Tricalcium phosphate as an adjunct to apical closure in pulpless permanent teeth

Sidney C. Roberts, Jr., DDS, MS, and J. David Brilliant, DDS, MS, Columbus, Ohio

Tricalcium phosphate was effective in inducing apical closure in human permanent pulpless teeth with flaring apices. However, it was not more effective than the calcium hydroxide that was used as a control.

One of the basic principles of endodontic therapy has been the obliteration of the root canal space. This goal has been achieved by condensing an inert material into the root canal. This can be effectively accomplished only when an apically diminishing taper exists, that is, when the diameter of the apical portion of the canal is less than the diameter of the more coronal portion.

Incompletely formed pulpless teeth have been a special problem because the apical diameter of the canal is greater than the cervical diameter. This problem has been approached from the surgical and nonsurgical aspect. The surgical method has proved unsatisfactory because, in young patients, such treatment has resulted in dental management problems or in a deleterious effect on the crown-root ratio, or both.[1-6]

The goal of the nonsurgical approach has been to induce apical closure so that the root canal can be completely filled. The continuation of apical development after endodontic therapy has indicated the capability of the apex to resume formation.[2,5-17] Continued apical development has been seen with a variety of materials and methods.[2-5,7-10,12,17-27] Calcium hydroxide, used in different techniques, has been the most favored method of inducing apical closure.[1-5,7-10,12,18-20,22,24,25,28,29]

Tricalcium phosphate ($Ca_3(PO_4)_2$) has been successfully used to induce apical closure in monkeys.[13] The purpose of this study was to evaluate clinically the effect of tricalcium phosphate used as a canal dressing in human pulpless teeth with open apices.

Method and Materials

This study used clinical patients at Ohio State University who had pulpless teeth with open apices (Tables 1-4). Sixteen teeth were used. The canal dressings, tricalcium phosphate* and calcium hydroxide†, were placed in identical glass vials, sealed, coded, and dry-heat sterilized at 162 C for 1½ hours. They were used alternately as the patients were treated. The identities of the canal dressings were not available to the clinician when the powders were inserted into the canals.

Technique of Clinical Procedure

At the first appointment, the medical and dental histories, diagnostic tests, and pretreatment radiographs (Fig 1A; 2, left; 3, top) were made; the diagnoses were established (Tables 1, 2). A local anesthetic was administered; then, a rubber dam was applied to isolate the tooth. After the access opening was made, the canal was biomechanically prepared (Fig 1B) with files and Gates-Glidden burs, using 5.25% sodium hypochlorite as an irrigating solution. After drying the canal, a sterile cotton pledget was moistened with Formocresol, blotted dry, and placed into the pulp chamber. The access opening was sealed with a reinforced zinc oxide and eugenol temporary restoration.

After seven to ten days, all patients were asymptomatic. The local anesthetic was administered, and the rubber dam was placed. The canal was irrigated with 5.25% sodium hypochlorite after the temporary restoration was removed. Subsequently, the canals were dried with paper points. If no blood was present, a no. 40 file was manipulated apical to the working length to initiate bleeding. The dry, powdered canal dressing was condensed in a stepwise fashion in the canal from the apex to within 4 mm of the access opening (Fig 1C) Radio-

graphs were taken to confirm the condensation. The access opening and pulp chamber were sealed with a reinforced zinc oxide and eugenol temporary restoration, and posttreatment radiographs were made.

Paralleling technique radiographs were taken at 12-week intervals to evaluate apical development, periapical radiolucent areas and internal and external resorption. After six months, the root canal was opened; a no. 25 curved file and the largest file used at the working length were used to evaluate an apical stop (Fig 1D, E). If an apical stop was not found, the canal was refilled with the same canal dressing by the previous method. When an apical stop was evident, the root canal was obturated in the following manner. All master cones were fitted tightly to within 1 mm of the apical stop. The master cone then was soaked in chlororosin for 20 to 25 seconds and pushed apically until it could not be compressed further. The accessory gutta-percha cones were individually dipped in chlororosin for approximately five seconds before their condensation into the canal space with spreaders. The pulp chamber and access opening were sealed with a reinforced zinc oxide and eugenol temporary restoration. Posttreatment radiographs (Fig 1F) were evaluated for density of filling, accessory and lateral canal filling, extrusion of the plasticized gutta-percha past the apex, apical development and closure, periapical radiolucent areas, and internal and external resorption (Tables 3,4).

