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Effects of Addition of Quaternary Ammonium Antimicrobial Compounds into Root Canal Sealers

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Abstract

Objective The aim of this study is to determine the effect of the addition of benzalkonium chloride and cetylpyridinium chloride in three commercial root canal sealers.
Materials and Methods Three different root canal sealers were used: EndoRez, N2, and Apexit Plus. The samples were prepared by mixing the components according to the manufacturers' guidelines and adding 2% in weight of the antimicrobials to the newly mixed cement. The paste was placed in molds and stored in an incubator (37°C, 24 h). The samples were then stored in 5-mL distilled water. Samples without antimicrobials served as a control. All samples were tested at 3 time intervals: 1 day, 1 week, and 1 month following their storage in distilled water. The impact of the antimicrobials on the solubility of the sealers, the release of chloride ions (Cl^-), and the pH value were examined.
Statistical Analysis Used Analysis was done using one-way analysis of variance and the post hoc Tukey's honestly significant difference test.
Results Chloride ions are present in storage media with EndoRez, N2, and Apexit Plus samples (without antimicrobials) following all tested storage intervals. The addition of the antimicrobials increased the release of chloride ions. Endodontic cements without addition of antimicrobials show an increase in weight after 1 month. The highest pH value is measured in Apexit Plus samples. The solutions in which N2 samples (with and without addition of antimicrobials) were stored did not have a significant change in their pH, while in the EndoRez solutions, a significant decrease in the pH value after the first week was measured.
Conclusions The addition of antimicrobials might lead to improved characteristics of the root canal sealers.

Keywords
► benzalkonium chloride
► chloride
► pH
► root canal sealers
► solubility

Introduction

Infected root canals may contain many different microbial strains, mostly Gram-negative anaerobes.[1–3] The most frequent species of bacteria detected in the root canal are *Enterococcus faecalis, Streptococcus anginosus, Bacteroides gracilis,* and *Fusobacterium nucleatum*.[4]

The root canal sealers come into direct contact with the remaining microorganisms in the dentinal tubules and the inaccessible parts of the root canal system.[5,6] Therefore, the antimicrobial characteristics of these agents are desirable.[7]

One of the principal requirements of a sealer is that it should be bacteriostatic or at least not encourage bacterial growth. The sealers play an important role in sealing the root canal system by the entombing the remaining microorganisms and filling the inaccessible areas within the prepared canals. Therefore, a sealer with antimicrobial activity is highly beneficial in the elimination of the remaining

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microorganisms present in the root canal after chemomechanical debridement and preventing the reinfection. Some root canal sealers are known to be inherently antimicrobial, a feature which can help to control the microorganism population.[8,9] However, these antimicrobial properties are generally short term and rarely extend beyond 1 week,[9] which is insufficient to provide protection against persistent bacterial infection in a clinical situation.[10]

Different antimicrobial agents (such as chlorhexidine, cetylpyridinium chloride [CPC], and benzalkonium chloride [BC][11–13]) have been used in order to improve the antimicrobial characteristics of various dental materials.

CPC is a quaternary ammonium compound which has a strong surface activity, and its effect on the reduction of plaque and calculus has been demonstrated previously.[14] It has been widely used as an active component of oral antiseptics, and it is known to have broad-spectrum antimicrobial properties, with a strong bactericidal effect on Gram-positive pathogens and yeasts in particular.[13] The mechanism of action of CPC is that when it is in contact with the bacterial cell membrane, inhibition of the cellular functions and cell death (bacteriolysis) occurs.[14]

BC is recognized by the United States Pharmacopoeia as an auxiliary antimicrobial agent recognizes.[14] It is the major antimicrobial component in numerous toothpastes and mouthrinses as well as in dental restoratives,[15] and it is active against bacteria as well as certain viruses, fungi, and protozoa.[16]

The purpose of the study was to determine whether the addition of CPC and BC to root canal sealers has an impact on the dissolution of tested materials, the release of chloride ions (Cl^-), and the pH value.

