EVALUATION OF FOUR CALCIUM HYDROXIDE PLACEMENT TECHNIQUES USING CBCT

by

Blake Aaron Donaldson, DDS
Lieutenant, Dental Corps
United States Navy

A thesis submitted to the Faculty of the
Endodontics Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

June 2019

Distribution Statement

Distribution A: Public Release.

The views presented here are those of the author and are not to be construed as official or reflecting the views of the Uniformed Services University of the Health Sciences, the Department of Defense or the U.S. Government.

Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
Bethesda, Maryland

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Blake Aaron Donaldson

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Oral Biology at the June 2019 graduation.

Research Committee:

[redacted]

Glen M. Imamura, DDS, MS
CAPT (ret), DC, USN
Research Committee Chair

[redacted]

Calvin B. Suffridge, DDS, MS
CDR, DC, USN
Chairman, Endodontics Dept

[redacted]

John J. Neal, DDS, MS
Program Director, Endodontics Dept

The author hereby certifies that the use of any copyrighted material in the thesis manuscript titled:

"EVALUATION OF FOUR CALCIUM HYDROXIDE PLACEMENT TECHNIQUES USING CBCT"

is appropriately acknowledged and, beyond brief excerpts, is with the permission of the copyright owner.

RESIDENT SIGNATURE

[redacted]

Blake Aaron Donaldson, LT, DC, USN
Endodontics Graduate Program
Naval Postgraduate Dental School
6 June 2019

NAVAL POSTGRADUATE DENTAL SCHOOL
BLAKE AARON DONALDSON

2019

This thesis may not be re-printed without the expressed written permission of the author.

ABSTRACT

EVALUATION OF FOUR CALCIUM HYDROXIDE
PLACEMENT TECHNIQUES USING CBCT
M.S., ENDODONTICS, 2019

Directed by: GLEN M. IMAMURA, RESEARCH COMMITTEE CHAIR
NAVAL POSTGRADUATE DENTAL SCHOOL

Introduction: Calcium hydroxide ($Ca(OH)_2$) is a commonly used inter-appointment antimicrobial medicament placed in root canal systems to kill bacteria and dissolve tissue. Previous studies have relied on 2-dimensional radiographs to evaluate $Ca(OH)_2$ placement techniques. **Purpose:** Utilize 3-dimensional cone beam computed tomography (CBCT) to evaluate the effectiveness of four different intracanal $Ca(OH)_2$ placement techniques. **Method:** A model was designed to mimic a maxillary first molar, curved second mesiobuccal canal, instrumented to size 30/.04 with a 12.5mm working length. Sixty models were 3D printed and divided into four groups (n=15) for $Ca(OH)_2$ placement using: Lentulo spiral (LS), direct injection (DI), hand file (HF), and EndoActivator (EA), followed by CBCCT imaging. Measured $Ca(OH)_2$ extent of fill and calculated the void volume within the canals using Invivo 5 software. $Ca(OH)_2$ extrusion was detected using pH paper placed at canal exit. Data were analyzed using one-way Analysis of Variance (ANOVA) and Tukey post-hoc comparisons (α=0.05). **Results:** Mean apical extent of fill: DI=11.83mm HF=12.73mm, LS=13.03mm, EA=13.5mm. Because EA reached maximum extent of fill (13.5 mm) every placement, it was excluded from $Ca(OH)_2$ fill analysis due to lack of variability. ANOVA revealed no significant differences between the remaining 3 groups (P=0.06). Mean void volumes:

EA=0.76mm^3, DI=0.96mm^3, HF=1.97mm^3, LS=2.19mm^3. ANOVA revealed significant differences between the 4 groups ($P<0.001$). Tukey post hoc comparisons revealed EA and DI ($P=0.878$), and LS and HF ($P=0.842$) statistically equivalent. Comparisons of EA to LS ($P<0.001$) and HF ($P<0.001$), or DI to LS ($P<0.001$) and HF ($P=0.002$) were significant. Incidence of extrusion: LS=20%, DI=26.67%, HF=26.67%, EA=86.67%.

