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Radiographic outcome of endodontic treatment and retreatment of teeth with apical periodontitis using two different root canal irrigants. A prospective cohort study

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Abstract

Aim: The aim of this prospective cohort study was to compare the radiographic outcome of endodontic treatment and retreatment of teeth with apical periodontitis using either 1% sodium hypochlorite (NaOCl) or 2% chlorhexidine digluconate (CHX) for root canal irrigation.

Materials and Methods: In the years from 2013 to 2015 standard irrigation varied by semester between NaOCl and CHX at the Department of Endodontics at the Faculty of Dentistry. During that time, 912 teeth received treatment for apical periodontitis in 744 patients, of whom 532 responded to the request for a 1-year follow-up. Only one tooth per person (the most distally located) were included; 285 teeth treated with NaOCl and 247 with CHX. One hundred cases were then randomly sampled from each irrigation group and analysed for outcome by periapical index (PAI) scoring using criteria for success, uncertain and failure. Clinical and other radiographic parameters were scored or recorded and analysed for associations with radiographic outcome using chi-square, ANOVA and regression analyses.

Results: Success rates (PAI score 1 or 2 at control) were nearly identical for the two irrigation liquids. The use of irrigating solution also did not significantly influence the outcome in chi-square analyses of subgroups of teeth or regression analyses with other variables included. Ordinal regression analysis established that preoperative lesion size or preoperative PAI score were significantly associated with outcome, and teeth in the mandible had significantly better outcomes than in the maxilla.

Conclusions: No significant differences in the radiographic outcome using either 1% NaOCl or 2% CHX as irrigants were found. The outcome was better for teeth with small lesions or lower PAI scores at completion of treatment and for mandibular teeth.

KEYWORDS

apical periodontitis, chlorhexidine, clinical, outcome, sodium hypochlorite

INTRODUCTION

Chronic apical periodontitis (CAP) is caused by microorganisms colonizing the necrotic root canal system, resulting in radiographically visible lesions in the periapical area (Ørstavik, 2020a, 2020b). The goal of treating CAP is to eliminate the infection, or at least reduce it to levels that are compatible with tissue healing (Ørstavik, 2020a, 2020b).

Mechanical instrumentation is the principal method for bacterial reduction in the infected root canal (Haapasalo et al., 2005). However, large areas of the main root canal wall may remain untouched by the instruments, emphasizing the importance of chemical means of cleaning and disinfecting the root canal system (Peters et al., 2001; Siqueira Jr. et al., 2018).

Irrigation with sodium hypochlorite (NaOCl), which has antimicrobial and tissue-dissolving abilities, may promote cleaning of the areas that were not touched by instruments (Siqueira Jr. et al., 2018). NaOCl is the most widely used irrigating solution, commonly in concentrations varying from 0.5% to 5.25%. It is a potent antimicrobial agent that rapidly kills vegetative and spore-forming bacteria, fungi, protozoa and viruses, and it effectively dissolves pulpal remnants and organic components of dentine (Haapasalo et al., 2014; Siqueira Jr. et al., 2007; Zehnder, 2006). NaOCl exerts its antibacterial effect by irreversible oxidation of sulfhydryl groups of essential bacterial enzymes but may also have deleterious effects on bacterial DNA and membrane-associated activities (Schraufstätter et al., 1990).

Chlorhexidine (CHX) is an alternative to NaOCl as an endodontic irrigation liquid. It is a cationic bisbiguanide with good efficacy against several gram-positive and gram-negative bacteria as well as yeasts found in endodontic infections. It is bacteriostatic at low concentrations and bactericidal at high concentrations (Poppolo Deus & Ouanounou, 2022). CHX crosses the cell wall, presumably by passive diffusion and subsequently attacks the cytoplasmic membrane followed by leakage of intracellular constituents (Poppolo Deus & Ouanounou, 2022). It is typically used in 2% concentration in water.

While the antibacterial activity of NaOCl is well documented, it is toxic to tissues and painful complications may follow if apically extruded (Guivarc'h et al., 2017; Zhu et al., 2013). Chlorhexidine (CHX) does not have the tissue-dissolving ability of NaOCl, but has low cytotoxicity and exhibits substantivity, which may result in prolonged antibacterial effects (Mohammadi & Abbott, 2009).

