PULP REACTIONS TO A SYNTHETIC HYDROXYAPATITE
AND CHLORHEXIDINE IN MONKEYS

by

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INTRODUCTION
Tooth preservation has been the main concern of the dental profession through the years. When pulp capping was attempted many years ago, the goal was to alleviate pain and avoid tooth extraction. Since then, different materials and techniques have been used for pulp capping, with clinical observations often being the only criteria for success. It was not until 1949, that Glass and Zander reported a histologic study of capped pulps under calcium hydroxide, which showed that the dental pulp was capable of healing when this material was used.

More recently, other agents like antibiotics, corticosteroids, cyano-acrylates, and polycarboxylate cements have been tested under more controlled circumstances, and new techniques for pulp treatment have been developed.

At present, calcium hydroxide is still the most popular of the pulp capping materials. Recent formulations of this material have been developed in order to improve its physical properties. However the ideal material for capping is not yet available.

Recently ceramic-like materials, such as tricalcium phosphate, which has a similar structure to bone and dentin mineral, have been tested as implants and for pulp capping with satisfactory biological response.

Dickey, Kafrawy and Phillips recently evaluated a crystalline form of pure calcium hydroxyapatite as a pulp capping agent in monkeys. Although the material was well tolerated by the dental pulp, calcific bridging of the exposure occurred infrequently due to the difficulty of localizing the capping material to the area of the exposure.
This study evaluated pulp reactions to synthetic hydroxyapatite material, prepared in the form of a paste with either one percent chlorhexidine or distilled water as a mixing vehicle. It was thought that the difference in consistency of the material might facilitate its localization at the area of the exposure, and then might promote more frequent bridging formation.

Since hydroxyapatite takes and releases chlorhexidine slowly, the antiseptic effect of chlorhexidine would be maintained at the exposure site, promoting pulp healing, if the pulps were contaminated. However, the study was conducted on healthy pulps under aseptic conditions to determine if the addition of chlorhexidine to the apatite would have any adverse effect on the pulp.
REVIEW OF LITERATURE
Early History of Direct Pulp Capping

"Of the capping of pulps there is no end."\(^3\) This statement was made as early as 1904. Many years before this date and until the present time, pulp treatment and direct pulp capping have been discussed and practiced over and over, with the main purpose of preserving the pulp vitality and avoiding more radical and unnecessary procedures.

In ancient times, the remedies and materials used were purely for relieving pain. Early Chinese (2,700 B.C.), according to Dabrey\(^4\) (1863), used arsenic which was placed near the tooth or in the ear to alleviate pain.

Hippocrates (460-355 B.C.)\(^4\) in his book "De Affectionibus," recommended cauterization and masticatories for toothache, if the tooth was painful but not loose.

Diocles (350 B.C.) recommended application of safron for the painful tooth. Cornelius Celsus (30 B.C.-A.D. 50) discussed remedies for toothache in his book "De Medicina."\(^4\)

Others, like Pliny (a Roman writer), recommended strange remedies. One of those was the use of "a small worm which has the power of curing dental pains, when the worm is killed by rubbing it on the tooth or when it is closed up with wax in the hollow teeth."\(^4\)

Galen Claudius about A.D. 200,\(^4\) was the first who spoke of the nerves of teeth and by personal observation discovered that inflammation may occur in a tooth. Among his remedies were warm applications either on the cheek or directly on the tooth.
Abulcasis, in 1050-1122 A.D., advocated cauterization of sinuses and fistulae using a red hot iron for an aching tooth; the application of the iron was maintained until the heat had reached the apex of the tooth. Guy de Chauliac, in 1363 A.D., referred to the following materials as being used for toothache: mastick, myrrh, sulfur, camphor and wax. Arculanus was probably the one who made the significant contribution of filling teeth with gold leaf.

Pierre Fauchard (1690-1761) who is recognized as the founder of modern scientific dentistry, recommended the use of oil of cloves or oil of cinnamon in deep cavities to relieve pain, and he advised the immediate capping of an exposed pulp with lead, tin or gold.

However, Pfaff, a dentist of Frederick the Great, King of Prussia, is said to be the first German to write on pulp capping. He described a procedure in 1756 using a small piece of gold plate sufficiently large to cover the exposure which was then covered with a suitable filling.

During the nineteenth century the amount of dental literature related to pulp and its treatment started to grow. Koecker in 1826 advocated pulp capping by cauterizing with a red hot wire. The pulp was then covered with leaf of lead and the cavity was filled with gold.

In 1852, Hullihen introduced a new method of treating exposed dental pulps, which consisted of boring a hole through the root of the tooth and into the pulp chamber or canal to serve as a vent for the escape of gases from the dying pulp.