Materials and Methods

Three commercial materials for root canal sealing were used (►**Table 1**). Three sets of six samples were prepared from each material: (a) without addition of an antimicrobial agent, (b) addition of 2% by weight of CPC, and (c) addition of 2% by weight of BC.

The samples were prepared by mixing the components according to the manufacturers' instructions, following the method as described by Dimkov et al.[16] The samples with the antimicrobial agents were prepared by mixing 2% weight of the antimicrobial substances to the newly mixed cement. The resulting paste was then placed in metal molds with dimensions 6 mm (height) and 4 mm (diameter). Sample-filled molds were placed in an incubator with constant temperature of 37°C for a period of 24 h. Then, each sample was stored in 5-mL distilled water. All samples were tested at 3 time intervals: 1 day, 1 week, and 1 month following their storage in distilled water.

Table 1 Materials used in the study

Materials	Manufacturer
EndoRez	Ultradent Products, Inc. (South Jordan, UT, United States)
N2	Hager and Werken GmbH and Co. KG
Apexit Plus	Ivoclar Vivadent AG, Schaan, Liechtenstein

Examination of the pH Value of the Storage Solution

The pH value is a measure of activity of hydrogen ions (H^+) in the solution that determines whether a given solution is acid or base. The pH value is measured based on the activity of hydrogen ions within the solution.[8] The formula to calculate pH is as follows:

$$pH = -\log 10[H^+]$$

The pH meter is an electrical instrument used to measure the pH value of liquids. A typical pH meter is made of a special glass electrode, connected with an electronic measuring device. The test was performed with the use of a digital pH meter (Whatman PHA2000).

At the very beginning, the instrument was calibrated with standard solutions with predetermined pH value (pH = 7.0 and pH = 4.0), and subsequently, the pH of the storage solutions was measured after the storage time intervals.

Examination of the Solubility of the Material

The solubility of the material was determined by analytical laboratory balance (Sartorius, A&D GR-202 Semi-Micro-Balance) with an accuracy of 0.0001 g. The test was conducted by measuring the mass of samples before and after expiration of the predetermined time intervals.

Release of Cl^-

The examination of the amount of free Cl^- in the tested solutions was performed by an ion-selective electrode, specific for the chloride (ORION 4-Star pH-ISE Benchtop instrument, Thermo Electron Corporation). The electrode is designed to respond to chloride ions in aqueous solutions.[7]

The test starts by an instrument calibration with NaCl solutions with predetermined concentrations (0.1 ppm, 1.0 ppm, 10.0 ppm, 100.0 ppm, and 1000.0 ppm NaCl); then, a calibration curve is prepared and followed by measurement of the released Cl^- of the storage solution.

Statistical Analysis

The statistical analysis was performed by one-way analysis of variance and the post hoc Tukey's honestly significant difference test, in STATISTICA 7.1 (TIBCO Software Inc., Palo Alto, CA) and SPSS 17.0 (SPSS, IBM, NY, United States) platform for Windows. The level of significance was set at $P < 0.05$.

Results

The release of Cl^- from the materials is an indicator for the increase of their antimicrobial activity.

The results obtained in regard to the release of Cl^- (►**Table 2**) from Apexit, N2, and EndoRez (without the addition of antimicrobials) indicate the presence of Cl^- in the solutions following the predetermined storage intervals. Apexit Plus shows highest release level after day 1, although all the tested materials with the addition of an antimicrobial agent show higher level of released Cl^- compared to the Apexit samples without incorporation of antimicrobials. The previous findings are an indicator that the addition of antimicrobial agents leads to an increased release of Cl^-.