Clinical studies comparing the antibacterial effectiveness of chlorhexidine and NaOCl when used as root canal irrigants during chemo-mechanical preparation in both primary and persistent infections have demonstrated conflicting results (Ruksakiet et al., 2020). The occurrence of postoperative pain is similar with the two irrigants (Martins et al., 2020). Few studies on treatment outcome have been performed, but one randomized clinical trial found no significant difference in the treatment outcome using either 1% sodium hypochlorite (NaOCl) or 2% chlorhexidine digluconate (CHX) as the irrigating solution (Zandi et al., 2019).

The aim of the present prospective study was to compare, in a prospective cohort study, the outcome of root canal treatment using either 1% sodium hypochlorite (NaOCl) or 2% chlorhexidine digluconate (CHX) as the root canal irrigant in teeth with primary apical periodontitis and in teeth with post-treatment apical periodontitis. The null hypothesis tested was that there would be no significant differences between the two irrigants on the radiographic outcome.

MATERIALS AND METHODS

Patient selection

The study population was patients treated between 2013 and 2015 by undergraduate students or endodontic postgraduate students at the Faculty of Dentistry. The study is part of a project that has been reviewed and accepted by the Regional Ethics Board (REC southeast) in Norway (64 996 Resultatanalyse av endodontisk behandling).

From 2013 through 2015 1% NaOCl and 2% CHX alternated by semesters as mandatory irrigation liquid for all endodontic treatments. Standard operative procedures were otherwise identical from January 2013 through December 2015. These included local anaesthesia, rubber dam placement, cleaning with pumice, build-up with composite/glass ionomer to secure aseptic treatment when necessary, traditional access cavity preparation, surface disinfection with 1% chlorhexidine, working length determination by electronic and/or radiographic means, chemo-mechanical instrumentation with hand- and machine-operated instruments, use of EDTA as a final rinse, dressing with calcium hydroxide (except in 11 cases treated in one session), root filling with gutta-percha and AH plus, an orifice plug with IRM, a temporary filling with IRM or permanent filling with a composite filling material. The procedures were in general accordance with ESE guidelines and current clinical practices at the time (ESE, 2006; Trope & Debelian, 2008).

Figure 1 shows the selection process for the teeth to be analysed in the study. A total of 1759 teeth were treated

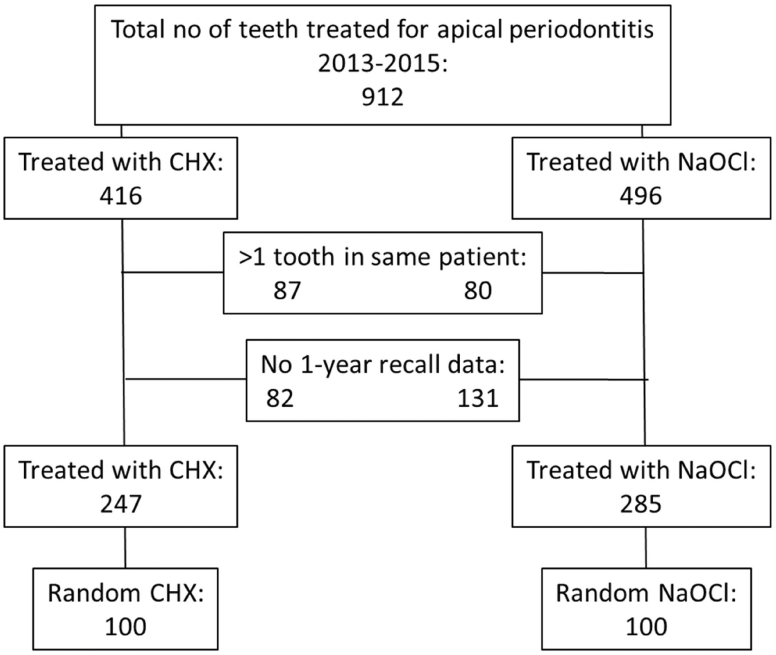

FIGURE 1 Case flow and selection process.

endodontically by graduate and undergraduate students during the period. Of these, 912 were diagnosed with apical periodontitis by a PAI score >2 (Ørstavik et al., 1986). Two or more root-filled teeth occurred in 121 patients. From these patients 168 teeth were excluded after selecting the most distal of root-filled teeth in each mouth, leaving 744 patients each with one tooth available for investigation. All patients were invited by mail and telephone to a recall after 1 year, and 532 responded positively (recall rate 72%). Of these, 285 had been treated with NaOCl, and 247 with chlorhexidine. From the pool treated with NaOCl, 100 teeth were randomly picked for analyses, of which 56 were primary treatments and 44 were retreatments. From the pool treated with CHX, 100 teeth were randomly picked for analyses, of which 52 were primary treatments and 48 were retreatments.

