

REVIEW ARTICLE



Effects and Effectiveness of Cavity Disinfectants in Operative Dentistry: A Literature Review

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ABSTRACT

The degree of success in the elimination of bacteria during cavity preparation and prior to the insertion of a restoration may increase the longevity of the restoration and therefore the success of the restorative procedure. The complete eradication of bacteria in a caries-affected tooth, during cavity preparation, is considered a difficult clinical task. In addition to weakening the tooth structure, attempts to excavate extensive carious tissue completely, by only mechanical procedures, may affect the vitality of the pulp. Therefore, disinfection of the cavity preparation after caries excavation can aid in the elimination of bacterial remnants that can be responsible for recurrent caries, postoperative sensitivity, and failure of the restoration. However, the effects of disinfectants on the restorative treatment have been a major concern for dental clinicians and researchers. This review aims to explore existing literature and provide information about different materials and techniques that have been used for disinfecting cavity preparations and their effects and effectiveness in operative dentistry and, therefore, helps dental practitioners with clinical decision to use cavity disinfectants during restorative procedures. Antimicrobial effectiveness and effects on the pulp and dental restorations, in addition to possible side effects, were all reviewed in this paper.

Keywords: Bond strength, Cavity disinfectants, Microleakage, Operative dentistry.

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INTRODUCTION

During tooth cavity preparation, the success of restorative treatment can be affected by bacterial remnants in the cavity walls. It has been documented that bacteria remaining after restorative procedure may survive and multiply, especially in the presence of microleakage, which may lead to pulpal irritation,^{1,2} risk of recurrent caries,³ and/or postoperative sensitivity,⁴ and therefore failure of the dental restoration.^{5,6}

Attempts at the complete removal of deep carious dentin, by solely mechanical means, may result in pulpal violation and/or gross destruction of the tooth structure.^{7,8} Moreover, the complete mechanical caries removal approach has failed to generate a completely caries-free cavity.^{9,10}

Interest in the study of antimicrobial agents and their effects on the pulp originated in the early 1970s with Brännström and Nyborg,¹¹ who emphasized the importance of eliminating bacteria remaining on cavity walls, including dentin and enamel, after caries excavation by means of antibacterial agents, and therefore recommended disinfecting the cavity preparation before inserting the restoration.¹²

Thereafter, cleaning the cavity preparation with antibacterial agents, to aid in bacterial elimination, began to gain wide acceptance among dental practitioners.¹³ Multiple disinfectants have been used in clinical dentistry, in an effort to reduce or eliminate bacteria during cavity preparation and prior to the placement of dental restorations. Some of these agents have been reported to cause pulpal irritation, due to their inherent chemicals, and therefore have fallen into disuse.¹⁴

In addition to their effectiveness in sterile cavity preparation, the effects of these different agents and techniques on restorations, especially bond strength, and tooth structure have been a major concern for researchers. This paper reviews the literature on different disinfectant materials

and techniques that have been reported to be used during cavity preparation and their efficacy as antimicrobial agents and reported effects on dental restorations.

CAVITY DISINFECTANTS

Chlorhexidine

Chlorhexidine digluconate (CHX) is a biguanide biocide that inhibits the formation and progression of dental plaque and has been used as an oral antimicrobial agent since the 1970s.¹⁵ Presently, CHX is one of the most widely used antimicrobial agents in oral health¹⁶ and is considered the “gold standard” of oral antiseptics.^{17,18}

Different concentrations and forms of CHX are available: 0.12 to 0.2% mouthrinses, 2% cavity-cleaning solutions, and 0.5 to 1% gels. It has been reported that the 2% solution is the most widely used CHX form in clinical dentistry and dental research.¹⁹

Antimicrobial Effectiveness

Chlorhexidine digluconate has been documented to have high antibacterial activity against both Gram-positive, especially *Streptococcus mutans*, and Gram-negative bacteria,^{20,21} although their effects on Gram-negative were to a lesser extent than those on Gram-positive bacteria.^{22,23} Moreover, CHX has been reported to suppresses the growth of *S. mutans*.^{24,25} However, reduced susceptibility of *Staphylococci* to CHX has also been reported.²⁰ Chlorhexidine digluconate is bactericidal at high concentrations and bacteriostatic at low concentrations.^{15,26} At low concentrations, CHX destroys the cell wall then attacks the cytoplasmic membrane. At high concentrations, it causes coagulation of intracellular components, leading to cytoplasmic congealing.²⁶

Wide range of application times has been reported in the literature, this range varied from 5 to 120 minutes. However, most of researchers applied the CHX for 60 seconds.¹⁹

In a study conducted by Sassone et al,²⁷ the antimicrobial effects of different concentrations of CHX (0.12, 0.5, and 1%) after immediate, 5-, 15-, and 30-minute applications were evaluated. They found that 0.12% CHX did not eliminate *Enterococcus faecalis* at any time interval and therefore recommended using CHX at a concentration greater than 0.12%.

