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pH changes in external root surface cavities after calcium hydroxide is placed at 1, 3 and 5 mm short of the radiographic apex

Thaddeus M. Chamberlain[1], Timothy C. Kirkpatrick[2], Richard E. Rutledge[3]

[1]Lt Col, USAF, DC, Endodontic Resident, Wilford Hall Medical Center, Lackland AFB, TX, USA; [2]Col, USAF, DC, Endodontic Program Director, Wilford Hall Medical Center, Lackland AFB, TX, USA; [3]Col, USAF, DC, Endodontic Program Director, Keesler AFB, MS, USA

Abstract – The purpose of this study was to test the null hypothesis that there is no difference in the pH on the external apical dentin surface when the canal is completely filled with calcium hydroxide or when it is placed 3 or 5 mm short of the apical foramen in extracted human teeth. The root canals of single-rooted anterior human teeth were cleaned and shaped after decoronation. Cavities about 0.50 mm deep and 1.0 mm wide located at 1, 3 and 5 mm from the radiographic apex were prepared on the external root surface and the teeth were randomly divided into four groups. The roots were filled with calcium hydroxide at 1, 3 and 5 mm from the radiographic apex, and the control group was left empty. pH readings were obtained at intervals over a 28-day study. The roots which were filled within 1 mm of the radiographic apex had the greatest increase in pH in each of the cavities. These results demonstrate that the greatest pH change on the external root surface near the apex is obtained when the canal is more completely filled with calcium hydroxide.

Correspondence to: Thaddeus M. Chamberlain, DDS, Lt Col, USAF, DC, Endodontic Resident, Wilford Hall Medical Center, Lackland AFB, TX 78236, USA
Tel.: (210) 292 7831
Fax: (210) 292 6431
e-mail: endohawk@gmail.com

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In 1920, Hermann introduced calcium hydroxide to dentistry and due to its many positive capabilities, it has been widely used in endodontic treatments. The major biological properties include antibacterial activity, tissue-dissolving ability, induction of repair by hard tissue formation and inhibition of tooth resorption (1). The biological properties of calcium hydroxide have only been observed when the material is in direct contact with dentin and pulp tissue, and are attributed to its high-alkaline pH of approximately 12.5 (1, 2).

One of the critical steps in successful endodontic therapy is to clean the complex anatomy of the root canal space and remove as much of the tissue as possible. Sodium hypochlorite is used extensively as an irrigant during the cleaning and shaping phase because of its tissue-dissolving properties. In 1988, Hasselgren's study showed that calcium hydroxide caused swelling of the porcine muscle tissue and that pretreatment with calcium hydroxide had a synergistic effect with sodium hypochlorite and reduced the time necessary to dissolve the tissue. He speculated that the alkaline pH of calcium hydroxide contributed to a breakdown of intracanal soft tissue remnants, thus rendering a cleaner root canal (3). Based on these findings, calcium hydroxide has been widely used as an intracanal medicament with the intent to dissolve pulp tissue between appointments and to maximize the removal of the affected pulp tissue.

Calcium hydroxide is frequently used in endodontics to treat the sequelae of traumatic injuries to teeth (4). According to the *Recommended Guidelines of the American Association of Endodontists for the Treatment of Traumatic Dental Injuries*, calcium hydroxide is the recommended intracanal medicament for the management of an avulsed tooth with a closed apex. At 7–10 days, endodontic treatment should be initiated and calcium hydroxide be placed into the canal space. Generally, if the root canal treatment is initiated at the end of the ideal 7-day study period, external inflammatory root resorption is prevented, and obturation can take place within a month. If, however, the endodontic treatment is initiated when root resorption is already visible, calcium hydroxide is recommended for an extended period before obturation can take place (5). Calcium hydroxide acts to stop the resorptive process in cases where the pulp tissue of a traumatized tooth is irreversibly damaged and root canal therapy is indicated. Pulp extirpation and placement of calcium hydroxide into the canal space can elevate the dentinal tubule pH to

a bactericidal level (6, 7), inhibit osteoclastic activity and create a favourable environment for hard tissue formation (2). Segura found that calcium hydroxide inhibited macrophages from adhering to the dentin surface, and therefore may contribute to inhibition of resorption (8). For calcium hydroxide to be effective as an intracanal medicament, the hydroxyl ions need to diffuse through the dentin (9).