Data regarding patients' age, sex, tooth and treatment type (primary apical periodontitis or retreatment) were retrieved from the written records (see Table S1). Observations of pain, complications, root-filling voids, file fractures and perforations were also noted, but preliminary analyses of these variables showed that their incidence was too low for statistical analyses. The radiographs taken on admission, on completion of treatment and at control were analysed in the ImageJ program (Schneider et al., 2012). A plug-in addition (Preus et al., 2015) modified for registrations of endodontic parameters (Jordal et al., 2022) was used for recording radiographic features of interest (see Table S1). The radiographs were anonymized and randomly mixed and the observers were blinded for all clinical data, including the type of irrigation that was used. Two postgraduate students in endodontics (E.K. and D.P.) scored all radiographs.

Outcome assessments

Periapical conditions were scored by the PAI scoring system (Ørstavik et al., 1986). Two observers (DP and EK) were calibrated by scoring a reference set of 100 radiographs twice, obtaining a weighted Cohen kappa score above 0.7, which indicated good conformity with the references. Both observers scored all 200 cases. If disagreement occurred, the evaluators discussed divergent scores to reach a consensus. If no consensus was reached, an experienced endodontist (HZ) decided a final score for the case. Multi-rooted teeth were evaluated as one unit and the root with the highest PAI score at the time of filling was selected. PAI scoring was used to define the outcome measures: PAI scores at control 1–5; success/uncertain/failure; success by strict criteria; and success by lenient criteria (see Table S1 with comments).

Statistical analysis

Relationships between outcome and independent variables were explored in bivariate analyses by Pearson's chi-square for ordinal and binary data, and t-test and ANOVA for comparisons of means of numerical data. The influence of independent variables on outcome was tested further in multiple regression analyses. Analyses with logistic and ordinal multiple regression suggested near identical results when using binominal (strict success/failure criteria) and ordinal (full PAI scale or success/uncertain/failure criteria) data. Lenient success/failure criteria showed less good correlation with the independent variables. For this study, we chose success/uncertain/failure criteria in

the final analyses. The statistical analyses were done using Stata/SE 17.0 for Windows (Stata, 2021).

RESULTS

Characteristics of patients and cases

There was a tendency for NaOCl-treated teeth to have higher initial PAI scores at completion of treatment ($p = .074$) and to have larger apical taper at filling ($p = .088$). In retreatment cases, CHX-treated teeth tended to show a greater increase in root filling length ($p = .086$). All other recorded independent variables did not vary conspicuously between the two irrigation groups ($p > .14$) (Table S2).

Overall effect of irrigation liquid

Outcome results were nearly identical for the two irrigation groups irrespective of outcome measure. Success rates were approximately 70% by strict and 80 per cent by lenient criteria (Table 1).

Association of outcome with other recorded parameters

The detailed results of bivariate comparisons are given in Table S3.

Age and sex were unrelated to the outcome in bivariate analyses. Mandibular teeth had a tendency to fare better than maxillary, a reflection of poorer outcome in maxillary premolars and molars and better outcome in mandibular premolars. Undergraduate students performed better than graduates, but the undergraduates had significantly fewer molars and retreatments, which again tended to have poorer outcome. Measures of disease extent or severity, that is, PAI score and lesion size at completion of treatment, were clearly correlated with outcome ($p < .01$), whereas the apical width and taper of the root filling and the apex-to-gutta-percha-point distance were not.

Separate analyses of irrigation groups

Some recorded variables appeared to have a differential effect on outcome for the irrigation groups analysed separately (Tables S4 and S5). Teeth in the CHX group were less dependent on jaw location ($p = .516$) compared with the NaOCl group, which showed potentially better outcome for mandibular teeth ($p = .069$). Retreatments with CHX showed a weak relationship of outcome to the ability to instrument and fill closer to the radiographic apex ($p = .085$) with no such tendency for the NaOCl group ($p = .985$). The preoperative PAI score was strongly associated with outcome for both groups ($p < .01$ for both); however, preoperative lesion size was significantly related to outcome only for the NaOCl group ($p = .018$ vs. $p = .310$ for the CHX group).