Effects on the Pulp

Chlorhexidine digluconate in the form of 2% aqueous solution has been considered as a biocompatible^{28,29} and toxicologically safe disinfectant.^{29,30}

Chlorhexidine digluconate pretreatment in deep caries lesions during restorative treatment has been

reported to increase the clinical success of both direct³¹ and indirect³² pulp-capping procedures.

Pameijer and Stanley³¹ found that 2% CHX applied for 60 seconds immediately after contamination of the exposed pulp was an effective hemostatic agent and aided in dentin bridge formation.

Effects on Restorative Treatment

The reported effects of CHX, in different concentrations, on the restorative treatment varied according to the type of adhesive system used, the form and concentration of CHX, and the aging process.

Meiers and Shook³³ found the effects CHX disinfectant on composite restorations to be material-specific, with Syntac reported to have an adverse effect on bonding compared with the tenure-adhesive system when used after the cavity was cleaned with 2% CHX.

Chlorhexidine digluconate wash, in the form of 2% solution, before composite bonding has been shown to successfully preserve the bond strength, up to 6 months, when etch-and-rinse adhesive systems were used.³⁴⁻³⁶ Moreover, Manfro et al³⁷ and Breschi et al³⁸ have reported this bond in the CHX-treated samples to be significantly stronger than the nontreated samples after 12 months of aging. However, the immediate microtensile bond strength (μ TBS) on these studies has not been affected after CHX application. On the contrary to these results, Gunaydin et al³⁶ found the immediate μ TBS of the non-CHX-pretreated specimens were significantly higher than pretreated dentin specimens.

The preserved bond interface associated with the use of CHX can be explained by the inhibitory ability of CHX to the matrix metalloproteinases (MMPs) found in etched dentin. Matrix metalloproteinases in dentin have been shown to play a role in the degradation of the unprotected collagen fibrils within the hybrid layer. Therefore, MMP inhibitors, such as CHX can play a role in the longevity of the resin bond to dentin.^{39,40}

Several studies have reported higher bond strengths of resin composite to dentin when etch-and-rinse adhesive systems, rather than self-etch systems, were used after CHX pretreatment.⁴¹⁻⁴⁵

One study⁴² evaluated the effects of 0.12% and 2% CHX on the μ TBS of four adhesive systems – two etch-and-rinse (Adper Scotchbond Multipurpose and Adper Single-Bond) and two self-etch adhesive (Clearfil SE Bond and Clearfil Tri S Bond) – in bovine teeth. For etch-and-rinse adhesives, CHX solutions were applied before or after an acid-etching procedure. The authors found that 2% CHX exhibited lower μ TBS for the self-etch adhesives. However, the bond strength was not significantly affected in the etch-and-rinse adhesive groups. Di Hipólito et al⁴⁶ found

that the μ TBS of self-adhesive luting cements (RelyX U100 and Multilink Sprint) to dentin were negatively affected by dentin pretreatment with 0.2% or 2% CHX.

The adverse effect on bond strength of 2% CHX solutions associated with self-etch bonding systems and cements may be explained by the presence of functional monomer, 10-methacryloyloxydecyl dihydrogenphosphate (MDP), in the bonding resin of self-etch adhesive systems, which might have been affected by CHX bonding.¹⁴

Another factor is the residual moisture of the 2% CHX solution, which contaminates the bonded surface and alters the ability of the hydrophilic resin in the self-etch system to seal the dentin.^{1,10} This may also explain why the bond at the tooth-resin interface was not altered by the 1% CHX gel application prior to the use of self-etch adhesive systems, which has been reported in several studies.^{10,45,47} The gel form of disinfectant does not wet the dentin surface and penetrate the dentinal tubules as does the solution form.

