The Antibacterial Efficacy of Photo-Activated Disinfection, Chlorhexidine and Sodium Hypochlorite in Infected Root Canals: An in Vitro Study

Mohammad Samiei, Shahriar Shahi, Amir Ardalan Abdollahi*, Mahsa Eskandarinezhad, Ramin Negahdari, Zahra Pakseresht

*Department of Endodontics, Dental and Periodontal Research Center, Dental School, Tabriz University of Medical Sciences, Tabriz, Iran; b Department of Prosthodontics, Dental and Periodontal Research Center, Dental School, Tabriz University of Medical Sciences, Tabriz, Iran; c Private Practice, Urmia, Iran

ARTICLE INFO

Article Type: Original Article
Received: 07 Dec 2015
Revised: 04 Apr 2016
Accepted: 22 Apr 2016
Doi: 10.7508/iej.2016.03.006

*Corresponding author: Amir Ardalan Abdollahi, Student's Research Committee, Dental School, Tabriz University of Medical Science, Tabriz, Iran.
Tel: +98-914 4091317
E-mail: ardalan_2000a@yahoo.com

INTRODUCTION

The main aim of root canal treatment is to achieve a root canal system free from damaging irritants; because the residual microorganisms in necrotic pulps might cause persistent inflammation in periradicular tissues and treatment failure [1, 2]. Many microorganisms such as Enterococcus faecalis (E. faecalis) play important roles in the etiology of persistent periradicular lesions after root canal treatment [1, 3]. E. faecalis has been found in 24-77% of the cases of teeth with treatment resistant periradicular lesions [3, 4].

It is well established that complete debridement and thorough elimination of bacteria from the root canal is very difficult, if not impossible, because of the complexity of the root canal system [5-7]. Thus in addition to mechanical preparation, it is highly recommended to use disinfecting irrigants, due to their ability to dissolve organic and inorganic tissues, lubricate the root canal and eliminate bacteria and their by-products [8, 9].

Sodium hypochlorite (NaOCl) is an irrigation solution predominantly used in endodontic treatment in concentrations ranging from 0.5 to 5.25%, although alternative solutions have already been studied [10]. The use of
chlorhexidine gluconate (CHX) as an irritant during root canal therapy has been suggested based on its antibacterial effect, substantivity and milder malodor and cytotoxicity in comparison with NaOCl [11]. In spite of the disinfecting effect of CHX, it is unable to eliminate necrotic tissues from the root canals and remove the smear layer. In addition, it may cause toxicity, induce an inflammatory response and in some cases result in allergic reactions [12, 13].

Researchers have studied alternative techniques due to the presence of a smear layer that reduces the efficacy of disinfectants [14] and the complexity of the root canal system which makes it impossible to completely eliminate debris and achieve a sterile root canal by the use of irrigating solutions [15].

Photo-activated disinfection (PAD) (aka photodynamic therapy, PDT) is a novel method of disinfection for use in both caries removal and root canal treatment [16]. The laser light is thought to be able to reach areas that are inaccessible with conventional techniques [17]. High-power lasers such as Nd: YAG and Er: YAG may induce periradicular necrosis and charring of dentinal tubules through generation of heat. The new method for eradication of microorganisms from the root canal is the application of low-power lasers [18, 19]. PAD is an antimicrobial strategy in which low-energy laser is used to activate a nontoxic photosensitizer like toluidine chloride, and the singlet oxygen released from these dyes damages the membranes and DNA of microorganisms [19, 20]. It has been recommended for use in root canal treatment as an alternative or supplement to other disinfection methods [21-23] since it produces heat that is not clinically significant (less than 0.5°C) [19]. In addition, photosensitizers have a high degree of selectivity to kill microorganisms without affecting the host cell viability. Application of PAD has shown to be successful in the eradication of multi-drug-resistant microorganisms [24]. According to a study by Fonseca et al. [25], this method is very effective in eliminating E. faecalis from the root canal system.

The aim of this in vitro study was to compare the antibacterial activities of photo-activated low-level lasers and two conventional irrigation methods naming 2% CHX and 2.5% NaOCl against E. faecalis in infected root canals.

