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Review

Influence of pH changes on chlorine-containing endodontic irrigating solutions

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Abstract

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Chlorine-containing solutions are used for broad disinfection purposes. Water disinfection literature suggests that their disinfectant action depends on pH values as this will influence the available free chlorine forms. Hypochlorous acid (HOCl) has been suggested to have an antimicrobial effect around 80–100 times stronger than the hypochlorite ion. The aim of this paper was to review the influence of pH changes on the efficacy of chlorine-containing endodontic irrigating solutions. An electronic and hand search (articles published through to 2010, including 'in press' articles; English language; search terms 'root canal irrigants AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; 'antimicrobial action AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; 'tissue dissolution AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; 'smear layer AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution') was performed to identify publications that compared chlorine water solutions with different pH. Of 1304 publications identified, 20 were considered for inclusion in the review. The search resulted in the retrieval of articles studying sodium hypochlorite (NaOCl), superoxidized waters (SOW) and sodium dichloroisocyanurate (NaDCC). Regarding antimicrobial efficacy, the literature suggested that reducing the pH value of NaOCl to between 6 and 7.5 would lead to improved action; SOW was described as having a lower antimicrobial effect. The tissue dissolution activity NaOCl decreased when the pH reached values between 6 and 7.5; NaDCC and SOW had no clinically relevant tissue dissolution capability. Chlorine solutions of different characteristics appeared to have some cleaning efficacy although they should to be used in conjunction with chelating and/or detergent agents.

Keywords: electrochemically activated solution, hypochlorous acid, pH, sodium hypochlorite, superoxidized water, root canal irrigants.

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Introduction

Chlorine solutions are widely used for disinfection purposes including potable and sewage water, swimming pools, flowers, environmental surfaces, medical equipment and laundry (Rutala & Weber 1997). In dentistry, they are also currently suggested for the disinfection of dental water lines (Martin & Gallagher 2005) and impression materials (Martin *et al.* 2007) and, in the form of sodium hypochlorite (NaOCl), are widely suggested as the main root canal irrigant because of its broad antimicrobial activity, its function

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to prevent formation and to dissolve the smear layer and its ability to dissolve tissue remnants (Zehnder 2006).

Chlorine has a strong tendency to acquire electrons in order to achieve greater stability, and this translates into chlorine's oxidizing activity (Fair *et al.* 1948); its oxidizing capacity is retained by hypochlorous acid (HOCl), its hydrolysis product, which, according to classic water treatment literature (Butterfield *et al.* 1943, Fair *et al.* 1948, Brazis *et al.* 1958), is responsible for the disinfectant action of chlorine solutions. The relative amount of hypochlorite ion and HOCl present in chlorine solutions at a given pH and temperature is constant (Fair *et al.* 1948), as HOCl in water undergoes an instantaneous and reversible ionization into hypochlorite (OCl^-) and hydrogen (H^+) ions, having an ionization constant that depends only on temperature (Fair *et al.* 1948). Subsequently, pH changes will reflect the relative amounts of hypochlorite ion and HOCl present in the solution (Fair *et al.* 1948); if HOCl is consumed, then the balance will shift and new HOCl will form at the expense of OCl^-. Therefore, the OCl^- in the aqueous solution can work as reservoir for the formation of new HOCl and vice versa. By lowering the pH to values below 4 and 5, the relative amount of HOCl diminishes and chlorine gas (Cl_2) dissolved in water increases at the same rate (Fair *et al.* 1948). Chlorine in gas form is unstable because of its volatility (Lee *et al.* 2000); chlorine gas has been suggested to have a noxious odour and to be irritant to the respiratory tract, eyes and mucous membrane and, at higher concentrations, can have fatal effects (Baumgartner & Ibay 1978).

It would be reasonable to have different antimicrobial actions at different pH values, with a decrease in disinfection efficacy with a pH increase starting from neutral to alkaline values (Weber & Levine 1944, Fair *et al.* 1948, Brazis *et al.* 1958, Bloomfield & Miles 1979, Death & Coates 1979). The relative antimicrobial actions of HOCl and OCl^- against waterborne pathogens have been estimated to be around 80–100 : 1 in laboratory conditions (Fair *et al.* 1948, Brazis *et al.* 1958). A pH value around 6 has been proposed as ideal as the HOCl concentration is optimal for disinfection (Rutala & Weber 1997); at pH 7, 78% of the chlorine in a solution is available as HOCl, whilst at pH 8, this drops to 26% (Claesen & Edmonson 2006).