Some authors reported no statistically significant differences in the bond strength with self-etch adhesive systems and after 2% CHX application.⁴⁸⁻⁵⁰ In one study, Sampaio de-Melo et al⁴⁸ evaluated the effect of CHX on the μ TBS of composite resin restorations in the presence of a self-etch adhesive system (All-Bond SE) on sound and demineralized dentin (artificially caries-affected dentin) and found that CHX pretreatment did not affect bond strength. Similar results have been reported by Mobarak and coworkers,^{49,50} who found no adverse effects of CHX pretreatment on microshear bond strength (μ SBS) of dentin bonded with a self-etch bonding system (Clearfil SE Bond). However, these studies did not compare the self-etch-systems to the etch-and-rinse adhesives.

To achieve better composite bonding when a self-etch adhesive system is used, Cha and Shin⁵¹ recommended rinsing the cavity walls after using 2% CHX and before applying the self-etch adhesive.

On permanent teeth, CHX solutions have been reported to not significantly affect the microleakage of the restorations bonded with etch-and-rinse adhesive systems.^{38,52,53}

In a recent study⁵³ that evaluated the effect of 2% CHX pretreatment on the nanoleakage of two etch-and-bond adhesive systems (Prime & Bond NT and Adper Single Bond 2), an increase in the nanoleakage after 24-month aging was reported in the nontreated groups.

On primary teeth, however, Memarpour et al⁵⁴ reported different results, since they found that 2% CHX pretreatment, after acid etching and before the application of Adper Single Bond 2, increased the microleakage of composite restorations.

Studies have reported controversial results on the effects of CHX on microleakage when self-etch adhesive bonding systems were used.^{10,55,56}

Arslan et al⁵⁵ found no significant differences between self-etch and etch-and-rinse in dentin margins. However, in enamel margins, the etch-and-rinse adhesive exhibited significantly less microleakage.

In contrast, an *in vitro* study by Singla et al¹⁰ has reported increased in microleakage of nanohybrid composite restorations when a single-bottle self-etching adhesive was used in samples pretreated with 2% CHX cavity disinfectant.

On amalgam restorations and before placement of the amalgam, 2% CHX pretreatment has been shown to decrease microleakage and postoperative sensitivity.^{13,57}

Disadvantages and Side Effects

Chlorhexidine digluconate has been reported to cause brownish staining of the teeth. However, this effect was seen after long-term use, as with the use of mouthrinses.^{58,59}

Although CHX allergy is rare, CHX may cause contact dermatitis, desquamative gingivitis, or taste alteration.²⁸ It has also been reported that CHX in a high concentration (18%) has toxic effects. However, concentrations of up to 10% were suitable for contact with tissue.⁶⁰

Sodium Hypochlorite

Sodium hypochlorite (NaOCl) is an effective organic solvent that has been widely used in clinical dentistry as a cleansing agent after having first been used (1920) in endodontics as an antimicrobial irrigant.⁶¹

Upon contact with the dentin surface, NaOCl breaks down to sodium chloride and oxygen, causing an oxidation process in the dentin matrix.⁶²

Antimicrobial Effectiveness

Sodium hypochlorite has been well documented as having excellent tissue-dissolving action and strong antimicrobial effectiveness on residual bacteria.^{27,63,64}

Vianna et al⁶⁵ found the application of 5.25% NaOCl solution for 15 seconds to eliminate *Staphylococcus aureus*, *Candida albicans*, *Porphyromonas endodontalis*, *Porphyromonas gingivalis*, and *Prevotella intermedia*.

However, the antimicrobial activity of NaOCl has been reported to be affected by the concentration of the solution.^{64,66}

Effects on the Pulp

Sodium hypochlorite has been reported to have cytotoxic effects in cell cultures.⁶⁷ In a review on the success of pulp-capping, Hilton⁶⁸ reported an increased

pulpal inflammatory response after the use of NaOCl. Furthermore, Pascon et al⁶⁹ did not recommend NaOCl to be used for disinfecting cavities.