Materials and Methods

Approval of this project was obtained from the Research and Ethics Committee of Tabriz University of Medical Sciences, Tabriz, Iran (Grant No.:1357) Sixty extracted human maxillary central incisors were selected for this study. All the teeth were extracted because of periodontal disease, and had completely developed single roots without caries, previous endodontic treatment and anomalies. Following extraction, each tooth was stored in 3% chloramine-T solution at 4°C. The external root surface was cleaned with ultrasonic tips to remove the remnants of periodontal soft tissues. Teeth were selected with apical foramina approximately matching the size of a #25 K-Flexofile (Dentsply, Maillefer, Ballaigues, Switzerland). Also teeth with cracks and calcifications in radiographic views were excluded. The teeth were decoronated to a standard 12-mm root segment. The working length was determined with #25 K-Flexofile (Dentsply, Maillefer, Ballaigues, Switzerland), 1 mm short of the apical foramen. All the root canals were instrumented in a crown-down manner. The coronal two-thirds of the canals were prepared with #4 and 3 Gates-Glidden drills (Dentsply, Maillefer, Ballaigues, Switzerland), followed by the use of 40/0.10, 35/0.08 and 30/0.06 RaCe rotary instruments (FKG Dentaire, La Chaux-de-Fonds, Switzerland). The size of master apical file was established at #40. Each canal was irrigated with 1 mL of normal saline solution throughout the instrumentation sequence. The smear layer was removed using 1 mL of 17% ethylenediaminetetraacetic acid (EDTA) (Pulpdent Corp., Watertown, MA, USA) for 3 min, followed by a final rinse with 1 mL of 5.25% NaOCl (Taj Corp, Tehran, IRI) for 3 min. The teeth were sterilized by autoclaving at 121°C and 15 psi pressure for 20 min. To confirm sterilization, the teeth were incubated in brain-heart infusion (BHI) broth (Merck, Darmstadt, Germany) at 37°C for 24 h.

A purified culture of E. faecalis (ATCC 29212, Reference Laboratories of Iran Research Center, Tehran, Iran) was provided. Then bacteria were incubated in BHI broth at 37°C for 24 h under aerobic conditions. The grown colonies were used to inoculate blood agar broth (Merck, Darmstadt, Germany) and incubated at 37°C for 24 h. A spectrophotometer was used to determine the E. faecalis culture in blood agar broth as 2.5×10⁶ colony forming units in mL (CFU/mL). Then 200 µL of the bacterial culture were transferred into the canal lumen using a micropipette. After 48 h, all the root canals were dried with sterile paper points [26].

Experimental groups

The 60 samples were randomly divided into three experimental groups and one control group (n=15). The experimental groups were subjected to each of the following experimental treatment protocols: group 1, PAD; after placement of 1.2 mg/mL of toluidine chloride for 30 sec, the root canals were irradiated with a diode laser beam (B&W TEK Inc., Newark, DE, USA) with a power output of 100 mW/cm² and 635 nm of wavelength for 120 sec, using a flexible Endo tip (Denfotex Technologies Ltd., Inverkeithing, Fife, UK) measuring 15 mm in length and 300 µm in diameter (4), group 2, CHX; the root canals were irrigated with 5 mL of 2% CHX (Perio-Kin, Laboratories Kin, Barcelona, Spain) for 60 sec, and group 3, NaOCl; the root canals were irrigated with 5 mL of 2.5% NaOCl for 60 sec. In the control group no other procedures were carried out. Then all the teeth (control and experimental groups) were placed in a freezer at -25°C to prevent E. faecalis from being killed by the heat produced during drilling for sampling procedures [26, 27].
The efficacy of disinfection was evaluated by collecting 10 µg of dentin shavings from each canal by drilling the walls of canals using #5 and 6 Gates-Glidden drills. The drills were inserted into the canals until they reached 1 mm short of the working length. The samples were transferred into tubes containing 2 mL of normal saline and vortexed for 20 sec. Serial dilutions of 10 times were provided up to $10^{-7}$. Then 100 µL of each solution was added to three plates of agar blood culture and incubated at 37°C for 48 h. All the procedures were carried out in a laminar flow chamber with sterile instruments and by obtaining aseptic conditions. A classic colony counting technique was used for counting the *E. faecalis* bacteria in blood agar plates. The average CFU values of plates related to concentrations of $10^{-2}$, $10^{-3}$ and $10^{-4}$ were counted. For the clarity and deletion of less significant measurements, the bacterial growth in agar plates related to the concentrations of $10^{-2}$, $10^{-4}$ and $10^{-7}$ was not considered.