The diffusion dynamics of the hydroxyl ions from calcium hydroxide has been previously studied and it has been shown that diffusion is continuous and capable of maintaining elevated pH levels at the root surface for over 120 days (10). It has also been shown that the hydroxyl ion diffuses more quickly through cervical dentin than apical dentin. This fact has been attributed to having less permeable dentin with fewer dentinal tubules in the apical region (11).

Many studies have been accomplished to determine the pH changes on the external surface of apical root dentin. Some have used different formulations of calcium hydroxide pastes (12–14), while others tested the use of gutta-percha points with calcium hydroxide incorporated in their matrix (15), but in all of the previous studies, the canals have been completely obturated. It is a common observation that many practitioners fail to completely obturate the canals with calcium hydroxide, yet, none of the previous studies have examined whether filling the canals short of the apex has any effect on the ability of calcium hydroxide to affect the pH of the apical external dentin surface. The purpose of this study was to test the null hypothesis that there is no difference in the pH on the external apical dentin surface when the canal is completely filled with calcium hydroxide or when it is placed 3 or 5 mm short of the apical foramen in extracted human teeth.

Materials and methods

About 40 previously extracted human permanent maxillary and mandibular anterior single-rooted teeth stored in chloramine-T were used in this *in vitro* study. The teeth were decoronated 10 mm from the apex to create roots of equal length. The teeth were then instrumented using a crown down technique. After coronal flaring, working length was determined by visualizing a 10 K-flex file (Sybron Endo, Orange, CA, USA) at the apical foramen and deducting 0.5 mm. The canals were enlarged to a size 20 K-flex hand file, creating a guide path for the use of rotary instruments, and then instrumented with ProTaper and 0.04 taper ProFile nickel–titanium rotary files (Dentsply, Caulk L.D. division, Milford, ME, USA) to a final apical preparation size of 50. The canals were irrigated with 3 ml of 6% NaOCl, over a 30-s period, between each file size. After the final instrumentation, the smear layer was removed with 3 ml of 17% EDTA followed by 3 ml of 6% NaOCl. The canals were then dried with paper points. Using a Kavo (Biberach, Germany) Mira Lux 3 high-speed handpiece, a Brasseler (Brasseler, Savannah, GA, USA) round bur with a 1.0 mm diameter and a 1.0 mm head length was used to make cavities on the external root surface with 0.50 mm deep and 1.0 mm in diameter at 1, 3 and 5 mm coronal to the apical foramen (see Fig. 1).

Fig. 1. Cavities were created on the external root surface 0.50 mm deep and 1.0 mm in diameter at 1, 3 and 5 mm coronal to the apical foramen.

The roots were randomly divided into four groups of 10. All of the canals with the exception of the controls were filled with 35% calcium hydroxide (UltraCal XS, UltraDent Products, INC. South Jordan, UT, USA) using 30 gauge tips (NaviTip, UltraDent Products, INC.). Group A ($n = 10$) was filled 1 mm short of the apical foramen, Group B ($n = 10$) was filled 3 mm short of the apical foramen, Group C ($n = 10$) was filled 5 mm short of the apical foramen and Group D ($n = 10$) was left empty. Calcium hydroxide placement was accomplished by using a NaviTip placed at either 1, 3 or 5 mm from the apical foramen. Proper placement of calcium hydroxide was verified using digital radiographs (Schick CDR sensor size 2, Dentsply). After verification, the apical foramen and the canal orifice were sealed with sticky wax to prevent any liquid from entering the canal space. The teeth were attached to the lid of a plastic scintillation vial using sticky wax to preclude the need to handle the roots during pH testing. Between test periods, the teeth were stored in un-buffered isotonic saline at 37°C.

The pH was measured in the cavities located at 1, 3 and 5 mm from the apical foramen, at 0 (immediately prior to placement of the calcium hydroxide), 1, 3, 5, 7, 14, 21 and 28 days. Each tooth was removed from its individual vial and rinsed with distilled water, then blotted dry. Distilled water was placed in each cavity preparation and allowed to stand for 10 min. The pH was then measured using a calibrated microelectrode (Orion 2 star pH meter Thermo Electron Corporation, Waltham, MA, USA) which was calibrated at the beginning of each experimental day using solutions of known pH (see Fig. 2). After pH values were obtained, each tooth was returned to its vial.