In contrast to these results, NaOCl has been described to be biocompatible with pulp⁷⁰ and to promote pulpal healing,⁷¹ with inflammatory effects limited to superficial cells without affecting the deep pulp tissues.⁷²

Effects on Restorative Treatment

Controversial results on the effect of NaOCl on resin bond have been reported. Some authors found this treatment to affect the hybrid layer – and therefore the resulting bond strength and microleakage – adversely,^{44,73,74} while others found no effects on bond strength.⁷⁵⁻⁷⁷ However, the effect of NaOCl pretreatment on the bond strength of composite resin is believed to depend on the adhesive system used.^{45,78}

Ercan et al⁴⁵ recommended NaOCl disinfectant to be used with etch-and-rinse bonding systems, since they found that 2.5% NaOCl pretreatment negatively affected the shear bond strength (SBS) of self-etching bonding systems.

Fawzy et al⁷⁸ reported similar results with a 2-minute application of 5.25% NaOCl, as they found the tensile bond strength (TBS) of the self-etching adhesive to be negatively affected by the NaOCl pretreatment, with no significant effect reported when etch-and-rinse adhesive was used.

However, on primary teeth, Correr et al⁷⁶ found that 10% NaOCl application for 60 seconds did not significantly affect the SBS regardless of the adhesive system used.

In an *in vivo* pilot study, Saboia Vde et al⁷⁷ evaluated the 2-year effect of 10% NaOCl solution on collagen removal, after acid etch and prior to the use of Prime & Bond 2.1 or Single Bond SB on the properties of composite restorations. They found that NaOCl application did not significantly affect the clinical performance of the restorations.

In contrast, Shinohara et al⁷⁴ found 10% NaOCl gel pretreatment followed by Single Bond, Prime & Bond NT, or Gluma One Bond significantly increased the microleakage at the dentin interface.

Disadvantages and Side Effects

Sodium hypochlorite solution is a very strong oxidizer that produces a corrosive reaction; therefore, it should be applied with great care. In addition to its tendency to bleach clothes, it has a bad taste and possesses irritant effects on the surrounding tissue, especially at high concentrations.⁷⁹⁻⁸¹

Benzalkonium Chloride

Benzalkonium chloride (BAC) is a mixture of alkylbenzyl-dimethyl ammonium chlorides and is a nitrogenous cationic agent containing a quaternary ammonium group with broad antimicrobial activity.⁸²

Tubulicid (Global Dental Products, Bellmore, NY, USA) is a quaternary ammonium compound with ethylenediaminetetraacetic acid (EDTA) that comes in three forms: Tubulicid Red contains 1.0% sodium fluoride, which has been recommended by the manufacturer to be used for cleaning without removing the smear layer; Tubulicid Blue is used to disinfect the whole tooth or multiple teeth, prior to the cementation of crowns or bridges; and Tubulicid Plus has been claimed to be a stronger cleaner and used as a root canal irrigant to remove the smear layer and open dentinal tubules.

Antimicrobial Effectiveness

Although BAC has been described as a strong antibacterial agent against microorganisms like *S. mutans*, *Streptococcus salivarius*, and *S. aureus*.^{83,84} This activity was reported to be less than CHX.⁸³

Effects on the Pulp

Benzalkonium chloride as a cavity disinfectant has been reported to be compatible with the dental pulp.¹⁴

Effects on Restorative Treatment

As with CHX, BAC has been documented to be an effective MMP inhibitor that may preserve the adhesive bond of the resin restoration to dentin.^{40,56,85,86}

Sabatini and Patel⁸⁶ evaluated the effects of different concentrations of BAC on the preservation of adhesive interfaces by using two etch-and-rinse adhesives (Optibond Solo Plus and All-Bond 3). They reported improvement in the bond strength in groups pretreated with 0.5% BAC and 1.0% BAC and using Optibond Solo Plus, and in groups pretreated with 0.25 and 0.5% BAC and using All-Bond 3. They found that BAC at all concentrations improved bond stability after 18 months.

Based on two *in vitro* studies, Sharma et al^{47,56} recommended that only etch-and-rinse bonding systems be used when Tubulicid Red is used as a cavity disinfectant. In contrast to the results of Sharma et al, Türkün et al⁸⁷ found that Tubulicid Red did not significantly affect the sealing ability of Clearfil SE Bond and Prompt L-Pop (both are self-etched adhesives).

Disadvantages and Side Effects

Benzalkonium chloride solutions in high concentration can cause allergic reactions and toxic effects,⁸⁸ and when

a concentration of 10% or more is ingested, severe complications may occur which may even lead to death.⁸⁹

Iodine-based Disinfectants

Iodine-based disinfectants are unstable solutions with wide-ranging effects on microorganisms. The antibacterial effects of these agents are attributed to the presence of molecular iodine (I₂) in these solutions.²⁹

Different iodine solutions have been used for disinfection purposes in clinical dentistry, including: Iodine-potassium iodide (I₂-KI), potassium iodide/copper sulfate (I₂-KI/CuSO₄), iodine disclosing/disinfection solution (I₂DDS), and providone-iodine (PVP-I).