### Statistical analysis

Statistical analysis was performed using SPSS software (SPSS version 20.0, SPSS, Chicago, IL, USA). The Kolmogorov-Smirnov test showed that the data of the study was non-parametric. Therefore the Kruskal-Wallis test was used to compare the CFU values of the bacteria and post-hoc Bonferroni test was used for pairwise comparisons. The level of significance was set at 0.05.

### Results

Table 1 presents the bacterial counts in four groups. The results of Kruskal-Wallis test showed statistically significant differences between the groups ($P<0.05$). The inhibition of bacterial growth in all the experimental groups was significantly superior to the control group. The results of pairwise analysis using post hoc Bonferroni test were presented in Table 2.

The effect of PAD and 2% CHX solution were significantly different at $10^{-2}$ concentration ($P<0.05$). The effect of NaOCl at all concentrations was significantly better than PAD ($P<0.05$).

The effect of NaOCl at mean dilutions was superior to that of 2% CHX ($P=0.007$). In comparison to the control group, the residual bacteria in PAD, NaOCl and CHX groups was 4.56, 2.93 and 0.82%, respectively.

### Discussion

In this study, we compared the antibacterial effects of photo-activated low-level lasers, 2% CHX and 2.5% NaOCl on *E. faecalis* in infected root canals. The results of this study showed that all the three antibacterial agents significantly decreased CFU counts of *E. faecalis* compared to the control group. However, there was no significant difference between PAD and 2% CHX solution; also the efficacy of 2.5% NaOCl was superior to the other antibacterial agents.

*E. faecalis* is able to produce extra- and intra-radicular biofilms which are very difficult to eliminate from the infected root canals [28, 29]. On the other hand, many of the common antibacterial agents may have no effect on the deep layers of dentin [30]. Various types of lasers have been used in dentistry, particularly in endodontics, exhibiting some efficacy in eradication of *E. faecalis* [31-35]. The advantage of laser in this respect has been stated as having the ability to control and set sufficient intervals should be applied between laser applications until the surrounding tissues are cooled. However, the risk of temperature increase for hard and hard and soft tissues in PDT using low-power lasers is minimal and water coolant spray is not required [38, 40]. The other advantage of

### Table 1. Mean (SEM) [standard error of mean IQR (Interquartile range)] of bacterial counts at different dilutions between the test materials

| Test groups (Dilutions) | 2% Chlorhexidine | Photo-activated laser | 5% NaOCl | Control |
|------------------------|------------------|----------------------|----------|---------|
| $10^{-2}$              | 1.53 (0.27)      | 2.33 (0.19)          | 0.33 (0.19) | 46.5 (1.35) |
| $10^{-3}$              | 1.13 (0.31)      | 1.8 (0.19)           | 0.47 (0.27) | 38.33 (1.18) |
| $10^{-4}$              | 0.73 (0.23)      | 1.2 (0.21)           | 0.2 (0.2)  | 32.53 (1.0)  |
| Mean                   | 1.13 (0.25)      | 1.82 (0.15)          | 0.33 (0.19) | 38.82 (0.88) |

### Table 2. Pairwise comparison of groups in terms of the bacterial growth in different dilutions. Reported data are $P$-values

| Groups                  | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | Mean dilution |
|------------------------|-----------|-----------|-----------|---------------|
| Laser-Chlorhexidine    | <0.001    | <0.001    | <0.001    | <0.001        |
| NaOCl-Chlorhexidine    | <0.001    | <0.001    | <0.001    | <0.001        |
| Laser-NaOCl            | <0.001    | <0.001    | <0.001    | <0.001        |
| Chlorhexidine-Control  | <0.001    | <0.001    | <0.001    | <0.001        |
| Laser-Control          | <0.001    | <0.001    | <0.001    | <0.001        |
| NaOCl-Control          | <0.001    | <0.001    | <0.001    | <0.001        |
application of PDT in canals with curvature and structures like delta is that the thin and elastic tip of the light source could penetrate up to the apical areas. According to research, use of PDT alone and along with other disinfection methods is effective in the eradication of bacteria in these areas up to 95% and 98%, respectively [41]. Photo-sensitive materials can penetrate into the dentinal tubules and may be effective in eliminating bacterial colonies [40].