It has been suggested that the reaction of chlorine solutions with inorganic matter is rapid and stoichiometric, whilst that against organic matter is normally slower and depends on excess concentration (Fair *et al.* 1948). Organic matter reacts strongly with NaOCl, and the reaction depends on the relative amount of NaOCl and organic matter, with initially a relatively fast reaction followed by a slower second phase; the presence of organic matter in excess depletes the solution (Moorer & Wesselink 1982). The reactivity of chlorine is limited to particular organic sites (Deborde & von Gunten 2008) and appears to depend on pH: in an alkaline environment, many biological polymers are susceptible to hydrolysis (Baumgartner & Ibay 1978) and protein removal from apatite surfaces has been suggested to be more efficient (Haikel *et al.* 1994), whilst the hypochlorite ion is more reactive against amines at a pH around 8.5 (Hawkins *et al.* 2003). On the other hand, high HOCl concentrations can induce protein fragmentation (Hawkins *et al.* 2003).

Hypochlorous acid-releasing agents described for root canal treatment include NaOCl (Zehnder 2006), sodium dichloroisocyanurate (NaDCC) (Naenni *et al.* 2004) and 'electrochemically activated solutions/waters' (ECA solutions), denominated also 'superoxidized waters' (SOW), 'oxidative potential waters' (OPW) or 'functional waters' (Marais 2000, Solovyeva & Dummer 2000, Hata *et al.* 2001, Serper *et al.* 2001, Gulabivala *et al.* 2004, Garcia *et al.* 2010).

Hypochlorous acid dissociates in water as follows:

$$HOCl \leftrightarrow H^+ + OCl^-$$

Commercially available NaOCl products are 1–15% aqueous solutions with an alkaline pH (circa 11) and often contain 0.01–0.75% sodium hydroxide salts and other basic salts or buffers to increase its stability (Rutala & Weber 1997). This group includes the so-called Dakin's solution, which has pH 10 and a 0.5% concentration and is obtained by the addition of carbonate (Moorer & Wesselink 1982). Sodium hypochlorite hydrolyses in water as follows:

$$NaOCl \rightarrow Na^+ + ClO^-$$

Sodium dichloroisocyanurate is commonly used for the disinfection of baby-feeding equipment and treatment of drinking water (Claesen & Edmonson 2006). It is an organic compound available in tablet or powder form that releases chlorine when in solution at pH 5.9 (Dychdala 1991); its acidic pH is attributable to the effervescent base of the tablets (Claesen & Edmonson 2006). A NaDCC solution has only 50% of its chlorine available in solution, with the remnant part bound in the organic compound in equilibrium, which serves as the reservoir for free chlorine. NaDCC has been previously shown to have a significantly higher antimicrobial activity compared with NaOCl, and this is suggested to be dependent not entirely on their pH but also on the differences between their properties and mode of action (Bloomfield & Miles 1979). Sodium dichloroisocyanurate dissolves in water as follows:

$$NaCl_2(NCO)_3 + 2H_2O \leftrightarrow 2HOCl + NaH_2(NCO)_3$$

Electrochemically activated solutions are a group of disinfectants regularly used in endoscope disinfection containing a mixture of oxidizing substances that have different oxidation–reduction potentials (ORP), chlorine concentrations and/or pH (Fraise 1999). These factors depend on the concentration of the saline precursor, the generation rate and applied potential, as ECA solutions are obtained via electrolysis, a process similar to the commercial production of NaOCl. Production of anolyte and catholyte solutions at the different electrolytic chambers occurs during this procedure (Gulabivala *et al.* 2004). It is necessary to highlight that the chlorine concentrations of ECA solutions are normally smaller than those of NaOCl. For example, a 0.5% NaOCl solution will have a solvent concentration approximately 18 times larger than a 200-ppm 'high-concentration' SOW (Rossi-Fedele *et al.* 2010b). Disinfectants vary in their susceptibility to organic matter (Fraise 1999), and the presence of large amounts of organic matter influences the concentration of NaOCl required for disinfection (Bloomfield & Miles 1979). In root canal irrigation, this might be relevant particularly for solutions with low concentrations as there might be the risk that there is insufficient 'available chlorine' in order to obtain the desired actions. Dentine by weight consists of seventy per cent of inorganic matter, twenty per cent of organic matter and the remnant is water (Berkovitz *et al.* 2002). Therefore, some of the available chlorine potentially can be consumed by contact with tooth tissues. The use of a solution with an excessive chlorine concentration should be considered more dangerous because of the increased toxicity of higher NaOCl concentrations (Pashley *et al.* 1985) as well as its dentine-weakening action (Grigoratos *et al.* 2001, Sim *et al.* 2001), amongst other reasons. The use of a solution combining a reasonably high antimicrobial effect and low toxicity has been suggested in the absence of an ideal irrigating solution (Spanberg *et al.* 1973). Several studies, mainly *ex vivo* investigations, have been conducted in order to study the use of chlorine solutions as root canal irrigants for its antimicrobial, tissue dissolution, smear layer and debris removal actions. The goal of this paper is to review studies regarding the use of chlorine irrigants that compare solutions with different pH in order to achieve those desired effects. A literature search in the electronic database MEDLINE was conducted using the following search terms and combinations: 'root canal irrigants AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; 'antimicrobial action AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; 'tissue dissolution AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'; and 'smear layer AND sodium hypochlorite or hypochlorous acid or superoxidized water or electrochemically activated solution'. Furthermore, in order to include the most recent publications, a hand search of articles published online, 'in-press' and 'early view' in the International Endodontic Journal, Journal of Endodontics, Australian Endodontic Journal and Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology was performed on 31 December 2010 using the same search criteria as the electronic search. Publications were included if they compared chlorine water solutions with different pH and were published in English. Titles and abstracts of the publications identified by electronic database using the search terms mentioned above and those identified from the hand search were screened initially by two independent reviewers (GRF and EJD). Publications were included for full-text evaluation by one reviewer (GRF) if the content of the abstracts met the inclusion criteria. Full-text assessment and data extraction were performed by one reviewer (GRF). Publications were excluded if they did not meet the inclusion criteria (i.e. if they did not study antimicrobial action, tissue dissolution, smear layer removal and root canal irrigation) and also if they did not compare different pH chlorine-containing solutions. Of 1304 publications identified, 20 were included in the review.