Retreatments vs. treatment of primary apical periodontitis

The recorded variables were also analysed in relation to the subpopulations of teeth treated for primary or post-treatment apical periodontitis. The results are given in Tables S6 and S7.

Lesion size and preoperative PAI score were consistently associated with outcome. Mandibular teeth were

TABLE 1 Results of treatment by different outcome criteria.

Outcome measure	Score	CHX	NaOCl	Total %	*p*-value
PAI	1	30	25	27.5	.767
	2	40	46	43	
	3	20	21	20.5	
	4	9	6	7.5	
	5	1	2	1.5	
SUF	Success	70	71	70.5	.806
	Uncertain	10	12	11	
	Failure	20	17	18.5	
Strict	Success	70	71	70.5	.877
	Failure	30	29	29.5	
Lenient	Success	80	83	81.5	.585
	Failure	20	17	18.5	

more successful than maxillary teeth in the primary apical periodontitis group ($p = .014$), but this was not found for retreatments ($p = .582$). There was a slight tendency for retreatments that resulted in a root filling closer to the radiographic apex to be more successful, but the association was not significant ($p = .185$).

Regression analysis

The total material of 200 teeth was analysed in logistic regression analysis. All independent variables were included in primary calculations, and variables that did not contribute to the improved fit of the model were sequentially removed except for irrigation and type of treatment, which were considered to be of particular interest.

PAI score and lesion size at completion were highly correlated in bivariate analysis, so one would not be expected to add to the other in regression analysis. PAI score at the completion of treatment correlated with jaw, whereas the size of lesion did not. The size of lesion at the completion of treatment was, therefore, selected over PAI in the final model (Table 2), despite losing 10 teeth with incomplete data. The size of lesion significantly impacted outcome in ordinal regression, and jaw location and treatment type (primary vs. retreatments) added to the fit of the model, whereas all other parameters including type of irrigation did not (Table 2). The null hypothesis of no difference between the two irrigation liquids in promoting healing could not be rejected. The final model was significant, but the overall predictive ability of the model was low (pseudo $R^2 = 0.0413$).

DISCUSSION

In this study, as previously in the study by Zandi et al. (2019), 1 per cent NaOCl was used. While *in vitro* and *ex vivo* studies may show increased antibacterial (and general) toxicity by higher concentrations of NaOCl, this is not a uniform finding (Pereira et al., 2021) and clinical follow-up studies have not found a significant effect of higher (5%) vs. lower (1%) concentrations of NaOCl (Verma et al., 2019).

Data on follow-up of apical periodontitis treated with irrigation using CHX are scarce. There are studies where specially selected cases treated with CHX have been included (Ng et al., 2011), case series (Ercan et al., 2007; Salas et al., 2020) and one randomized study comparing CHX with NaOCl (Zandi et al., 2019). The present study was designed as a cohort study. Similar to Zandi et al. (2019) we did not find a significant difference in treatment outcome with the two irrigants.

The detailed scoring of relevant parameters in the x-rays is time-consuming and we therefore chose to randomly select 100 cases from each of the two treatment cohorts. One hundred cases would seem adequate to represent the population of teeth in the groups and at the same time provide enough data for clinically meaningful comparisons in statistical analyses. We also chose to use the radiographic results by PAI scoring as the sole criterion for success. Although subjective symptoms will be part of the clinical diagnosis of persistent apical periodontitis, all teeth in this category also had a failing PAI score in our material. The use of two calibrated observers and an experienced arbiter in cases of doubt should ensure the validity of the final scores.

The success rate of primary root canal treatment in teeth with apical periodontitis completed at least 1 year previously ranges considerably, from 68% to more than 85% (Ng et al., 2007). Reported success rates for retreatments vary even more, from 53% to 80% (Jokinen et al., 1978; Ng et al., 2008; Ponsri & Jirathanyanatt, 2022; Signor et al., 2021). We found a success rate by strict criteria of 75% for primary apical periodontitis and 65% for retreatments, corresponding well to data reported in the literature. A prolonged follow-up would likely improve the success rates, as healing may continue for several years

TABLE 2 Final ordinal logistic regression with factors contributing to the model with $p < .10$. Irrigation fluid is included, illustrating no influence.

