reduction of microorganisms in the pulp space and subsequent closure will result in healing.

## Pulpitis and apical periodontitis

Dental pulp inflammation (pulpitis) is most commonly caused by microorganisms reaching the pulp tissue through caries or periodontal disease. Leakage of microbes, or their antigens, around the cavity mar-

gins of leaking restorations also cause significant pulp injuries in the form of chronic pulpitis. These microbial insults are all directly associated with diffusion of bacterial components or the direct invasion of microorganisms.

In addition, there are other insults to the pulp which are not initially dependent on microorganisms. Examples of such insults are traumatic injuries, traumatic cavity preparation, inappropriate cavity treatment and the use of non-physiological restorative materials. If the pulp tissue remains sterile, the pulp damage caused by these insults may heal over time. In many cases, when the inflammation has resulted in some form of pulp necrosis, microorganisms are able to reach and colonize the inflamed tissue surface. The direct invasion of microorganisms is the beginning of a more definitive pathological process that is considered irreversible. The bacterial colonization of the surface of the pulp will cause local tissue breakdown with an increasing degree of pulp necrosis. The necrosis provides more microbial nutrients and the process escalates. There are occasions when the pulp breakdown proceeds very slowly with several attempts to heal. The ultimate end of the process is total pulp necrosis, apical periodontitis and hard tissue resorption. (Fig. 1). This dynamic disease process makes pulpal diagnosis difficult. It is important to understand that the pathological process from incipient pulp inflammation to total necrosis is a continuum,

which can result in a severely diseased pulp in the coronal portion of the pulp and practically no tissue inflammation in the apical part of the pulp (Fig. 2).

During the expansion of the infected necrosis of the pulp with subsequent dentin infection, the immunological defense will be activated. Depending on ecological microbiological factors, the development of an apical osteolytic process ensues. The regulation of this inflammatory and tissue-destroying process is complex, involving a number of host-derived factors including cytokines, antibodies, complement, arachidonic acid products such as prostaglandins, and neuropeptides. The bone resorption provides space for the formation of inflammatory tissue around the apical foramen to the periradicular tissues. These resorptive bone lesions can be diagnosed easily on a periapical radiogram. The inflamed tissue serves a significant

defensive role, preventing bacterial invasion of the periradicular bone tissue. The bone changes following a pulp necrosis can be late in appearing radiographically (7). Often, however, osteolysis develops rapidly, sometimes before total pulp necrosis is complete. This makes diagnosis difficult as the pulp may respond normal to electrometric pulp test despite radiographic bone changes (Fig. 2).

There are, however, conditions where an infected, necrotic pulp will not initially cause an osteolytic lesion. It has been well documented that some bacteria, colonizing the root canal space, may not by themselves result in bone resorption, visible on a radiograph. The specie or combination of species are important factors for progressive disease (2, 8).

The blood supply to the pulp is often severed after traumatic injuries. This will result in an aseptic necrosis. Although unusual, the necrotic pulp tissue may revascularize. If the pulp tissue remains necrotic, osteolysis will not occur until the necrotic pulp becomes infected (8). This will ultimately happen, resulting in an apical resorbing periodontitis (7).

## Microbial ecology of the endodontium

The composition of the microflora in the necrotic root canal is dependent on the type of bacteria present in the oral cavity, especially in plaque, and on the ecological conditions in the root canal. The ecological conditions of the infective microbial flora in the root canal system are dependent on the amount of oxygen present (redox potential), the availability of nutrients, and the host's defense. In pulp necrosis, the redox potential is very low. As a consequence of these underlying factors, the microflora in primary apical periodontitis is characterized by a strong dominance of obligately anaerobic bacteria (2, 9–12). The pathogenicity of different species is different, and certain species (*Porphyromonas* spp., *Prevotella buccae*, *Fusobacterium nucleatum*, *Peptostreptococcus* spp.) are suggested to be more closely related to the occurrence of symptoms such as pain and abscess formation (13–16). However, with regard to the treatment outcome of primary apical periodontitis, there is no evidence that the presence of these species in the root canal flora has a negative effect on the long-term prognosis of the treatment, except in special situations such as periapical actinomycosis. Nevertheless,

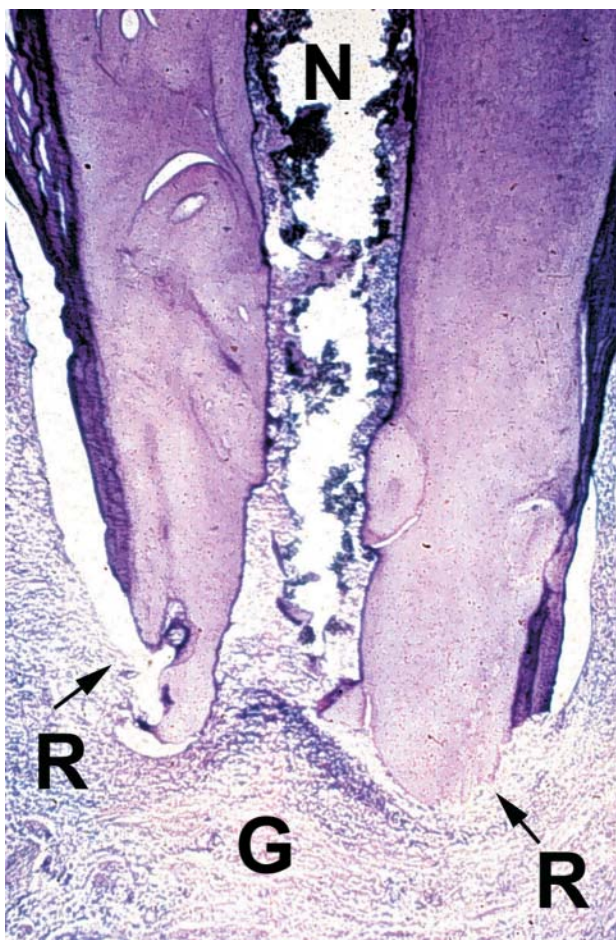


Fig. 1. Apical portion of a tooth with total necrosis of the pulp (N). Subsequent to the infected necrosis, a resorbing apical periodontitis has developed (G) and the apical dentin is undergoing resorption (R).

the excellent outcome of the treatment of primary apical periodontitis may be related to the fact that the anaerobic microflora is very sensitive to the ecological changes caused by the chemomechanical preparation and the local intracanal environment. The dramatic cut in the availability of nutrients caused by the treatment is also supposed to effectively reduce the possibilities for survival of anaerobic bacteria in particular. In general, the anaerobic microflora is more sensitive to treatment procedures than other bacteria (17).

In retreatment cases of apical periodontitis, the ecological environment in the (partly) filled root canal is quite different from that of primary apical periodontitis. *Enterococcus faecalis* is the dominant species in retreatment cases (18–21). Generally, the availability of nutrients is limited, and the canal may be filled with materials with some antibacterial activity (20). As a consequence, bacteria present in retreatment cases can be more resistant to endodontic treatment than in primary cases.

## Bacterial colonization

The great majority of microorganisms in apical periodontitis are located in the main root canal. Usually, the infection does not proceed through the apical foramen and bacteria cannot be detected outside the root (22), although sometimes bacteria may also be found in the periapical tissues (22–31). Light and electron microscopic studies have shown that the apical microbes often are delineated from the periradicular tissues by a zone of polymorphonuclear leukocytes at the apical foramen (32).

The location of bacteria in lateral canals in various parts of the root canal system has not been studied in great detail. However, bacterial penetration into lateral canals has been demonstrated in apical periodontitis, and is supposed to occur frequently. Lesions of lateral periodontitis often seen in radiographs also indicate the presence of bacteria in lateral canals. Bacteria from the main canal can also spread into surrounding dentin

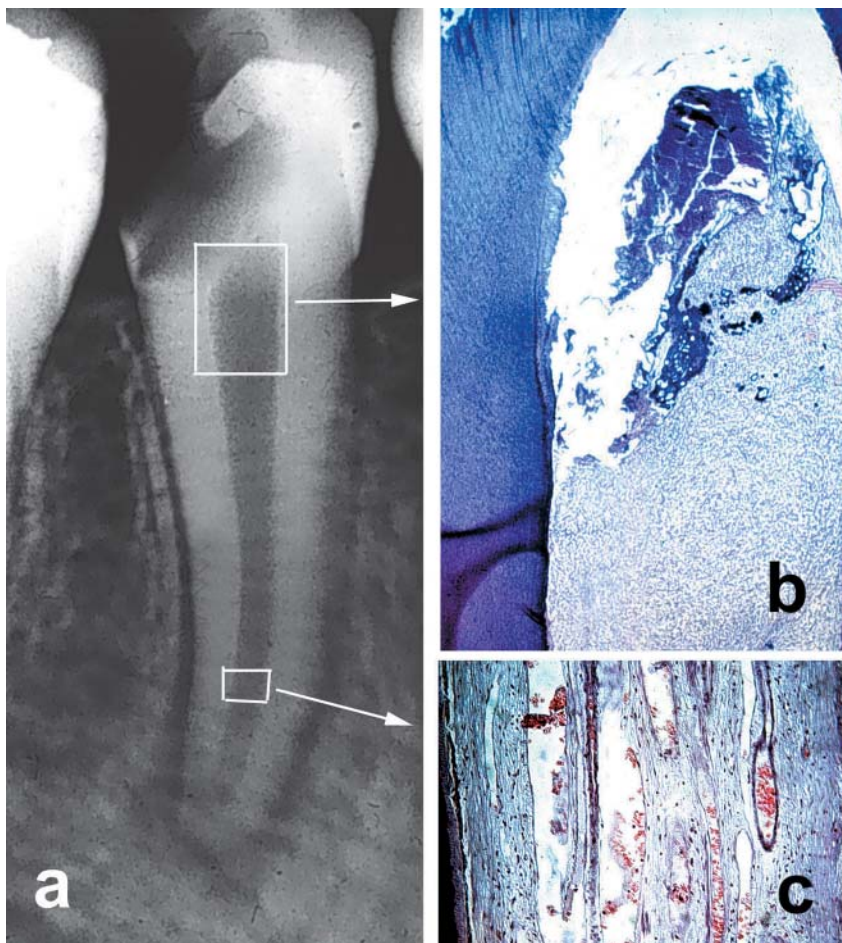


Fig. 2. a. Mandibular premolar with a deep caries lesion and apical radiolucency. b. The coronal pulp is partially necrotic with dense accumulation of inflammatory cells. c. Apical pulp with some extended capillaries but no signs of severe inflammation.

by invading the dentinal tubules (33). Although the importance of dentin canal invasion is difficult to evaluate, there is increasing evidence that even deep dentinal invasion (Fig. 3) from the main root canal occurs in most cases of apical periodontitis (34). It seems that several gram-positive species, such as streptococci, enterococci, actinomyces and lactobacilli, can invade dentin tubules more readily than gram-negative species (35–39). Histological observations indicate that invasion from the root canal occurs seemingly at random. Bacteria in dentin canals are typically seen as sporadic accumulations of cells, not as a continuously growing chain of cells extending out towards the periphery from the main canal (Fig. 3).