Conclusions: This model of instrumented curved canals found EndoActivator consistently filled the entire canal with the smallest volume of voids, but was more prone to extrusion compared to the other techniques. Of the remaining groups, direct injection demonstrated similar low void volumes with a relatively low incidence of extrusion.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CA	California
$Ca(OH)_2$	Calcium Hydroxide
CBCT	Cone Beam Computed Tomography
Cm	centimeter
DI	Direct Injection
EA	EndoActivator
GA	Georgia
HF	Hand File
kV	kilovolt
LS	Lentulo Spiral
MA	Massachusetts
mA	milliamp
mL	milliliters
mm	millimeters
P	probability value (significance)
rpm	revolutions per minute
s	seconds
UT	Utah
µm	micrometers

I. REVIEW OF THE LITERATURE

The bacterial etiology of pulpal and periradicular disease pathogenesis has been firmly established in endodontic literature[1-6]. Accordingly, the ultimate goal of endodontic therapy is the complete removal of bacteria, their byproducts, and any tissue debris that could serve as a bacterial substrate, in order for healing to occur[7]. Byström demonstrated that many root canal systems still harbor bacteria after mechanical instrumentation[8], even with the use of antimicrobial irrigation solutions[9], and that bacterial numbers increased rapidly between appointments when an antimicrobial intracanal medicament was not used[8-10]. Additionally, it has been shown that endodontic treatment outcomes are significantly increased when a negative culture is obtained prior to obturation[11,12]. For these reasons, placement of an antimicrobial intracanal medicament has been recommended between appointments[13,14].

Calcium hydroxide ($Ca(OH)_2$) was first introduced to dentistry (in the form of Calxyl) by Hermann, who recommended its use as a root canal filling in 1920[15]. Matsumiya and Kitamura published the first significant English language calcium hydroxide study in 1960, demonstrating that $Ca(OH)_2$ paste killed bacteria and allowed periapical healing in experimentally infected dog teeth[16]. Many subsequent studies have supported the antimicrobial action of $Ca(OH)_2$[17-20]. It has also been demonstrated that $Ca(OH)_2$ is able to proteolytically dissolve pulp tissue[21-23], and to degrade bacterial lipopolysaccharide[24,25]. Although $Ca(OH)_2$ is capable of diffusing through dentinal tubules[26,27], it must be in direct contact to dissolve pulpal tissue, and to exert its maximum antimicrobial effects[28,29].

Because of the need for direct contact, the goal of $Ca(OH)_2$ placement should be a dense and homogenous three-dimensional fill of the entire canal. Any voids in the $Ca(OH)_2$ fill could harbor bacteria or undissolved necrotic tissue. Several studies have been published with the aim of determining the most effective $Ca(OH)_2$ placement technique[30-39]. Traditionally, $Ca(OH)_2$ placement has been performed using hand files, Lentulo spirals, and by direct injection. The EndoActivator is a handheld device with disposable agitation tips designed to provide subsonic activation as an adjunct to canal irrigation. The EndoActivator has been shown to be effective in $Ca(OH)_2$ removal from the canal[40], and has been suggested as a method for intracanal placement[41], though only one study has evaluated it for this purpose[42]. A major limitation of previous $Ca(OH)_2$ placement studies is the use of traditional two-dimensional radiographs to subjectively evaluate fill quality[30-39,42].

Cone beam computed tomography (CBCT) is an imaging modality that is increasingly used in endodontics[43-45], and has been shown to produce a three-dimensional representation of maxillofacial structures with an extremely high degree of accuracy[46-49]. The use of CBCT allows three-dimensional (3D) measurement of voids and length discrepancies of canal obturation materials. A literature review failed to return any studies utilizing CBCT evaluation of $Ca(OH)_2$ intracanal placement techniques. The aim of this study is to utilize CBCT to evaluate the effectiveness of four different intracanal $Ca(OH)_2$ placement techniques.

II. MATERIALS AND METHODS

Simulated curved canals were designed according to the following specifications: 13.5 mm canal length[50], with a 26° angle of curvature and 8.5 mm radius of curvature[51]. The canal diameter at the orifice was 0.8 mm, decreasing with a continuous 0.04 mm taper to a diameter of 0.3 mm located 1 mm from the canal exit. Beginning 0.524 mm from the canal exit, the diameter gradually increased to a final diameter of 0.502 mm at the patent canal exit[52]. Using a Form 2 stereolithography 3D printer and High Temp Resin (Formlabs, Somerville, MA), the simulated canals were 3D printed in poly lactic acid blocks with the canal orifice at the top of the block and the patent apex exiting the lateral side.

$Ca(OH)_2$ powder and saline were combined in a 1 g:1 mL ratio and vacuum mixed to a paste consistency[53]. Four $Ca(OH)_2$ placement techniques were evaluated: Lentulo spiral (LS; Dentsply Sirona, Ballaigues, Switzerland), direct injection (DI), hand file (HF), and EndoActivator (EA; Dentsply Sirona). In the LS group, excess $Ca(OH)_2$ was placed at the orifice, and a size RA 001 Lentulo spiral was rotated at 15,000 rpm[38] and introduced into the canal as apically as possible due to curvature[30]. This process was repeated three times. In the DI group, a 29 gauge NaviTip syringe (Ultradent, West Jordan, UT) was inserted into the canal 1mm short of working length and $Ca(OH)_2$ was gently expressed[30]. In the HF group, a size 25 Flex-O file (Dentsply Sirona) with a rubber stopper was measured to 12.5 mm, loaded with excess $Ca(OH)_2$, inserted to working length, and rotated counterclockwise[30]. This procedure was repeated three times. In the EA group, the hand file technique was initially utilized to place $Ca(OH)_2$, followed by the EndoActivator with a medium (#25/0.04) tip inserted to a distance 2 mm

short of working length and activated at 6,000 cycles per minute for 20 seconds [42]. This process was repeated three times.