Review

Antimicrobial effect

Different acidic and neutral chlorine-containing solutions have been suggested for root canal disinfection. Two kinds of 'functional waters' have been tested: strong acid–electrolysed water 'SAEW' [pH 2.8, residual chlorine concentrations of 10 ppm (Aoi Engineering Inc, Mishima, Japan)] and hypochlorous water 'HAW' [pH 6, residual chlorine concentration of 50 ppm (Tecnomax Corporation, Yoshikawa, Japan)] with a 3% NaOCl as the control. *Enterococcus faecalis* and *Candida albicans* were used as test organisms in a culture medium, and the effect was measured following changes in colony-forming units (CFUs); different irrigating volumes and the presence or absence of organic substance in the medium were tested. The results showed good microbicidal activity of NaOCl against both microorganisms; HAW's activity was slightly inferior to NaOCl's, whilst SAEW was overall weaker than HAW. The presence of organic matter did not significantly change the antimicrobial capacity of any of the solutions (Gomi *et al.* 2010). Further ECA waters containing chlorine of different pH (pH 3 and 6.5 – chlorine concentrations, ORP and source not described in the article) and 3% NaOCl have been tested in an *ex vivo*-infected root canal model. Following irrigation and serial dilution, CFUs were analysed as ratio against the negative controls. Although NaOCl gave by far the highest bacterial kills, the pH 3 and 6.5 'anolyte solutions' were shown to have antibacterial action against *E. faecalis*, with ultrasonic activation of the solutions enhancing their antibacterial effect (Gulabivala *et al.* 2004). A neutral SOW called Dermacyn (Oculus Innovative Sciences, Petaluma, CA, USA; pH value, chlorine concentration and ORP not described in the manuscript) has been tested on *E. faecalis* following inoculation in agar Petri dishes. The disinfectants were delivered by saturating paper discs and placing them in direct contact with the growth medium. Amongst other medicaments tested, 5.25% NaOCl had larger zones of inhibition than Dermacyn, which showed no microbial inhibition (Davis *et al.* 2007). Another neutral SOW [pH between 5.0 and 6.5 chlorine concentration of 144 mg L^{-1} (Aquatine Sterilox, Ilkley, UK)] has been tested by comparing it against a 4% NaOCl in a bovine root canal model inoculated with *E. faecalis*. By looking into CFUs following serial dilutions, the SOW was shown to have antimicrobial action; however, only NaOCl was capable of consistently eradicating the infection in the assays (Rossi-Fedele *et al.* 2010a). Other SOWs with different pH (7 and 9), chlorine concentration not described, [STEDS, Radical Waters (Pty) Ltd, Vorna Valley, South Africa], were tested against a 3.5% NaOCl in an *ex vivo* human tooth model inoculated with *E. faecalis, Actinobacillus actinomycetemcomitans*, *Prevotella intermedia* and *Porphyromonas gingivalis*. When measuring for CFUs and spectrophotometric values immediately after irrigation and 7 days later, both SOWs were not as effective as NaOCl in eliminating bacteria. NaOCl showed no CFUs, whilst SOWs showed some reduction only in bacterial number (Marais & Williams 2001). The antimicrobial efficacy of NaOCl 4.2% solutions at pH 12, 7.5 and 6.5 (by adding acetic acid) was tested in infected *ex vivo* root canals by assessing bacterial growth (presence or absence) following irrigation. A significant increase in the disinfecting capacity of the pH 6.5 solution against the pH 12 solution group was shown; however, the intermediate value (pH 7.5) showed no difference with the other group. (Mercade *et al.* 2009). Similarly, different NaOCl solutions [2.5% pH 12 'unbuffered', 0.5% pH 12 'unbuffered', 0.5% pH 9 'buffered' by adding sodium bicarbonate (Dakin's solution) and 0.5% pH 12 'buffered' by adding sodium carbonate] were tested on *E. faecalis.* Studies using filter papers assessed CFU reduction (with different disinfectant concentration and incubation times) and dentinal blocks looking into degree of growth (with different concentrations), which showed no differences between the solutions regarding antibacterial effect (Zehnder *et al.* 2002). Furthermore, Dakin's solution (0.5% pH 10), NaOCl 'unmodified' 2.5% pH 12.5 and 'neutralized' 2.5% pH 7.5 [by the addition of hydrochloric acid (HCl)] were tested in human teeth following infection with *E. faecalis*, with the irrigants left *in situ* for 5 or 20 min. By the analysis of the number of sterile roots per group, it was concluded that the 'neutralized' solution was the most efficient for elimination of intracanal bacteria and that Dakin's solution was less effective than the 2.5% unmodified solution (Camps *et al.* 2009). In terms of the antimicrobial ability of chlorine-containing solutions, there is no alternative to NaOCl with similar proven efficacy. Attempts to enhance the pH and/or concentration of SOW may be considered, provided that they have low toxicity and limited dentine-weakening properties.

Tissue dissolution

Only two studies that included chlorine-containing solutions different than NaOCl were found on the subject of tissue dissolution ability, with both irrigants having a neutral pH value. The first compared 1% (wt/vol) NaOCl against 5% NaDCC (pH and source not described) and found that after 120 min, NaDCC caused a loss of 13% of the original weight of necrotic porcine palatal tissue against 97% when NaOCl solution was used, with significant differences shown consistently over increasing times of incubation in the solutions until 120 min (Naenni *et al.* 2004). The second investigation compared Aquatine [200 ppm pH

