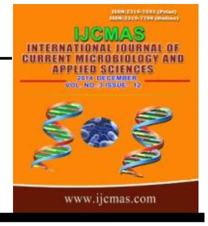

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 3 Number 12 (2014) pp. 941-952**
http://www.ijcmas.com

Original Research Article

Recent trends in irrigation in endodontics

John Paul*

Department of Conservative Dentistry and Endodontics, Indira Gandhi Institute of Dental Science, Kothamangalam, Kerala, India

**Corresponding author*

A B S T R A C T

Local wound debridement in the diseased pulp space is the main step in root canal treatment to prevent the tooth from being a source of infection. Successful root canal therapy is always based on the combination of proper instrumentation, irrigation and obturation of the root canal. Of these three essential steps of root canal therapy, irrigation of the root canal is the most important technique which aids in the healing of the periapical tissues. The root canal is shaped under constant irrigation to remove the inflamed and necrotic tissue, microbes, biofilms and other debris from the root canal space. There is no single irrigating solution that can alone cover all of the functions required from an irrigant. Optimal irrigation is based on the combined use of 2 or several irrigating solutions, in a proper sequence, to predictably obtain the goals of safe and effective irrigation. This article highlights various irrigants, ideal requirements of irrigants and newer irrigants used for irrigation.

Keywords

Root canal treatment, Irrigation, Sodium hypochlorite

Introduction

The success of endodontic treatment depends on the eradication of microbes (if present) from the root-canal system and prevention of reinfection. The root canal is shaped with hand and rotary instruments under constant irrigation to remove the inflamed and necrotic tissue, microbes/biofilms, and other debris from the root-canal space. The main goal of instrumentation is to facilitate effective irrigation, disinfection and filling. The quality of root canal cleanliness is affected by the design of the cutting blade of rotary instruments. Several studies using advanced techniques such as microcomputed tomography (CT) scanning have demonstrated that proportionally large areas of the main root-canal wall remain untouched by the instruments (Peters *et al.*, 2001; Jeon et al., 2003), emphasizing the importance of suitable instruments (such as nickel-titanium rotary reamers for straight root canals) and chemical means of cleaning and disinfecting all areas of the root canal. Any new concepts and techniques to be used in the clinic should ideally be assessed in randomized controlled clinical trials against their respective gold standards. This, however, poses a major problem in endodontic research. A favorable outcome of root canal treatment is defined as the reduction of a radiographic lesion and absence of clinical symptoms of the affected tooth after a minimal observation period of 1 yr (Ørstavik, 1996). Alternatively, so-called surrogate outcome (dependent) variables yielding quicker results, such as the microbial load remaining in the root canal system after different treatment protocols can be defined. However, these do not necessarily correlate with the "true" treatment outcome (Peters *et al.,* 2002). Local wound debridement in the diseased pulp space is the main step in root canal treatment to prevent the tooth from being a source of infection. Though NaOCl is the recommended main irrigant (Zehnder, 2006), several ethnobotanical treatments revealed alternatives to chemical irrigants. The *Morinda citrifolia* juice (MCJ) appears to be the first fruit juice to be identified as a possible alternative to the use of NaOCl as an intracanal irrigant (Murray *et al.,* 2008).

Endodontic success is dependent on multiple factors (Ørstavik *et al.,* 2004), and a faulty treatment step can thus be compensated. For instance if cultivable microbiota remain after improper canal disinfection, they can theoretically be entombed in the canal system by a perfect root canal filling (Saleh *et al.,* 2004), and clinical success may still be achieved (Peters and Wesselink, 2002). Therefore, many of the compounds used for irrigation have been chemically modified and several mechanical devices have been developed to improve the penetration and effectiveness of irrigation. The endodontic success rate is less than 50–70% for retreatment of endodontically failed teeth. But recent advances and promising approaches for pulp regeneration, including isolation and characteristics of pulp stem/progenitor cells and partial and complete regeneration of pulp is helpful. The complete pulp regeneration with other tissue stem cells is also addressed (Nakashima and Iohara, 2014).

This article summarizes the chemistry, biology and procedures for safe and efficient irrigation and provides cutting-edge information on the most recent developments.

Goals of irrigation

Irrigation has a central role in endodontic treatment. During and after instrumentation, the irrigants facilitate removal of microorganisms, tissue remnants, and dentin chips from the root canal through a flushing mechanism (Box 1). Irrigants can also help prevent packing of the hard and soft tissue in the apical root canal and extrusion of infected material into the periapical area. Some irrigating solutions dissolve either organic or inorganic tissue in the root canal. In addition, several irrigating solutions have antimicrobial activity and actively kill bacteria and yeasts when introduced in direct contact with the microorganisms. However, several irrigating solutions also have cytotoxic potential, and they may cause severe pain if they gain access into the periapical tissues (Hu¨lsmann and Hahn, 2000). An optimal irrigant should have all or most of the positive characteristics listed in Box 1, but none of the negative or harmful properties. None of the available irrigating solutions can be regarded as optimal. Using a combination of products in the correct irrigation sequence contributes to a successful treatment outcome.