All procedures were performed by a single operator that was not involved in the design of the simulated canals. The provider was allowed to view a periapical radiograph of the canal, and was given a working length measurement of 12.5 mm. Litmus paper was attached over the apical foramen to detect any apical extrusion of calcium hydroxide. Blocks were masked with electrical tape to prevent direct visualization of the canal system during the procedures[53]. After placement of $Ca(OH)_2$ using the various techniques, a CS 9300 (Carestream Dental, Atlanta, GA) CBCT was used to acquire a 5 x 5 cm small volume scan with a 90 μm^3 voxel size. The exposure settings were 80 kV and 5 mA for 19.96 s.

The image volumes were viewed with Invivo 5 3D imaging software (Anatomage, San Jose, CA). $Ca(OH)_2$ placement techniques were evaluated by three criteria: extent of apical fill, amount of voids, and incidence of apical extrusion. To calculate the extent of apical fill, the distance between the most apical extent of $Ca(OH)_2$ and the canal exit was measured on the CBCT scan, and this number was subtracted from the total canal length of 13.5 mm. To evaluate the amount of voids, the image volume was viewed slice-by-slice in the coronal plane, using the free-form area measuring tool to calculate the area of each void. The void areas were multiplied by the volume slice thickness (0.09 mm) and summed to obtain a total void volume for each fill[54]. To evaluate the incidence of apical extrusion, the litmus paper was inspected under a light microscope to determine if any alkaline color change was present.

Statistical analysis of data was performed using a one-way analysis of variance (ANOVA). Post-hoc comparisons of groups were performed using Tukey's Honest Significant Difference test.

III. RESULTS

Apical extent of fill data is shown in Figure 1. EA exhibited the greatest extent of apical fill, completely filling the entire canal every time (mean: 13.5 mm). Because of the lack of variability in the EA data, this group was excluded from statistical analysis of extent of apical fill. ANOVA revealed no significant difference between the remaining three groups (P = .06).