Physical and Chemical Properties of the Canal Dressings

Both canal dressings were white, odorless powders. The particle size for both dressings was measured using a light microscope with a micrometer disk. For tricalcium phosphate, the smallest particles were less than 1 micrometer (μm) and the largest particles were 10μm. These latter particles were seen infrequently in the sample specimen. The bulk of tricalcium phosphate particles ranged from about 3μm to about 5μm. For calcium hydroxide, the smallest particles were less than 1μm; the larger particles were 10μm with a few particles measuring approximately 18μm. Most particles ranged in size from 2μm to 5μm.

Both materials were hexagonal crystalline substances. The solubility of calcium hydroxide was reported to be 0.185 gm per 100 ml of water at 0 C and 0.077 gm per 100 ml of water at 100 C.[30] For tricalcium phosphate, the solubility was reported to be 0.002 gm per 100 ml water at 20 C.[30] In hot water, tricalcium phosphate decomposed.[30] The water solubility produce constant (K°) for calcium hydroxide was reported to be 1.65×10^{-1} at 20 C.[30] The measured pH for calcium hydroxide in water at 25 C was 11.8. For tricalcium phosphate, the K° value was reported to be 1.15×10^{-29} at 25 C.[31] The measured pH for tricalcium phosphate in water at 25 C was 8.6.

Results

The radiopacity of calcium hydroxide and tricalcium phosphate at the time of initial condensation was about equal. However, at the three- and six-

Table 1 • Criteria used for the establishment of diagnoses of 16 pulpless teeth.

Patient No.	Age	Sex	Medical history	Tooth	Percussion	Palpation	Sinus tract	Discoloration	Fracture	Pain
1	23	F	NSF[b]	Max left lateral incisor	NR[c]	NR	Palatal	Present	Absent	Absent
2	21	M	NSF	Max right lateral incisor	PR[d]	NR	Labial	Present	Absent	Absent
3	10	M	NSF	Max right central incisor	PR	NR	Absent	Absent	Class II[e]	Present
4	10	M	NSF	Max right central incisor	PR	PR	Labial	Present	Absent	Present
5	16	F	NSF	Max right central incisor	PR	NR	Absent	Present	Class II	Absent
6	9	M	NSF	Max left central incisor	PR	PR	Absent	Absent	Class III[e]	Present
7	10	F	NSF	Mand left 2nd premolar	PR	PR	Absent	Absent	Absent	Present
8	11	M	NSF	Max left central incisor	NR	NR	Absent	Absent	Class II	Absent
9	22	M	NSF	Max left central incisor	NR	NR	Absent	Present	Absent	Absent
10	8	F	NSF	Max right central incisor	PR	PR	Absent	Absent	Absent	Present
10	8	F	NSF	Max left central incisor	PR	PR	Absent	Present	Absent	Present
11	16	M	NSF	Max right central incisor	PR	NR	Absent	Present	Class II	Absent
11	16	M	NSF	Max left central incisor	NR	NR	Absent	Present	Class II	Absent
12	13	M	NSF	Max right central incisor	PR	NR	Absent	Absent	Class III	Absent
12	13	M	NSF	Max left central incisor	PR	NR	Absent	Absent	Absent	Absent
13	20	F	NSF	Max left lateral incisor	NR	NR	Absent	Present	Absent	Absent

b = No significant findings; c = Negative response; d = Positive response; and e = Ellis classification.