Box 1

Desired functions of irrigating solutions

- Washing action (helps remove debris)
- Reduce instrument friction during preparation (lubricant)

- Facilitate dentin removal (lubricant)
- Dissolve inorganic tissue (dentin)
- Penetrate to canal periphery
- Dissolve organic matter (dentin collagen, pulp tissue, biofilm)
- Kill bacteria and yeasts (also in biofilm)
- Do not irritate or damage vital periapical tissue, no caustic or cytotoxic effects
- Do not weaken tooth structure.

Irrigating solutions

Sodium hypochlorite

Sodium hypochlorite (NaOCl) is the most popular irrigating solution. NaOCl ionizes in water into Na1 and the hypochlorite ion, OCl^-, establishing equilibrium with hypochlorous acid (HOCl). At acidic and neutral pH, chlorine exists predominantly as HOCl, whereas at high pH of 9 and above, OCl^- predominates (Mcdonnell and Russell, 1999). Hypochlorous acid is responsible for the antibacterial activity; the OCl^- ion is less effective than the undissolved HOCl. Hypochloric acid disrupts several vital functions of the microbial cell, resulting in cell death (Barrette *et al.,* 1989; McKenna and Davies, 1988). Hypochlorite preparations are sporicidal and virucidal and show far greater tissue dissolving effects on necrotic than on vital tissues. These features prompted the use of aqueous sodium hypochlorite in endodontics as the main irrigant as early as 1920. There has been much controversy over the concentration of hypochlorite solutions to be used in endodontics. The antibacterial effectiveness and tissue dissolution capacity of aqueous hypochlorite is a function of its concentration, and so is its toxicity (Zehnder, 2006). It appears that the majority of American practitioners use “full strength” 5.25% sodium hypochlorite as it is sold in the form of household bleach leading to several adverse reactions like irritation and decrease in flexural strength of dentin. Also decrease in microbiota was also not significantly altered with this high concentration. It must be realized that during irrigation, fresh hypochlorite consistently reaches the canal system, and concentration of the solution may thus not play a decisive role (Zehnder, 2006). One of the methods to improve the efficacy of sodium hypochlorite was to use heated solution. This improves their immediate tissue-dissolution capacity. Furthermore, heated hypochlorite solutions remove organic debris from dentin shavings more efficiently than unheated counterparts (El karim *et al.,* 2007). The weaknesses of NaOCl include the unpleasant taste, toxicity, and its inability to remove the smear layer by itself, as it dissolves only organic material (Spa°ngberg *et al.,* 1973). The limited antimicrobial effectiveness of NaOCl in vivo is also disappointing. The poorer in vivo performance compared with in vitro is probably caused by problems in penetration to the most peripheral parts of the root-canal system such as fins, anastomoses, apical canal, lateral canals, and dentin canals. Also, the presence of inactivating substances such as exudate from the periapical area, pulp tissue, dentin collagen, and microbial biomass counteract the effectiveness of NaOCl (Haapasalo *et al.,* 2000). Recently, it has been shown by in vitro studies that long-term exposure of dentin to a high concentration sodium hypochlorite can have a detrimental effect on dentin elasticity and flexural strength (Sim *et al.,* 2001; Marending *et al.,* 2007). Although there are no clinical data on this phenomenon, it raises the question of whether hypochlorite in some situations may increase the risk of vertical root fracture. In summary, sodium hypochlorite is the most important irrigating solution and the only one capable of dissolving organic tissue, including biofilm and the organic part of the smear layer. It should be used throughout the instrumentation phase. However, use of hypochlorite as the final rinse following EDTA rapidly produces severe erosion of the canal-wall dentin and should probably be avoided (Niu *et al.*, 2002).

Chlorhexidine

Chlorhexidine was developed in the late 1940s in the research laboratories of Imperial Chemical Industries Ltd. (Macclesfield, England). The original salts were chlorhexidine acetate and hydrochloride, both of which are relatively poorly soluble in water (Zehnder, 2006). Hence, they have been replaced by chlorhexidine digluconate. Chlorhexidine is a potent antiseptic, which is widely used for chemical plaque control in the oral cavity. Aqueous solutions of 0.1 to 0.2% are recommended for that purpose, while 2% is the concentration of root canal irrigating solutions usually found in the endodontic literature (Zehnder, 2006). It is commonly held that chlorhexidine would be less caustic than sodium hypochlorite. However, that is not necessarily the case (Zehnder, 2006). A 2% chlorhexidine solution is irritating to the skin (Zehnder, 2006). As with sodium hypochlorite, heating a chlorhexidine irrigant of lesser concentration could increase its local efficacy in the root canal system while keeping the systemic toxicity low. Despite its usefulness as a final irrigant, chlorhexidine cannot be advocated as the main irrigant in standard endodontic cases, because (a) chlorhexidine is unable to dissolve necrotic tissue remnants, and (b) chlorhexidine is less effective on Gram-negative than on Gram-positive bacteria.