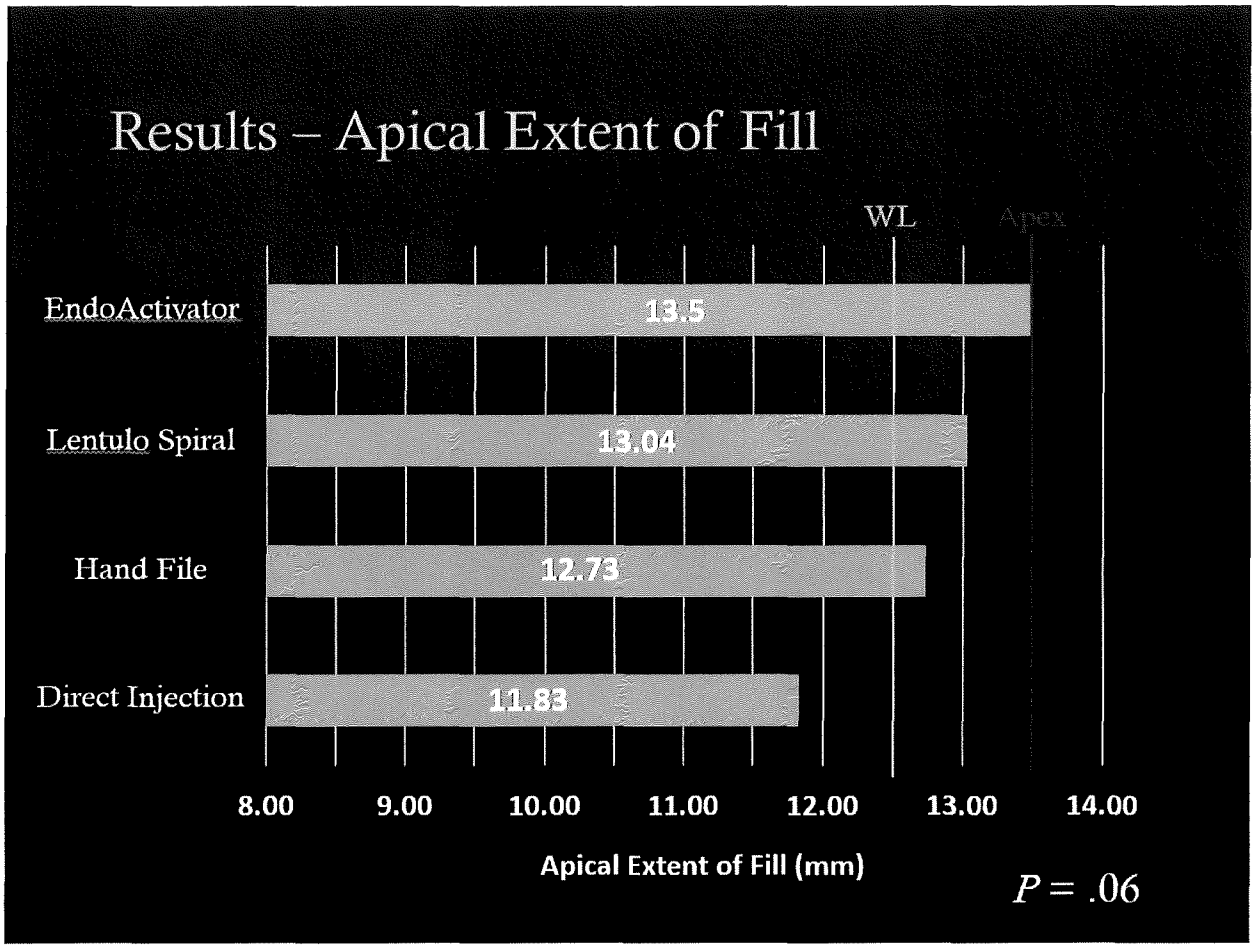

Figure 1

Data concerning the amount of voids is shown in Figure 2. EA produced the lowest total void volume (mean: 0.76 mm^3), followed by DI (mean: 0.96 mm^3), HF (mean: 1.97 mm^3), and LS (mean: 2.19 mm^3). ANOVA revealed significant differences between the 4 groups (P = <

.001). Post hoc comparisons of EA to LS (P = < .001) and HF (P = < .001) were statistically significant, as were DI to LS (P = < .001) and HF (P = .002). EA and DI were statistically equivalent (P = .878), as were HF and LS (P = .842).