It is obvious that endodontic treatment can most effectively reach the microbes present in the main root canal. Bacteria that have invaded the lateral canals and dentin canals, in particular, are largely beyond the reach of mechanical preparation. These bacteria can probably be targeted by irrigation by antibacterial solutions and, in particular, intracanal medicaments like calcium hydroxide, chlorhexidine or iodine compounds. The relative importance for the prognosis of treatment of deep dentinal infection and its elimination is, however, not known.

## Treatment and prevention of endodontic infection

The antibacterial strategy in the treatment of apical periodontitis consists of several steps. Before the en-

dodontic therapy is started, the host's defense system, and occasionally systemic antibiotic therapy, prevent the spreading of the infection from the root canal to the periapical tissues and bone. However, they cannot eliminate the microbial flora because of the lack of circulation in the necrotic root canal. Mechanical preparation together with irrigation with antibacterial solutions greatly reduces the number of microbes in the canal, and in some cases a bacteria-free canal may be attained (40). Intracanal medicaments with long-lasting antibacterial activity are then used to complete the elimination of the bacteria (40). Finally, a root filling of good technical quality and a permanent restoration are needed to prevent reinfection of the root canal.

## The concept of infected and non-infected roots

During the early stages of pulp inflammation caused by microorganisms the microbes grow on the exposed vital pulp (Fig. 4). It is important to understand that this colonization of microorganisms is limited to the surface of the pulp tissue. The vital pulp tissue organ is generally sterile and contains only transient bacterial cells. During these conditions, surgical procedures of the pulp can be undertaken with a high degree of asepsis. To be able to succeed with this, there are important details to observe to prevent cross-contamination during the initial tissue removal.

The importance of asepsis in endodontic treatment

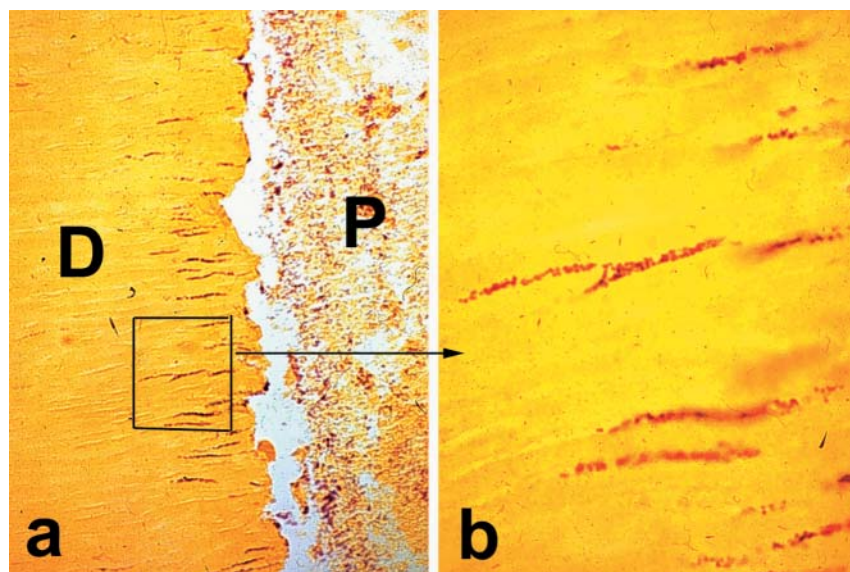


Fig. 3. a. Section of root canal wall stained with Brown and Brenn. Dark colored objects represents microorganisms. b. The necrotic pulp (P) is infected and microbes have entered the dentin (D). Section is a magnification of framed area in a.

is often overlooked. Most conscientious operators use rubberdam for tooth isolation. It is, however, essential that the tooth surface has been cleaned and that the tooth surface is effectively disinfected before access is made. The standard protocol for this is to clean the tooth surface with 30%  $\text{H}_2\text{O}_2$  followed by disinfection with 5% iodine in alcohol (41). The disinfection may also be done with a solution of 0.5% chlorhexidine in alcohol. There are no proven substitutes for this meticulous process. This disinfection process will establish a surgical field, allowing a high degree of asepsis.

When parts of the pulp become necrotic, the microorganisms can invade the dentin tubules. The depth of the invasion may vary with the quality of the dentin, the specie, and the duration of the infection. The infection will reach the root canal proper and the dentin tubules of the root canal wall will be invaded by microbes (Fig. 3). This invasion of the dentin body introduces a very complex problem of disinfection. The pulp chamber is easy to access and disinfect, but the root canal walls present some special problems. The further apical the infection has spread, the more difficult will the disinfection become. It is well documented in the literature that failure to eliminate microorganisms from the root canal space significantly decreases the chances for successful treatment (42).

Therefore, the important treatment challenge is to deliver a therapeutic approach that achieves an optimal treatment outcome with minimal tissue damage from antimicrobial agents.

From this progression of disease it is easy to understand that the difficulty of disinfection increases with the advance of the inflammation and subsequent infection. The rate of success decreases with increased severity of pulp and periapical pathosis. This underscores the importance of early diagnosis and treatment in order to achieve an optimal result for the patient. Pulp inflammation should be diagnosed before necrosis occurs, and necrosis should be diagnosed and treated before apical periodontitis occurs.

### Endodontic medicaments: past and current use

During endodontic treatment, the root canal content must be removed using mechanical instruments. To remove the debris from the instrumentation, the root canal is irrigated and the fluid is evacuated with a suction device. Antimicrobial agents have been used in endodontic therapy for more than a century. Saline, various antimicrobial agents and their combinations have been used for irrigation. Most common has been quaternary ammonium compounds (cationic deter-

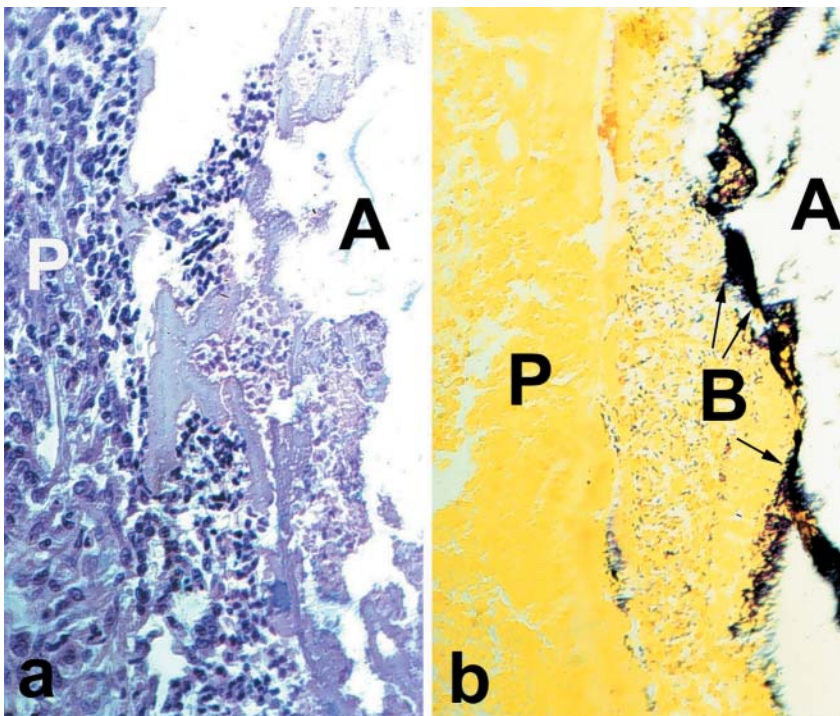


Fig. 4. Sections of pulp tissue exposed through caries lesion. a. The pulp tissue (P) is severely inflamed. A microabscess is located at (A). Htx-Eosin. b. Section adjacent to section a. Brown and Brenn stain. No bacteria can be identified in the pulp tissue (P). The surface of the pulp tissue shows dense localization of bacteria (B).

gents), iodophores, and sodium hypochlorite solutions.

It was well known that after the instrumentation of the infected pulp space, some type of further disinfection would be required to enhance the chances for treatment success (4, 40, 43). For many years, phenol, phenol derivatives, and mixtures with formaldehyde were used as the main disinfectant. These materials are very irritating (44). Due to the lack of scientific understanding of the precise role of bacteria in the endodontic disease process, the endpoint of the disinfection was often not clear. Various standardized protocols were developed for disinfection. Often, an excess of chemicals as well as time were spent on this process. During the last 40 years, calcium hydroxide has also been commonly used. Some suggestions for using calcium hydroxide has been its mixture with phenol derivatives, formaldehyde derivatives and chlorhexidine. This is not advisable, however, as it renders the calcium hydroxide less resorbable and adds unnecessary toxicity (Fig. 5).

Bacteriological culturing has often been used for the monitoring of root canal disinfection. Not until the middle of the last century were culturing methods improved to such a degree that the results could be used for assessment of disinfection (41). More predictable and less tissue-damaging disinfection methods have been developed as the sophistication of culturing has improved.

## Principles of and rationale for irrigation: irrigation materials

Irrigation is used for the removal of tissue remnants and dentin debris during mechanical instrumentation of the root canal. Despite this rather simple objective there has been great controversy over the effectiveness of irrigation, the fluid to use, and the delivery system. Paired with an effective suction device, irrigation is today the most effective way of evacuating tissue debris from the canals.