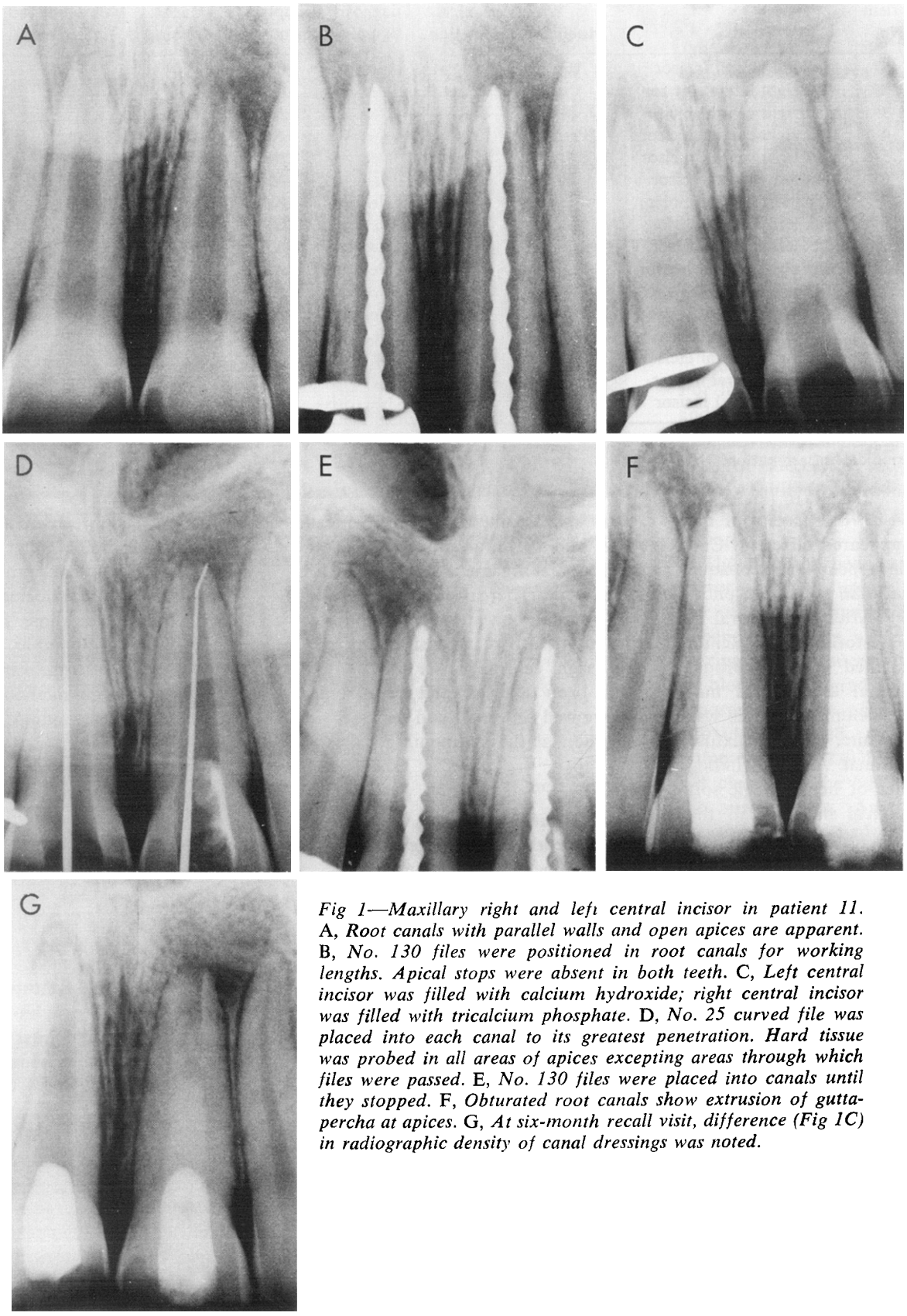

Fig 1—Maxillary right and left central incisor in patient 11. A, *Root canals with parallel walls and open apices are apparent.* B, *No. 130 files were positioned in root canals for working lengths. Apical stops were absent in both teeth.* C, *Left central incisor was filled with calcium hydroxide; right central incisor was filled with tricalcium phosphate.* D, *No. 25 curved file was placed into each canal to its greatest penetration. Hard tissue was probed in all areas of apices excepting areas through which files were passed.* E, *No. 130 files were placed into canals until they stopped.* F, *Obturated root canals show extrusion of gutta-percha at apices.* G, *At six-month recall visit, difference (Fig 1C) in radiographic density of canal dressings was noted.*

Table 2 • The diagnoses and treatment of 16 pulpless teeth.