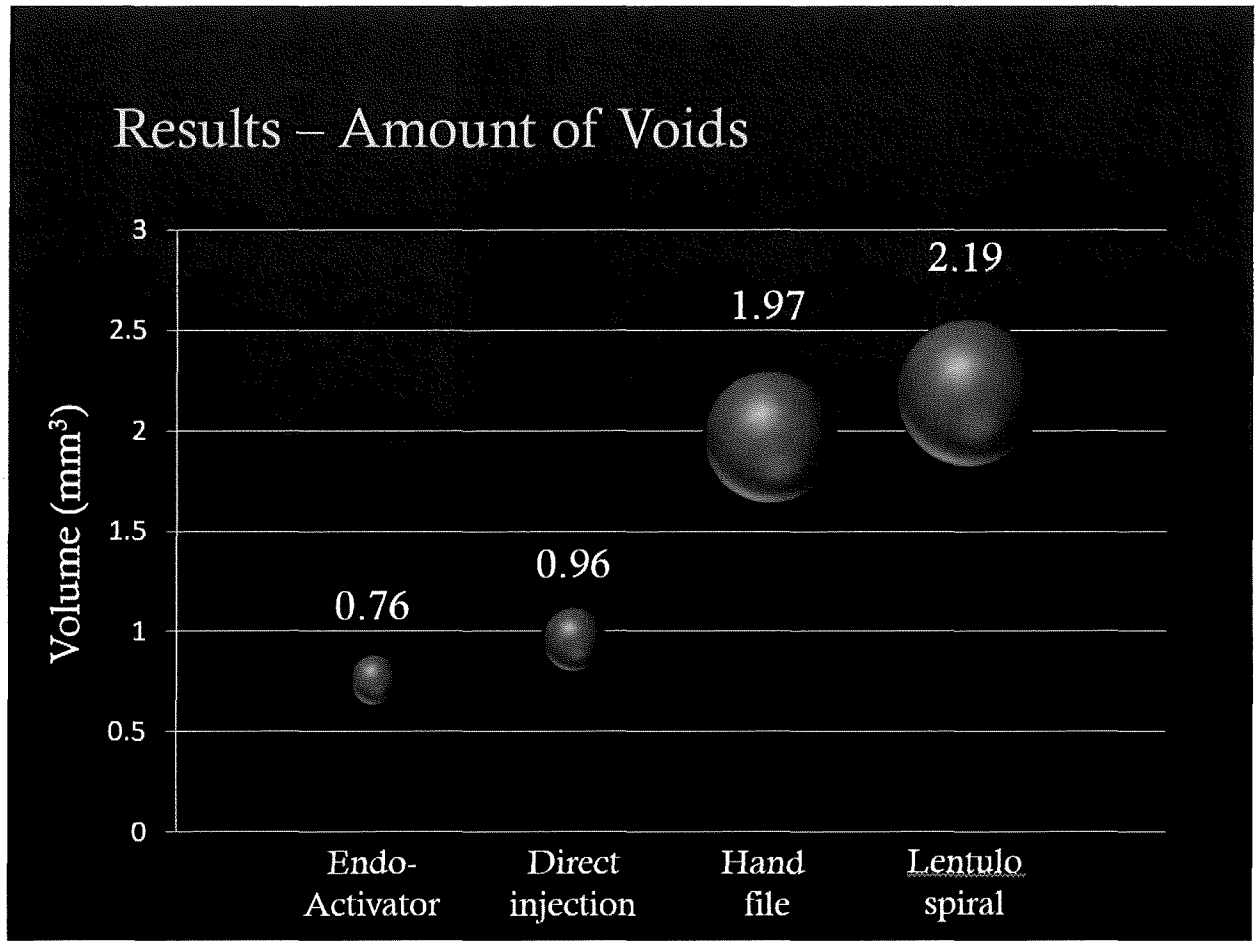

Figure 2

The incidence of extrusion data is shown in Figure 3. Extrusion incidence was highest in the EA group, with occurrence in 13 of 15 samples. DI and HF groups both had extrusion in 4 of 15 samples. The LS group had the lowest incidence of extrusion in 3 of 15 samples.

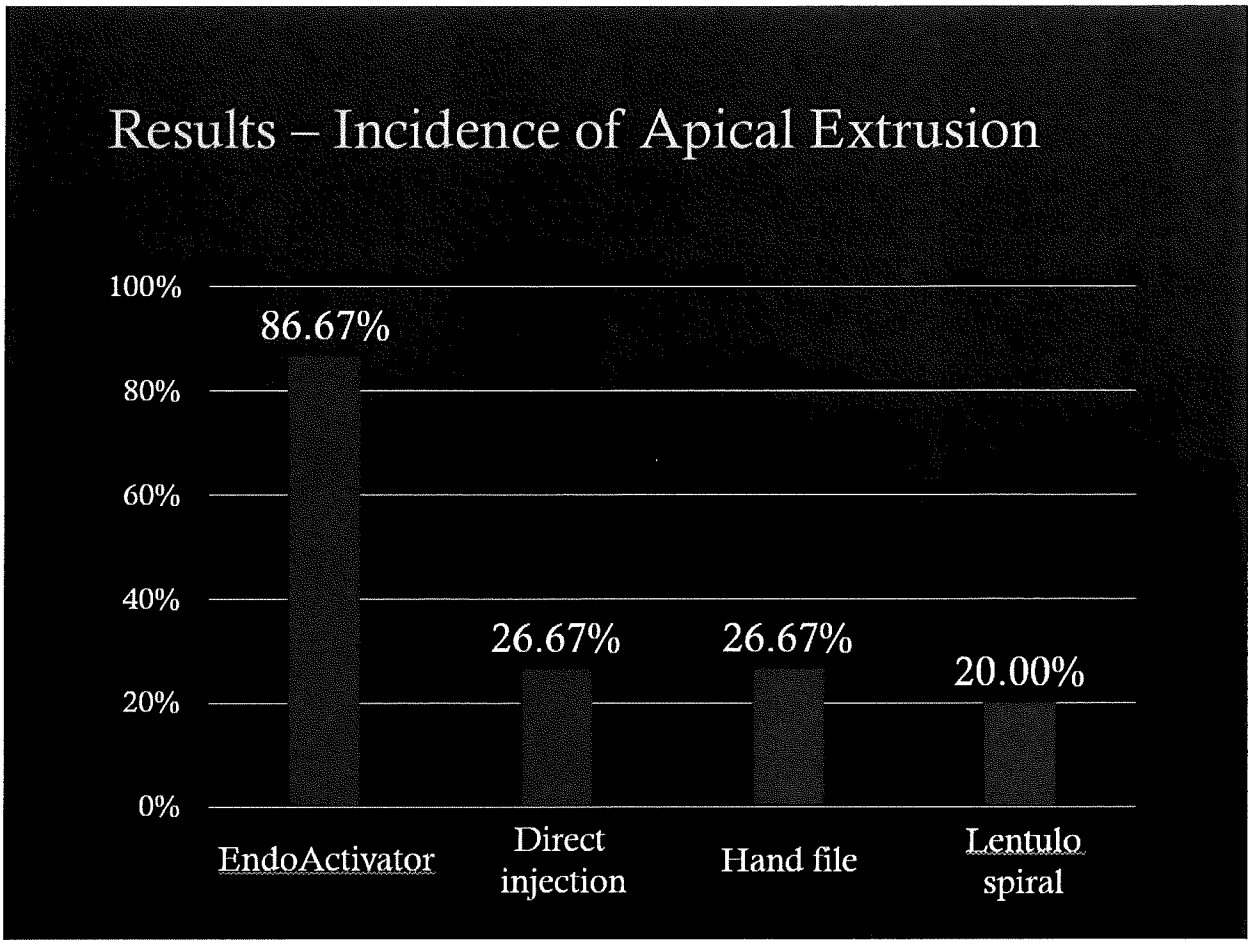
Results – Incidence of Apical Extrusion
100%
80%
60%
40%
20%
0%
86.67%
26.67%
26.67%
20.00%
EndoActivator
Direct injection
Hand file
Lentulo spiral