The pH reading for each cavity at each time interval was recorded. The pH changes in each group over time were compared using a one-way repeated measures analysis of variance (RM ANOVA). A Dunnett's *t*-test was used as a post-hoc test to evaluate treatment vs. control differences, and a Student–Newman–Keuls test was used as a post-hoc

Fig. 2. pH readings were obtained from the experimental cavity prepared on the surface of the filled roots.

test to evaluate between treatment differences. The line graphs represent the dataset of each individual cavity on the external surface of the roots over the measured time. Data were analysed using a RM ANOVA to examine the effects of group [how filled the canal was with $Ca(OH)_2$] and reading distance (1, 3 or 5 mm cavities on the external root surface) on pH over time which was measured eight times over a period of 4 weeks. Due to a significant interaction term ($P < 0.001$), the main effects were not interpretable and therefore the data were split into three datasets based on reading distance, and the RM ANOVA was repeated to determine if there was a significant group effect and a Bonferroni correction to the alpha level was applied so that $P < 0.01$ was considered statistically significant.

Results

As shown in the figures for each of the 3 RM ANOVAs, the group effect was statistically significant ($P < 0.001$). Post-hoc analysis using Dunnett's pair-wise multiple comparison *t*-test showed that Group A (filled 1 mm from the radiographic apex) had significantly higher average pH levels in the cavities located at 1, 3, and 5 mm from the apex over time than Groups B (filled 3 mm short of the apex), C (filled 5 mm short of the apex), or D (the control group) (Figs 3–5). In the cavities which were at 3 mm from the apex, Group A showed a significantly higher pH than Groups B, C and D, and Group B showed a significantly higher pH than Groups C and D (Fig. 4). There was no difference between Groups C and D at any level or time ($P < 0.001$). In the cavities which were at 1, 3 and 5 mm from the apex Group A showed significantly higher pH than control Group D immediately after the placement of calcium hydroxide and steadily increased through day 14. At day 28, the average pH in Group A had dropped to the level of control Group D.

Discussion

Nerwich et al. found that the hydroxyl ions passed more rapidly through the cervical dentin than the apical dentin and attributed this to the fact that apical tubules were

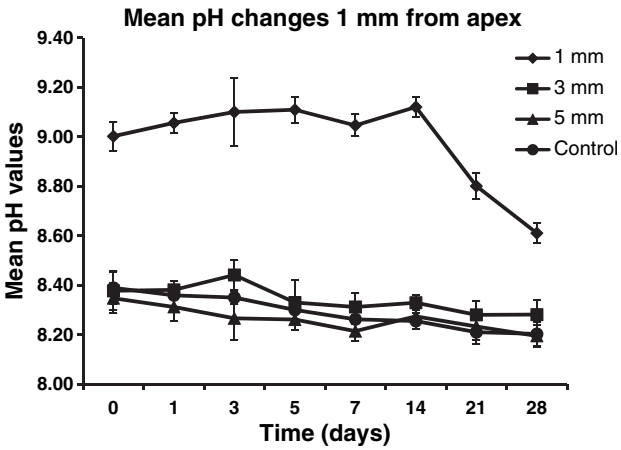

Fig. 3. Pattern of pH changes at the surface of root dentin in the prepared cavities 1 mm from the apex. pH levels measured in Group A were significantly different from the pH levels in all other groups ($P < 0.001$).

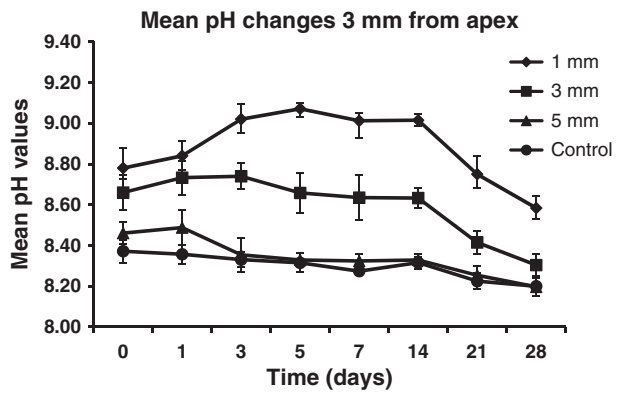

Fig. 4. Pattern of pH changes at the surface of root dentin in the prepared cavities 3 mm from the apex. pH levels measured in Group A were significantly different from the pH levels in all other groups ($P < 0.001$), and pH levels in Group B were significantly different from Groups C and D.