Patient No.	Tooth	Mobility	Periapical rarefaction	Diagnosis of pulp	Periapical diagnosis	Canal dressing	Months under treatment
1	Max left lateral incisor	Absent	Present	Necrosis	CPI[b]	TCP[c]	6
2	Max right lateral incisor	Absent	Present	Necrosis	CPI	$Ca(OH)_2$[d]	8
3	Max right central incisor	Absent	Present	Necrosis	API[e]	TCP	9
4	Max right central incisor	Present	Present	Necrosis	API	TCP	11
5	Max right central incisor	Absent	Present	Necrosis	API	$Ca(OH)_2$	10
6	Max left central incisor	Absent	Present	Necrosis	API	$Ca(OH)_2$	7
7	Mand left 2nd premolar	Present	Present	Necrosis	API	TCP	6
8	Max left central incisor	Present	Present	Necrosis	CPI	$Ca(OH)_2$	—
9	Max left central incisor	Absent	Present	Necrosis	API	TCP	6
10	Max right central incisor	Present	Present	Necrosis	API	TCP	6
10	Max left central incisor	Present	Present	Necrosis	API	$Ca(OH)_2$	6
11	Max right central incisor	Absent	Present	Necrosis	CPI	TCP	5
11	Max left central incisor	Absent	Present	Necrosis	CPI	$Ca(OH)_2$	5
12	Max right central incisor	Absent	Present	Necrosis	CPI	$Ca(OH)_2$	5
12	Max left central incisor	Absent	Present	Necrosis	CPI	TCP	5
13	Max left lateral incisor	Absent	Present	Necrosis	CPI	$Ca(OH)_2$	6

b = Chronic periapical inflammation; c = Tricalcium phosphate; d = Calcium hydroxide; and e = Acute periapical inflammation.

month recall visits, the opacity of the two materials appeared different. Calcium hydroxide appeared less opaque within the canal than tricalcium phosphate (Fig 1G). After the removal of the temporary restoration, tricalcium phosphate remained in the coronal third of the canal as a dense material; whereas calcium hydroxide was found as a white, fluid mixture throughout the canal. Another finding was the presence of hemorrhagic soft tissue in the apical third of all the root canals.

Judging the deposition of hard tissue or the extent of apical closure by radiographs was impossible. It was found by probing that the hard tissue deposition occluded most of the apical surface. In all teeth, the curved no. 25 file was pushed beyond the apex at some point in its 360° rotation at the apex (Fig 1D).

After filling the root canals, some gutta-percha extruded into the crevices of the hard tissue at the apex. None of the teeth were filled beyond the apex by a mass of gutta-percha (Fig 1F; 2, right; 3, bottom).

Radiographic examinations disclosed the following information. Periapical radiolucent areas remained approximately the same size in five teeth and became smaller in five teeth. The lamina dura and width of the periodontal ligament were normal in five teeth. There was no progression of internal or external resorption at the six-month recall visit. The maxillary right central incisor of patient 10 had been avulsed and reimplanted; it showed internal and external resorption at the six-month recall visit.

Discussion

Both canal dressings were missing from the root canal after six months of treatment. Tricalcium phosphate was missing from the apical half whereas calcium hydroxide was missing from the whole canal; this may have been due to a difference in solubility. Radiographic determination of apical closure was unreliable. This supports other studies that relate the error of radiographic interpretation of periapical lesions[32-34] and calcific repair.[35] Friend[5] and Duell[26] emphasized the discrepancy between radiographic appearance and anatomical configuration of the root apex in immature teeth. Steiner and Van Hassel[29] reported their impression that apical closure occurred by concentric, circular depositions of cementum. Frank[18] described four morphological possibilities and recommended verification of the radiographic appearance with an instrument probe of the apical area. In consideration of the morphological variations and the inadequacies of radiographs, apical closure was evaluated with a small, curved file adopted from methods suggested by Weine,[2] Duell,[26] and Mullaney and Petrich.[36]

There were three teeth in which apical closure did not occur. One tooth containing tricalcium phosphate had been under treatment for 11 months. In the other teeth (both teeth in patient 10), treatment had been in progress for six months. The maxillary right central incisor had been avulsed and reimplanted; it was treated with tricalcium phosphate. After six months, radiographic interpretation of external and internal root resorptions was made. The maxillary left central incisor had been treated with calcium hydroxide. External or internal root resorption was not seen in the radiographs. Because of the differences in dental histories, the observations were not comparable.