Figure 3

IV. DISCUSSION

When placing $Ca(OH)_2$, many providers today use a pre-mixed paste in a propylene glycol or cellulose medium, which provides different flow characteristics. It has been demonstrated that $Ca(OH)_2$ in a glycerin medium produced superior fills in the apical third when compared with a sterile water medium[53]. This study utilized $Ca(OH)_2$ powder and sterile saline in a 1 g:1 mL ratio vacuum mixed to a creamy, homogenous consistency. Pre-mixed $Ca(OH)_2$ pastes could not be used in this study because they contain barium sulfate radiopacifier, which produces CBCT artifacts that could obscure void and length measurements. In the DI group, $Ca(OH)_2$ powder repeatedly clogged inside the 29 gauge NaviTip syringe. The difficulties experienced with this placement technique likely explains why this group demonstrated the shortest fill lengths. The direct injection technique may have produced better results with a larger gauge syringe, or with a propylene glycol medium instead of saline.

The standardized canal designed for this study simulated the dimensions and average curvature[51] of a second mesiobuccal canal of a maxillary first molar instrumented to a 30/.04 preparation size. The 13.5 mm length of the canal was based on average lengths of the maxillary first molar mesiobuccal root[50], and this length served as the maximum value for extent of apical fill. The apical terminus of the canals replicated the dimensions measured by Kuttler[52], and was designed to be patent to allow evaluation of each placement technique's propensity for extrusion. The EndoActivator was most prone to extrusion, which occurred in 86.7% of the samples. During placement, the tip was introduced to a depth 2 mm short of the working length, replicating the methodology of the only other study that has evaluated the EndoActivator for $Ca(OH)_2$ placement,

although that study did not evaluate extrusion[42]. The manufacturer's instructions for the EndoActivator also recommend using the instrument 2 mm short of working length when activating irrigant solutions. In order to avoid extrusion, this distance may need to be increased if using the EndoActivator to place $Ca(OH)_2$. While limited extrusion of $Ca(OH)_2$ may not have an effect on treatment outcomes[55], it is caustic to tissues and can be extremely destructive if extruded into the inferior alveolar canal[56], so extreme caution should be exercised during placement.

Voids have the potential to harbor bacteria and undissolved necrotic tissue which are protected from the direct contact effects of $Ca(OH)_2$. The EA group produced the lowest total volume of voids, followed by DI, with no statistical difference between them. The void volumes in the LS and HF groups were greater than double the volumes in the EA and DI groups, and the difference was statistically significant. To account for the differing amounts of $Ca(OH)_2$ present in the canals, the void volumes were divided by apical fill length measurements, giving a value that allowed a more fair comparison between groups; the statistically significant differences of void volumes between groups remained unchanged when accounting for apical fill lengths. These results contradict a previous study which found that the EndoActivator produced significantly more voids than hand files and Lentulo spiral[42].

This *in vitro* model for $Ca(OH)_2$ placement in a simulated curved canal has several limitations. Although the simulated canals are standardized and designed to closely mimic apical anatomy, it is difficult to speculate how the results would translate to an in-vivo clinical situation. $Ca(OH)_2$ extrusion when using the EndoActivator may be reduced when apical tissues and canal contents/debris are present. The results may also

have been different if the mixture utilized a glycerin or propylene glycol medium, especially in the case of the direct injection technique. This possibility should be evaluated in a future study.

V. CONCLUSION

Under the limitations of this *in vitro* model for $Ca(OH)_2$ placement in simulated curved canals, the EndoActivator demonstrated the most dense, three-dimensional fills of the entire canal system with the smallest volume of voids present, but was significantly more prone to extrusion than the other techniques. Of the remaining groups, direct injection produced low void volumes similar to EndoActivator, but with a much lower incidence of extrusion, and may represent the safer choice for $Ca(OH)_2$ placement.