Table 2 Average values and standard deviations of measures for the release of Cl^- ions in the materials: Apexit Plus, N2, and EndoRez (without and with addition of benzalkonium chloride and cetylpyridinium chloride)

Chloride ions (ppm)	Materials used	Mean (SD)			*p*-Value
		1 day	1 week	1 month	
Cl^- ions (ppm)	Apexit	0.07 (0.03)[a,b]	0.02 (0.00)[a]	0.02 (0.00)[b]	0.00
	Apexit + BC	0.14 (0.01)[a,b]	0.08 (0.02)[a,c]	0.03 (0.010)[b,c]	0.00
	Apexit + CPC	0.96 (0.02)[a,b]	0.01 (0.00)[a,c]	0.06 (0.03)[b,c]	0.00
Cl^- ions (ppm)	N2	0.25 (0.03)[a,b]	0.15 (0.02)[a]	0.12 (0.02)[c]	0.00
	N2 + BC	0.34 (0.01)[b]	0.32 (0.04)	0.27 (0.02)[b]	0.01
	N2 + CPC	0.33 (0.04)[b]	0.29 (0.01)	0.26 (0.03)[b]	0.00
Cl^- ions (ppm)	EndoRez	0.07 (0.01)[a,b]	0.02 (0.02)[a]	0.02 (0.01)[b]	0.00
	EndoRez + BC	0.15 (0.03)[a,b]	0.02 (0.00)[a]	0.02 (0.00)[b]	0.00
	EndoRez + CPC	0.43 (0.09)[a,b]	0.02 (0.00)[a]	0.02 (0.00)[b]	0.00

Abbreviations: BC, benzalkonium chloride; CPC, cetylpyridinium chloride; SD, standard deviation.
The difference between the arithmetic means is statistically significant at $P > 0.05$.
[a]1 day–1 week.
[b]1 day–1 month.
[c]1 week–1 month.

The endodontic cements without BC and CPC show an increase in mass after 1-month storage (►**Table 3**), except EndoRez which reduces its mass. When BC was added, only EndoRez marked an increase in the mass. When CPC was added, Apexit Plus and N2 decreased in weight after 1 month compared to EndoRez that did not alter its mass.

The pH value of Apexit Plus gradually increased between the first day and the end of the first month. In the sealers with incorporation of BC and CPC, the pH gradually increased in the first week, whereas after 1 month, the pH value lowered (►**Table 4**). The solutions where N2 samples were stored did not significantly change their pH value. The solutions where the EndoRez samples without addition of antimicrobials were stored showed a significant continuous reduction ($P < 0.01$) of the pH values, while the solutions from EndoRez samples with addition of antimicrobials these changes were statistically significant at the level of $P < 0.01$.

Discussion

A study by Dimkov et al was performed by adding BC and CPC in two glass-ionomer cements, and the results showed that the release of Cl^- is linear to the increase of the concentration of the solutions.[16] These results are in line with the current study, where the tested endodontic cements release Cl^-, although with lower values. Once antimicrobial agents have been added, the values of released Cl^- increased.

Another study suggests that the sealers based on calcium hydroxide show high solubility.[17] Mushtag et al studied the solubility of some endodontic materials during removal from the canal system using several types of solvents: xylene, refined orange oil, and tetrachloroethylene; distilled water was used as a control. Apexit Plus is most soluble in xylene and then in refined orange oil and tetrachloroethylene.[18] The results obtained in this study are in accordance with the previous studies and prove that the highest level of solubility was found in Apexit Plus.

Table 3 Average values and standard deviations of the mass of Apexit, N2, and EndoRez (without and with addition of benzalkonium chloride and cetylpyridinium chloride)

Mass (g)	Materials used	Mean (SD)		*p*-Value
		At the beginning	After 1 month	
Mass (g)	Apexit	0.09 (0.01)	0.10 (0.01)	0.04
	Apexit + BC	0.09 (0.02)	0.09 (0.01)	0.82
	Apexit + CPC	0.11 (0.01)	0.10 (0.01)	0.07
Mass (g)	N2	0.12 (0.01)	0.14 (0.01)	0.01
	N2 + BC	0.15 (0.01)	0.15 (0.03)	0.99
	N2 + CPC	0.15 (0.02)	0.14 (0.02)	0.29
Mass (g)	EndoRez	0.11 (0.01)	0.10 (0.02)	0.42
	EndoRez + BC	0.10 (0.03)	0.11 (0.03)	0.64
	EndoRez + CPC	0.10 (0.02)	0.10 (0.02)	0.87

The difference between the arithmetic means is statistically significant at the level $P > 0.05$. [a]1 day–1 week, [b]1 day–1 month, [c]1 week–1 month.
BC, benzalkonium chloride, CPC, cetylpyridinium chloride, SD, standard deviation.