Du Bouchet in 1853 mentioned that capping nerves has never been proved to be an eminently successful operation. He believed that if a dental nerve has become exposed by decay, or has been seriously wounded
during excavating a carious tooth, it is worse than useless to attempt capping. He considered extirpation of the pulp as the operation of choice. However, he mentioned the following instances in which capping was indicated:

1. When in excavating a tooth, it comes so near the pulp as to see it through the thin layer of dentin remaining over it.

2. When in excavating a tooth, the pulp has become exposed (small pin).

3. When it is considered useful to interpose a horn material which is a good non-conductor in teeth, preventing entirely the unpleasant effect of heat and cold.

In the same year, Lee\textsuperscript{8} recommended pulp capping with gold foil, predicting success in nine of 10 cases. Hirschfield in 1874\textsuperscript{3} described methods for pulp capping using carbolic acid.

McDonnell in 1875\textsuperscript{9} proposed pulp capping with oxychloride of zinc for simple exposures. If there was hemorrhage after the exposure, he advised the application of cresote and then the oxychloride of zinc.

He mentioned that he had capped over 50 teeth with only six failures.

Years later in 1898, Hopewell Smith\textsuperscript{5} made a most important contribution to the subject, reporting on histopathological material and stating that an exposed pulp was capable of healing.

\textbf{The Present Century}

Guilford in 1904\textsuperscript{3} emphasized the importance of preserving pulp vitality because a vital pulp is free from the danger of apical abscess.
He recommended three important factors in doing the capping:

1. Non-irritating material should be used.
2. Pressure over the organ should be avoided.
3. The covering dressing must be in absolute contact with the pulp organ.

Mills\textsuperscript{10} suggested one year later that pulp capping was indicated when the exposure was small, recent and no vascular disturbances have manifested themselves.

In 1906 Clapp\textsuperscript{11} pointed out the indications and contraindications for pulp capping. He limited his cappings to those exposures which were of very recent date and limited area. He mentioned the importance of the use of rubber dam.

Abar, in 1921,\textsuperscript{12} mentioned two particular situations in which pulp capping was recommended: when roots are not fully developed, and when the rubber dam can be placed. He used a calcium phosphate and phenol compound, with oil of cloves and eugenol as capping material.

In 1922, Noel\textsuperscript{13} supported the use of pulp capping, especially in the first permanent molars and anterior teeth in very young subjects. His dressing material was carbolized resin and powder of copper cement.

Grove in 1928\textsuperscript{14} believed that the odontoblasts do not possess the capacity of regeneration, and pulp capping procedure cannot be expected to be successful. However, he justified pulp capping only in those teeth in which the root end has not been fully developed. He stressed the need of a rubber dam during the procedure.

Later in 1935, Hess et al.\textsuperscript{15} treated 119 human teeth in which pulps were freshly exposed with three different materials: (1) zinc oxide
and eugenol, (2) ignipuncture together with zinc oxide and eugenol and (3) paraffin with thymol. All teeth were examined clinically six to nine months after treatment; however, only 25% of the teeth were examined histologically. Results showed pulp healing in all instances. However, this report did not show the histologic results and had some shortcomings in its design.

Bodecker in 1938\textsuperscript{16} supported a point of view, expressed by McBeath, saying that pulp exposures in deciduous molars are common owing to the proximity of the pulp horns to the dentino-enamel junction; since root canal therapy is a difficult procedure, and premature extraction leads to complications, the alternative form of treatment of pulp exposure is pulp capping. He reported 85% success in capping of 250 deciduous teeth, based only on the cases which returned for checking. Silver nitrate in combination with various dental cements like zinc oxyphosphate were used for treatment. Success was not based only on clinical results. Some teeth were examined histologically, showing healing in some instances and localized area of round cell infection in others.

In the following year, Zander\textsuperscript{17} mentioned that Hermann prepared a capping agent containing calcium hydroxide in combination with other salts. The agent was named calxyl (which is a German combination composed of 99% Ca OH\textsubscript{2} and 1% NaCl, CaCl\textsubscript{2}, KCl, and Na HCO\textsubscript{3}). He explained the possible mode of action for this preparation; saying that the inorganic component of dentin is a hydrated tricalcium phosphate; blood is saturated or supersaturated with calcium and phosphate ions, hence any increase in calcium or phosphate ions would cause a precipitation or laying down of calcium salts. A material which contains either calcium or phosphate in
combination would be easily ionized when it is brought in contact with the surface of the pulp. Zander later demonstrated that plain calcium hydroxide produced the same results. A total of 150 teeth were treated, using calxyl in 60 cases and calcium hydroxide in the other 90. Radiographic examination showed no apical change in 71% of the cases. The same method has been used in deciduous teeth producing favorable results after three and a half months. Zander concluded that dentin formation takes place not only in a healthy pulp but also in the presence of inflammation.