REFERENCES

1. Miller WD. An introduction to the study of the bacterio-pathology of the dental pulp. The Dental Cosmos. 1894;36(7):505-28.
2. Henrici AT, Hartzell TB. The bacteriology of vital pulps. J Dent Res. 1919;1(4):419-22.
3. Kakehashi S, Stanley HR, Fitzgerald RJ. The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Pathol. 1965;20:340-9.
4. Sundqvist G. Bacteriological studies of necrotic dental pulps. Odontol Dissertation No 7, Univ of Umeå, Sweden. 1976.
5. Möller, ÅJR, Fabricius L, Dahlén G, Öhman AE, Heyden G. Influence on periapical tissues of indigenous oral bacteria and necrotic pulp tissue in monkeys. Scand J Dent Res. 1981;89(6):475-84.
6. Pitt Ford TR. The effects on the periapical tissues of bacterial contamination of the filled root canal. Int Endod J. 1982;15(1):16-22.
7. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18(2):269-96.
8. Byström 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.
9. Byström A, Sundqvist G. The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy. Int Endod J. 1985;18(1):35-40.
10. Byström 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.
11. Sjögren 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. 1997;30(5):297-306.
12. Waltimo T, Trope M, Haapasalo M, Ørstavik D. Clinical efficacy of treatment procedures in endodontic infection control and one year follow-up of periapical healing. J Endod. 2005;31(12):863-6.
13. Heithersay G. Calcium hydroxide in the treatment of pulpless teeth with associated pathology. J Brit Endod Soc. 1975;8(2):74-93.
14. Chong BS, Pitt Ford TR. The role of intracanal medication in root canal treatment. Int Endod J. 1992;25(2):97-106.
15. Hermann BW. Kalziumhydroxid als mittel zum behandeln und füllen von zahnwurzelkanälen. Würzburg, Dissertation, 1920.
16. Matsumiya S, Kitamura M. Histo-pathological and histo-bacteriological studies of relation between the condition of sterilization of the interior of the root canal and the healing processes of periapical tissues in experimentally infected root canal treatment. Bull Tokyo Dent Coll. 1960;1:1-19.
17. Cvek M, Hollender L, Nord CE. Treatment of non-vital permanent incisors with calcium hydroxide. Odontol Revy. 1976;27(2):93-108.
18. Byström A, Claesson R, Sudqvist G. The antibacterial effect of camphorated paramonochlorophenol, camphorated phenol and calcium hydroxide in the treatment of infected root canals. Endod Dent Traumatol. 1985;1(5):170-5.
19. Sjögren U, Figdor D, Spångberg L, Sundqvist G. The antimicrobial effect of calcium hydroxide as a short-term intracanal dressing. Int Endod J. 1991;24(3):119-25.
20. Siqueira JF, Guimarães-Pinto T, Rôças IN. Effects of chemomechanical preparation with 2.5% sodium hypochlorite and intracanal medication with calcium hydroxide on cultivable bacteria in infected root canals. J Endod. 2007;33(7):800-5.
21. Hasselgren G, Olsson B, Cvek M. Effects of calcium hydroxide and sodium hypochlorite on the dissolution of necrotic porcine muscle tissue. J Endod. 1988;14(3):125-7.
22. Andersen M, Lund A, Andreasen JO, Andreasen FM. In vitro solubility of human pulp tissue in calcium hydroxide and sodium hypochlorite. Endod Dent Traumatol. 1992;8(3):104-8.
23. Wadachi R, Araki K, Suda H. Effect of calcium hydroxide on the dissolution of soft tissue on the root canal wall. J Endod. 1998;24(5):326-30.