The radiographic appearance of the periapical tissue historically has been a major criterion of judging the success of endodontic therapy. Bender

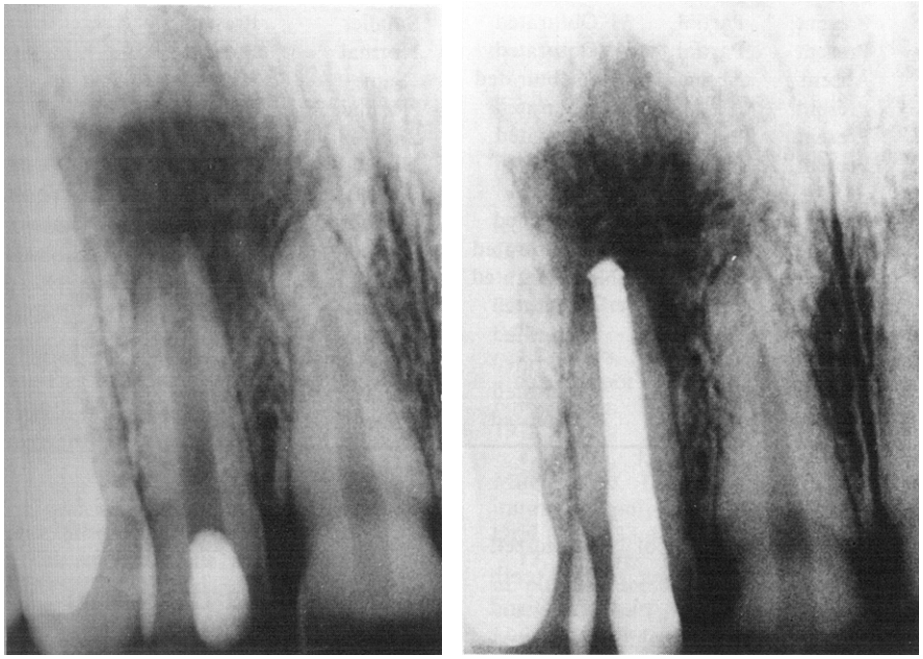

Fig 2—Maxillary left lateral incisor of patient 13. Left: Root canal with parallel walls and open apex is apparent. Right: Minute strands of plasticized gutta-percha extruded from apex following obturation after six months of treatment with calcium hydroxide.

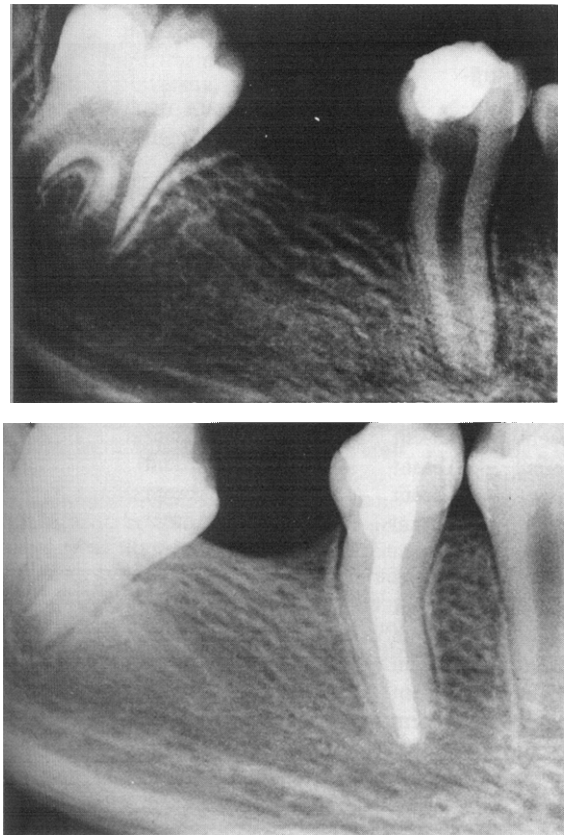

Fig 3—Mandibular left second premolar of patient 7. Top: Root canal with parallel walls and open apex is apparent. Bottom: After six months of treatment with tricalcium phosphate, root canal was obturated. Extrusion of plasticized gutta-percha at apex can be seen.