In a systematic review, Arneiro et al. [34] concluded that PDT had better antimicrobial effects when used as an adjunct to NaOCl during endodontic treatment. In accordance with our study, Vaziri et al. [42] reported that PDT was less effective than 2.5% NaOCl in reducing E. faecalis counts and also combination of PDT and 2.5% NaOCl exhibited maximum efficacy. Furthermore, Meire et al. [43] reported that 2.5% NaOCl was very effective in elimination of E. faecalis biofilms from dentin disks and PDT resulted in an insignificant reduction in E. faecalis counts. However, Yildirim et al. [44] and Xhevdet et al. [32] reported that PDT was as effective as conventional 5% and 2.5% NaOCl irrigation regarding efficacy against E. faecalis, respectively.

Rios et al. [22] demonstrated that a combination of PDT and irrigation with NaOCl was an efficient technique in decreasing bacterial load of the root canal system since the survival rate of E. faecalis in this group was 0.1%, whereas in root canals treated with PDT alone the survival rate was 2.9%. Recently, Komine and Tsujimoto [45] showed that 0.01–0.001% methylene blue was effective in the application of PDT in root canals contaminated with E. faecalis.

In this study we found that the effect of NaOCl at mean dilutions was superior to that of 2% CHX. In contrast to this finding, Ahangari et al. [46] concluded that there was no difference between these solutions in terms of their antimicrobial effect on E. faecalis, which can be attributed to different methods.

The results of the present study showed that the load of remaining bacteria in the group receiving photodynamic therapy decreased significantly compared to the control group. Although this reduction was lower than the conventional irrigation solutions to some extent, it demonstrated the significant role of this technique in eradication of one of the most resistant microorganisms from the root canal system. The best results of antibacterial efficacy were obtained with the use of NaOCl. However, to determine the most effective endodontic disinfection protocol, the efficacy of the techniques should be further determined with various bacterial species in root canals. Finally, it is necessary to evaluate the real contribution of PAD method to conventional chemomechanical preparation in vivo.

**Conclusion**

Based on the results of this in vitro study, photodynamic therapy was as effective in reducing Enterococcus faecalis counts as chlorhexidine, but this effect was less than that of 2.5% sodium hypochlorite irrigation solution.

**Acknowledgment**

The authors wish to thank the Vice Chancellor of Research, Tabriz University of Medical Sciences for financial support.

Conflict of Interest: ‘None declared’.

**References**

1. Love RM. Enterococcus faecalis--a mechanism for its role in endodontic failure. Int Endod J. 2001;34(5):399–405.
2. Molander A, Reit C, Dahlen G, Kvist T. Microbiological status of root-filled teeth with apical periodontitis. Int Endod J. 1998;31(1):1–7.
3. Stuart CH, Schwartz SA, Beeson TJ, Owatz CB. Enterococcus faecalis: its role in root canal treatment failure and current concepts in retreatment. J Endod. 2006;32(2):93–8.
4. Giardino L, Estrela C, Generali L, Mohammadi Z, Asgary S. The in vitro Effect of Irrigants with Low Surface Tension on Enterococcus faecalis. Iran Endod J. 2015;10(3):174–8.
5. Bonsor SJ, Nichol R, Reid TM, Pearson GJ. Microbiological evaluation of photo-activated disinfection in endodontics (an in vivo study). Br Dent J. 2006;200(6):337–41, discussion 29.
6. Bystrom A, Sundqvist G. Bacteriologic evaluation of the effect of 0.5 percent sodium hypochlorite in endodontic therapy. Oral Surg Oral Med Oral Pathol. 1983;55(3):307–12.
7. Sjogren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J. 1999;30(5):297–306.
8. Safavi KE, Nichols FC. Alteration of biological properties of bacterial lipopolysaccharide by calcium hydroxide treatment. J Endod. 1994;20(3):127–9.
9. Jeansonne MJ, White RR. A comparison of 2.0% chlorhexidine gluconate and 5.25% sodium hypochlorite as antimicrobial endodontic irrigants. J Endod. 1994;20(6):276–8.
10. Hand RE, Smith ML, Harrison JW. Analysis of the effect of dilution on the necrotic tissue dissolution property of sodium hypochlorite. J Endod. 1978;4(2):60–4.
11. Dametto FR, Ferraz CC, Gomes BP, Zaia AA, Teixeira FB, de Souza-Filho FJ. In vitro assessment of the immediate and prolonged antimicrobial action of chlorhexidine gel as an endodontic irrigant against Enterococcus faecalis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005;99(6):768–72.
12. Mohammadi Z, Abbott PV. The properties and applications of chlorhexidine in endodontics. Int Endod J. 2009;42(4):288–302.
13. Ryan S. Chlorhexidine as a canal irrigant: a review. Compend Contin Educ Dent. 2010;31(5):338–42; quiz 43, 64.
14. Bystrom A, Sundqvist G. Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy. Scand J Dent Res. 1981;89(4):321–8.
15. Orstavik D, Haapasalo M. Disinfection by endodontic irrigants and dressings of experimentally infected dentinal tubules. Endod Dent Traumatol. 1990;6(4):142-9.