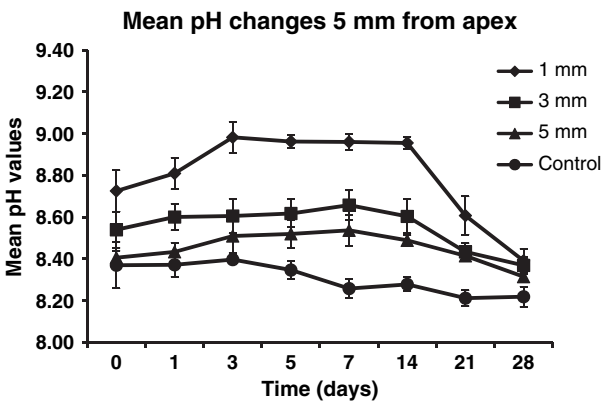

Fig. 5. Pattern of pH changes at the surface of root dentin in the prepared cavities 5 mm from the apex. pH levels measured in Group A were significantly different from the pH levels in all other groups ($P < 0.001$).

fewer in number and smaller in diameter than cervical tubules (11). The results of this study showed that the pH levels changed more slowly in the 5 mm cavities than the 1 mm cavities which agree with their findings. There was also a trend seen in all three levels of the external root surface where the pH readings dropped to the level of the control group between the 21- and 28-day readings. This finding is contrary to that of Esberard et al. who found that the external pH remained at a high level for the duration of his 120-day study (10). A major difference between the studies is that he used intact teeth and completely obturated all of his canals with calcium hydroxide and compared different brands, so the quantity of calcium hydroxide was greater in each of his experimental groups, whereas this protocol used only the apical 10 mm of the root which decreased the volume of calcium hydroxide used.

The key to successful endodontic therapy is identifying and eliminating all of the factors which are involved in the development of apical periodontitis for each of our patients. It has long been recognized that bacteria and their byproducts are the major players in the pathogenesis of apical periodontitis (16). Byström and Sjögren completed classic research protocols that demonstrated a significant reduction in bacterial loads after instrumentation and irrigation using only saline, but also found that all of the canals still had bacteria present after the initial appointment. Later, they showed that the combined use of NaOCl and EDTA improved the elimination of bacteria in the canals even more than just saline, but again, there were bacteria left in the canals (17, 18). More recently, Safavi stated that lipopolysaccharide from the cell walls of Gram-negative bacteria could be detoxified by calcium hydroxide (19).

In 1993, Foster et al. found that the removal of the smear layer facilitated the diffusion of hydroxyl ions through the dentinal tubules and improved the ability to kill bacteria (20). Therefore in this study, 17% EDTA followed by 6% NaOCl were used as part of the final irrigation sequence to ensure that the smear layer was removed from the internal canal wall prior to the placement of calcium hydroxide (21). Although a smear layer was created when the 1 mm wells were created on the side of the root to facilitate the pH reading, it was not removed. Leaving the smear layer did not prevent the hydroxyl ions from penetrating from the internal canal space into the wells, and it may be useful to repeat the protocol to see if more hydroxyl ions are able to penetrate when the smear layer is removed.

Although several different methods of calcium hydroxide intracanal placement have been reported in the literature (22), we chose to place the calcium hydroxide with a NaviTip based on a pilot study that confirmed our ability to precisely control the level to which the calcium hydroxide was placed.

The results of this study demonstrated that the pH in the experimental cavities increased significantly as the canals were more completely filled with calcium hydroxide. There was an immediate and rapid increase in the pH of the experimental cavities of Groups A and B from the control cavities of Group D over the first 14 days, and then a gradual return to the average pH level of the control Group D at days 21 and 28. These results confirm previous reports that calcium hydroxide provides hydroxyl ions that diffuse through the dentinal tubules to the root surface. It also demonstrated that the pH dropped after 14 days returning to the pH level of the control group which had no calcium hydroxide treatment. These results also indicate that it may be efficacious to replace calcium hydroxide at least every 4 weeks. Thus, the beneficial effects of calcium hydroxide appear to be related not only to time but also to the placement of calcium hydroxide to within 1 mm of the radiographic apex.

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