and Seltzer[32,34] have shown that the absence of rarefied areas in bone may be misleading. Spedding and others[35] have shown the fallacy in radiographic interpretation of repair of hard tissue. Seltzer[37] said that the deposition of cementum on a previously resorbed root surface was an indication of repair. On the assumption that the formation of hard tissue at the root apex was evidence of repair, initial success was attained in all cases obturated in this study. For immature teeth with open apices and periapical radiolucent areas, the achievement of a radiographic appearance of successful endodontic treatment required additional time and necessitated continued clinical observation.

The pH has been suggested as a factor inducing apical closure. The pH of calcium hydroxide has varied depending on the solvent or vehicle. Mixing the substance with tissue fluids or blood has altered the pH. Laws[24] reported that the pH of calcium hydroxide removed from a treated pulpotomy was 7.4. He attributed the pH change to the buffering effect of the tissue fluids. Any effect which the tissue fluids had on altering the pH of tricalcium phosphate was considered small; any stimulating influence on the pulpal or periapical tissue due to chemical irritation was probably minimal. Therefore, the use of a highly alkaline material to induce apical closure was unnecessary. Particle size is possibly a factor for inducing apical closure. In this study, the particle size of calcium hydroxide and tricalcium phosphate was practically identical. The design of this study did not involve an evaluation of the influence of particle size on apical closure.

Results of several histologic studies have indicated incomplete apical closure after the use of calcium hydroxide.[3,7,8,22,29] Torneck and others[22]

Table 3 • Criteria used for evaluation of posttreatment radiographs

Patient No.	Tooth	Large file stop	Small file stop	Obturated/ not obturated	Periapical rarefaction	Gutta-percha strands
1	Max left lateral incisor	Present	Partial	Obturated	Same	Present
2	Max right lateral incisor	Present	Partial	Obturated	Smaller	Present
3	Max right central incisor	Present	Partial	Obturated	Normal	Present
4	Max right central incisor	Absent	Absent	Not obturated	Same	Absent
5	Max right central incisor	Present	Partial	Obturated	Normal	Present
6	Max left central incisor	Present	Partial	Obturated	Smaller	Present
7	Mand left 2nd premolar	Present	Partial	Obturated	Normal	Present
8	Max left central premolar	N/A[b]	N/A	N/A	N/A	N/A
9	Max left central incisor	Present	Partial	Obturated	Smaller	Present
10	Max right central incisor	Absent	Absent	Not obturated	Same	Absent
10	Max left central incisor	Present	Partial	Not obturated	Same	Absent
11	Max right central incisor	Present	Partial	Obturated	Normal	Present
11	Max left central incisor	Present	Partial	Obturated	Normal	Present
12	Max right central incisor	Present	Partial	Obturated	Smaller	Present
12	Max left central incisor	Present	Partial	Obturated	Smaller	Present
13	Max left lateral incisor	Present	Partial	Obturated	Same	Present

b = Nonapplicable

reported irregularities in the apical calcified tissue which contained entrapped remnants of soft tissue. Holland and others[7] described irregular canaliculi containing connective tissue that permitted a communication between the root canal and the periodontal tissues. With the use of tricalcium phosphate, Koenigs[13] found a mineralized tissue closing the open apices of monkeys' teeth. A small canal containing blood vessels and connective tissue was observed within this mineralized tissue. The similar appearance radiographically of the extrusion of minute strands of plasticized gutta-percha at the apex of the teeth treated with tricalcium phosphate and of teeth treated with calcium hydroxide suggested communications between the root canal and periapical tissues for both canal dressings. This also was substantiated by the previous probing.

Further experimentation on animals is required to evaluate the apical calcified tissue and periodontal tissues during a period of time. It is suggested that studies be made that compare the influence of particle size and pH on apical closure.

Summary and Conclusions

In a clinical study, 16 pulpless human permanent teeth with open apices were studied. Apical closure occurred in 12 teeth. One patient failed to return for further treatment after the second appointment. Three teeth failed to close during the length of the one-year study.