Ordered logistic regression				Number of obs		190
				LR $\chi^2(4)$		12.78
				Prob > chi^2		0.0124
				Pseudo R^2		0.0413
Succ/Uncertain/Fail	**Odds ratio**	**Std. err.**	**z**	***p*>*z***	**95% conf. interval**	
Size of lesion at start	1.025	0.011	2.35	0.019	1.004	1.046
Maxillary vs. mandibular	0.514	0.183	−1.86	0.062	0.256	1.035
Primary vs. retreatment	1.678	0.540	1.61	0.107	0.894	3.152
CHX vs. NaOCl	1.099	0.352	0.29	0.768	0.586	2.060

after treatment (Byström et al., 1987; Fristad et al., 2004; Strindberg, 1956). Our 'uncertain' category at follow-up had a decreased PAI score compared with the preoperative score and was associated with large preoperative lesions, which would strongly indicate healing in progress rather than an endodontic failure. While reconciled criteria are especially important for across-studies comparisons, comparisons among groups in the same study should be valid as long as the criteria are uniform throughout.

The overall outcome of the treatment provided was primarily associated with the preoperative periapical status, by PAI score or lesion size, corresponding to longitudinal epidemiological (Kirkevang et al., 2014) and clinical (Herbst et al., 2022; Ricucci et al., 2011) studies. This association was evident and dominant over most other variables tested, in bivariate and multivariate analyses. The strongest correlation in bivariate analyses was with preoperative PAI score. PAI scores at the start of treatment were significantly higher for maxillary teeth (data not shown), so there could be a possible moderating effect of tooth location. However, jaw location appeared unrelated to the initial size of lesion; therefore, the preoperative lesion size rather than the preoperative PAI score was chosen in the final model. While significant in predicting outcome ($p = .012$), the model had very limited explanatory power (pseudo $R^2 = .041$). This is perhaps to be expected given the single-factor, microbial aetiology of apical periodontitis: the presence and extent of disease is uniquely dependent on the presence and extent of infection (Kakehashi et al., 1965; Sundqvist, 1976; Zandi et al., 2019). The factors shown to impact the regression can all be related to the presence or amount of infection: lesion size is known to reflect the degree of infection (Zandi et al., 2018); radiographic signs of healing may be more easily followed in the lower jaw; and the eradication of microbes may be more difficult in retreatment cases.

In conclusion, the present study showed similar radiographic outcomes with no significant difference between the use of 1% NaOCl and 2% CHX as root canal irrigants in the treatment of teeth with apical periodontitis. Preoperative radiographic status of the periapical tissues and the tooth's jaw location were the major predictors of outcome. Primary treatments tended to succeed more often than retreatments.

AUTHOR CONTRIBUTIONS

Design of study: EK, DP, HZ, PTS, DØ; collection and retrieval of data from records: EK, DP; scoring of data: EK, DP, HZ; analyses and statistics: GRT, EK, DØ; manuscript preparation and finalization: EK, PTS, DØ.

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The study has no external funding.

CONFLICT OF INTEREST STATEMENT

None of the authors has any conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

Acceptance for using the patient data was obtained from The Regional Committee for Medical and Health Research Ethics in Norway (REK 2018/64996).

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REFERENCES

Byström, A., Happonen, R.P., Sjögren, U. & Sundqvist, G. (1987) Healing of periapical lesions of pulpless teeth after endodontic treatment with controlled asepsis. *Endodontics & Dental Traumatology*, 3(2), 58–63.

Ercan, E., Dalli, M., Duülgergil, C.T. & Yaman, F. (2007) Effect of intracanal medication with calcium hydroxide and 1% chlorhexidine in endodontic retreatment cases with periapical lesions: an in vivo study. *Journal of the Formosan Medical Association*, 106(3), 217–224.

ESE. (2006) Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. *International Endodontic Journal*, 39(12), 921–930.

Fristad, I., Molven, O. & Halse, A. (2004) Nonsurgically retreated root filled teeth – radiographic findings after 20–27 years. *International Endodontic Journal*, 37(1), 12–18.

Guivarc'h, M., Ordioni, U., Ahmed, H.M., Cohen, S., Catherine, J.H. & Bukiet, F. (2017) Sodium hypochlorite accident: a systematic review. *Journal of Endodontia*, 43(1), 16–24.

Haapasalo, M., Endal, U., Zandi, H. & Coil, J. (2005) Eradication of endodontic infection by instrumentation and irrigation solutions. *Endodontic Topics*, 10, 77–102.