Various irrigation fluids have been suggested for the irrigation of root canals during instrumentation. Theoretically, the required properties of an irrigation fluid may vary depending on the pulpal diagnosis. During vital pulp extirpation and root canal shaping, saline could serve as the transport vehicle for vital tissue debris and fresh dentin chips. When the pulp has become necrotic and infected, however, there are a great

number of tissue breakdown compounds as well as microbial metabolic products that require a better solvent. The most common irrigation fluid used is sodium hypochlorite. Its use originated during the First World War when a war surgeon described the effectiveness of using a 0.5% sodium hypochlorite solution for the cleaning of necrotic wounds (45–47). Commercially available sodium hypochlorite is manufactured by passing chlorine through NaOH. Consequently, most standard preparations of sodium hypochlorite have a high content of alkali and therefore are highly alkaline (48). Dakin described the proper way of preparing a non-irritating sodium hypochlorite solution relatively free of alkali (46). Unfortunately, this method has been forgotten and today, the common method for obtaining sodium hypochlorite for patient care is to purchase laundry bleach. In some instances, this bleach is diluted with water. This lowers the hypochlorite concentration but does not substantially lower the pH. For some pH adjustments during dilution, 1% sodium bicarbonate may be used as the diluent. To obtain satisfactory tissue dissolution during instrumentation there is no compelling reason to use sodium hypochlorite at any concentration above 0.5% (49). Sodium hypochlorite is also a very potent antimicrobial agent, totally killing enterococci at 0.5% (50).

After the Second World War, quaternary ammonium compounds became very popular for wound treatments as they were believed to be very effective and to have very low toxicity. They soon became popular for root canal irrigation at concentrations between 0.1% and 1%. Later, it became known that the antimicrobial effect in living tissue was sharply inhibited by tissue proteins and that the tissue toxicity was higher than earlier expected (51). This led to a decline in the use of quaternary ammonium compounds for endodontic irrigation, although they are still being used. Being detergents, quaternary ammonium compounds clean fatty tissue deposits.

Sterile saline has also been suggested as an irrigant but its usefulness is questionable. Saline does not support cleaning as it does not have a low surface tension like quaternary ammonium compounds or the ability to enhance tissue dissolution like sodium hypochlorite. Furthermore, having no antimicrobial effect it will not support the maintenance of asepsis during treatment, allowing cross-contamination.

It has been well documented during the last 30 years that the antimicrobial strength of the irrigation

fluid has only marginal importance for the elimination of all bacteria from the pulp space (43, 52, 53). Therefore, the selection of irrigation fluid and its concentration should not focus on high antimicrobial effect but, more importantly, on good tissue compatibility and high cleaning efficacy. Chlorhexidine, an antimicrobial agent with strong affinity to dental hard tissues, has recently been the object of some interest. It does not have any properties making it useful for

debridement of root canals. However, due to its affinity to hard tissue, it has been suggested that the chlorhexidine would be retained and contribute to the maintenance of a bacteria-free root canal for some time after completed endodontic therapy.

Citric acid and EDTA have been suggested as auxiliary irrigation aids to remove the smear layer that develops during the mechanical root canal preparation (54, 55). Both these regimens are effective in

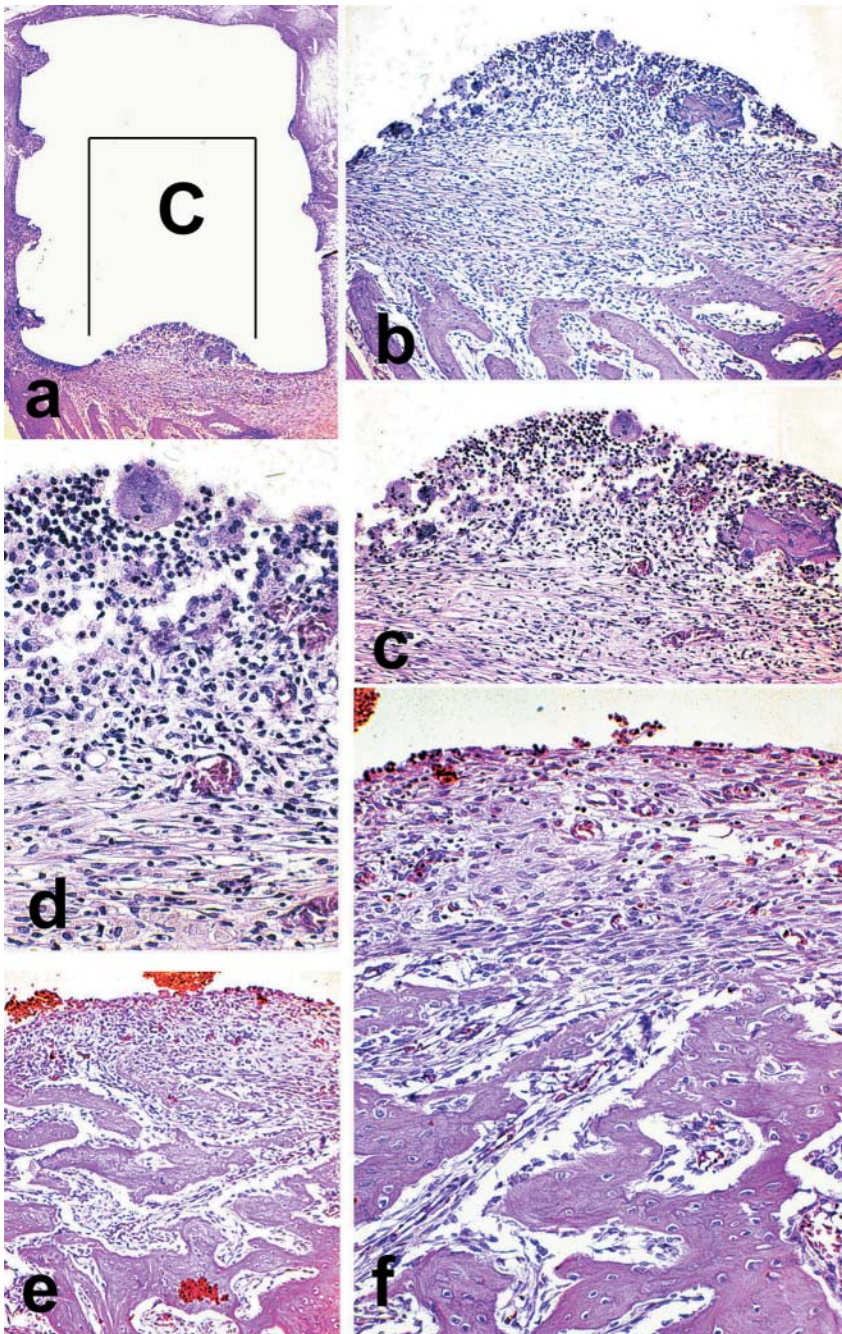


Fig. 5. Two-week-old implants in mandible of guinea pigs. a. Overview of the entire implant area. The applicator, made of Teflon, has a central cavity (C), which can be loaded with the material to be implanted. For details see (71). b-d. Implant of calcium hydroxide with 5% monochlorophenol added. Poor bone healing with severely inflamed granulation tissue. e-f. Aqueous calcium hydroxide. The tissue in contact with calcium hydroxide is healing without any signs of inflammatory cell infiltrate.

removing the smear layer, but acidic solutions tend to more aggressively demineralize the dentin surface (56–58). There is no clear evidence that this additional procedure enhances the disinfection process or treatment outcome (43). However, it has been shown *in vitro* that removal of the smear layer facilitates the penetration into dentin and killing of microbes by intracanal disinfectants (38).

Ultrasonics has been suggested as a method to better agitate the irrigation fluid and obtain a better cleaning effect than by irrigation alone (59, 60). This effect appears to be limited to the coronal part of the root canal (61).

Most instrumented root canals are too narrow to

be effectively reached even when very fine gauge needles are used. Thus, the effect of any presently available irrigation system will be limited. Therefore, any effective cleaning of the root canal must include the intermittent agitation of the canal content with a small size instrument. This is time consuming but will effectively prevent the debris from setting at the apical end of the root canal. A good suction system with fine caliber suction tip is indispensable.

## Instrumentation

Instrumentation plays an important role in the process of eliminating endodontic infections. The hand-

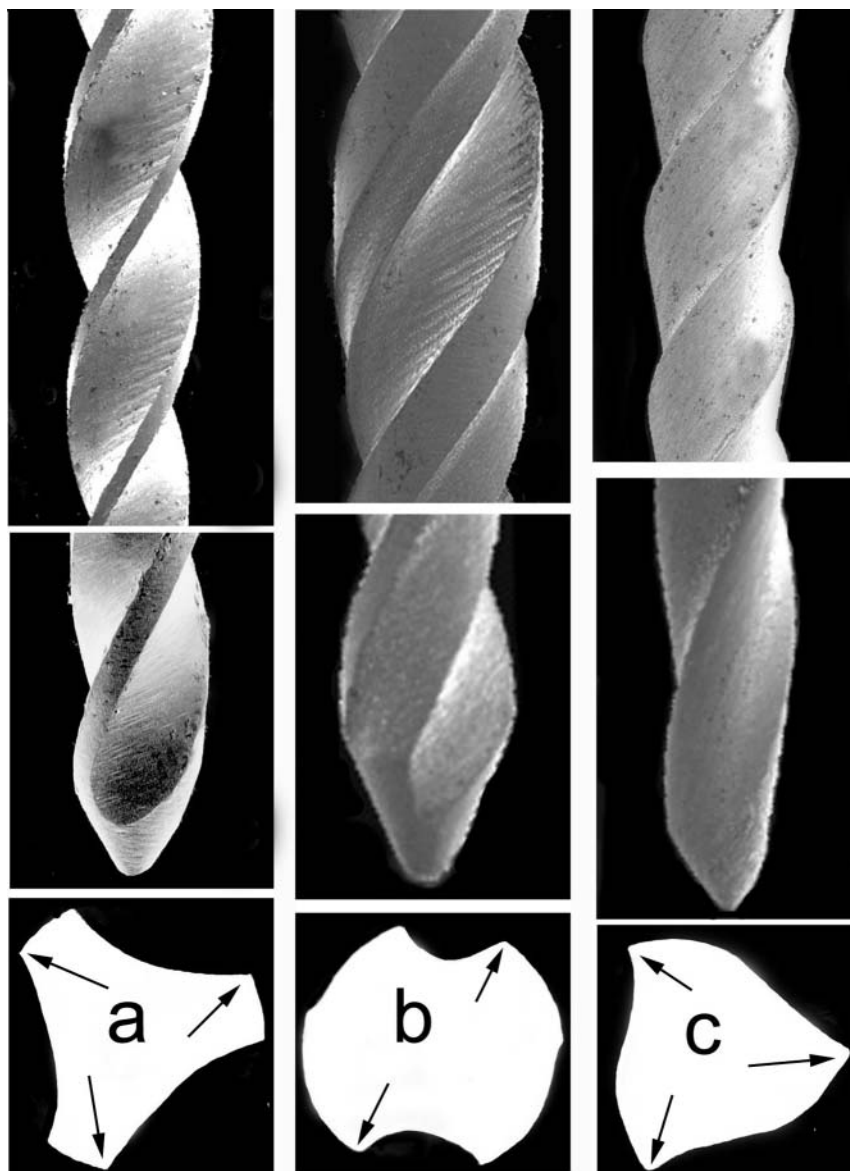


Fig. 6. SEM visualization of ProFile® (a), Quantec® (b), and Hero642® (c) nickel-titanium rotary instruments. The white inserts are ground cross-section of the instruments. The arrows point to the machining edges. ProFile® and Hero642® are trihelical instruments while Quantec® has only two helical machining edges.