Table 4 Average values and standard deviations of the pH value of the solutions with Apexit, N2, and EndoRez (without and with addition of benzalkonium chloride and cetylpyridinium chloride)

pH value	Materials used	Mean (SD)			*P*
		1 day	1 week	1 month	
pH	Apexit	7.46 (0.11)	8.41 (0.87)	8.65 (0.87)	0.35
	Apexit + BC	7.69 (0.03)[a,b]	9.35 (0.00)[a,c]	8.13 (0.00)[b,c]	0.00
	Apexit + CPC	7.48 (0.14)[a,b]	9.02 (0.08)[a,c]	8.03 (0.08)[b,c]	0.01
pH	N2	6.58 (0.36)	6.95 (0.25)	6.93 (0.25)	0.46
	N2 + BC	6.56 (0.09)	6.74 (0.15)	6.58 (0.15)	0.44
	N2 + CPC	6.39 (0.04)	6.54 (0.28)	6.52 (0.28)	0.79
pH	EndoRez	6.78 (0.01)[a,b]	6.65 (0.01)[a,c]	6.55 (0.01)[b,c]	0.00
	EndoRez + BC	6.5 (0.04)[a,b]	6.35 (0.01)[a,c]	6.87 (0.01)[b,c]	0.01
	EndoRez + CPC	5.83 (0.06)[a,b]	4.75 (0.07)[a,c]	6.83 (0.01)[b,c]	0.00

Abbreviations: BC, benzalkonium chloride; CPC, cetylpyridinium chloride; SD, standard deviation.
The difference between the arithmetic means is statistically significant at the level $P > 0.05$.
[a]1 day–1 week.
[b]1 day–1 month.
[c]1 week to–1 month.

According to this research, the largest stability related to the solubility was demonstrated by EndoRez, which is basically a positive feature, because it does not lead to progressive loss of material.

The root canal sealers based on zinc oxide are frequently used in endodontics (with or without additions). In this study, N2 has been used. Along with the zinc oxide, it contains traces of paraformaldehyde in order to improve its antimicrobial activity. Previous studies indicate that this agent has its own inherent antimicrobial activity toward the different types of micro-organisms even without the addition of an antimicrobial agent.19,20 However, the current examination demonstrated that N2 following addition of BC and CPC shows a statistically significant increase in the release of Cl^- (and consequent improvement of the antimicrobial effect) on a statistically significant level of $P < 0.01$.

In the study by Flores et al, antibacterial activity of four different root canal sealers against bacteria commonly found in endodontic infections were tested. The results suggested that the materials based on zinc oxide have highest antibacterial activity, while EndoRez showed lowest antibacterial activity of all tested materials.[21]

The current results obtained for the release of chloride ions from Apexit, N2, and EndoRez (without the addition of antimicrobial agents) indicate the presence of Cl^- in solutions following different storage intervals. The addition of antimicrobial agents increases the release of Cl^-, which is considered as an indicator of a stronger antimicrobial activity.

The increase of the pH value of the solutions in which endodontic cements are stored is directly linked to their antimicrobial activity, which is supported by the results of several previous studies, where the increase of the pH value of the solutions results with an increase in their antimicrobial activity.[22,23] Solutions where N2 samples were stored did not have a significant change in their pH value. The EndoRez samples demonstrated a significant continuous reduction of the pH values; therefore, in EndoRez solutions, these changes are important because they will lead to a decrease in the antimicrobial activity. Consequently, the addition of BC and CPC, especially in the first week, is beneficial because it leads to lower pH values and an increase in the antimicrobial activity.

Conclusions

The addition of antimicrobials leads to improved characteristics of the root canal sealers. After addition of antimicrobials, the release of Cl^- increases and the level of pH decreases, which are indicators of stronger antimicrobial activity.

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Conflict of Interest
None declared.