The following conclusions were drawn:

—Apical closure occurred clinically when pulpless teeth were treated

Table 4 • Evaluation of periapical rarefaction and internal and external resorption in 16 pulpless teeth.

Patient No.	Tooth	Periapical rarefaction before	Periapical rarefaction after	Internal resorption before	Internal resorption after	External resorption before	External resorption after
1	Max left lateral incisor	Present	Present	Present	Absent	Absent	Absent
2	Max right lateral incisor	Present	Present	Present	Absent	Absent	Absent
3	Max right central incisor	Present	Absent	Absent	Absent	Absent	Absent
4	Max right central incisor	Present	Present	Present	Absent	Present	Absent
5	Max right central incisor	Present	Absent	Absent	Absent	Absent	Absent
6	Max left central incisor	Present	Present	Absent	Absent	Absent	Absent
7	Mand left 2nd premolar	Present	Absent	Absent	Absent	Absent	Absent
8	Max left central incisor	Present	N/A[b]	N/A	N/A	N/A	N/A
9	Max left central incisor	Present	Present	Present	Absent	Absent	Absent
10	Max right central incisor	Present	Present	Absent	Present	Absent	Present
10	Max left central incisor	Present	Present	Absent	Absent	Absent	Absent
11	Max right central incisor	Present	Absent	Absent	Absent	Absent	Absent
11	Max left central incisor	Present	Absent	Absent	Absent	Absent	Absent
12	Max right central incisor	Present	Present	Absent	Absent	Absent	Absent
12	Max left central incisor	Present	Present	Absent	Absent	Present	Absent
13	Max left lateral incisor	Present	Present	Absent	Absent	Absent	Absent

b = Nonapplicable

with tricalcium phosphate and when they were treated with calcium hydroxide. Apical closure did not occur in every case.

—Interpretation from radiographs of apical closure was unreliable.

—Probing with a small, curved endodontic file gave a clinically reliable indication of apical closure.

—The use of a very alkaline material to induce apical closure was unnecessary.

*Tricalcium phosphate resorbable ceramic, Miter Inc., Worthington, Ohio.

†Calcium hydroxide powder USP, Eli Lilly and Co., Indianapolis, Ind.

This article is based on a thesis submitted by the senior author in partial fulfillment of the requirements for the degree of MS in the graduate school, Ohio State University, Columbus, Ohio.

Dr. Brilliant is the director of graduate section, department of endodontics, Ohio State University. Requests for reprints should be directed to Dr. J. David Brilliant, Department of Endodontics, Ohio State University, College of Dentistry, 305 W 12th Ave, Columbus, Ohio 43210.

References

1. Steiner, J.C.; Dow, P.R.; and Cathey, G.M. Inducing root end closure of nonvital permanent teeth. J Dent Child 35:47 Jan 1968.

2. Weine, F.S. Endodontic therapy. St. Louis, C. V. Mosby Co. 1972, pp 2, 208, 211-215.

3. Heithersay, G.S. Stimulation of root formation in incompletely developed pulpless teeth. Oral Surg 29:620 April 1970.

4. Michanowicz, J.P.; and Michanowicz, A.E. A conservative approach and procedure to fill an incompletely formed root using calcium hydroxide as an adjunct. J Dent Child 34:42 Jan 1967.

5. Friend, L.A. The treatment of immature teeth with non-vital pulps. J Br Endodont Soc 1:28 Autumn 1967.

6. Nygaard-Östby, B. Nyere Undersokelser Over Rotbehandlings Problemet. Odontol Tidskrift 71:467, 1963.

7. Holland, R.; De Souka, V.; and De Campos Russo, M. Healing process after root canal therapy in immature human teeth. Rev Fac Odontol Aracatuba 2:269, 1973.

8. Dylewski, J. Apical closure of nonvital teeth. Oral Surg 32:82 July 1971.

9. Goldman, M. Root-end closure techniques including apexification. Dent Clin North Am 18:297 April 1974.

10. Dannenberg, J. Pedodontic endodontics. Dent Clin North Am 18:367 April 1974.

11. Laws, A.J. Condensed calcium hydroxide root filling following partial pulpectomy. NZ Dent J 67:161 July 1971.

12. Ham, J.W.; Patterson, S.S.; and Mitchell, D. Induced apical closure of immature pulpless teeth in monkeys. Oral Surg 33:438 March 1972.