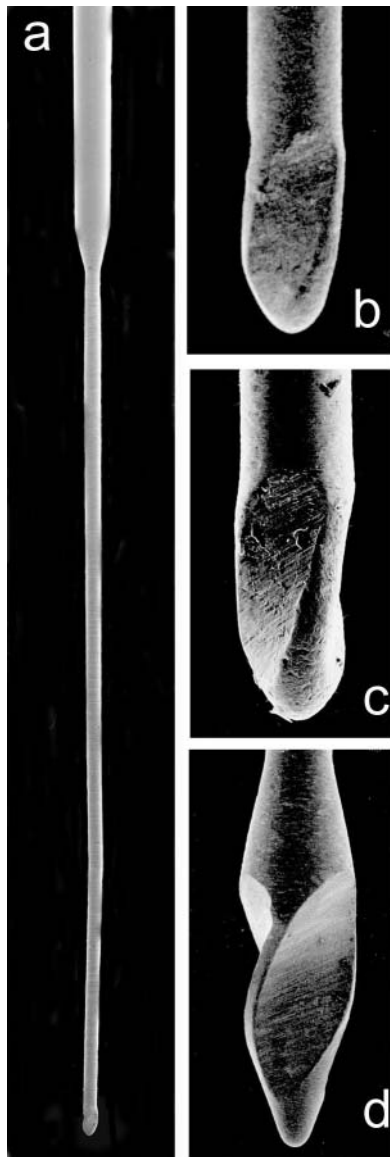


Fig. 7. SEM visualization of LightSpeed® nickel-titanium rotary instrument. The working head of the instrument is intended to look like figure d. The smaller sizes, however, look more like figures b and c.

held endodontic file in its various forms has served as an excellent tool for root canal debridement, but the work with the endodontic file is tedious and time consuming.

Stainless steel has been the principal material for fabrication of endodontic files. In 1989, nickel-titanium was proposed as a new alloy for endodontic files (62). Although more flexible and more durable than the steel file, the nickel titanium hand file did not become an early success (63). The new alloy became very popular, however, when rotary nickel ti-

tanium instruments were developed. In recent years, the nickel-titanium rotary instrument has become a part of the routine endodontic armamentarium. It is an important timesaving instrument. Provided the root canals are without excessive anatomical variations, it is easy to complete the instrumentation in a short time. Although resulting in a more time efficient root canal instrumentation, there are no evidence that the result is any better than hand instrumentation when measured by elimination of micro-organisms (64, 65).

The initial rotary instruments developed were high

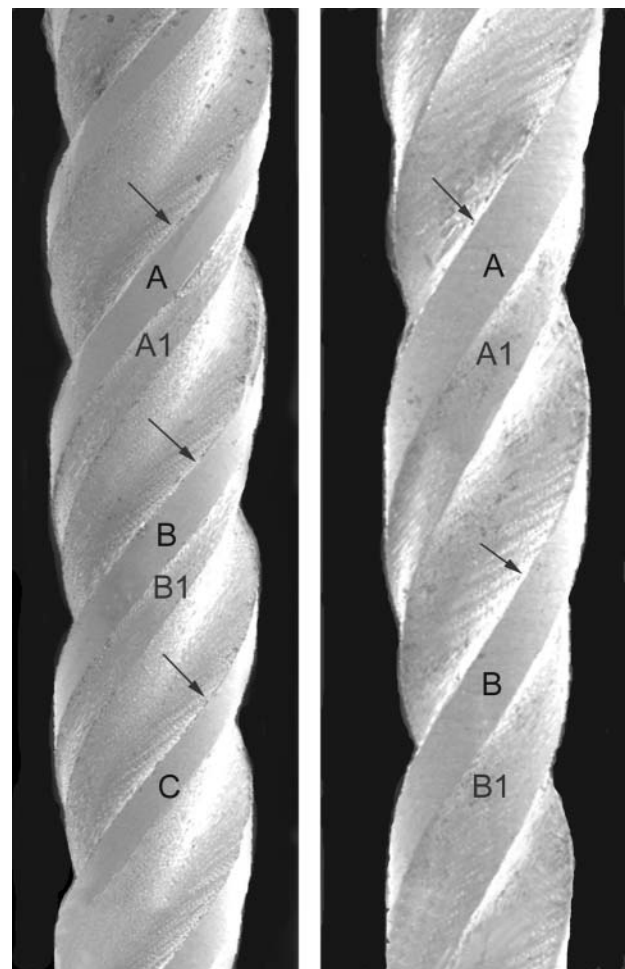


Fig. 8. SEM visualization of K3® (left) and Quantec® (right) nickel-titanium instruments. K3® is a 'third' generation instrument with a more aggressive rake angle but similar in design to Quantec®. The basic design of Quantec® can be seen to the right. The instrument has dual helical lands with a cutting edge (arrows). It also has an extension of the lands (A1, B1) which increases the peripheral strength but does not participate in the machining process. The K3® has lands like Quantec® (A/A1 and B/B1) but has a third land with a sharper rake angle.

torque instruments. Examples of these instruments are ProFile® (Tulsa Dentsply, Tulsa, OK, USA) and Quantec® (Tycom Corp, Irvine, CA, USA) (Fig. 6). These instruments are grinding instruments with negative rake angles (figure cross-section). Due to the dull configuration, the torque forces on the instruments are very high. Their rotational speed should not exceed 300 r.p.m. to avoid premature breakage. LightSpeed® (LightSpeed Technology Inc., San Antonio, TX, USA) is a high torque design which is operated at 1500–2000 r.p.m. By shortening the working tip of the instrument to a couple of millimeters, the torque force on its core is reduced (Fig. 7), which allows for a higher rotational speed. More recently developed instruments have neutral to positive rake angles (Fig. 6). This allows the instrument to cut instead of grind the dentin (Figs 8 and 9). Conse-

quently, less friction is generated and the rotational speed can be increased to around 500–600 r.p.m.

The traditional file instrument was standardized to a taper of 0.02 mm/1.00 mm in length (2% taper). When moving to rotating file instruments it was necessary to develop instruments with different tapers, like 2%, 4%, 6%, etc. By using different tapers during the reaming of the canal, taper lock of the rotary instrument will be avoided. If the canal is successively increased with the same taper instrument, a point will be reached when the entire canal has the same continuous taper. At this time, any instrument with that taper will fit very well in the root canal, pressed into perfect fit and break. This complication of taper lock is prevented by the use of instruments of different taper. Sharper instruments with a positive rake angle are less likely to become taper locked.

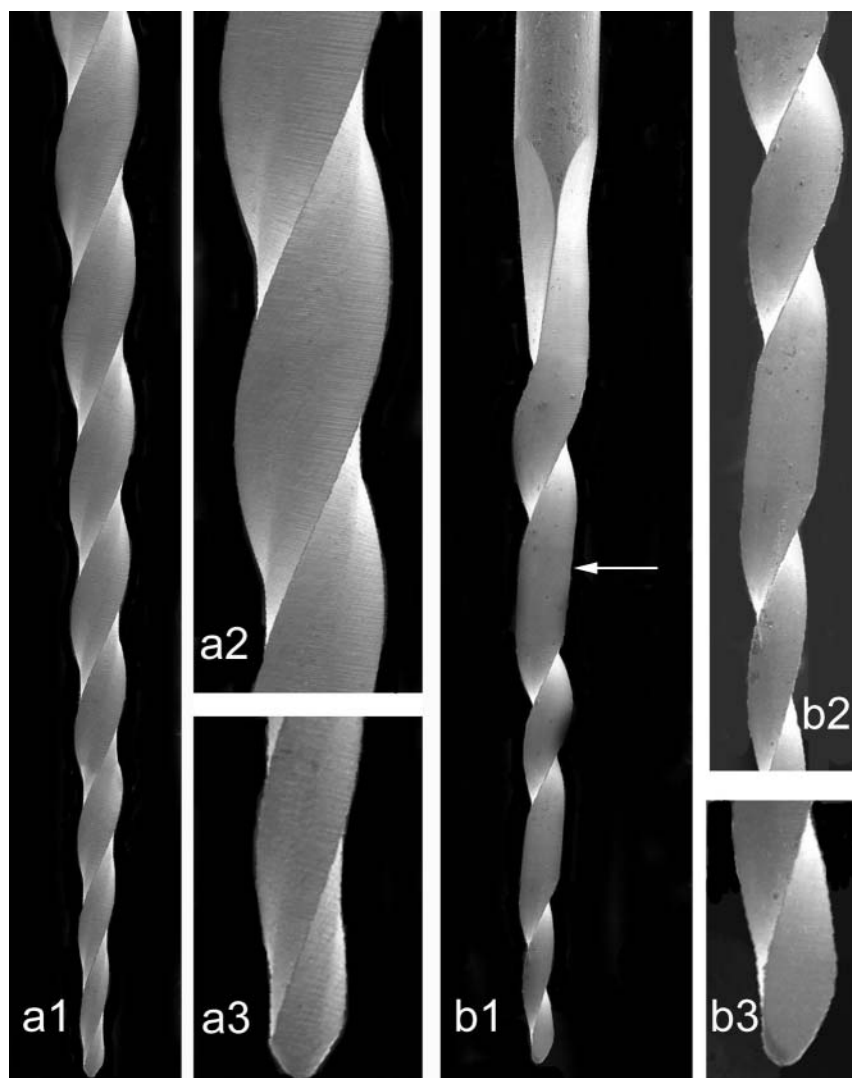


Fig. 9. SEM visualization of Pro-Taper® (a) and RaCe® (b) A third generation of nickel-titanium instruments. Both instruments have very sharp rake angles and operate at low torque. Note the uneven helix on the RaCe® instrument (arrow), which is supposed to prevent the instrument from being pulled into the root canal.