Antimicrobial Effectiveness

Iodine disinfectants are bactericidal biocides. Iodine has the ability to destroy the bacterial cell by attacking its proteins, nucleotides, and fatty acids.⁹⁰ It has been reported to disclose and eliminate bacteria in plaque,^{91,92} and their effectiveness against cariogenic bacteria has been also documented.⁹³⁻⁹⁵

Simratvir et al⁹³ evaluated the efficacy of 10% PVP-I on *S. mutans* counts in children with early childhood caries and found that 10% PVP-I significantly reduced *S. mutans* levels after 12 months of treatment. In another study, Xu et al⁹⁵ found the application of PVP-I/fluoride foam, in 6- to 9-year-old children with caries lesions, to significantly decrease salivary *S. mutans* over 6 months. However, after 1 year, PVP-I/fluoride foam did not exhibit statistically significant differences compared with the regular fluoride foam.

Effects on Restorative Treatment

Although data regarding the effects of iodine disinfectants on the restorative treatment are limited, these effects vary according to the type of material used.^{87,91,96,97}

da Silva et al⁹¹ found the effect of 2% I₂DDS on the μ TBS of different adhesive systems to be material-specific. They found μ TBS to be significantly decreased for ethanol- and water-based adhesive systems (Single Bond, Clearfil SE Bond, and Opti-Bond Plus). However, in cases of an acetone-based adhesive system (Prime & Bond NT), I₂DDS did not affect the bond strength.

In another study, Cunningham and Meiers⁹⁷ compared the effect of 0.11% I₂-KI/CuSO₄ with that of 2% CHX on the SBS of resin-modified glass-ionomer cements (Fuji II LC, Photac-Fil, and Vitremer) to sound dentin. They found that the I₂-KI/CuSO₄ solution significantly lowered the bond strengths of Vitremer and Fuji II LC to dentin. In contrast, CHX did not significantly affect the bond of any of the tested materials to dentin.

Ora-5 (Mchenry Laboratories, Edna, TX, USA) is a commercially available I₂-KI/CuSO₄-based oral disinfectant

composed of 0.3% iodine, 0.15% potassium iodide, and 5.5% copper sulfate. Compared with CHX and BAC disinfectants, Ora-5 was found to have a negative effect on the sealing of composite restorations when used to pretreat dentin before bonding with Clearfil SE Bond.⁵⁶ These results were in agreement with those of Türkün et al,⁸⁷ who described Ora-5 as not being an appropriate disinfectant with Clearfil SE Bond or Prompt L-Pop (self-etch bonding systems) and caused gap formations at the bond interface compared to other disinfectants (2% CHX and BAC).

Meiers and Shook³³ have stated that Ora-5 adversely affects the SBS of composite to dentin when the Syntac adhesive system is used. However, they have not reported negative effects with the Tenure adhesive system.

Disadvantages and Side Effects

Iodine hypersensitivity is a documented side effect that mandates care when these products are used. Iodine is contraindicated to be used during pregnancy, and because it can cause metabolic complications, it is also contraindicated in patients with thyroid pathosis.⁹⁸

Lasers

Lasers are devices that emit beams of different wavelengths. The word "LASER" is an acronym for "light amplification by stimulated emission of radiation." In a laser device, the active medium is responsible for creating the beams upon stimulation. Different kinds of lasers have been manufactured with different active media that create the beams. These media can be of solid state as in erbium-doped yttrium, aluminum, and garnet lasers (Er:YAG); gas as in carbon dioxide (CO₂) lasers; or semiconductor as in diode lasers.