Restarski in 1940 did a study in permanent and deciduous teeth, using zinc oxide eugenol and calxyl, as capping agents. With zinc oxide and eugenol granulation tissue was evident adjacent to the capping agent; below the granulation tissue, the pulp was fibrous. In the teeth capped with calxyl, complete bridging with secondary dentin took place as early as 28 days, and the remaining tissue was normal.

Rosentein in 1942 reported an extensive clinical study on pulp capping in which 628 teeth were treated from 1932 to 1940. Only deciduous teeth were used. He did a total of 463 cappings, reporting a 90.4% rate of success. The patients were recalled for examination twice a year. He used zinc oxide and eugenol, and thymol with zinc oxide and copper cement as capping agents. In 1947 Bonner did 162 pulp capping procedures and of these only eight teeth were lost. Of 113 cases in which crystalline penicillin was used exclusively as capping agent, there were no losses. Six of these teeth were reopened for examination and all showed the pulp to be alive and sensitive to touch.
Glass and Zander\textsuperscript{1} in 1949 stated that most of the previous studies on pulp capping were based only on clinical or roentgenographic results, without taking into consideration that pulp necrosis may occur without clinical signs. They pointed out that pulp studies should be substantiated by histologic examination. In disagreement with Grove, who in 1928 stated that odontoblasts were not capable of regeneration, they found histologic evidence that a bridge of dentin was formed at the line of amputation. Such a bridge could not be formed unless the pulp was capable of healing. They did a study of 40 sound teeth to be extracted for orthodontic purposes, using zinc oxide and eugenol and calcium hydroxide with tap water as capping agents. The teeth were extracted at 24 hours, 2, 4, 6, 8 and 12 weeks. Pulps capped with calcium hydroxide healed within four weeks, whereas pulps capped with zinc oxide and eugenol remained vital and without clinical symptoms but regularly showed chronic inflammation.

In the same year Zander and Glass\textsuperscript{21} did another study on 44 sound teeth. They used phenol to determine if it would reduce or enhance the beneficial action of calcium hydroxide. The histologic results were similar to those of the previous study. The use of phenol prior to capping did not influence the healing process.

In 1950 Berk\textsuperscript{22} reported on the use of calcium hydroxide incorporated in aqueous solution of methyl cellulose. Dogs' teeth which were mechanically exposed and capped, were extracted after two and a half months. Histologic examination showed no evidence of pathosis.
Kutscher in 1950 reported on the use of sodium penicillin and a penicillin zinc-oxide eugenol paste, as a capping agent. Of 154 teeth that were treated, 151 were clinically successful for periods of two years and one and half years.

His criteria for success were based on no sensitivity to percussion, negative radiographic image and normal response to thermal tests.

In 1950 Hess included 600 teeth in his study, using calxyl as a capping agent. Exposed healthy pulps with healthy dentin showed 95% success. Exposed healthy pulps with carious dentin showed 88% success. Results were checked by clinical, radiographic and histologic means.

One year later, Cohen reported the use of calcium hydroxide water paste in permanent teeth. Capped pulps included many with carious exposures as well as those exposed from accidental trauma. Of the 239 cases in which follow-up was possible, 79% success was obtained.

Tananbaum in 1951 pulp capped a total of 128 teeth in his private practice, and 116 were clinically successful. Teeth treated with zinc-oxide showed 89% success whereas teeth treated with calcium hydroxide showed 92% success. Only 4% of the zinc-oxide treated teeth showed a radiographically secondary dentin barrier after two years, while 89% of the calcium hydroxide treated teeth showed this barrier within one year. Rubber dam was not used.

In 1952 Rosen evaluated penicillin for pulp capping in primary teeth, using 100,000 units of penicillin dissolved in a small drop of sterile distilled water. The solution was applied to the pulp and the remainder was incorporated with the zinc-oxide. He treated 40 teeth. More than the 90% of the patients returned showing no evidence of failure.
Bonner\textsuperscript{28} reported in 1953 the healing of pulps capped with calcium hydroxide, in agreement with Zander. He mentioned that:

Histological findings of pulp healing under calcium hydroxide reveal that after 24 hours under the capping, the superficial portion of the pulp in contact with this material is necrotic with little or no cellular detail present. Below this necrotic area is a zone comprised of basophilic elements that are probably made up of a calcium proteinate. Since calcium hydroxide is basic with a pH around 11, it causes necrotization of the superficial tissue and the location of the proteinate globules probably represents the depth of penetration of calcium hydroxide, which finally reacts with tissue protein to form this new structure.