Recommended use for many of the new NiTi rotary instruments ignores the normal anatomical size of the apical portion of most root canals. Several studies of root canal diameters clearly suggest that in adult teeth it is not unusual for the apical root canal diameter to be 0.35–0.40 mm (66). Thus, the canals cannot be adequately instrumented with a #20 or #25 instrument as suggested by several proposed standardized techniques. Depending on tooth and root, the final apical preparation should be somewhere between #30 and #50. To reach these apical dimensions, the final preparation may have to be done with a 2% or 4% tapered instrument. A 6% or 8% instrument will be too stiff in a curved canal.

## Persistent infections

Despite careful instrumentation and antimicrobial irrigation, many initially infected root canals remain infected at the end of the first treatment session. Published studies suggest that more than 1/3 of all root canals still harbor cultivable microorganisms at that time (40, 42, 43, 52, 53). The logical conclusion is that there is no predictable way in one treatment session to ensure complete elimination of root canal in-

fection by instrumentation and irrigation only. Thus, in a routine clinical practice, further steps are required to insure that reasonable steps have been taken to eliminate bacteria from the root canal system before final root filling. The proven step to take is to apply an effective antimicrobial agent in the root canal for a predetermined time period to further eradicate the remaining bacteria.

During the instrumentation of the necrotic pulp space, it is important to pay special attention to the apical last couple of millimeters of the root canal. This area is difficult to reach with good control and effective disinfection. The bacteria in the very apical part of the root canal are normally delineated from the periapical tissues by a solid accumulation of inflammatory cells (Fig. 10) (32).

## Inter-appointment dressing

Deposit of antimicrobial agents in the pulp space has long been a practiced technique in an effort to reduce bacterial content of the root canal system. Although theoretically correct, the choice of antimicrobial agents and methods of applications have been less than effective.

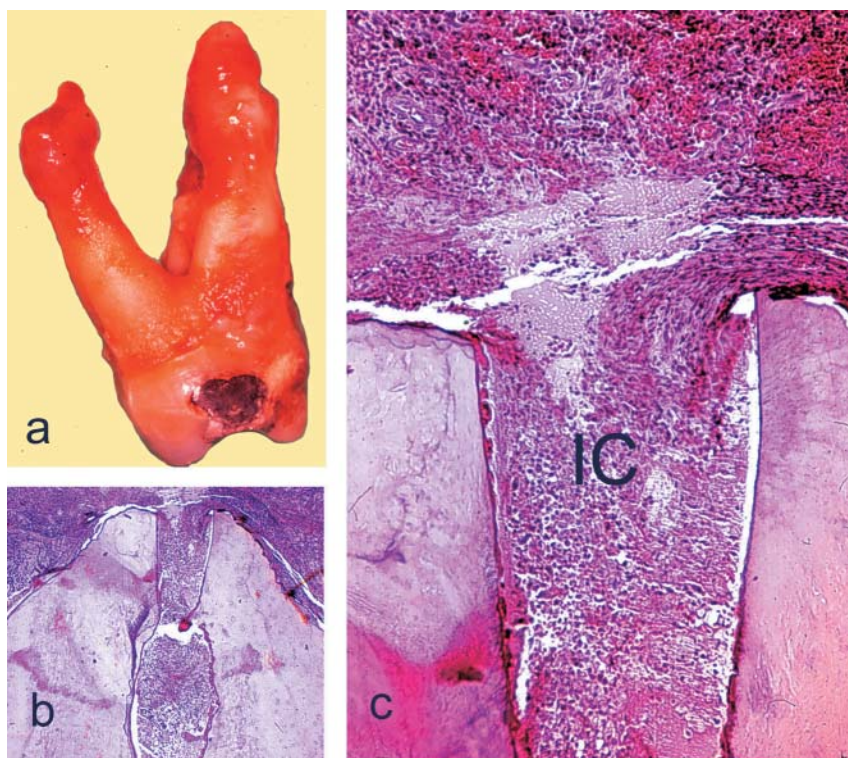


Fig. 10. a. Extracted maxillary molar with attached periapical lesions. b. Cross-section of apex of the palatal root. c. The apical foramen is packed with inflammatory cells (IC). Htx-cosin.

The classic antimicrobial agent was phenol, a phenol derivative, a formaldehyde, or a combination of these. Due to the extreme toxicity of these chemicals they could not be placed in direct contact with living tissue. The antiseptic was either applied on a cotton pellet, which was placed in the pulp chamber, or on an absorbent paper cone placed in the root canal. The rationale was that the antimicrobial effect could be delivered through a vapor effect. Phenolic compounds do not have effective antimicrobial vapors. Vapors from formaldehyde preparations, however, may be effective but the delivery to the apical part of the root canal is unpredictable. An endodontic deposit antiseptic that is not in direct contact with the root canal walls in the very apical end of the pulp space is unreliable at best (4, 40).

## Calcium hydroxide: indications and forms of application

Calcium hydroxide has proven to be an excellent antimicrobial agent for intracanal dressing. The use of calcium hydroxide as an intracanal antiseptic was first suggested by Hermann in 1920 (67). With the limited resources available, he undertook both laboratory as well as limited clinical trials on humans. Although well documented, his findings were not generally accepted and applied to intracanal use until a generation later. Hermann also recommended calcium hydroxide as wound dressing after superficial pulp surgery such as pulp capping and pulpotomy. Calcium hydroxide also became used for temporary root fillings after vital pulpectomy (Fig. 11) (68, 69).

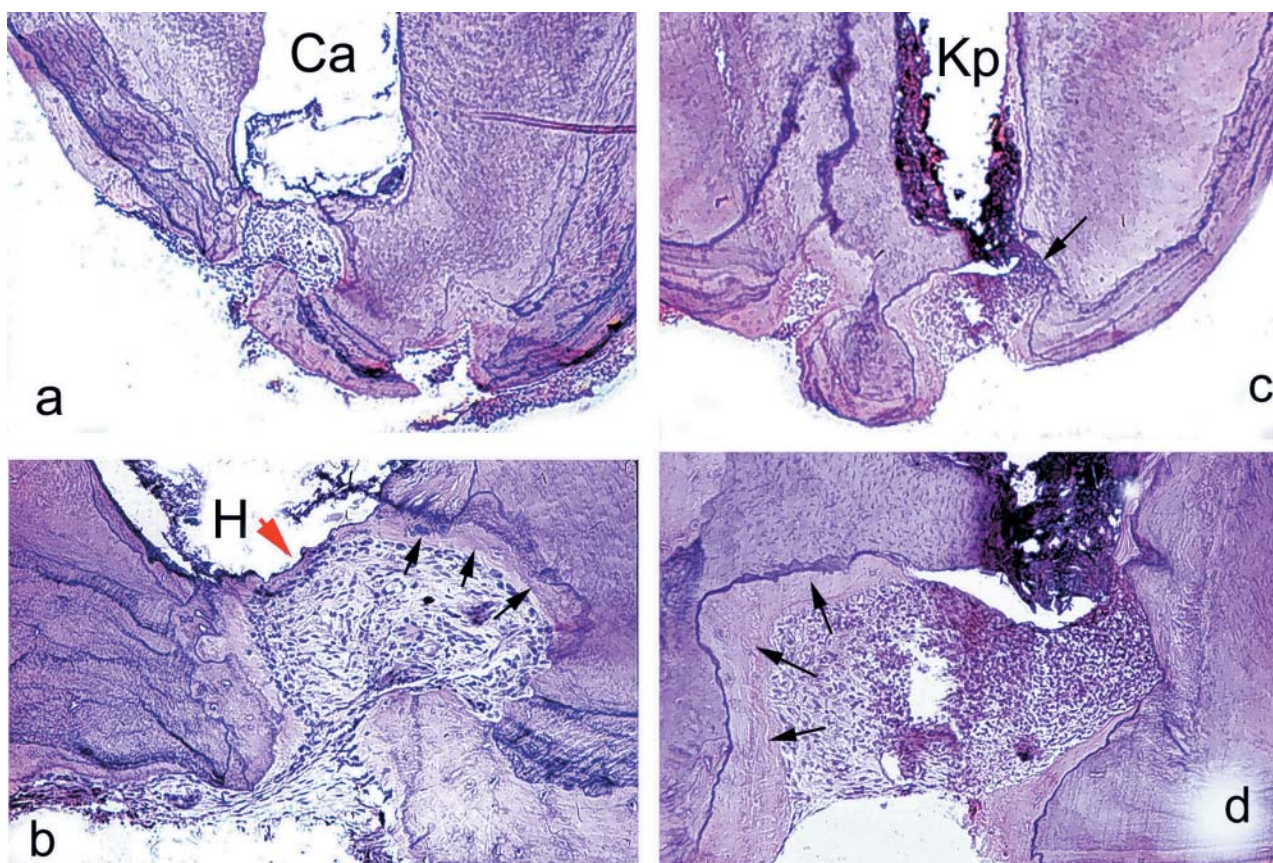


Fig. 11. Vital pulp extirpation of contralateral human teeth: 23-week observation period. a. Apical sections of root canal where the pulp was extirpated and packed with calcium hydroxide. b. Higher magnification of (a). A thin area of hard tissue healing has formed (large arrow) and the apical tissue is free of inflammation. Signs of early resorption healing with apposition of cementum (arrows). c. Apical sections of root canal where the pulp was extirpated, dressed with 2% iodine potassium iodide for 3–5 days and subsequently obturated with gutta percha and Klorperka N-Ø. d. Higher magnification of (c). A significant inflammatory response is seen. Some cementum repair is ongoing (arrows).

Calcium hydroxide was rediscovered in the 1960s for the treatment of necrotic infected pulp. Today it is the intracanal dressing of choice in contemporary endodontic practice (40, 70, 71). Calcium hydroxide in a water vehicle has antimicrobial qualities that are believed to be due to the very high pH resulting from the dissociation of  $\text{OH}^-$  ions. The powder is poorly dissociated into calcium and hydroxide ions (40). An aqueous solution is saturated at 0.17%. Thus, most of the calcium hydroxide powder forms a slurry in water. This results in some difficulties when depositing the powder in narrow root canals. Glycerine as a vehicle has also been used for the suspension of calcium hydroxide powder (72). A glycerine paste has a better flow as the  $\text{Ca}(\text{OH})_2$  dissolves better in glycerine than water. This is deceptive, however, as the hydroxide ion is not dissociated in glycerine. Water must be present for the antimicrobial effect of calcium hydroxide (73). Bacteria like *Enterococcus faecalis* are killed with a high degree of certainty at pH 11.5. The environment in the root canal, however, is such that it is a great challenge to deliver such high pH into the dentin tubules and lateral canals (74, 75). Pulpdent® (Pulpdent Corporation, Watertown, MA, USA) is another calcium hydroxide preparation where the powder is suspended in methylcellulose. This paste cannot deliver the same amounts of hydroxide ions as calcium hydroxide in a water vehicle (76). Calcium hydroxide has been added to several sealer cements. These sealers are not capable of delivering enough hydroxide ions to increase the pH of the root dentin and are therefore less valuable (77).