Since their introduction to clinical dentistry in the 1960s,⁹⁹ multiple kinds of lasers with different applications – for hard tissues, soft tissues, light-curing, tooth-whitening, and disinfecting – have been used in dental practice. These lasers include neodymium-doped yttrium aluminum garnet (Nd:YAG), Er:YAG, neodymium-doped yttrium aluminum perovskite (Nd:YAP), diode, argon (KTiOPO₄), erbium chromium-doped yttrium scandium gallium garnet (Er,Cr:YSGG), and potassium-titanyl-phosphate (KTP).¹⁰⁰

After U.S. Food and Drug Administration (FDA) approval of Er:YAG and Er,Cr:YSGG lasers for cutting tooth structures, these lasers have been extensively used and researched in restorative dentistry.¹⁰¹

Antimicrobial Effectiveness

Laser irradiation causes expansion of intratubular water of the bacterial cell and has thermal and photodisruptive effects on bacteria, leading to cell growth impairment and

lysis.¹⁰² de Sousa Farias et al¹⁰³ found that antimicrobial photodynamic therapy (aPDT) with a low-level laser significantly reduced the numbers of viable bacteria in the *S. mutans* biofilm.

In an *in vivo* study, Mohan et al¹⁰² used 80 primary molars in 68 children with occlusal caries lesions to compare the antimicrobial activities of different disinfectants (including diode laser). Results showed significant decreases in *S. mutans* and *Lactobacilli* with the diode laser group compared with the control group; however, this antimicrobial activity was not significantly different from that achieved with 2% CHX. The effectiveness of the Er:YAG laser as an antimicrobial agent as well as smear layer remover has also been documented.^{104,105}

Effects on the Pulp

The damaging effect of laser irradiation on pulpal tissues and surrounding soft tissues is influenced by multiple factors, such as the temperature and the magnitude of the absorbed energy, wavelength, and exposure time.¹⁰⁶ To minimize these harmful effects, the recommended settings should be observed and precautions taken.¹⁰⁷ For example, when using Er:YAG lasers, water must always be used in conjunction with the laser to avoid any pulpal irritation.^{108,109}

Effects on Restorative Treatment

Multiple studies have reported that the use of Er,Cr:YSGG or KTP lasers does not adversely affect the bond strength of the restoration.^{41,55,110-113} The use of the Er,Cr:YSGG laser as a cavity disinfectant with etch-and-rinse (Adper Single Bond 2) adhesive system was found by Celik et al,⁴¹ to significantly increase the μ TBS compared with those not preradiated or bonded with self-etch adhesive (Clearfil Bond). On primary teeth, Oznurhan et al¹¹¹ found that teeth pretreated with KTP before the application of Prime and Bond NT adhesive exhibited significantly higher μ TBS than did those without laser pretreatment.

Disadvantages and Side Effects

In addition to being an expensive treatment modality, lasers require special training of personnel before they can be used intraorally, and certain safety precautions must be taken when these machines are manipulated. Eye protection to avoid any possible eye damage should be mandatory for patients, dentists, and staff. The manufacturer's instructions must be strictly followed for each procedure performed to avoid any side effects on the hard/soft tissues or dental pulp complex.¹⁰¹

Ozone

Ozone (O₃) is a pale, nonstable gas, naturally produced by the photodissociation of oxygen into activated oxygen atoms, which then react with further oxygen molecules.¹¹⁴ Ozone is known to be a strong oxidizer. Hence, it possesses antibacterial activities by disrupting the cell wall and cytoplasmic membrane of bacteria and therefore destruction of the microorganism.¹¹⁵ Its oxidizing potential has been reported to be 1.5 times greater than that of chloride.¹¹⁶ In dental applications, O₃ can be used in one of three forms: Gaseous, water, or oil.¹¹⁷ Ozone was first used as a disinfectant in clinical practice in the 1920s by Dr Parr.¹¹⁸ In 1950, Dr Fisch was the first to use ozonated water for dental procedures in Germany.¹¹⁴

Antimicrobial Effectiveness

The antimicrobial effectiveness of O₃ against oral microorganisms, especially against *S. mutans*, has been well-documented in the literature.¹¹⁹⁻¹²² Times of O₃ application for effective antimicrobial activity have been reported to be between 10 and 60 seconds.^{120,122,123} Baysan et al¹²⁰ found that O₃ application for 20 seconds can eliminate 99.9% of microorganisms in primary caries lesions. For 10-second application, O₃ was able to reduce the numbers of *S. mutans* and *Streptococcus sobrinus*. Similarly, Fagrell et al¹²² found O₃ treatment for 20 seconds or more to be effective in eliminating different oral microorganisms *in vitro*. However, they reported limited effect on bacterial growth for 5- to 10-second applications, but 60-second treatment was able to eliminate bacterial growth completely.