EDTA

Although sodium hypochlorite appears to be the most desirable single endodontic irrigant, it cannot dissolve inorganic dentin particles and thus prevent the formation of a smear layer during instrumentation (Garberoglio and Becce, 1994). Demineralizing agents such as ethylenediamine tetraacetic acid (EDTA) and citric acid have therefore been recommended as adjuvants in root canal therapy (Garberoglio and Becce, 1994; Ayad, 2001). These are highly biocompatible and are commonly used in personal care products. Although citric acid appears to be slightly more potent at similar concentration than EDTA, both agents show high efficiency in removing the smear layer (Zehnder, 2006). In addition to their cleaning ability, chelators may detach biofilms adhering to root canal walls. An alternating irrigating regimen of NaOCl and EDTA may be more efficient in reducing bacterial loads in root canal systems than NaOCl alone (Zehnder, 2006). Antiseptics such as quaternary ammonium compounds (EDTAC) or tetracycline antibiotics (MTAD) have been added to EDTA and citric acid irrigants, respectively, to increase their antimicrobial capacity. The clinical value of this, however, is questionable (Torabinejad *et al.,* 2003; Baker *et al.*, 1983). Generally speaking, the use of antibiotics instead of biocides such as hypochlorite or chlorhexidine appears unwarranted, as the former were developed for systemic use rather than local wound debridement and have a far narrower spectrum than the latter. Both citric acid and EDTA immediately reduce the available chlorine in solution, rendering the sodium hypochlorite irrigant ineffective on bacteria and necrotic tissue. Hence, citric acid or EDTA should never be mixed with sodium hypochlorite (Zehnder, 2006).

Calt and Serper (2002) demonstrated that 10mL irrigation with 17% EDTA for 1 minute was effective in removal of smear layer, but a 10-minute application caused excessive peritubular and intertubular dentinal erosion. Increasing contact time and concentration of EDTA from 10% to 17% as well as a pH of 7.5 versus pH 9.0 has been shown to increase dentin demineralization.

Need for newer root canal irrigants

All the irrigation solutions at our disposable have their share of limitations and the search for an ideal root canal irrigant continues with the development of newer materials and methods. Newer root canal irrigants in the horizon are as follows:

(1) MTAD,
(2) Electrochemically activated solutions,
(3) Photon-activated disinfection,
(4) Herbal irrigants.

The article reviews the advantages and shortcomings of these newer irrigating agents and their potential role in endodontic irrigation in near future.

MTAD

Bio Pure MTAD (Dentsply, Tulsa, OK) is a mixture of a tetracycline isomer, an acetic acid, and Tween 80 detergent (MTAD)—was designed to be used as a final root canal rinse before obturation (Torabinejad *et al.*, 2003). Tetracycline has many unique properties of low pH and thus can act as a calcium chelator and cause enamel and root surface demineralization (Bjorvatn *et al.*, 1985). Its surface demineralization of dentin is comparable to that seen using citric acid (Wikesjo *et al.,* 1986). In addition, it has been shown that it is a substantivemedication (becomes absorbed and gradually released from tooth structures such as dentin and cementum (Baker *et al.*, 1983; Wikesjo *et al.,* 1986). Finally, studies have shown that tetracycline significantly enhances healing after surgical periodontal therapy. Manufacturer instructions for using this irrigant were flooding the root canal with 1mL of the irrigant and soaking for 5 minutes, and the remaining 4mL is then delivered with continuous irrigation and suction (Torabinejad *et al.,* 2003). MTAD has some advantages over conventional irrigants and solutions used in root canal treatment.MTAD is effective in removing the smear layer along the whole length of the root canal and in removing organic and inorganic debris and does produce any signs of erosion or physical changes in dentine, whereas a mixture of 5.25% sodium hypochlorite and 17% EDTA does (Shabahang *et al.,* 2003; Shabahang and Torabinejad, 2003; Torabinejad *et al.*, 2003; Zhang *et al.,* 2003). In particular, MTAD mixture is effective against *E. faecalis*, and it is also less cytotoxicthan a range of endodontic medicaments, including eugenol, hydrogen peroxide (3%), EDTA, and calcium hydroxide paste (Shraev *et al.*, 1993; Legchilo *et al.,* 1996; Raab *et al.*, 1900; Dougherty *et al.,* 1998). Torabinejad *et al.* showed that the effectiveness of the MTAD was enhanced when low concentration of NaOCl isused as an intracanal irrigant before the use of MTAD as a final rinse. MTAD does not seem to significantly change the structure of the dentinal tubules (Torabinejad *et al.*, 2003).