Calcium hydroxide in water has a thixotropic behavior. This means it will be very fluid when agitated. Therefore, the calcium hydroxide paste can be mixed very thick but will flow well when agitated. An optimally thick paste is best applied with a Lentulo spiral of appropriate size. The filling action of the Lentulo spiral is due to the spiral's action in relation to the fixed canal walls. Therefore, for the best effect the Lentulo spiral must be as large as possible relative to the root canal size. Some calcium hydroxide preparations come in injectable dispensing forms. This may be convenient but, due to the thixotropic character of calcium hydroxide paste, it will not sufficiently fill a narrow canal without increasing the hydraulic pressure. Although the accidental deposit of calcium hydroxide into a periapical lesion normally is without consequence, at least one case has been reported

where the calcium hydroxide has spread in the vascular bed with serious complications.

Calcium hydroxide is a slow acting agent and, in order to achieve sufficient antimicrobial effect, the dressing has to be left in the root canal for at least one full week (71, 78). It appears that when well packed and allowed sufficient working time, the calcium hydroxide will completely disinfect the root canal with a high degree of predictability (40, 71, 79). This may not be true, however, when retreatreating failed endodontic cases where the microflora is very different (18–21). In a study of retreatments, 11% of the root canals still contained bacteria after two consecutive dressings with calcium hydroxide. Two-thirds of these teeth failed (21). It has been demonstrated that the ability of *Enterococcus faecalis* to use a proton pump to control intracellular pH, when exposed to calcium hydroxide, may be responsible for the resistance of this bacteria (50). In a study of retreatment cases where there was one dressing with 5% iodine potassium iodide followed by one dressing with calcium hydroxide, there were still microorganisms present in the pulp space in a quarter of the cases (80). In a histological study in the dog, long-term dressing of calcium hydroxide eliminated major portions of the infection (81).

Bacterial lipopolysaccharide (LPS) plays a major role in the development of periapical bone resorption. Treatment with an alkali such as calcium hydroxide may alter biological properties of bacterial LPS. It was demonstrated that calcium hydroxide hydrolyzed the lipid moiety of bacterial LPS, resulting in the release of free hydroxy fatty acids (82). Such altered LPS did not stimulate monocytes to secrete prostaglandin  $\text{E}_2$  (83). These results suggest that calcium hydroxide-mediated degradation of LPS may be an additional important reason for the beneficial effects obtained with calcium hydroxide use in clinical endodontics.

## Treatment outcome and the disinfection concept

The elimination of microorganisms from the root canal and surrounding dentin is essential to achieve the optimal rate of success when treating endodontic cases. This axiom is rarely questioned today by endodontic scholars. Some 30–40 years ago, however, the debate was intense, supported by studies with rela-

tively short observation periods and poorly defined criteria (84, 85).

Using improved culture techniques, there is today little doubt that the root canal should be effectively disinfected before a root canal filling is placed (4, 6, 42). Disinfection is normally uncomplicated when treating teeth with infected necrotic pulps. The microflora is susceptible to calcium hydroxide (40, 71). The disinfection of the pulp space during retreatment of a failed endodontic case is much more difficult due to the dominance of numerous gram-positive species, and especially enterococci. These bacteria are more resistant to calcium hydroxide and may require repeated dressings and treatment with 2% iodine potassium iodide, which has proven effective against enterococci (78). The role of gram-positive bacteria in the development of osteolytic lesions is not clear. Gram-positive bacteria do not contain LPS but their cell walls contain muramyl dipeptide (MDP), which has a similar action on monocytes as LPS. This mechanism of MDP, although less strong than LPS, may induce bone resorption (86).

### The one-visit treatment controversy

It is an established fact that the periapical osteolytic process associated with an infected pulp necrosis is caused by microorganisms located in the pulp space (2, 8). It is also well established that with known instrumentation techniques and antimicrobial irrigation agents, only 40–70% of the treated root canals are disinfected successfully in one treatment session (40, 42, 53). This would mean that in a one-step therapy of apical periodontitis, many of the filled root canals still would contain living bacteria at the time of root filling. Theoretically, killing of bacteria could continue after the filling because of the antibacterial properties of sealer/gutta percha, or by blocking access to nutrients by the root filling. However, there is no information available about the effects of the root filling on the residual microbes in the root canal.

The debate on one-visit endodontic treatment is often confused by lack of clear diagnostic understanding. The diagnostic difference between a tooth with a vital pulp and one with a necrotic, often infected, pulp is not clearly understood by the proponents. The two conditions, pulpitis and necrosis, represent widely different pathological conditions that require dif-

ferent therapy. Some necrotic pulps are not yet infected and there is no osteolysis visible radiographically. Without further testing, the lack of infection is difficult to determine clinically as bacterial invasion and osteolysis are continuous temporal events (7). Therefore, it is prudent to consider all necrotic pulps infected when deciding on therapy.

The vital pulp should be treated as fast and decisively as possible as the root pulp is free of infection. This treatment should be completed in one visit. To temporize after vital pulp removal will only invite the risk of re-contamination of the fresh pulp wound and thereby establish a permanent infection in the apical pulp tissue. This infection will be difficult to treat later. The essential part of vital pulp extirpation lies in maintaining a high level of asepsis during the removal of the pulp tissue and subsequent obturation of the pulp space. The principles involved in the treatment of the necrotic pulp are in sharp contrast to the concept of aseptic pulp extirpation. Although asepsis is important when treating the infected pulp, antisepsis is the key element to successful treatment outcome. Infected root canals normally harbor 10–100 millions of bacterial cells (52, 71). Mechanical instrumentation with saline may lower that count 1000 times (52). Adding an antimicrobial irrigant may further reduce the numbers. There is no indication, however, that one good session of instrumentation with the best antimicrobial agent will predictably eliminate all bacteria in an infected root canal (40, 42, 43, 52).

Retreatment of root-filled teeth with apical periodontitis requires special attention to antisepsis, and there is evidence that one dressing with calcium hydroxide is insufficient for elimination of root canal infections with a degree of predictability (21, 81). At least two dressings with calcium hydroxide and careful instrumentation are needed in these cases before obturation should be attempted.

To complete the treatment with the placement of a root filling before complete disinfection has been obtained, will jeopardize the predictability of the endodontic treatment (21, 42). There is no study published that contradicts such a conclusion.

### Principles of root canal filling

After removal of the pulp space content and disinfection, when indicated, there is a need to ensure that

the pulp space is permanently eliminated as a source of periradicular tissue irritation. This is achieved with the placement of a root canal filling.

An instrumented and disinfected root canal does not need to be obturated if the root canal can be completely sealed from external contamination (87, 88). However, even if thoroughly disinfected, the root canal space will in time be reinfected by leakage of microorganisms through restoration margins, tooth substance or circulation. The time period for this reinfection process may vary (7) but may be very short (89).

There are also practical reasons why a root canal filling must be placed. In many cases there is a need to anchor a crown restoration in the pulp space. This will require that there is some type of physical occlusion of the root canal. This hydraulic seal of the root canal would prevent oral-periapical communication.

## **The purpose of and methods for root canal filling**

Much has been written about the importance of the root canal filling and its quality. It has even been stated that the quality of the root canal filling is the most critical part of a successful endodontic treatment (90). This can and should, however, be criticized based on our present understanding of the pathogenesis of periapical disease. The root canal filling is expected to effectively prevent egress of fluid from the coronal part of a tooth to the various foramina exiting from the root canal into the periradicular tissues. A hydraulic seal is the expected outcome. Therefore, a root canal filling must be made of materials that support such function. Despite major advances in clinical endodontics, a good predictable root filling material has not yet been developed. Furthermore, the methods of placing root canal fillings are complicated.

In addition to difficulties during the placement of a root canal filling there are major long-term problems associated with maintaining a fully functioning hydraulic seal. The root dentin, which is flexible, is constantly compressed and released during function. This is incompatible with the often rigid endodontic sealer and aged brittle gutta percha (91, 92). This will lead to breakage of the hydraulic seal if it was ever achieved.

There are several methods to place a root canal fill-

ing. The most common method is cold lateral condensation using gutta percha cones and a sealer. The other often practiced method is warm vertical compaction of heat softened gutta percha, still using a sealer as the cementing medium. This method is often referred to as a three-dimensional method of root canal filling (93). This is erroneous terminology as three dimensions are applicable to all types of root canal fillings. The warm vertical compaction was originally practiced with a heat carrying instrument and open flame. Today, it is more common to use an electrical, temperature controlled device such as Touch'n Heat (Kerr/SybronEndo, Orange, CA, USA) or System B (Analytic/SybronEndo, Orange, CA, USA). These devices transfer significant heat to the root dentin. Although more controlled than open flame, there is a potential risk for overheating of the periodontal structures in thin roots. In experiments comparing these two heat sources, the root surface temperature was higher for Touch'n Heat than when using System B (94, 95). Other studies suggest that the risk is minimal (96).

In addition to these two classic methods of obturation, there are many newly developed applicators to place heat-plasticized gutta percha into the root canal such as Thermafil<sup>®</sup> (Tulsa Dental Products, Tulsa, OK, USA), JS QuickFill<sup>®</sup> (J.S.Dental, Ridgefield, CT, USA) and MicroSeal<sup>®</sup> (Kerr/SybronEndo). The more well known is Thermafil, which is gutta percha attached to a file-like carrier. After heating these carriers with gutta percha they can easily be introduced to the desired working length and there appears to be no difference in quality compared to lateral condensation (97, 98). When the apical foramen is patent, the Thermafil technique shares the difficulty of managing heat-plasticized gutta percha, resulting in frequent overfilling (97, 98). JS QuickFill and MicroSeal are rotary thermocompactor systems.