In 1954, Patterson and Van Huysen\textsuperscript{29} did a study in which three non-caries teeth were pulp capped with calcium hydroxide, and one with a piece of sterile gold plate. The teeth were extracted two months later. In the pulps capped with the calcium hydroxide, complete bridging was observed and no inflammation was present. The pulp capped with gold plate showed incomplete bridging with no inflammation. They concluded that pulp capping should not be attempted when pulpitis is present. Exposed healthy pulps should be protected immediately with a non-irritating material. They felt that a pulp exposed for more than two hours should not be treated by pulp capping. They also suggested that the capping should not be disturbed, and finally that pulps are amenable to successful capping at almost any age.

Kalnins in 1955\textsuperscript{30} reported a study in which he capped 262 sound and carious permanent and deciduous teeth. The effect of a thick paste of calcium hydroxide, sulfathiazole and strontium salts was studied clinically and histologically. Clinical observations showed that 79\% of treated cases were asymptomatic. Of 127 permanent teeth, 107 gave a vitality response after two months to three years. Histologic sections
of 88 teeth showed compression of connective tissue. Stroma within the superficial part of the pulp showed fibrous metaplasia, beyond which the pulp tissue was normal.

Kalnins and Frisbie,\textsuperscript{31} one year later, reported histologic examination of 46 pulps of permanent and primary teeth capped with calcium hydroxide and sulfathiazole from two days to 14 months. Only four cases, with dentin fragments confined to the superficial portion of the wound, showed normal healing and dentin bridges. The authors suggested that dentin fragments in the pulpal wound should be avoided due to the foreign body reaction.

Results from 83 teeth with carious pulp exposure were reported by Feitelson\textsuperscript{32} in 1956, using calcium hydroxide and penicillin G in water as capping agent. Successful outcome was observed in 91\% of the cases.

Kalnins in 1957\textsuperscript{33} reported a roentgenographic and histologic study in which 86 sound and carious permanent and deciduous teeth were capped with calcium hydroxide paste. Results from one group showed complete healing and dentinal bridge development. Healing was delayed, in the second group, and dentinal bridge formation was preceded by the development of a radiolucent area, (inflammation zone), the so-called dysfunctional zone of the pulp. In these cases, Kalnins suggested curettage of the pulpal tissue and reapplication of the calcium hydroxide.

Jensen\textsuperscript{34} in 1957 compared two pulp capping agents in anterior teeth in three dogs: (1) calcium hydroxide and (2) a mixture of this with zinc oxide and eugenol, iodoform and phenol. Rubber dam was not used. Histologic sections showed formation of reparative dentin in four weeks. He found no differences in the rate of healing between the two agents, after four to eight weeks.
Mumaw and Cooper in 1957\textsuperscript{35} reported a clinical study of 164 teeth that were capped with calcium hydroxide. The observation period was one year. The success rate was 97\%, with 159 teeth found to be vital and in good condition. In some cases pulpotomies were done. Rubber dam was not used.

Nyborg\textsuperscript{36} in 1958 reported an extensive study in which 225 pulps were capped, including 221 that were exposed on the removal of caries and four that were already exposed. Calcium hydroxide in Ringer's solution was used. Clinical and histologic examinations were made of 81 teeth after periods from four hours to nine years. The histologic outcome of capping was satisfactory when the pulp lesion had healed and when little, if any, cellular infiltration was found deep in the lesion area. Of 144 teeth subjected only to clinical evaluation, 124 did not give symptoms of pulpitis while only 20 presented signs of pulpitis. Observation periods ranged from four hours to nearly 13 years.

Seltzer and Bender\textsuperscript{37} in the same year, capped 52 mechanically exposed pulps in three young healthy dogs using several capping agents: calcium salts suspended in distilled water, calcium hydroxide, calcium carbonate, tricalcium phosphate, ammonium hydroxide, aqueous solution of \textit{K} penicillin, and aqueous suspension of alkaline phosphatase. One animal was sacrificed within seven days and the other two at intervals of 30 and 90 days. Calcium hydroxide was the only agent capable of stimulating the pulp to lay down reparative dentin. Ammonium hydroxide and potassium penicillin caused pulp necrosis.

Kalnins in 1960\textsuperscript{38} studied 46 human pulps which had been capped with calcium hydroxide paste. Twenty-nine showed inflammation. Large dentin
fragments at the exposure site tended to cause an inflammation reaction characterized by an accumulation of lymphocytes, plasma cells and macrophages. He concluded that since fragments of dentin induce a foreign body reaction, all dentin chips resulting from pulp amputation or capping should be removed from the area of operation.