13. Koenigs, J. Induced apical closure in pulpless teeth of monkeys using tricalcium phosphate. Thesis, Ohio State University, 1974.

14. Feldman, G.; Solomon, C., and Notaro, P.J. Endodontic management of traumatized teeth. Oral Surg 21:100 Jan 1966.

15. Tegart, R. Pulpectomy in young permanent incisors. J Can Dent Digest 70:622, 1963.

16. Sommer, R.F.; Ostander, F.; and Crowley, M. Clinical endodontics, ed 3. Philadelphia, W. B. Saunders Co., 1966, p 219.

17. Nygaard-Östby, B. The role of the blood clot in endodontic therapy. An experimental histologic study. Acta Odontol Scand 19:323 Dec 1961.

18. Frank, A. Therapy for the divergent pulpless tooth by continued apical formation. JADA 72:87 Jan 1966.

19. Frank, A. Endodontic endosseous implants and treatment of the wide open apex. Dent Clin North Am 11:675, 1967.

20. Moodnik, R.M. Clinical correlation of the development of the root apex and surrounding structures. Oral Surg 16:600 May 1963.

21. Torneck, C.D.; Smith J.S.; and Grindall, P. Biologic effects of endodontic procedures on developing incisor teeth. Effect of debridement and disinfection procedures in the treatment of experimentally induced pulp and periapical disease. Oral Surg 35:532 April 1973.

22. Torneck, C.D.; Smith, J.S.; and Grindall, P. Biologic effects of endodontic procedures on developing incisor teeth. Effect of debridement procedures and calcium hydroxide-camphorated parachlorophenol paste in the treatment of experimentally induced pulp and periapical disease. Oral Surg 35:541 April 1973.

23. Cook, C., and Rowbotham, T. Root canal therapy in nonvital teeth with open apices. Br Dent J 108:147 Feb 16, 1960.

24. Laws, A. Calcium hydroxide as a possible root filling material. NZ Dent J 58:199 Oct 1962.

25. Cvek, M. Clinical procedures promoting apical closure and arrest of external root resorption in non-vital permanent incisors. In Transactions of the Fifth International Conference on Endodontics, Grossman, L.I. (ed.) Philadelphia, University of Pennsylvania, 1973, pp 30-41.

26. Duell, R. Conservative endodontic treatment of the open apex in three dimensions. Dent Clin North Am 17:125 Jan 1973.

27. Myers, W., and Fountain, S. Dental pulp regeneration aided by blood and blood substitutes after experimentally induced periapical infection. Oral Surg 37:441 March 1974.

28. Kaiser, J.H. Management of wide open canals with calcium hydroxide. Presented to the American Association of Endodontists, Washington, DC, 1964.

29. Steiner, J.C., and Van Hassel, H. Experimental root apexification in primates. Oral Surg 31:409 March 1971.

30. Hodgman, C., and Holmes, H. (eds.) Handbook of chemistry. Cleveland, Ohio, Chemical Rubber Publishing Co., 1941, pp 357, 359, 1306.

31. Moreno, E., and others. Solubility of Whitlockite. IADR Program and Abstracts of Papers 48:94 March 1970.

32. Bender, I.B., and Seltzer, S. Roentgenographic and direct observation of experimental lesions in bone. Part I. JADA 62:152 Jan 1961.

33. Ramadan, A., and Mitchell, D. A roentgenographic study of experimental bone destruction. Oral Surg 15:934 Aug 1962.

34. Bender, I., and Seltzer, S. Roentgenographic and direct observation of experimental lesions in bone. Part II. JADA 62:708 June 1961.

35. Spedding, R.H.; Mitchell, D.F.; and McDonald, R.E. Formocresol and calcium hydroxide therapy. J Dent Res 44:1023 Sept-Oct 1965.

36. Mullaney, T., and Petrich, J. The ledged root canal: cause, prevention and correction. J Ky Dent Assoc 20:15 April 1968.

37. Seltzer, S. Endodontology; biologic considerations in endodontic procedures New York, McGraw-Hill Book Co., 1971, pp 341-379.