There are several other delivery systems for heat-plasticized gutta percha. The most well known is ObturaII<sup>®</sup> (Obture/Spartan, Fenton, MI, USA). This device dispenses heated gutta percha through a cannula. The material is extruded at a temperature of between 80°C and 135°C (99, 100).

## **Endodontic filling materials**

The root filling is an implant in connective tissue. Therefore, the materials are important as the root ca-

nal filling has a biologic role in the healing process. Most root fillings consist of a core material and a cementing medium. The most common core material is gutta percha. It has been used in dentistry for over 100 years. It is a polyisoprene. The clinically used gutta percha cones contain only about 20% gutta percha. The remainder is mainly zinc oxide (70%) with some additional proprietary additives. Gutta percha comes in two crystalline forms ( $\alpha$  and  $\beta$ ), but the regular endodontic gutta percha is the  $\alpha$ -form. Heating of gutta percha first changes the form to the  $\alpha$ -phase to an amorphous form above 54–60°C. For practical purposes, gutta percha for endodontic use, at room temperature, is the  $\alpha$ -crystalline form, which softens at temperatures above 64°C. Gutta percha has a low degree of toxicity but small particles are able to stimulate immune cell activity (101, 102).

Gutta percha does not bind or attach to the dentin root canal walls. In order to obtain some form of hydraulic closure of the root canal system, a sealing agent must be employed. The sealers are the most toxic of the materials used for obturation. There is a wide range of different sealers. The most common type of sealer is based on zinc oxide-eugenol cement. Zinc oxide-eugenol cements are generally toxic. Through hydrolysis there is always some loss of eugenol or zinc oxide. Zinc oxide is a valuable antimicrobial component in the sealer and provides cytoprotection to tissue cells (103). Many of the zinc oxide-eugenol sealers also contain rosins that increase adhesion and decrease the solubility of the cement. Rosin (colophony) is composed of approximately 90% resin acids. Resin acids are amphiphilic, with the carbon group being lipophilic affecting the lipids in the cell membranes. In this way the resin acids have a strong antimicrobial effect, which on mammalian cells is expressed as cytotoxicity. The antimicrobial effect of zinc oxide in both gutta percha cones as well as in many sealers will bring a low level of long-lasting antimicrobial effect. The resin acids are both antimicrobial and cytotoxic, but the combination with zinc oxide exerts a significant level of cytoprotection (104).

The flow of the ZOE sealer is adjusted by variation in powder particle size. Setting time can easily be manipulated. Zinc oxide-eugenol cements are very popular vehicles for various additives such as corticosteroids and formaldehyde.

There are several different types of polymer ma-

terials used as endodontic sealers. The more common are AH26, AH Plus (Caulk/Dentsply, Milford, DE, USA), Diaket (ESPE, Seefeld, Germany), RSA RoekoSeal (Coltène/Whaledent, Mahwah, NJ, USA), and Endofill (Lee Pharmaceuticals, South El Monte, CA, USA).

AH26 and AH Plus are toxic when freshly prepared (102, 105). This toxicity decreases rapidly during setting, and after 24 h the cements have one of the lowest levels of toxicity of endodontic sealers. The reason for the toxicity of the AH26 and AH Plus sealers is the release of a very small amount of formaldehyde as a result of the chemical setting process (106). After the initial setting, AH26 exerts little toxic effect *in vitro* or *in vivo* (105, 107–109). There are some questions related to the genotoxicity of AH26 which cannot be demonstrated with AH Plus (110–112). There are no reports in the literature of malignancies caused by AH26.

Diaket is a polyketone compound containing vinyl polymers that, when mixed with zinc oxide and bismuth phosphate, forms an adhesive sealer. It is highly toxic *in vitro* and causes extensive tissue necrosis (102, 105). The irritation is long lasting.

Endofill and RSA RoekoSeal are silicone-type sealers with a remarkably low initial toxicity that decreases further upon setting (105).

Sealapex (Kerr/SybronEndo), CRCS (Coltène/Whaledent) and Apexit (Vivadent-Schaan, Liechtenstein) are common calcium hydroxide-containing endodontic sealers. There are no indications that such sealers have any of the desirable biologic effects of calcium hydroxide paste (76, 77).

Ketac-Endo (ESPE) is a glass-ionomer cement modified for endodontic use. This type of cement is known to cause little tissue irritation (113, 114). Ketac-Endo also has low toxicity *in vitro* (115). There are few biologic data available relating to its use as an endodontic sealer.

Chloroform-based sealers such as rosin-chloroform (116), Chloropercha (Moyco, Union Broach, York, PA, USA), and Kloroperka N-Ø (N-Ø Therapeutics, Oslo, Norway) are common. Rosin chloroform contains 5–8% of various rosins that are toxic. Thus, after the evaporation/absorption of chloroform, the resin continues to be irritating (101). Chloropercha, which consists of white gutta percha and chloroform, draws its toxicity from the chloroform component. Kloroperka N-Ø powder contains about 20% white gutta

percha and 50% zinc oxide. The remaining components are Canada balsam and rosins. After the loss of chloroform, the sealer may be irritating due to its content of rosins and Canada balsam. The combination with zinc oxide, however, will provide a significant level of cytoprotection in clinical use (104).

## Consequences of obturation surplus

Excess of filling material may be introduced into periradicular tissues and most commonly around the apical foramen. This is more likely with certain obturation methods where the control is less good. This complication has been associated with lowering the rate of treatment success (3, 5, 6, 117).

The majority of modern root canal filling materials are relatively inert after setting. Some materials, such as gutta percha, can be implanted in bone tissue without any significant response (Fig. 12), while others, such as zinc oxide-eugenol cements, cause some chronic inflammatory response. No commonly used material, however, can by itself cause a progressively growing bone lesion. Therefore, it is logical to question the wisdom of the negative effect observed on treatment outcome of excess filling material. It appears that the increased rate of failures associated with excess of materials also has some association with failure to obtain a completely disinfected pulp space before obturation (5). An overfill, when the final culture before obturation was negative, did not result in increased failures. Other studies of primary endodontic treatment where the antimicrobial treatment has been well controlled confirm this observation (4, 21).

Excess of filling materials during retreatment of teeth with apical periodontitis appears to have more serious consequences. This is most likely associated with the very different microflora associated with failed endodontic treatments (18–21). In one study the effect of excess filling materials on outcome of retreating teeth with resorbing apical periodontitis was serious and resulted in over 60% failures (3). In a comparable group without apical periodontitis the failure rate was 20%. Another study reported a failure rate of 50% when root filling excess occurred during retreatment of teeth with resorbing apical periodontitis (6). In these early studies no special attention was given to the fact that there might be a need to use a more intensive disinfection protocol when retreating failed endodontic cases.

In another study of retreatments of teeth with apical periodontitis, with careful microbial monitoring, 11% of the root canals still contained bacteria after two consecutive dressings with calcium hydroxide. Two-thirds of these teeth failed. There was no report that teeth with excess filling materials affected the outcome (21).

From these more controlled studies, where a very high degree of microbial control was maintained, it appears that the negative influence of excess filling materials is not caused by the excess itself. Rather, the causative factor appears to be the microorganisms that are implanted from a poorly disinfected root canal into the tissue. This can occur through over-instrumentation and deposit of infected debris into the periapical tissue or via the extruded root filling material. If the disinfection of the pulp space before obturation has been successful, the difference between

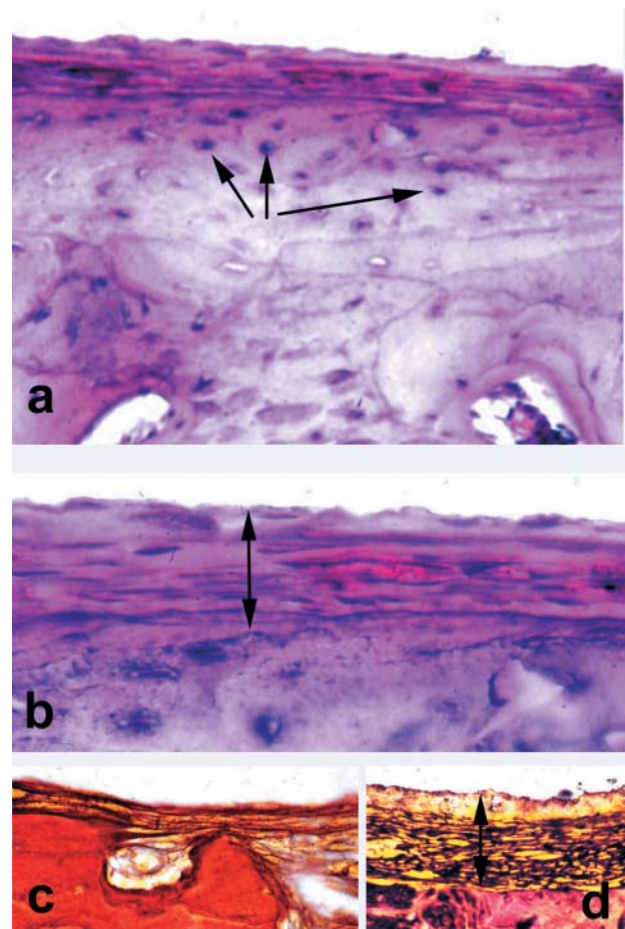


Fig. 12. Radiograms of two extracted teeth with root fillings. Buccal clinical view (a1 and b1) and lateral view (a2 and b2) illustrate the limitations of clinical radiograms when assessing the completeness of root fillings.

teeth with and without excess of filling material should be relatively insignificant.

## The effect of the root filling on treatment outcome

The technical quality of the root filling, judged from the radiographic film, has been given increasing

weight in recent years when assessing outcome of endodontic treatment. This has no foundation in science. Some degree of completeness when filling the pulp space is important but after a certain point, the return on effort may be insignificant.

Although clearly toxic materials should not be used as root canal filling material, there is little evidence that the selection of a specific sealer-cement is important or therapeutic. This is also a problem which does not lend itself to a simple clinical study. The effectiveness of instrumentation and disinfection has a strong influence on the treatment outcome. This, combined with the need to use a standardized obturation technique for placement of the final root canal filling, makes it nearly impossible to collect a clinical material large enough to observe differences in the effectiveness of different endodontic sealers, as this difference most likely will be small compared with other technical and microbial factors.