Due to the conflicting results from many pulp capping studies, Mitchell in 1961 developed a mass screening technique whereby many materials could be tested more simply. Small pellets of freshly mixed pastes of various materials were implanted under the skin of rats. The results showed that calcium hydroxide or zinc oxide and eugenol were well tolerated by connective tissue and therefore are recommended for vital pulp therapy. Mitchell stressed the importance of accurate diagnosis and careful selection of the case.

In 1962 Kalnins studied the pulpal changes in deciduous teeth when pressure had been applied. Ninety-six molars and cuspids were treated. A thick paste of calcium hydroxide plus sulfathiazole was applied. Histologic observations in 32 teeth showed compaction of the connective tissue stroma, which took on the appearance of a fibrous capsule; the remaining tissue was undisturbed and a dentinal bridge was evident. Rubber dam was not used. Kalnins suggested that the application of pressure favored the healing of the pulp.

Weiss in 1962 compared four capping materials in monkeys: zinc oxide, Dycal, calcium hydroxide in distilled water and calcium hydroxide with cresatin. Animals were sacrificed after periods of six, 14 and 30 days. When calcium hydroxide and cresatin was used, initial bridging started after six days. Dycal and calcium hydroxide with distilled
water showed repair with walling off of the exposure at 30 days. Zinc oxide did not cause an inflammatory reaction but rather a fibrous type of walling-off material.

Shankle in 1962 did a clinical study for the purpose of comparing his results with other studies. He wanted to determine: (1) the percentage of pulps capped that produced dentin bridges, (2) whether age of the patient influenced the bridging, (3) whether pre and postoperative pain indicates a failure in the ability of the pulp to form dentinal bridge, (4) whether the size of the exposure influences bridge formation, and (5) whether the operator is able to predict the likelihood of dentin bridging at the time of pulp exposure. A total of 70 pulps were capped with calcium hydroxide mixed with methyl cellulose. Of these teeth 52 formed a dentin bridge, and five others remained vital but failed to form a bridge. Neither the size of the exposure nor the age of the patient altered the ability of the pulp to produce bridging, however presence of pre and postoperative pain had a decided indication for capping.

Armstrong and Hoffman in 1962 carried out a pulp capping study during an 18 month period on personnel aboard an aircraft carrier. Of 181 pulp capping procedures that were performed, 46 teeth were still available at the time this investigation started, the remainder of the patients had been transferred to other station or discharged from the service. The material used was commercially prepared calcium hydroxide. Secondary dentin could be demonstrated roentgenographically in 31 of the 46 cases. On the basis of this study, 97.8% of the cases may be considered successful.
In 1963 Starkey\textsuperscript{44} reviewed the methods of preserving primary teeth which have exposed pulps. He advised that pulp capping should be limited to accidental exposures or a truly pin-point exposure. He noted that the amount of inflammation from which a pulp can recover has never been determined.

Dimaggio, Hawes and Kiryati\textsuperscript{45} in 1963 reported a study of 724 deeply carious primary and permanent teeth which were treated by indirect pulp therapy, direct pulp capping and pulpotomy. The capping material was either zinc oxide eugenol or calcium hydroxide. Of 305 direct pulp cappings only 33 were studied histologically. Mild chronic inflammation was more frequent during the first six months after direct treatment. Failure, as determined histologically, supports the clinical impression that direct treatment has a higher early failure rate (33\% in six months) than indirect (12\% in six months). Histologic evidence supported the hypothesis that approximately 75\% of the teeth selected for indirect treatment would have shown pulp exposure if all caries had been removed.

Sawusch in 1963\textsuperscript{46} did a pulp capping study on 231 primary teeth using a calcium hydroxide paste or another calcium hydroxide preparation (Dycal). Two teeth studied histologically after 24 and 27 days showed a thick layer of irregular reparative dentin at the exposure site.

In 1964 Pisanti and Sciaky\textsuperscript{47} studied the origin of the calcium in repair of dentin bridges under calcium hydroxide. Sixteen teeth of a two-year-old male dog were exposed and capped with calcium hydroxide with distilled water. During the following three weeks at seven-day intervals the dog was injected I.V. with 5 cc of a solution of labeled calcium hydroxide. After two weeks the animal was sacrificed. The
results showed that calcium in the dentin bridge comes from the bloodstream.

Baume in 1964\textsuperscript{48} capped 190 pulps affected with painful pulpitis, and examined them clinically and radiographically at regular intervals. The capping agents were compounds containing antibiotics and corticosteroids. Ninety-five of the treated teeth were extracted for prosthetic reasons after postoperative periods ranging from 15 to 300 days. Histologic examination showed absence of dentin bridges and the amputated area showed metaplastic fibrosis and chronic inflammation.