References

1 Hahn CL, Falkler WA Jr, Minah GE. Microbiological studies of carious dentine from human teeth with irreversible pulpitis. Arch Oral Biol 1991;36(2):147–153
2 Baumgartner JC, Khemaleelakul SU, Xia T. Identification of spirochetes (treponemes) in endodontic infections. J Endod 2003;29(12):794–797
3 Baumgartner JC, Falkler WA Jr. Bacteria in the apical 5 mm of infected root canals. J Endod 1991;17(8):380–383
4 Sundqvist G, Figdor D, Persson S, Sjögren U. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative re-treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85(1):86–93
5 Nair PN, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after “one-visit” endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99(2):231–252
6 Falk KW, Sedgley CM. The influence of preparation size on the mechanical efficacy of root canal irrigation in vitro. J Endod 2005;31(10):742–745

7 Grossman L. Antimicrobial effect of root canal cements. J Endod 1980;6(6):594–597
8 Ørstavik D. Materials used for root canal obturation: technical, biological and clinical testing. Endod Topics 2005;12:25–38
9 Sagsen B, Er O, Kahraman Y, Orucoglu H. Evaluation of microleakage of roots filled with different techniques with a computerized fluid filtration technique. J Endod 2006;32(12):1168–1170
10 Kayaoglu G, Erten H, Alaçam T, Ørstavik D. Short-term antibacterial activity of root canal sealers towards *Enterococcus faecalis*. Int Endod J 2005;38(7):483–488
11 Palmer G, Jones FH, Billington RW, Pearson GJ. Chlorhexidine release from an experimental glass ionomer cement. Biomaterials 2004;25(23):5423–5431
12 Botelho MG. Inhibitory effects on selected oral bacteria of antibacterial agents incorporated in a glass ionomer cement. Caries Res 2003;37(2):108–114
13 Radford JR, Beighton D, Nugent Z, Jackson RJ. Effect of use of 0.05% cetylpyridinium chloride mouthwash on normal oral flora. J Dent 1997;25(1):35–40
14 Namba N, Yoshida Y, Nagaoka N, et al. Antibacterial effect of bactericide immobilized in resin matrix. Dent Mater 2009;25(4):424–430
15 Block SS. Disinfection, Sterilization and Preservation. 4th ed. Philadelphia, London: Lea & Febiger; 1991
16 Dimkov A, Nicholson JW, Gjorgievska E. On the possibility of incorporating antimicrobial components into glass-ionomer cements. Prilozi 2009;30(2):219–237
17 Valera MC, Leonardo MR, Bonetti I. Sealers—Apical sealing immediately and after storage for six months. Odontol Rev Univ Sao Paulo 1998;12:355–360
18 Mushtaq M, Masoodi A, Farooq R, Yaqoob Khan F. The dissolving ability of different organic solvents on three different root canal sealers: in vitro study. Iran Endod J 2012;7(4):198–202
19 Gjorgievska E, Apostolska S, Dimkov A, Nicholson JW, Kaftandzieva A. Incorporation of antimicrobial agents can be used to enhance the antibacterial effect of endodontic sealers. Dent Mater 2013;29(3):e29–e34
20 Queiroz AM, Nelson-Filho P, Silva LA, Assed S, Silva RA, Ito IY. Antibacterial activity of root canal filling materials for primary teeth: zinc oxide and eugenol cement, Calen paste thickened with zinc oxide, Sealapex and EndoREZ. Braz Dent J 2009;20(4):290–296
21 Flores DS, Rached FJ Jr, Versiani MA, Guedes DF, Sousa-Neto MD, Pécora JD. Evaluation of physicochemical properties of four root canal sealers. Int Endod J 2011;44(2):126–135
22 Duarte MA, Demarchi AC, Giaxa MH, Kuga MC, Fraga SC, de Souza LC. Evaluation of pH and calcium ion release of three root canal sealers. J Endod 2000;26(7):389–390
23 Faria-Júnior NB, Tanomaru-Filho M, Berbert FL, Guerreiro-Tanomaru JM. Antibiofilm activity, pH and solubility of endodontic sealers. Int Endod J 2013;46(8):755–762