Electrochemically activated solutions

Electrochemically Activated (ECA) solutions are produced from tap water and low-concentrated salt solutions (Solovyeva and Dummer, 2000; Bakhir *et al.,* 1986; Bakhir *et al.*, 1989). The ECA technology represents a new scientific paradigm developed by Russian scientists at the All-Russian Institute for Medical Engineering (Moscow, Russia, CIS). Principle of ECA is transferring liquids into a metastable state via an electrochemical unipolar (anode or cathode) action through the use of an element/reactor ("Flow-through Electrolytic Module" or FEM). The FEM consists of an anode, a solid titanium cylinder with a special coating that fits coaxially inside the cathode, a hollow cylinder also made from titanium with another special coating. A ceramic membrane separates the electrodes. The FEM is capable of producing types of solutions that have bactericidal and sporicidal activity; yet they are odourless, safe to human tissue and essentially noncorrosive for most metal surfaces (Solovyeva and Dummer, 2000).

Electrochemical treatment in the anode and cathode chambers results in the synthesis of two types of solutions: that produced in the anode chamber is termed an Anolyte, and that produced in the cathode chamber is Catholyte. Anolyte solutions containing a mixture of oxidizing substances demonstrate pronounced microbiocidal effectiveness against bacteria, viruses, fungi, and protozoa (Solovyeva and Dummer, 2000; Prilutskii *et al.*, 1996). Anolyte solution has been termed Superoxidized Water or Oxidative Potential Water (Selkon *et al.*, 1999; Hata *et al.*, 1996). Depending on the type ECA device that incorporated the FEM elements the pH of anolyte varies; it may be acidic (anolyte), neutral (anolyte neutral), or alkaline (anolyte neutral cathodic); acidic anolyte was used initially but in recent years the neutral and alkaline solutions have been recommended for clinical application. Under clean conditions, freshly generated superoxidized solution was found to be highly active against all these microorganisms giving a 99.999% or greater reduction in two minutes or less. That allowed investigators to treat it as a potent microbiocidal agent (Selkon *et al.*, 1999; Shetty *et al.*, 1999). It is nontoxic when being in contact with vital biological tissues (Shraev and Legchilo, 1989; Shraev *et al.*, 1993). Clinical applications of anolyte and catholyte were reported to be effective (Legchilo *et al.*, 1996). ECA solutions demonstrated more pronounced clinical effect and were associated with fewer incidences of allergic reactions compared to other antibacterial irrigants tested (Legchilo *et al.*, 1996). Cleaning efficiency and safety for surfaces of dental instruments and equipment has been demonstrated in a number of studies. ECA is showing promising results due to ease of removal of debris and smear layer, nontoxic and efficient in apical one third of canal. It has a potential to be an efficient root canal irrigant.

Photon-activated disinfection

The use of photodynamic therapy (PDT) for the inactivation of microorganisms was first shown by Oscar Raab who reported the lethal effect of acridine hydrochloride on Paramecia caudatum (Raab, 1900; Dougherty *et al.*, 1998). PDT is based on the concept that nontoxic photosensitizers can be preferentially localized in certain tissues and subsequently activated by light of the appropriate wavelength to generate singlet oxygen and free radicals that are cytotoxic to cells of the target tissue (Dougherty *et al.*, 1998). Methylene blue (MB) is a well established photosensitizer that has been used in PDT for targeting various gram-positive and gram-negative oral bacteria and was previously used to study the effect of PDT on endodontic disinfection (Harris *et al.*, 2005; Soukos *et al.*, 2006; Foschi *et al.*, 2007; George and Kishen, 2007a; George and Kishen, 2007b; Fimple *et al.*, 2008; George and Kishen, 2008; Lim *et al.*, 2009). Several studies have shown incomplete destruction of oral biofilms using MB-mediated PDT due to reduced penetration of the photosensitizer (Soukos *et al.*, 2000; Ogura *et al.*, 2007; Muller *et al.*, 2007;