24. Safavi K, Nichols F. Effect of calcium hydroxide on bacterial lipopolysaccharide. J Endod. 1993;19(2):76-8.
25. Silva L, Nelson-Filho P, Leonardo MR, Rossi MA, Pansani CA. Effect of calcium hydroxide on bacterial endotoxin in vivo. J Endod. 2002;28(2):94-8.
26. Tronstad L, Andreasen JO, Hasselgren G, Kristerson L, Riis I. pH changes in dental tissues after root canal filling with calcium hydroxide. J Endod. 1981;7(1):17-21.
27. Mohammadi Z, Dummer PMH. Properties and applications of calcium hydroxide in endodontics and dental traumatology. Int Endod J. 2011;44(8):697-730.
28. Stevens RH, Grossman LI. Evaluation of the antimicrobial potential of calcium hydroxide as an intracanal medicament. J Endod. 1983;9(9):372-4.
29. Siqueira JF, Lopes HP. Mechanisms of antimicrobial activity of calcium hydroxide: a critical review. Int Endod J. 1999;32(5):361-9.
30. Sigurdsson A, Stancill R, Madison S. Intracanal placement of $Ca(OH)_2$: a comparison of techniques. J Endod. 1992;18(8):367-70.
31. Staehle HJ, Thomä C, Müller H-P. Comparative in vitro investigation of different methods for temporary root canal filling with aqueous suspensions of calcium hydroxide. Endod Dent Traumatol. 1997;13(3):106-12.
32. Deveaux E, Dufour D, Boniface B. Five methods of calcium hydroxide intracanal placement: an in vitro evaluation. Oral Surg Oral Med Oral Pathol. 2000;89(3):349-55.
33. Estrela C, Mamede Neto I, Lopes HP, Estrela CRA, Pécora JD. Root canal filling with calcium hydroxide using different techniques. Braz Dent J. 2002;13(1):53-6.
34. Öztan MD, Akman A, Dalat D. Intracanal placement of calcium hydroxide: a comparison of two different mixtures and carriers. Oral Surg Oral Med Oral Pathol. 2002;94(1):93-7.
35. Torres CP, Apicella MJ, Yancich PP, Parker MH. Intracanal placement of calcium hydroxide: a comparison of techniques, revisited. J Endod. 2004;30(4):225-7.
36. Peters CI, Koka RS, Highsmith S, Peters OA. Calcium hydroxide dressings using different preparation and application modes: density and dissolution by simulated tissue pressure. Int Endod J. 2005;38(12):889-95.
37. Simcock, RM, Hicks ML. Delivery of calcium hydroxide: comparison of four filling techniques. J Endod. 2006;32(7):680-2.
38. Deonizio MD, Sydney GB, Batista A, Estrela C. Root canal filling with calcium hydroxide paste using Lentulo spiral at different speeds. Dental Press Endod. 2011;1(3):58-63.
39. Tan JME, Parolia A, Pau AKH. Intracanal placement of calcium hydroxide: a comparison of specially designed paste carrier technique with other techniques. BMC Oral Health. 2013;13:52.
40. Alturaiki S, Lamphon H, Edrees H, Ahlquist M. Efficacy of 3 different irrigation systems on removal of calcium hydroxide from the root canal: a scanning election microscopic study. J Endod. 2015;41(1):97-101.
41. Ruddle CJ. Endodontic advancements: game-changing technologies. Dent Today. 2009;28(11):82,84.
42. Galvão T, Camargo B, Armada L, Alves F. Efficacy of three methods for inserting calcium hydroxide-based paste in root canals. J Clin Exp Dent. 2017;9(6):e762-6.
43. Patel S. New dimensions in endodontic imaging: part 2-cone beam computed tomography. Int Endod J. 2009;42(6):463-75.
44. Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology. Use of cone-beam computed tomography in endodontics. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;111(2):234–7.
45. Setzer FC, Hinckley N, Kohli MR, Karabucak B. A Survey of cone-beam computed tomographic use among endodontic practitioners in the United States. J Endod. 2017;43(5):699-704.
46. Baumgaertel S, Palomo JM, Palomo L, Hans MG. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop. 2009;136:19-28.
47. Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. Am J Orthod Dentofacial Ortho. 2010;137(4 Suppl):S130-5.

48. Bornstein MM, Wasmer J, Sendi P, Janner SFM, Buser D, von Arx T. Characteristics and dimensions of the Schneiderian membrane and apical bone in maxillary molars referred for apical surgery: a comparative radiographic analysis using limited cone beam computed tomography. J Endod. 2012;38(1):51-7.
49. Jeger FB, Janner SFM, Bornstein MM, Lussi A. Endodontic working length measurement with preexisting cone-beam computed tomography scanning: A prospective, controlled clinical study. J Endod. 2012;38(7):884-8.
50. J. Craig Baumgartner MS, DDS, PHD, John I. Ingle, DDS, MSD, Leif K. Bakland, DDS, eds. 2008. Ingle's Endodontics. Hamilton, Ontario. BC Decker Inc.
51. Schäfer E, Diez C, Hoppe W, Tepel J. Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. J Endod. 2002 Mar;28(3):211-6.
52. Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc. 1955;50(5):544-52.
53. Rivera EM, Williams K. Placement of calcium hydroxide in simulated canals: comparison of glycerine versus water. J Endod. 1994;20(9):445-8.
54. Singh R, Chaudhary S, Manuja N, Chaitra TR, Sinha AA. Evaluation of different root canal obturation materials in primary teeth using cone beam computerized tomography. J Clin Pediatr Dent. 2015;39(5):462-9.
55. De Moor RJG, De Witte AMJC. Periapical lesions accidentally filled with calcium hydroxide. Int Endod J. 2002;35(11):946-58.
56. Olsen JJ, Thorn JJ, Korsgaard N, Pinholt EM. Nerve lesions following apical extrusion of non-setting calcium hydroxide: a systematic case review and report of two cases. J Craniomaxillofac Surg. 2014;42(6):757-62.