5.0–6.5 (Sterilox, Optident, Ilkley, UK)] and 0.5% NaOCl using bovine pulp fragments placed in Eppendorf tubes containing the test solution, with half of the samples 'activated' using an ozone delivery system. The fragments were assessed for total dissolution, and it was found that the pulp tissue was completely dissolved only by NaOCl, whilst application of ozone enhanced the speed of dissolution (Rossi-Fedele *et al.* 2010b). An investigation analysed alkaline NaOCl solutions [2.5% pH 12 'unbuffered', 0.5% pH 12 'unbuffered', 0.5% pH 9 'buffered by adding sodium bicarbonate' (Dakin's solution) and 0.5% pH 12 'buffered' by adding sodium carbonate] for tissue-dissolving capacity on decayed and fresh porcine palate tissue and assessed the percentage of remaining weight. When comparing solutions of similar concentration (0.5%), Dakin's solution was equally effective on both types of tissues, whilst the other dissolved solutions decayed tissue more rapidly. No differences were found on fresh tissues, but significant differences in necrotic tissue were found between Dakin's solution and the unbuffered solution at 60, 90 and 120 min. Overall, it was concluded that pH changes and buffering NaOCl solutions had modest effects on their tissue-dissolving capacity, as no other significant difference between these three 0.5% NaOCl solutions was found (Zehnder *et al.* 2002). Sodium hypochlorite at various concentrations has been tested for tissue dissolution capacity following the addition of acids to the original solution in order to lower their pH values. By the addition of boric acid (0.5% at pH 11.6 and pH 9; 0.36% at pH 11.6 and pH 7), the speed for complete dissolution of the pulp fragments was reduced to half for the 0.5% and to a third for the 0.36% groups with lower pH (Spanó *et al.* 2001). By adding hydrochloric acid, four different investigations have been carried out; first, a study compared percentage of weight loss in porcine muscle three solutions at different pH values (12, 9 and 6) and concentrations (5.25% and 2.6%); no significant differences were found between the pH 12 and 9 groups; however, there was significant difference between the pH 6 group and the other groups with the higher value showing greater weight loss (Christensen *et al.* 2008). Also, 'neutralized' (pH 7.5) and pH 12 2.5% solutions were tested on porcine palatal mucosa by measuring weight variation every 10 min until 120 min whilst soaking in NaOCl. It was found that the dissolution action of high-pH solution was around five times higher than that of the neutralized one (Aubut *et al.* 2010). Subsequently, NaOCl 'unmodified' (2.5% pH 12.5) and 'neutralized' (2.5% pH 7.5) and Dakin's solutions (0.5% pH 10) were tested on bovine dental pulp, with the changes in weight recorded after the immersion of the specimens for 5, 10, 15 or 20 min in a rotating agitator. Overall, the 'unmodified' NaOCl was more effective than the 'neutralized' solution, which was more effective than Dakin's solution; however, no statistically significant difference was present within the 5-min group and, considering that regular replenishment of the irrigants is suggested in routine practice, the authors suggested the differences were not clinically relevant (Camps *et al.* 2009). Finally, the tissue-dissolving capability of NaOCl at alkaline pH values (12 and 10) was tested on necrotic rabbit liver at different concentrations (3.0%, 1.2% and 0.6%). When measuring percentage of tissue dissolved, it was concluded that concentration of available chlorine rather than pH is the factor that influences the results in the experimental conditions (Moorer & Wesselink 1982). Superoxidized water and NaDCC have no proven tissue dissolution ability. This is a key factor for the option of NaOCl as the main current irrigating solution. Experiments using associations with tissue-dissolving agents may provide light into the use of other chlorine-containing substances in place of NaOCl.

Cleaning effectiveness

Electrochemically activated solutions of different characteristics, including acidic and neutral compounds, have been tested for their smear layer and debris removal ability in *ex vivo* human teeth. Various neutral solutions have been tested for this purpose: Aquatine endodontic cleanser [pH 6, 180–200 ppm available free chlorine (Sterilox Puricore, Malvern, PA, USA)] was compared with a 6% NaOCl solution. When used in association with 17% EDTA, they were similarly effective at removing debris and the smear layer from the entire root canal when assessed using scanning electron microscopy (SEM) and semi-quantitative visual criteria. If no chelating agents were used, then a large amount of smear layer was present for both irrigants (Garcia *et al.* 2010). A different investigation compared a solution denominated 'Anolyte neutral cathodic (ANC)' [pH 7.7 ± 0.5, active chlorine 300 mg L^{-1} (STEL-10H-120-01)] alone and together with a catholyte solution (not containing chlorine) against 3% NaOCl used to irrigate during root canal preparation. Smear layer and debris removal was evaluated via SEM on selected sites in the coronal, middle and apical segments of the canals. ANC and