Studies on the importance of a good seal for the outcome is complicated by the fact that a seal cannot be assessed on a radiogram. First, the entire circumference of the root filling is not visible under any conditions (Fig. 13). Furthermore, 50–100 µm defects that are avenues for microorganisms cannot be visualized. Thus, the correlation between ‘seal’ and outcome will be impossible to establish with any validity. In a study where ‘poor seal’ was defined as lumen apical to the filling or voids in the apical part of the filling, there was no difference in outcome when evaluating necrotic teeth with apical periodontitis (6).

The quality of the root canal filling is important for long-term outcome, but the disinfection and instrumentation process is the part of the endodontic treatment most critical for the final outcome.

## Root-end filling materials

Endodontic surgery is used when orthograde access to the pulp space is not available. It can also be used for the correction of treatment complications such as perforation and as the last option when repeated orthograde treatment has failed. Root-end fillings are placed during endodontic surgery in order to close exit portals from the pulp space to the periradicular tissues. A great number of materials have been used for this purpose. The expectation that a material placed in the last 3 mm of a root orifice, under clinical conditions, will be able to hydraulically close the exit

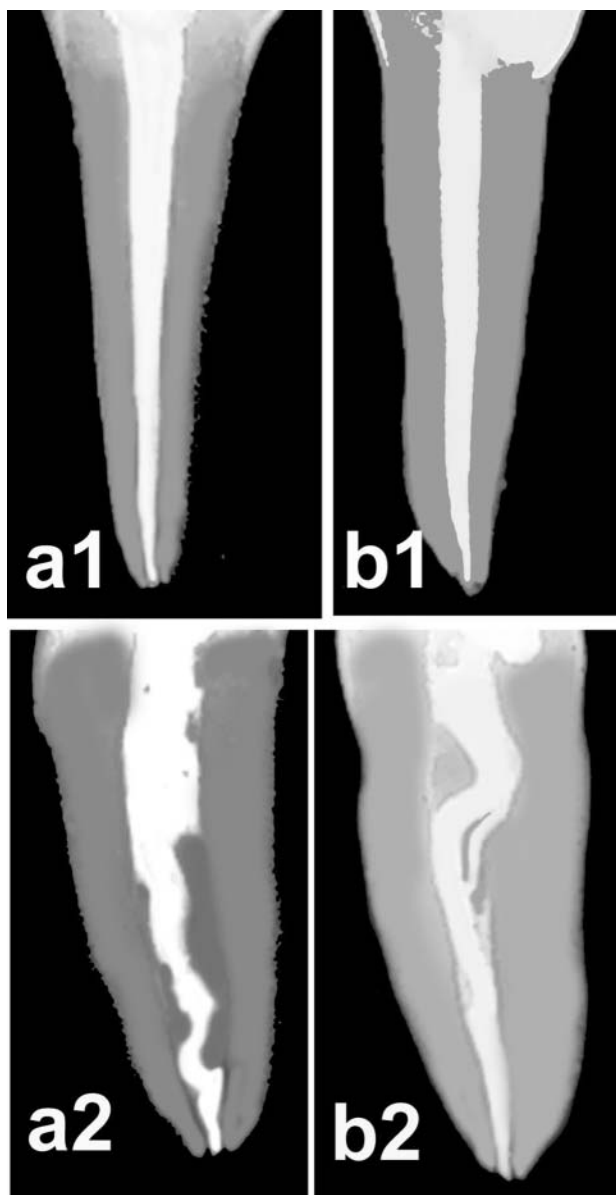


Fig. 13. Implant of gutta-percha in guinea pig; 12-week observation period. a. The bone has healed very well with new vital bone with healthy osteocytes (arrows). b. Higher magnification of (a). Only a thin layer of fibrous connective tissue separates the gutta percha from the healthy bone. c–d. Silver stain of the tissue shows well organized collagen fibers.

portal is unrealistic. In numerous studies *in vitro* there has been no material capable of consistently hydraulically occluding the apical part of the root canal. There are some clinical observations that validate such findings (118). For many years, silver amalgam was the predominant material for root-end fillings. This procedure has been reported to have a success rate in the range of 60–80%. Silver amalgam, however, is well known for its poor sealing capacity. It has a mild antimicrobial effect and the corrosion products formed *in vivo* are also antimicrobial. This, in combination with the removal of the apical part of the root with its infected content, is most likely responsible for the successes recorded. Other materials used for root-end fillings with some success are IRM and Super EBA, both materials with significant antimicrobial qualities (119).

Recently, mineral trioxide aggregate (MTA) has been suggested as a superior material and is now commercially available as ProRoot® (Tulsa Dental Products, Tulsa, OK, USA). This material, which basically

consists of Portland cement, has an antimicrobial effect due to its high alkaline surface, which exerts an effect on tissue similar to calcium hydroxide (120). Thus, MTA delivers a setting and non-resorbable form of calcium hydroxide treatment. In experimental implantation, the tissue response to Portland cement and MTA appears equivalent (Fig. 14) (121).

Although these materials offer interesting alternatives, there is no valid study suggesting that any one is superior to the other when it comes to outcome.

## Coronal leakage and restorations

When placed, the root filling is assumed to hydraulically close the root canal space. This assumption may not be correct, however, as many studies *in vitro* on extracted teeth have shown that even under the most controlled laboratory bench conditions, some root canal fillings tend to leak. The root filling, which consists of a gutta percha core cemented with a sealing cement, is, *in vivo*, under constant physical forces that

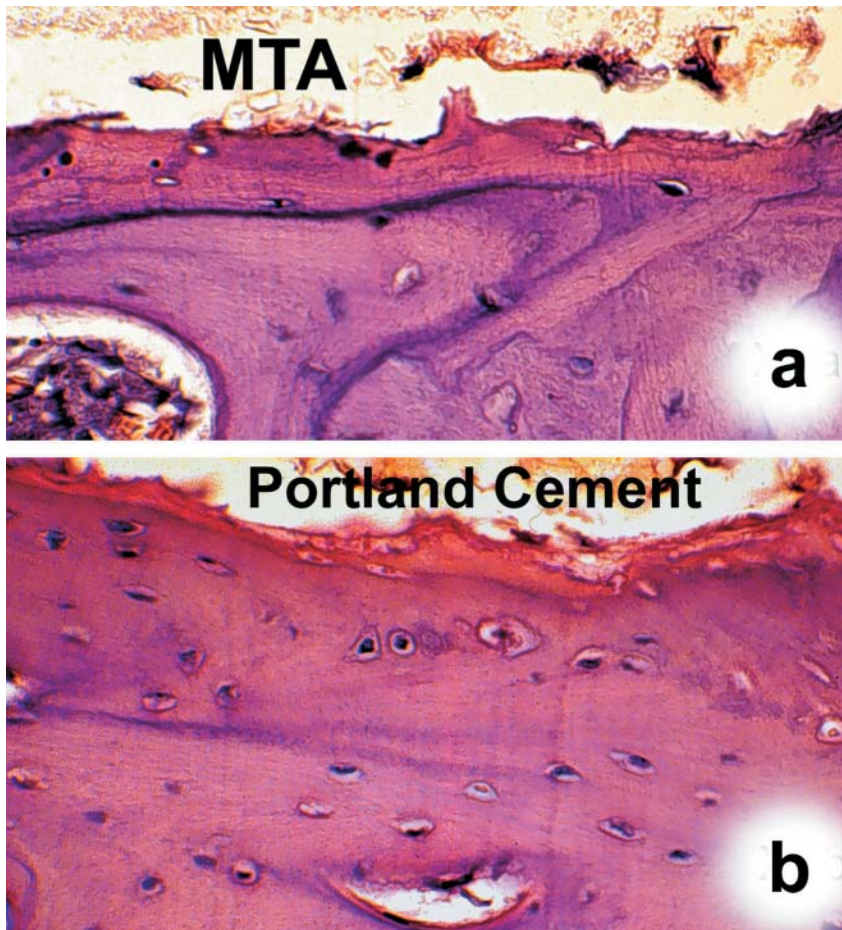


Fig. 14. Implants of MTA and Portland cement in the mandible of guinea pig. Twelve weeks after implantation. Both implants have established direct bone contact during healing. Htx-cosin.

tend to disrupt the seal that might have been achieved. Therefore, it is believed, the root-filled tooth needs to be restored to decrease the risk of coronal leakage. In addition, leakage around restorations may affect the sealer cement if it is not stable in oral fluids, which may be acidic due to plaque accumulation or caries.

## Coronal leakage: effect on treatment outcome

Some studies have attempted to explore the effect of coronal egress of pro-inflammatory agents on long-term outcome of endodontic treatment. Such agents could be anything from oral fluid to whole cell bacteria or their antigens. The results of these studies are not clear, although there is some indirect evidence that endodontically treated teeth without permanent restorations tend to have a less favorable long-term outcome than teeth that are restored in close time proximity to the placement of the root filling.

The technical quality of the root filling and the permanent restoration was correlated to the presence of periradicular inflammation (122). This retrospective study was done on full mouth radiographs. They found that the quality of the coronal restoration had a greater effect on treatment outcome than the quality of the endodontic treatment. This may not be such a surprising finding, as endodontic treatment is very dependent on careful instrumentation and filling. Someone who is poor at or irresponsible when restoring teeth may very well be similarly careless when performing endodontic treatment. Another factor which is not often considered is the poor bonding between gutta percha and most sealers. Only the sealers that have a solvent content will provide an integrated mass between the gutta percha core and the sealer.

The seal of a well placed root canal filling should not be seen as a continuous hydraulic seal but rather as a series of 'o-rings' that prevent fluid flow between the oral cavity and the periapical tissues. The better the quality of the root filling, the more 'o-rings' are present. However, to prevent a contamination of the periapical tissues, only one o-ring needs to be present.

The importance of coronal leakage for endodontic failures is debated and there is no objective clinical study to show that it is a significant clinical problem (123). Some retrospective observations have been

done suggesting that root fillings directly exposed to the oral fluids may have a higher rate of failures. There is, however, always a theoretical need for improved seal and it has become the practice of many to apply a cement-like restoration in the coronal part of the root canal.

## Concluding remarks

Many practices in clinical endodontics are still empirical and a great deal of clinical research will be needed to develop a more scientific basis for treatment regimens. This goal can only be achieved with more emphasis on controlled clinical outcome studies of treatment variables.

In the meantime, substantial help in developing treatment protocols can be obtained from accepting the fact that endodontic diseases are infectious in origin. There are great differences in degree of infection, ranging from simple pulp exposure due to caries to profound infectious problems associated with failure of root canal treatment. Based on this fact, variable treatment protocols should be prescribed fitting the seriousness of the infection.

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