Haapasalo, M., Shen, Y., Wang, Z. & Gao, Y. (2014) Irrigation in endodontics. *British Dental Journal*, 216(6), 299–303.

Herbst, C.S., Schwendicke, F., Krois, J. & Herbst, S.R. (2022) Association between patient-, tooth- and treatment-level factors and root canal treatment failure: a retrospective longitudinal and machine learning study. *Journal of Dentistry*, 117, 103937.

Jokinen, M.A., Kotilainen, R., Poikkeus, P., Poikkeus, R. & Sarkki, L. (1978) Clinical and radiographic study of pulpectomy and root canal therapy. *Scandinavian Journal of Dental Research*, 86(5), 366–373.

Jordal, K., Skudutyte-Rysstad, R., Sen, A., Torgersen, G., Ørstavik, D. & Sunde, P.T. (2022) Effects of an individualized training course on technical quality and periapical status of teeth treated endodontically by dentists in the public dental Service in Norway: an observational intervention study. *International Endodontic Journal*, 55(3), 240–251.

Kakehashi, S., Stanley, H.R. & Fitzgerald, R.J. (1965) The effects of surgical exposures of dental pulps in germ-free and

conventional laboratory rats. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology*, 20, 340–349.

Kirkevang, L.L., Ørstavik, D., Wenzel, A. & Vaeth, M. (2014) Prognostic value of the full-scale periapical index. *International Endodontic Journal*, 48, 1051–1058.

Martins, C.M., da Silva Machado, N.E., Giopatto, B.V., de Souza Batista, V.E., Marsicano, J.A. & Mori, G.G. (2020) Post-operative pain after using sodium hypochlorite and chlorhexidine as irrigation solutions in endodontics: systematic review and meta-analysis of randomised clinical trials. *Indian Journal of Dental Research*, 31(5), 774–781.

Mohammadi, Z. & Abbott, P.V. (2009) The properties and applications of chlorhexidine in endodontics. *International Endodontic Journal*, 42(4), 288–302.

Ng, Y.L., Mann, V. & Gulabivala, K. (2008) Outcome of secondary root canal treatment: a systematic review of the literature. *International Endodontic Journal*, 41(12), 1026–1046.

Ng, Y.L., Mann, V. & Gulabivala, K. (2011) A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *International Endodontic Journal*, 44(7), 583–609.

Ng, Y.L., Mann, V., Rahbaran, S., Lewsey, J. & Gulabivala, K. (2007) Outcome of primary root canal treatment: systematic review of the literature – part 1. Effects of study characteristics on probability of success. *International Endodontic Journal*, 40(12), 921–939.

Ørstavik, D. (2020a) Apical periodontitis: microbial infection and host responses. In: Ørstavik, D. (Ed.) *Essential endodontology*. Singapore: Wiley-Blackwell, pp. 313–344.

Ørstavik, D. (2020b) Endodontic treatment of apical periodontitis. In: Ørstavik, D. (Ed.) *Essential Endodontology*. Singapore: Wiley Blackwell, pp. 313–344.

Ørstavik, D., Kerekes, K. & Eriksen, H.M. (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics & Dental Traumatology*, 2(1), 20–34.

Pereira, T.C., Boutsioukis, C., Dijkstra, R.J.B., Petridis, X., Versluis, M., de Andrade, F.B. et al. (2021) Biofilm removal from a simulated isthmus and lateral canal during syringe irrigation at various flow rates: a combined experimental and computational fluid dynamics approach. *International Endodontic Journal*, 54(3), 427–438.

Peters, O.A., Schonenberger, K. & Laib, A. (2001) Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. *International Endodontic Journal*, 34(3), 221–230.

Ponsri, S. & Jirathanyanatt, T. (2022) Treatment outcome and prognostic factors of orthograde retreatment: a retrospective study. *Journal of International Society of Preventive & Community Dentistry*, 12(4), 442–448.

Poppolo Deus, F. & Ouanounou, A. (2022) Chlorhexidine in dentistry: pharmacology, uses, and adverse effects. *International Dental Journal*, 72(3), 269–277.

Preus, H.R., Torgersen, G.R., Koldsland, O.C., Hansen, B.F., Aass, A.M., Larheim, T.A. et al. (2015) A new digital tool for radiographic bone level measurements in longitudinal studies. *BMC Oral Health*, 15, 107.