16. Williams JA, Pearson GJ, Colles MJ, Wilson M. The effect of variable energy input from a novel light source on the photoactivated bactericidal action of toluidine blue O on Streptococcus Mutans. Caries Res. 2003;37(3):190-3.

17. Odor TM, Watson TF, Pitt Ford TR, McDonald F. Pattern of transmission of laser light in teeth. Int Endod J. 1996;29(4):228-34.

18. Bahcall J, Howard P, Miserendino L, Walia H. Preliminary investigation of the histological effects of laser endodontic treatment on the periradicular tissues in dogs. J Endod. 1992;18(2):47-51.

19. Lee MT, Bird PS, Walsh LJ. Photo-activated disinfection of the root canal: a new role for lasers in endodontics. Aust Endod J. 2004;30(3):93-8.

20. Sun G, Tuner J. Low-level laser therapy in dentistry. Dent Clin North Am. 2004;48(4):1061-76, viii.

21. Bergmans L, Moisidou P, Huybrechts B, Van Meerbeek B, Quirynen M, Lambrechts P. Effect of photo-activated disinfection on endodontic pathogens ex vivo. Int Endod J. 2008;41(3):227-39.

22. Rios A, He J, Glickman GN, Spears R, Schneiderman ED, Honeyman AL. Evaluation of photodynamic therapy using a light-emitting diode lamp against Enterococcus faecalis in extracted human teeth. J Endod. 2011;37(6):856-9.

23. Silva TC, Pereira AF, Buzalaf MA, Machado MA, Crielaard W, Deng DM. Diverse outcomes of Photodynamic Antimicrobial Chemotherapy on five Enterococcus faecalis strains. Photodiagnosis Photodyn Ther. 2014;11(3):283-9.

24. Garcez AS, Nunez SC, Hamblin MR, Suzuki H, Ribeiro MS. Photodynamic therapy associated with conventional endodontic treatment in patients with antibiotic-resistant microflora: a preliminary report. J Endod. 2010;36(9):1463-6.

25. Fonseca MB, Junior PO, Pallota RC, Filho HF, Denardin OV, Rapoport A, Dedivitis RA, Veronese JF, Genovese WJ, Ricardo AL. Photodynamic therapy for root canals infected with Enterococcus faecalis. Photomed Laser Surg. 2008;26(3):209-13.

26. Yavari RH, Rahimi S, Shahi S, Lotfi M, Barbaghi MH, Fatemi A, Abdolrahimin M. Effect of Er, Cr: YSGG laser irradiation on Enterococcus faecalis in infected root canals. Photomed Laser Surg. 2010;28 Suppl 1:S91-6.

27. Bago I, Plecko V, Gabriel Panduric D, Schauerl Z, Baraba A, Anic I. Antimicrobial efficacy of a high-power diode laser, photo-activated disinfection, conventional and sonic activated irrigation during root canal treatment. Int Endod J. 2013;46(4):339-47.

28. Berutti E, Manini R, Angeretti A. Penetration ability of different irrigants into dentinal tubules. J Endod. 1997;23(12):725-7.

29. Samiei M, Aghazadeh M, Lotfi M, Shakoori S, Aghazadeh Z, Vahid Pakdel SM. Antimicrobial Efficacy of Mineral Trioxide Aggregate with and without Silver Nanoparticles. Iran Endod J. 2013;8(4):166-70.

30. Noiri Y, Ebara A, Kawahara T, Takemura N, Ebisu S. Participation of bacterial biofilms in refractory and chronic periapical periodontitis. J Endod. 2002;28(10):679-83.

31. Souza LC, Brito PR, de Oliveira JC, Alves FR, Moreira EJ, Sampaio-Filho HR, Ricas IN, Siqueira JF, Jr. Photodynamic therapy with two different photosensitizers as a supplement to instrumentation/irrigation procedures in promoting intracanal reduction of Enterococcus faecalis. J Endod. 2010;36(2):292-6.