Kalmins, Musin and Kisis\textsuperscript{49} in 1964 reported a human study in which a total of 22 noncarious teeth, were mechanically exposed and capped using calcium hydroxide in which zinc-oxide powder was substituted for sulfathiazole. Observation periods ranged from six days to six months. Histologic examination showed that pressure affected only the superficial portion of the pulp. Some pulps showed slight infiltration by lymphocytes and plasma cells. Histologic success was claimed in 20 pulps, only two failures were reported.

Burke and Knighton\textsuperscript{50} in 1964 used a calcium hydroxide compound (Dycal) and zinc oxide and eugenol to cap 116 rats' molars with mechanically exposed pulps. Animals were sacrificed on the third, seventh, 10th, 14th, 21st, 28th, and 31st day following operation. Teeth studied at three to seven days showed superficial acute reaction, pulpal tissue adjacent to the medicament was necrotic, and an early attempt of bridging was evident. At 10 to 31 days, bridging occurred more frequently on pulps capped with Dycal.
Cabrini, Maisto, and Manfredi\textsuperscript{51} in 1965, presented the results of a histologic study in which seven normal human dental pulps were exposed experimentally and then subjected for four to 10 minutes to saliva, and capped with a calcium hydroxide paste. After 62 to 84 days the teeth were extracted. Histologic findings showed formation of dentinal bridge, composed of tubular dentin with the underlying pulp normal.

In 1965 Kakehashi, Stanley and Fitzgerald\textsuperscript{52} did a very significant study on pulp capping, using 37 inbred Fisher rats. Twenty-one were germ free animals and 15 were conventional control animals. Pulp exposures were made with a bur and the exposures were not capped and sealed. The animals were killed at intervals from one to 42 days post-operation. Results from the conventional animals showed necrotic and purulent tissue, and there was no evidence of repair in any instance. In the germ free animals, pulpal inflammation was minimal and not a single apical abscess was found. Dentinal bridging was also evident at 14 days, and pulp tissue remained vital beneath the bridge. The authors concluded that microorganisms in the inflamed pulp are the most significant cause of failure in attempts at dentinal bridging.

Namba in 1966\textsuperscript{53} reported a clinical study of direct pulp capping with Cavital (special formulation of calcium hydroxide). One hundred human permanent teeth with non-infected pulps were used. Rubber dam was used in some instances. After pulp capping, the teeth were observed up to 594 days. Clinical results showed 63\% with no symptoms.

Collagen, chondroitin sulfate, sodium hyaluronate, lyophilized dentin chips, sterilized enamel chips, zinc oxide and eugenol, Reogan and provin-past were tested as pulp capping agents by Obersztyn in 1966.\textsuperscript{54} A total
of 151 rats were used. Pulp exposures were made on the root surfaces in which cavities were prepared. Calcium hydroxide was used as the control capping material. In all, 281 teeth were studied 10 days after capping. The best results were obtained after capping with lyophilized sterilized dentin chips.

Harris in 1966 reported the use of glucocorticosteroid compounds and calcium hydroxide in 15 children's teeth. The observation periods ranged from 23 to 314 days. Calcific repair was not complete with the calcium hydroxide and in the case of glucocorticosteroids repair did not occur. Areas of chronic inflammation persisted in the pulps treated by both procedures.

In 1966 Schneider and Lawson compared corticoid-antibiotic mixture with calcium hydroxide as a pulp capping agent, in primary teeth. A total of 58 teeth were treated and examined at varying intervals, with an average of 280 days. Clinical success was recorded as 59% using the corticoid-antibiotic and 84% when calcium hydroxide was used. Histologic results from 14 teeth showed slightly more inflammation in those teeth treated with corticoid-antibiotic mixture. Bridging was observed with both medicaments.

Weiss in 1966 did a clinical study in 160 teeth in which carious exposures were capped with calcium hydroxide mixed with distilled water or zinc oxide-eugenol and cresatin mixed with calcium hydroxide. Pulp capping was judged successful in 88% of cases. Histologic results were obtained from 39 sound teeth which needed to be extracted, after seven, 14 and 30 days. With the calcium hydroxide cresatin mixture, no inflammation was observed after seven days and after 30 days a thick band of calcified material separated the wound from the pulp.
Compton\textsuperscript{58} in 1966 reported in his thesis the use of Dycal on 27 monkeys' teeth, and 18 permanent human teeth extracted seven to 166 days after the pulp capping. Of the 45 teeth studied microscopically, no indication of significant inflammation was observed.

Sayegh\textsuperscript{59} in 1967 did a direct pulp capping study in vital teeth with deep carious lesions, using calcium hydroxide methyl cellulose as a capping agent. A total of 227 permanent teeth were treated, with 82 being prepared for histologic study. The results showed three types of tertiary dentin: cellular fibrilar, globular and tubular.