Ricucci, D., Russo, J., Rutberg, M., Burleson, J.A. & Spångberg, L.S. (2011) A prospective cohort study of endodontic treatments of 1,369 root canals: results after 5 years. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology*, 112(6), 825–842.

Ruksakiet, K., Hanák, L., Farkas, N., Hegyi, P., Sadaeng, W., Czumbel, L.M. et al. (2020) Antimicrobial efficacy of chlorhexidine and sodium hypochlorite in root canal disinfection: a systematic review and meta-analysis of randomized controlled trials. *Journal of Endodontia*, 46(8), 1032–1041.e1037.

Salas, H., Vieira, G.C.S., Palomino, I., Valero, J., Pacheco-Yanes, J., Campello, A.F. et al. (2020) Outcome of endodontic treatment with chlorhexidine gluconate as main irrigant: a case series. *Australian Endodontic Journal*, 46(3), 307–314.

Schneider, C., Rasband, W. & Eliceiri, K. (2012) NIH image to ImageJ: 25 years of image analysis. *Nature Methods*, 9, 671–675.

Schraufstätter, I.U., Browne, K., Harris, A., Hyslop, P.A., Jackson, J.H., Quehenberger, O. et al. (1990) Mechanisms of hypochlorite injury of target cells. *The Journal of Clinical Investigation*, 85(2), 554–562.

Signor, B., Blomberg, L.C., Kopper, P.M.P., Augustin, P.A.N., Rauber, M.V., Rodrigues, G.S. et al. (2021) Root canal retreatment: a retrospective investigation using regression and data mining methods for the prediction of technical quality and periapical healing. *Journal of Applied Oral Science*, 29, e20200799.

Siqueira, J.F., Jr., Pérez, A.R., Marceliano-Alves, M.F., Provenzano, J.C., Silva, S.G., Pires, F.R. et al. (2018) What happens to unprepared root canal walls: a correlative analysis using microcomputed tomography and histology/scanning electron microscopy. *International Endodontic Journal*, 51(5), 501–508.

Siqueira, J.F., Jr., Rôças, I.N., Paiva, S.S., Guimarães-Pinto, T., Magalhães, K.M. & Lima, K.C. (2007) Bacteriologic investigation of the effects of sodium hypochlorite and chlorhexidine during the endodontic treatment of teeth with apical periodontitis. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, 104(1), 122–130.

Stata. (2021) *Stata statistical software: release 17*. College Station, TX: Stata Corp.

Strindberg, L. (1956) The dependence of the results of pulp therapy on certain factors. *Acta Odontologica Scandinavica*, 14(Suppl 21), 1–175.

Sundqvist, G. (1976) Bacteriological studies of necrotic dental pulps.

Trope, M. & Debelian, G. (2008) Endodontic treatment of apical periodontitis. In: Ørstavik, D. (Ed.) *Essential Endodontology: prevention and treatment of apical periodontitis*. Oxford, UK: Wiley, pp. 347–380.

Verma, N., Sangwan, P., Tewari, S. & Duhan, J. (2019) Effect of different concentrations of sodium hypochlorite on outcome of primary root canal treatment: a randomized controlled trial. *Journal of Endodontia*, 45(4), 357–363.

Zandi, H., Kristoffersen, A.K., Ørstavik, D., Rocas, I.N., Siqueira, J.F., Jr. & Enersen, M. (2018) Microbial analysis of endodontic infections in root-filled teeth with apical periodontitis before and after irrigation using pyrosequencing. *Journal of Endodontia*, 44(3), 372–378.

Zandi, H., Petronijevic, N., Mdala, I., Kristoffersen, A.K., Enersen, M., Rôças, I.N. et al. (2019) Outcome of endodontic retreatment using 2 root canal Irrigants and influence of infection on healing as determined by a molecular method: a randomized clinical trial. *Journal of Endodontia*, 45(9), 1089–1098.e1085.

Zehnder, M. (2006) Root canal irrigants. *Journal of Endodontia*, 32(5), 389–398.

Zhu, W.C., Gyamfi, J., Niu, L.N., Schoeffel, G.J., Liu, S.Y., Santarcangelo, F. et al. (2013) Anatomy of sodium hypochlorite accidents involving facial ecchymosis - a review. *Journal of Dentistry*, 41(11), 935–948.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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