Fontana *et al.,* 2009). Soukos *et al.* used the combined effect of MB and red light (665 nm) exhibited up to 97% reduction of bacterial viability. The results suggested the potential of PDT to be used as an adjunctive antimicrobial procedure after standard endodontic chemomechanical debridement, but they also demonstrated the importance of further optimization of light dosimetry for bacterial photodestruction in root canals. Along with methylene blue, tolonium chloride has been also used as a photosensitizing agent. It is applied to the infected area and left in situ for a short period. The agent binds to the cellular membrane of bacteria, which will then rupture when activated by a laser source emitting radiation at an appropriate wavelength (e.g., 635nm radiation emitted by SaveDent; Denfotex Light Systems Ltd., Inverkeithing, United Kingdom). The light is transmitted into the root canals at the tip of a small flexible optical fiber that is attached to a disposable hand piece. The laser emits a maximum of only 100mW and does not generate sufficient heat to harm adjacent tissues. Furthermore, tolonium chloride dye is biocompatible and does not stain dental tissue. The data quoted by the manufacturer suggest that this PAD system has antimicrobial efficacy (Williams *et al.,* 2003). Lethal photosensitization of *Streptococcus intermedius* biofilms in root canals is unable to achieve a total kill rate when a combination of a helium-neon laser and tolonium chloride is used (Seal *et al.,* 2002). Leticia *et al.* investigated the antibacterial effects of photodynamic therapy (PDT) with methylene blue (MB) or toluidine blue (TB) (both at 15mg/mL) as a supplement to instrumentation/irrigation of root canals experimentally contaminated with *Enterococcus faecalis* (Leticia *et al.,* 2010). The study revealed that PDT with either MB or TB may not exert a significant supplemental effect to instrumentation/irrigation procedures with regard to intracanal disinfection, until further adjustments in the PDT protocol are modified before clinical use is recommended.

In contrast, irrigation with sodium hypochlorite (3%) eliminated the entire bacterial population. The difference could be because the optical fiber was not properly introduced into the root canals, and so the light could not transmit through the tooth structure. Thus, PAD might not be able to achieve a 100% kill rate in infected root canals that have complex anatomic features and colonized by polymicrobial biofilms of varying properties. Pagonis *et al.* studied the in vitro effects of poly(lacticcoglycolic acid) (PLGA) nanoparticles loaded with the photosensitizer methylene blue (MB) and light against *Enterococcus faecalis* (ATCC 29212) (Pagonis *et al.,* 2010). The study showed that utilization of PLGA nanoparticles encapsulated with photoactive drugs may be a promising adjunct in antimicrobial endodontic treatment. PAD can currently be considered a useful adjunct to conventional root canal treatment.

Herbal

Murray *et al.* (2008) evaluated Morinda citrifolia juice in conjunction with EDTA as a possible alternative to NaOCl. Triphala (IMPCOPS Ltd, Chennai, India) is an Indian ayurvedic herbal formulation consisting of dried and powdered fruits of three medicinal plants, *Terminalia bellerica*, *Terminalia chebula*, and *Emblica officinalis*, and green tea polyphenols (GTPs; Essence and Flavours, Mysore, India); the traditional drink of Japan and China is prepared from the young shoots of tea plant *Camellia sinensis* (Murray *et al.,* 2008; Jagetia *et al.,* 2002; Hamilton-Miller, 2001; Prabhakar *et al.,* 2010). Herbal alternatives showed promising antibacterial efficacy on 3- and 6-week biofilm along with MTAD and 5% sodium hypochlorite (Prabhakar *et al.*, 2010). Although Triphala and green tea polyphenols (GTPs) exhibited similar antibacterial sensitivity on *E. faecalis* planktonic cells, Triphala showed more potency on *E. faecalis* biofilm. This may be attributed to its formulation, which contains three different medicinal plants in equal proportions. In such formulations, different compounds may be of help in enhancing the potency of the active compounds resulting in an additive or synergistic positive effect. According to Prabhakar *et al.* 5% of sodium hypochlorite exhibited excellent antibacterial activity in both 3-week and 6-week biofilm, whereas Triphala and MTAD showed complete eradication only in 3-week biofilm (Prabhakar *et al.,* 2010). Triphala and GTPs are proven to be safe, containing active constituents that have beneficial physiologic effect apart from its curative property such as antioxidant, anti inflammatory, and radical scavenging activity and may have an added advantage over the traditional root canal irrigants (Vani *et al.,* 1997; Rasool and Sabina, 2007; Jagetia *et al.,* 2004; Zhao, 2003).

References

Ayad, M.F. 2001. Effects of rotary instrumentation and different etchants on removal of smear layer on human dentin. *J. Prosthet. Dent.*, 85(1): 67–72.

Baker, P.J., Evans, R.T., Coburn, R.A., Genco, R.J. 1983. Tetracycline and its derivatives strongly bind to and are released from the tooth surface in active form. *J. Periodontol.*, 54(10): 580–585.

Bakhir, V.M., Kirpichnikov, P.A., Liakumovich, A.G. 1986. On the nature of electrochemical activation of media. *Rep. USSR Acad. Sci*., 286: 663–666.

Bakhir, V.M., Spector, L.E., ZadorozhnyYu, G., Lysenko, N.M., RudinskyYa, A. 1989. A device for electrochemical treatment of liquids. USSR certificate of authorship number 1719316, 1989.

Barrette, W.C. Jr., Hannum, D.M., Wheeler, W.D., *et al.* 1989. General mechanism for the bacterial toxicity of hypochlorous acid: abolition of ATP production. *Biochemistry,* 28: 9172–1978.