In 1967 Starkey\textsuperscript{60} discussed the management of deep caries and pulpally involved teeth in children. Calcium hydroxide is advocated when a small mechanical exposure is evident, surrounded by sound dentin.

Attalla in 1968\textsuperscript{61} capped minute exposures in pulps of 20 dogs' teeth. Eleven teeth with exposures were covered by mixing calcium hydroxide with the dental fluid that escaped into the cavities. Calcium hydroxide with distilled water was used to cap the pulps of the other nine teeth. After eight weeks, the pulps covered with the mixture of calcium hydroxide and dental fluid had a thicker layer of reparative dentin.

Shovelton in 1968\textsuperscript{62} discussed direct pulp capping saying that "It is indicated in those teeth where exposure is very small and is not potentially contaminated by caries or saliva." He mentioned also that "after several investigations, it must be concluded that there is still little really conclusive evidence as to which is the best capping material."

In 1969 Crispo\textsuperscript{63} indicated that direct pulp capping is favorable under the following conditions:

1. Mechanically exposed pulp.
2. Young tooth in which the vascular supply is greatest, especially those with an incompletely formed root end.

3. Mechanical injury.

4. No previous history of inflammatory reaction and

5. Exposure made under the rubber dam.

Furthermore Crispo considered three more factors which will influence whether or not a mechanically exposed pulp should be capped:

1. The size of the exposure.

2. Exposure to saliva.


He concluded that relationships between pulp exposure size and severity of the inflammation are highly significant statistically.

Sveen in 1969 reported a clinical and radiographical evaluation of pulp capping in 120 primary teeth using zinc-oxide and eugenol. Rubber dam was not always used. Check-ups were done every six months. A total of 105 cases were reported as meeting the criteria of success. Sveen concluded that pulp capping with zinc oxide-eugenol should be considered safe when the tooth is found to be clinically and radiographically free of symptoms, in spite of the histologic changes of the pulp thought to be caused by this material as reported by several investigations.

In the same year Hansen reported a pulp capping study with corticoid-containing materials. Seventy-five sound human teeth were capped after artificial exposure. Triamcinolone mixed with equal amounts of calcium hydroxide, corticoid and antibiotic, and a combination of corticoid, antibiotic and calcium hydroxide were used. Histologic results showed bridging, and inflammation was present in only a few teeth. Isobutyl
cyanoacrylate was evaluated as a pulp capping agent by Bhaskar,\textsuperscript{66} in a total of 67 pigs' teeth. Calcium hydroxide was used as a control. After eight weeks experimental and control teeth showed incomplete dentinal bridge formation. However, the experimental material caused immediate hemostasis and less inflammation.

Sayegh\textsuperscript{67} reported a study in which the pulps of 223 carious human teeth were capped with calcium hydroxide or zinc oxide and eugenol and extracted at intervals ranging from one day to 57 months. A total of 183 teeth received direct pulp capping with calcium hydroxide, and bridge formation was found in 64%.

In 1969 Kakehashi, Stanley and Fitzgerald\textsuperscript{68} reported the effects of topical corticosteroid medication upon surgically exposed dental pulps of germ-free and conventional rats. Dental pulps were sealed either by a temporary cement or left exposed to the oral environment. The results showed that regardless of medication, the pulps of the germ-free animals healed as substantiated by the formation of reparative dentine bridge, while pulps of the conventional animals degenerated.

Jones and Gibb\textsuperscript{69} did a clinical study using Dycal for direct pulp capping. Of 207 teeth with mechanical or carious pulp exposures, 194 were capped and clinical success was achieved in 94 percent. In 1970 Ripa\textsuperscript{70} suggested that direct pulp capping in primary teeth should be limited to a pin point opening surrounded by sound dentin with calcium hydroxide as the capping agent. He further stated that the dentinal bridge would form as early as four weeks. He said that bridging may be regarded as a desirable but not necessary criteria for success.
A histologic study of the effect of a combination of vancomycin and calcium hydroxide in direct pulp therapy was done by Gardner\(^\text{71}\) in 1970. The pulps of 74 teeth of three monkeys were capped after cavities were left open to the oral cavity for 48 hours to insure contamination. The teeth were extracted after 30 and 90 days. Complete bridging was observed in all teeth, treated with the antibiotic calcium hydroxide, methyl cellulose and water mixture.

In 1970 Goto, Imanishi et al.\(^\text{72}\) investigated the reaction of accidentally exposed pulps of human deciduous teeth without application of any therapeutic remedies. Twenty intact teeth were used, and all showed various histopathologic changes.