Effects on Restorative Treatment

Several studies have reported the effect of O₃ on the bond strength of dental composites. Some of these studies have evaluated the effect of O₃ pretreatment on the enamel bond, as in the case of pit-and-fissure sealants, and have reported no effects on enamel bond strength or microleakage.¹²⁴⁻¹²⁶ Further, good evidence has been reported for the prophylactic application of O₃ before the sealing of pits and fissures.¹²⁷

Marchesi et al¹²⁵ investigated the effect of an 80-second O₃ application on fissure sealants. In their study, the immediate enamel SBS and microleakage of Concise and UltraSeal XT Plus fissure sealants, with or without O₃ pretreatment, were not significantly different, and O₃ did not adversely affect the enamel bond strength or cause an increase in microleakage. Moreover, a few authors have reported improvement in enamel/restoration bond strength and/or microleakage.¹²⁸⁻¹³⁰ Cehreli et al¹²⁸ found that O₃ pretreatment significantly reduced the extent of microleakage and demonstrated better adaptation of the sealants. According to Schmidlin et al,¹³⁰ O₃ application

for 60 seconds, alone or followed by the application of a fluoride- and xylitol-containing antioxidant, resulted in a significant increase in the SBS of the enamel bond. However, Pires et al¹³¹ found SBS after 20-second O₃ application to be higher for the etch-and-rinse adhesive system than for the self-etch system.

On dentin, most of the studies have reported no effect of O₃ on the bond strength, regardless of the type of adhesive systems used.^{112,115,130,132} However, a study by Rodrigues et al¹³³ on the effect of O₃ application before acid-etching reported decreased μ TBS of the dentin-composite resin interface compared with that in a group of teeth treated with O₃ after acid-etching or the group without O₃ pretreatment. After comparing O₃ with different cavity disinfectants, Günes et al⁸⁴ found O₃ to be more successful as a cavity disinfectant than traditional methods. In their study, the least microleakage was observed in the O₃-treated group compared with the control group and groups treated with CHX, BAC, NaOCl, and diode lasers. However, the differences among disinfectants, including O₃, were not statistically significant from each other.

Disadvantages and Side Effects

Although O₃ is a promising treatment modality in clinical dentistry, as with lasers, these devices are fairly expensive compared with traditional disinfectants. O₃ devices should be handled with care due to its strong oxidizing effect and potential toxicity¹¹⁴; therefore, the manufacturer-recommended protocol for administration should be strictly followed.

Naturally based Disinfectants

Interest in the use of natural therapeutics as a complement to traditional medicine in dental applications has been reported to be increasing in recent years.^{134,135}

Different naturally derived disinfectants have been used and tested for their antimicrobial activities and effects on restorative procedures. These include, but are not limited to, propolis, *Salvadora persica*, and *Morinda citrifolia*.

Propolis

Propolis, or bee glue, is a resin-like material found in some tree buds and collected by honeybees, and therefore it contains bee products.

Antimicrobial Effectiveness

In addition to the possible abilities of these products to treat some health conditions, the antimicrobial effectiveness of propolis against *S. mutans* and other oral pathogens has been documented.¹³⁶⁻¹³⁸

In a recent study by Akca et al,¹³⁸ the effects of both CHX and propolis were found to be equal against biofilms of *Streptococci*, and the authors also found propolis to be more effective in inhibiting Gram-positive than Gram-negative bacteria. The potency of propolis against Gram-positive bacteria has also been reported by Nieva Moreno et al¹³⁹ and Kujumgiev et al.¹⁴⁰

Effects on Restorative Treatment

Several studies have evaluated the effects of propolis extract disinfectants on restorative treatment.^{55,111,112,141,142} Arslan et al⁵⁵ found that 30% propolis extract did not differ significantly from other disinfectants when the etch-and-rinse adhesive system (Adper Single Bond 2) was used. However, in self-etch adhesive system groups (All Bond SE), the propolis group exhibited more microleakage than the control group on dentin margins. However, in a recent study, Kalyoncuoğlu et al¹⁴¹ reported a favorable effect of 20% propolis extract as a root canal irrigant on dentin μ SBS in the presence of a self-etch adhesive system (Clearfil SE Bond).