Beltz, R.E., Torabinejad, M., Pouresmail, M. 2003. Quantitative analysis of the solubilizing action of MTAD, sodium hypochlorite, and EDTA on bovine pulp and dentin. *J. Endod.*, 29(5): 334–337.

Bjorvatn, K., Skaug, N., Selvig, K.A. 1985. Tetracycline-impregnated enamel and dentin: duration of antimicrobial capacity. *Scand. J. Dent. Res.*, 93(3): 192–197.

Calt, S., Serper, A. 2002. Time-dependent effects of EDTA on dentin structures. *J Endod.*, 28: 17–19.

Dougherty, T.J., Gomer, C.J., Henderson, B.W., *et al.* 1998. Photodynamic therapy. *J. Natl. Cancer Inst*., 90(12): 889–905.

El karim, I., Kennedy, J., Hussey, D. 2007. The antimicrobial effects of root canal irrigation and medication. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, 103(4): 560–569.

Fimple, J.L., Fontana, C.R., Foschi, F., *et al.* 2008. Photodynamic treatment of endodontic polymicrobial infection *in vitro*. *J. Endod.*, 34(6): 728–734.

Fontana, C.R., Abernethy, A.D., Som, S., *et al.* 2009. The antibacterial effect of photodynamic therapy in dental plaque-derived biofilms. *J. Periodont. Res.*, 44(6): 751–759.

Foschi, F., Fontana, C.R., Ruggiero, K., *et* *al.,* 2007. Photodynamic inactivation of *Enterococcus faecalis* in dental root canals in vitro. *Lasers Surg. Med.*, 39(10): 782–787.

Garberoglio, R., Becce, C. 1994. Smear layer removal by root canal irrigants. A comparative scanning electron microscopic study. *Oral Sur. Oral Med. Oral Pathol.*, 78(3): 359–367.

George, S., Kishen, A. 2007a. Advanced noninvasive light-activated disinfection: assessment of cytotoxicity on fibroblast versus antimicrobial activity against *Enterococcus faecalis*. *J. Endod.*, 33(5): 599–602.

George, S., Kishen, A. 2007b. Photophysical, photochemical, and photobiological characterization of methylene blue formulations for light-activated root canal disinfection. *J. Biomed. Opt.*, 12(3): 29–34.

George, S., Kishen, A. 2008. Augmenting the antibiofilm efficacy of advanced noninvasive light activated disinfection with emulsified oxidizer and oxygen carrier. *J. Endod.*, 34(9): 1119–1123.

Haapasalo, H.K., Siren, E.K., Waltimo, T.M., *et al.* 2000. Inactivation of local root canal medicaments by dentine: an in vitro study. *Int. Endod. J.,* 33: 126–131.

Hamilton-Miller, J.M.T. 2001. Anti-cariogenic properties of tea (*Camellia sinensis*). *J. Med. Microbiol.*, 50(4): 299–302.

Harris, F., Chatfield, L.K., Phoenix, D.A. 2005. Phenothiazinium based photosensitisers-photodynamic agents with a multiplicity of cellular targets and clinical applications. *Curr. Drug Targets*, 6(5): 615–627.

Hata, G., Uemura, M., Weine, F.S., Toda, T. 1996. Removal of smear layer in the root canal using oxidative potential water. *J. Endod.*, 22(12): 643–645.

Hu¨lsmann, M., Hahn, W. 2000. Complications during root canal irrigation: literature review and case reports [review]. *Int. Endod. J.,* 33: 186–193.

Jagetia, G.C., Baliga, M.S., Malagi, K.J., Sethukumar, M. Kamath, The evaluation of the radioprotective effect of triphala (an ayurvedic rejuvenating drug) in the mice exposed to *γ*-radiation. *Phytomedicine*, 9(2): 99–108.

Jagetia, G.C., Malagi, K.J., Baliga, M.S., Venkatesh, P., Veruva, R.R. 2004. Triphala, an ayurvedic rasayana drug, protects mice against radiation-induced lethality by free-radical scavenging. *J. Altern. Complement. Med.*, 10(6): 971–978.

In-Soo Jeon, I-S., Larz S.W. Spångberg, Yoon,T.C., Reza B. Kazemi, Kum, K.Y. 2003. Smear layer production by 3 rotary reamers with different cutting blade designs in straight root canals: a scanning electron microscopic study. *Oral Surg. Oral Med. Oral Pathol.*, 95(5): 601–607.

Legchilo, A.N., Legchilo, A.A., Mostovshchikov, I.O. 1996. Preparation of suppurative wounds for autodermatoplasty with electrochemically activated solutions. *Surgery,* 1: 57–58.