NaOCl had similar debris removal capacity, and both were ineffective in the removal of the smear layer, although ANC affected its thickness and surface. When the ANC was alternated to the catholyte solution, both smear layer and debris removal improved (Solovyeva & Dummer 2000). The cleaning efficacy of an ECA water anolyte solution during instrumentation [pH 7.4, ORP and chlorine concentration not described, STEDS, Radical Waters, Johannesburg, South Africa)] followed by a final flush with its catholyte solution (non-chlorine containing) was compared with 2.5% NaOCl alone in canals of *ex vivo* single-rooted teeth when delivered using an ultrasonic unit. ECA solutions produced surfaces cleaned of debris and bacteria and removed the smear layer in larger areas (Marais 2000). The use of an acidic 'OPW' [pH 2.5, chlorine concentration and ORP not reported in literature (NDX-250 KH; Nihon Aqua Co. Ltd, Kyoto, Japan)] in the removal of the smear layer was tested on human single-rooted teeth using a SEM on the root canal's middle and apical thirds. The OPW was tested alone or in association with 17% EDTA or 5% NaOCl, using either a syringe or an ultrasonic unit as irrigation methods. The authors concluded that OPW delivered by syringe after instrumentation effectively removed the superficial smear layer as specimens irrigated using OPW during and after instrumentation showed no smear layer or packing in the tubules. Similarly, OPW irrigation following EDTA showed clean surfaces, no smear layer and some visible tubule openings. Overall, this OPW was found to be as effective as 5% NaOCl or 17% EDTA used separately for the removal and prevention of smear layer formation (Hata *et al.* 1996). In a different investigation, the same OPW was compared when used alone against a combination consisting of 5% NaOCl during instrumentation followed by OPW as final irrigant. This investigation suggested that OPW alone removed the smear layer in the middle third more effectively than the combined irrigants and that neither of the irrigation regimes was capable of removing the smear layer from the apical third and left debris at the dentinal tubule openings (Serper *et al.* 2001). Finally, the effectiveness of the same OPW (pH described as lower than 2.7) in debris and smear layer removal was compared with those NaOCl and 15% EDTA. The different irrigants were delivered using either syringe or an ultrasonic unit using *ex vivo* human maxillary incisor root canals to understand the effects in the apical and middle thirds. The presence of the smear layer and debris was assessed via SEM observation using a three-point scale. NaOCl or OPW was used during instrumentation, whilst EDTA or OPW was used as a final rinse. This study suggested that the most effective technique for smear layer removal was NaOCl during instrumentation followed by EDTA using a syringe. OPW as a final rinse following NaOCl showed similar effects; however, when used alone, OPW did not remove the smear layer or debris effectively (Hata *et al.* 2001). Considering the large variability in the characteristics of the chlorine solutions tested and the need for a chelating agent in order to remove the smear layer, the association of detergents with chlorine-containing solutions should be tested further to better understand whether deeper penetration within the dentinal tubule system and more effective cleaning can be achieved. The information gathered about the antimicrobial effects, tissue dissolution and cleaning effectiveness of various chlorine-containing endodontic solutions, in a way, explains why NaOCl is still the main choice worldwide. Based on the literature search, it can be proposed that the use of conventional NaOCl for vital pulp treatments, when removing organic contents, is of primary importance. Using an acidified NaOCl for nonvital treatment is recommended when a strong antibacterial effect is required. The undesired properties of this irrigant, however, drive researchers to look at various factors affecting other chlorine solutions and their potential use as substitutes for NaOCl. If tissue dissolution and cleaning effectiveness remain a problem, at least the time of exposure to high pH solutions might be reduced.

Conclusions

Further investigations on chlorine-containing solutions should include chlorine concentration and pH analysis as part of the experimental methodology in order to understand the type of chlorine species present as well as their concentration. By modifying the pH of NaOCl solutions to values around 6 and 7.5 using specific acids, the antimicrobial effect seems to be increased. Low-concentration acidic and neutral chlorine-containing solutions appear to have antimicrobial effect; however, this is lower than currently used NaOCl concentrations. By modifying pH of NaOCl solutions to values below 7.5, the tissue dissolution capability appears to decrease. Sodium dichloroisocyanurate and SOW appear not to have clinically relevant pulp tissue dissolution effects. Neutral and acidic chlorine solutions appear to have potential cleaning effectiveness; however, the use of a chelating agent or detergent in combination might be necessary.

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