The action of propolis extracts as MMP inhibitors has been recently investigated by Perote et al¹⁴² In their study, they applied different propolis extracts (10% ethanol, aqueous extract, and 70% ethanol extract) for 60 seconds after acid-etching and before the application of Adper Single Bond 2. The results showed no adverse effects of these extract solutions on the μ TBS; however, they also found that these solutions did not prevent the loss of bonding interface after 6-month aging.

Salvadora persica

Salvadora persica (the toothbrush tree) is a member of the Salvadoraceae family. It features a crooked trunk, and its twigs have been used for many years as a natural toothbrush (miswak), which plays a role in the promotion of oral hygiene.¹⁴³

Antimicrobial Effectiveness

Many studies have revealed that *S. persica* extracts possess antibacterial effects against cariogenic pathogens.¹⁴⁴⁻¹⁴⁷ Additionally, few surveys have reported low caries levels among miswak users compared with nonusers.¹⁴⁸⁻¹⁵⁰

Furthermore, *S. persica* extracts have been reported to remove the smear layer upon application to dentin.^{144,151,152}

Effects on the Pulp

The effects of *S. persica* extracts on human gingival fibroblasts have been investigated by Balto et al,¹⁵³ who found that 0.5 to 1.0 mg/mL ethanol extract and 0.5 mg/mL hexane extract did not show any cytotoxic effect on the

dental pulp; however, 1 mg/mL hexane extract has been reported to cause cytotoxicity. They found maximum cytotoxicity when ethyl acetate extract at 1 mg/mL was used. Based on these findings, the authors recommended further research on the effects of *S. persica* on pulpal cells.

According to Tabatabaei et al,¹⁵⁴ high concentrations of ethanol extract (1.43–5.75 mg/mL) have been reported to cause cytotoxic effects on human pulpal cells.

Effects on Restorative Treatment

One study, by Salama et al,⁵ has investigated the effects of miswak extracts on the bond strength of composite restorations. The authors compared, *in vitro*, the effect of dentin pretreatment with 1 mg/mL ethanol extract of *S. persica* on the microleakage of class V resin-based composite restorations in primary teeth with that of 0.2% CHX and 1.3% NaOCl disinfectants and found no statistically significant difference in microleakage among the tested solutions. In their study, the Adper Single Bond 2 (etch-and-rinse) adhesive system was used.

Morinda citrifolia

Morinda citrifolia (noni) is a tropical tree that has been reported to have a broad range of therapeutic and nutritional values and, therefore, is considered to be an important adjunct in traditional medicine.¹⁵⁵

Antimicrobial Effectiveness

The antibacterial effects of *M. citrifolia* juice (MCJ) against oral pathogens have been well documented.^{136,156-158} Kandaswamy et al¹³⁶ found MCJ antimicrobial activity to be equal to that of propolis but lower than that of the 2% CHX.

The effectiveness of 6% MCJ as a smear layer remover has also been proven in the literature.^{156,157,159}

Effects on Restorative Treatment

Dikmen et al¹⁶⁰ compared the effects of the addition of MCJ to NaOCl with that of other antioxidant solutions on the μ TBS of adhesive systems. They compared the use of distilled water, 5.25% NaOCl, NaOCl with distilled water, NaOCl with proanthocyanidin (PA), and NaOCl with MCJ, in a self-etching adhesive system (Single Bond Universal Adhesive). The authors reported that the "NaOCl with MCJ" group exhibited significantly higher μ TBS than the group without MCJ. They concluded that the addition of MCJ to NaOCl as a dentin pretreatment solution significantly improved bond strength.

CONCLUSION

Within the limitations of this review, the following can be concluded:

- The antibacterial effectiveness of different disinfectants has been well documented; however, the antimicrobial potency of some agents varies according to the percentage and time of application.
- Selection of cavity disinfectant is guarded by the type of adhesive system.
- Although the effect of disinfectant pretreatment on the tooth/restoration bond is believed to be material-based, the literature strongly supports the use of 2% CHX solutions when etch-and-rinse adhesive systems are used.
- When a self-etch adhesive system is used, there is good evidence for the use of 1% CHX gel as a cavity disinfectant. However, more research is needed to evaluate its biocompatibility with different systems.
- Modern disinfection modalities like laser and O₃ devices exhibit promising results in terms of biocompatibility with adhesive systems and restorative materials. However, these devices should be manipulated with care to avoid any side effects.
- There is insufficient clinical and laboratory evidence for the use of naturally based disinfectants; therefore, more studies to evaluate these products are warranted.

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