Leticia, C.S., Brito, P.R.R., Machado de Oliveira, J.C., *et al.* 2010. Photodynamic therapy with two different photosensitizers as a supplement to instrumentation/ irrigation procedures in promoting intracanal reduction of *Enterococcus faecalis*. *J. Endod.*, 36(2): 292–296.

Lim, Z., Cheng, J.L., Lim, T.W., *et al.* 2009. Light activated disinfection: an alternative endodontic disinfection strategy. *Aust. Dent. J.*, 54(2): 108–114.

Machnick, T.K., Torabinejad, M., Munoz, C.A., Shabahang, S. 2003. Effect of MTAD on flexural strength and modulus of elasticity of dentin. *J. Endod.*, 29(11): 747–750.

Marending, M., Luder, H.U., Brunner, T.J., *et al.* 2007. Effect of sodium hypochlorite on human root dentine–mechanical, chemical and structural evaluation. *Int. Endod. J.*, 40: 786–793.

Mcdonnell, G., Russell, D. 1999. Antiseptics and disinfectants: activity, action, and resistance. *Clin. Microbiol. Rev.*, 12: 147–79.

McKenna, S.M., Davies, K.J.A. 1988. The inhibition of bacterial growth by hypochlorous acid. *Biochem. J.*, 254: 685–692.

Muller, P., Guggenheim, B., Schmidlin, P.R. 2007. Efficacy of gasiformozone and photodynamic therapy on amultispecies oral biofilm *in vitro*. *Eur. J. Oral Sci.*, 115(1): 77–80.

Murray, P.E., Farber, R.M., Namerow, K.N., Kuttler, S., Garcia-Godoy, F. 2008. Evaluation of *Morinda citrifolia* as an endodontic Irrigant. *J. Endod.*, 34(1): 66–70.

Nakashima, M., Iohara, K. 2014. Pulp regeneration by harnessing dental pulp stem cells. *INTECH,* doi: 10.5772/58905.

Niu, W., Yoshioka, T., Kobayashi, C., *et al.* 2002. A scanning electron microscopic study of dentinal erosion by final irrigation with EDTA and NaOCl solutions. *Int. Endod. J.*, 35: 934–939.

Ogura, M.A.A., Abernethy, A.D., Blissett, R.D., *et al.* 2007. Photomechanical wave-assisted molecular delivery in oral biofilms. *World J. Microbiol. Biotechnol.*, 23(11): 1637–1646.

Ørstavik, D. 1996. Time-course and risk analyses of the development and healing of chronic apical periodontitis in man. *Int. Endod. J.*, 29: 150 –155.

Ørstavik, D., Qvist, V., Stoltze, K. 2004. A multivariate analysis of the outcome of endodontic treatment. *Eur. J. Oral Sci.*, 112: 224–230.

Pagonis, T.C., Chen, J., Fontana, C.R., *et al.*, 2010. Nanoparticle based endodontic antimicrobial photodynamic therapy. *J. Endod.*, 36(2): 322–328.

Peters, L.B., van Winkelhoff, A.J., Buijs, J.F., Wesselink, P.R. 2002. Effects of instrumentation, irrigation and dressing with calcium hydroxide on infection in pulpless teeth with periapical bone lesions. *Int. Endod. J.*, 35: 13–21.

Peters, L.B., Wesselink, P.R. 2002. Periapical healing of endodontically treated teeth in one and two visits obturated in the presence or absence of detectable microorganisms. *Int. Endod. J.*, 35: 660 –667.

Peters, O.A., Scho¨nenberger, K., Laib, A. 2001. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *Int. Endod. J.*, 34: 221–30.

Prabhakar, J., Senthilkumar, M., Priya, M.S., Mahalakshmi, K., Sehgal, P.K., Sukumaran, V.G. 2010. Evaluation of antimicrobial efficacy of herbal alternatives (Triphala and green tea Polyphenols), MTAD, and 5% sodium hypochlorite against *Enterococcus faecalis* biofilm formed on tooth substrate: an *in vitro* study. *J. Endod.*, 36(1): 83–86.

Prilutskii, V.I., Bakhir, V.M., Popov, A.I. 1996. The disinfection of water, water-supply systems, tanks and pools by using an electrochemically activated solution of a neutral anolyte. *Vopr. Kurortol. Fizioter. Lech. Fiz. Kult.*, 4: 31–32.

Raab, O. 1900. Uber die Wirkung

Fluoreszierender Stoffe auf Infusorien. *Z. Biol.*, 39: 524–546.

Rasool, M., Sabina, E.P. 2007. Antiinflammatory effect of the Indian ayurvedic herbal formulation Triphala on adjuvantinduced arthritis in mice. *Phytother. Res.*, 21(9): 889–894.

Saleh, I.M., Ruyter, I.E., Haapasalo, M., Ørstavik, D. 2004. Survival of *Enterococcus faecalis* in infected dentinal tubules after root canal filling with different root canal sealers in vitro. *Int. Endod. J.*, 37: 193–198.