32. Xhevdet A, Stubljar D, Krizmari N, Jukic T, Skvarc M, Veranic P, Ihan A. The disinfecting efficacy of root canals with laser photodynamic therapy. J Lasers Med Sci. 2014;5(1):19-26.

33. Gordon W, Atabakhsh VA, Meza F, Doms A, Nissan R, Rizoiu I, Stevens RH. The antimicrobial efficacy of the erbium, chromium:yttrium-scandium-gallium-garnet laser with radial emitting tips on root canal dentin walls infected with Enterococcus faecalis. J Am Dent Assoc. 2007;138(7):992-1002.

34. Arneiro RA, Nakano RD, Antunes LA, Ferreira GB, Fontes K, Antunes LS. Efficacy of antimicrobial photodynamic therapy for root canals infected with Enterococcus faecalis. J Oral Sci. 2014;56(4):277-85.

35. Soukos NS, Chen PS, Morris JT, Ruggiero K, Abernethy AD, Som S, Foschi F, Doucette S, Bammann LL, Fontana CR, Doukas AG, Stashenko PP. Photodynamic therapy for endodontic disinfection. J Endod. 2006;32(10):979-84.

36. Odor TM, Chandler NP, Watson TF, Ford TR, McDonald F. Laser light transmission in teeth: a study of the patterns in different species. Int Endod J. 1999;32(4):296-302.

37. Matsumoto K, Hosssin M, Hosssin MM, Kawano H, Kimura Y. Clinical assessment of Er,Cr:YSGG laser application for cavity preparation. J Clin Laser Med Surg. 2002;20(1):17-21.

38. Dickers B, Lamard L, Peremans A, Geerts S, Lamy M, Limme M, Rompen E, De Moor RJ, Mahler P, Rocca JP, Nammour S. Temperature rise during photo-activated disinfection of root canals. Lasers Med Sci. 2009;24(1):81-5.

39. Sohrabi K, Sooratgar A, Zolfagharnasab K, Karzafiard MJ, Afkhami F. Antibacterial Activity of Diode Laser and Sodium Hypochlorite in Enterococcus Faecalis-Contaminated Root Canals. Iran Endod J. 2016;11(1):8-12.

40. Garcez AS, Nunez SC, Hamblin MR, Ribeiro MS. Antimicrobial effects of photodynamic therapy on patients with necrotic pulps and periapical lesion. J Endod. 2008;34(2):138-42.

41. Williams JA, Pearson GJ, Colles MJ. Antibacterial action of photoactivated disinfection (PAD) used on endodontic bacteria in planktonic suspension and in artificial and human root canals. J Dent. 2006;34(6):363-71.

42. Vaziri S, Kargarlou A, Shahbazi R, Nazari Nasab A, Naseri M. Comparison of the bactericidal efficacy of photodynamic therapy, 2.5% sodium hypochlorite, and 2% chlorhexidine against Enterococcus faecalis in root canals; an in vitro study. Dent Res J (Isfahan). 2012;9(5):613-8.

43. Meire MA, Coenye T, Nelis HJ, De Moor RJ. Evaluation of Nd:YAG and Er:YAG irradiation, antibacterial photodynamic therapy and sodium hypochlorite treatment on Enterococcus faecalis biofilms. Int Endod J. 2012;45(5):482-91.

44. Yildirim C, Karaarslan ES, Ozsevik S, Zer Y, Sari T, Usunmez A. Antimicrobial efficiency of photodynamic therapy with different irradiation durations. Eur J Dent. 2013;7(4):469-73.

45. Komine C, Tsujimoto Y. A small amount of singlet oxygen generated via excited methylene blue by photodynamic therapy induces the sterilization of Enterococcus faecalis. J Endod. 2013;39(3):411-4.

46. Ahangari Z, Samiei M, Yolmeh MA, Eslami G. Antimicrobial activity of three root canal irrigants on enterococcus faecalis: an in vitro study. Iran Endod J. 2008;3(2):33-7.

Please cite this paper as: Samiei M, Shahi S, Abdollahi AA, Eskandarinezhad M, Negahdari R, Pakseresht Z. The Antibacterial Efficacy of Photo-Activated Disinfection, Chlorhexidine and Sodium Hypochlorite in Infected Root Canals: An in Vitro Study. Iran Endod J. 2016;11(3):179-83. Doi: 10.7590/iej.2016.03.006.