Seal, G.J., Ng., Spratt, D., Bhatti, M., Gulabivala, K. 2002. An in vitro comparison of the bactericidal efficacy of lethal photosensitization or sodium hyphochlorite irrigation on *Streptococcus intermedius* biofilms in root canals. *Int. Endod. J.*, 35(3): 268–274.

Selkon, J.B., Babb, J.R., Morris, R. 1999. Evaluation of the antimicrobial activity of a new super-oxidized water, Sterilox, for the disinfection of endoscopes. *J. Hosp. Infect.*, 41(1): 59–70.

Shabahang, S., Pouresmail, M., Torabinejad, M. 2003. *In vitro* antimicrobial efficacy of MTAD and sodium hypochlorite. *J. Endod.*, 29(7): 450–452.

Shabahang, S., Torabinejad, M. 2003. Effect of MTAD on *Enterococcus faecalis*-contaminated root canals of extracted human teeth. *J. Endod.*, 29(9): 576–579.

Shetty, N., Srinivasan, S., Holton, J., Ridgway, G.L. 1999. Evaluation of microbicidal activity of a new disinfectant: sterilox_ 2500 against *Clostridium difficile* spores, *Helicobacter pylori*, vancomycin resistant *Enterococcus* species, *Candida albicans* and several *Mycobacterium* species. *J. Hosp. Infect.*, 41(2): 101–105.

Shraev, T.I., Legchilo, A.N. 1989. Use of electrochemically activated 0.8% potassium chloride solutions in the treatment of empyema and parietal abscesses of the lung. *Thorac. Cardiovasc. Surg.*, 4: 64–68.

Shraev, T.I., Legchilo, A.N., Kharlamov, A.T., Legchilo, A.A. 1993. Sanitization of bronchial pathways by electrochemically activated solution of 0.8% potassium chloride. *Anesthesiol. Intensive Care*, 1: 22–23.

Sim, T.P., Knowles, J.C., Ng, Y.L., *et al.* 2001. Effect of sodium hypochlorite on mechanical properties of dentine and tooth surface strain. *Int. Endod. J.*, 34: 120–32.

Solovyeva, A.M., Dummer, P.M.H. 2000. Cleaning effectiveness of root canal irrigation with electrochemically activated anolyte and catholyte solutions: a pilot study. *Int. Endod. J.*, 33(6): 494–504.

Soukos, N.S., Chen, P.S.Y., Morris, J.T., *et al.* 2006. Photodynamic therapy for endodontic disinfection. *J. Endod.*, 32(10): 979–984.

Soukos, N.S., Socransky, S.S., Mulholland, S.E., Lee, S., Doukas, A.G. 2000. Photomechanical drug delivery into bacterial biofilms. *Pharm. Res.*, 17(4): 405–409.

Spa°ngberg, L., Engstro¨m, B., Langeland, K. 1973. Biologic effects of dental materials. 3. Toxicity and antimicrobial effect of endodontic antiseptics in vitro. *Oral Surg. Oral Med. Oral Pathol.*, 36: 856–871.

Torabinejad, M., Cho, Y., Khademi, A.A., Bakland, L.K., Shabahang, S. 2003. The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. *J. Endod.*, 29(4): 233–239.

Torabinejad, M., Khademi, A.A., Babagoli, J., *et al*. 2003. A new solution for the removal of the smear layer. *J. Endod.*, 29(3): 170–175.

Torabinejad, M., Shabahang, S., Aprecio, R.M., Kettering, J.D. 2003. The antimicrobial effect of MTAD: an *in vitro* investigation. *J. Endod.,* 29(6): 400–403.

Vani, T., Rajani, M., Sarkar, S., Shishoo, C.J. 1997. Antioxidant properties of the ayurvedic formulation triphala and its constituents. *Int. J. Pharmacognosy*, 35(5): 313–317.

Wikesjo, U.M., Baker, P.J., Christersson, L.A. 1986. A biochemical approach to periodontal regeneration: tetracycline treatment conditions dentin surfaces. *J. Periodont. Res.*, 21(4): 322–329.

Williams, J.A., Pearson, G.J., Colles, M.J., Wilson, M. 2003. The effect of variable energy input from a novel light source on the photoactivated bactericidal action of toluidine blue on Streptococcus mutans. *Caries Res.*, 37(3): 190–193.

Zehnder, M. 2006. Root canal irrigants, *J. Endod.*, 32(5): 389–398.

Zhang, W., Torabinejad, M., Li, Y. 2003. Evaluation of cytotoxicity of MTAD using the MTT-tetrazolium method. *J. Endod.*, 29(10): 654–657.

Zhao, B. 2003. Antioxidant effects of green tea polyphenols. *Chin. Sci. Bull.*, 48(4): 315–319.