Clarke in 1970\(^\text{73}\) reported the morphology of the reparative dentin bridge from 48 molar teeth from 10 dogs. Teeth were capped with pure calcium hydroxide with distilled water, and extracted after periods ranging from one day to 16 weeks. Five zones in the area of exposure of reparative dentin were described. The first zone presented damaged pulp, debris, the dressing material and dentin fragments. The second zone showed necrosis, and the third contained blood. The fourth zone showed a matrix for calcification and the fifth was a zone of calcification.

Weiss in 1970\(^\text{74}\) investigated several capping agents in deciduous and permanent teeth of young adult monkeys. Calcium hydroxide mixed with distilled water, Dycal, Cresatin mixed with calcium hydroxide, and a hard setting zinc oxide and eugenol were used. Animals were killed after one, two, four and five weeks. Cresatin with calcium hydroxide showed the most favorable pulp response. There was only a narrow necrotic zone under the pulp capping material.
In 1971 Sekine\textsuperscript{75} reported a clinico-pathological study in which Calvital, Calcipulpe, Acrical, Dycal and Hydrex were evaluated. A total of 125 human permanent teeth with non-infected pulps were intentionally exposed. After pulp capping, the teeth were observed clinically at various intervals ranging from immediately after the operation to 618 days. The teeth were prepared for histologic study. Calvital showed the best results for favorable symptoms, pulp healing and dentinal bridge formation. Calvital has 78.5\% of calcium hydroxide.

Andrews in 1972\textsuperscript{76} reported a clinical study in which a total of 622 teeth were capped with Pulpdent, Cavitec, Hydrex, Dycal or Vitec. Rubber dam was not used. Results were recorded for only 231 teeth up to one year, using radiographic evaluations. Of the 231 only nine were unsuccessful. He was not very specific with his results.

Stanley\textsuperscript{77} in the same year reported dentinal bridge formation under Dycal. Thirty-five teeth were used. The study period ranged from one to 330 days. Histologic examination showed bridging directly in contact with Dycal at 23 days after capping.

Ulmansky\textsuperscript{78} in 1972 obtained information on the structure of calcium hydroxide induced bridges using electro microscopy. The apical surfaces were convex with round prominences. Tubular endings were concentrated in groups. A well defined groove delineated the bridge. The coronal faces of the bridges were concave and merged obliquely at their peripheries into the dentinal walls resulting in a funnel shape.

In the same year Anneroth\textsuperscript{79} studied the effects of dentin either demineralized or demineralized and primed in Ca Cl\textsubscript{2} as a pulp capping agent in Java monkeys. This study included 80 teeth. Histologic findings
indicate that demineralized dentin whether it was treated in Ca Cl₂ or
not, gave more successful and complete bridging after 30 days than silver
plate in the control teeth.

In 1973 Schroder⁸⁰ did a pulp capping and pulpotomy study in human
teeth in which he reported the effect of a pulpal blood clot on healing.
After amputation the blood clot was left between the wound surface and
the calcium hydroxide. Histologic findings showed that out of 18 teeth,
only four showed healing. He concluded that a blood clot seriously
impaired healing.

McWalter⁸¹ in 1973 did a histologic study on monkeys. Seventy-four
permanent teeth were mechanically exposed, contaminated with saliva and
capped. Calcium hydroxide, antibiotic and a polycarboxylate cement were
tested. Teeth were extracted at 15, 50, 100 and 200 days. Calcium
hydroxide gave a 96% satisfactory reaction. Polycarboxylate cement
showed 90% success and antibiotic showed the lowest success.

Berek in 1975⁸² suggested that there are some clinical situations
in which pulp amputation is preferred to pulp capping. The dentin formed
by the pulp may infringe on the pulpal cells, causing sufficient impair­
ment of circulation to render the coronal area of the pulp necrotic.

In 1975 Heller⁸³ reported the use of a reabsorbable form of tri­
calcium phosphate ceramic as a capping agent in permanent teeth of
monkeys. Twenty-nine teeth in four monkeys were used. Calcium hydroxide
was used as a control group. Rubber dam was used. The monkeys were
killed at 2, 3, 5, 8, 16 and 24 weeks. Calcific bridges formed as early
as five weeks postoperatively. No pulp inflammation was evident.
In 1977 McWalter, El-Kafrawy, and Mitchell\textsuperscript{84} reported the rate of reparative dentinogenesis under pulp capping in monkeys. Thirty-eight permanent teeth were mechanically exposed, contaminated with saliva and capped after five and one-half hours. Calcium hydroxide was used for capping. Teeth were extracted at intervals ranging from 15 to 880 days. Reparative dentinogenesis was assessed by estimating the average gain in bridge thickness at successive intervals by the aid of procion lines. Histologic results showed that the maximum rate of reparative dentinogenesis was between 15 and 30 days after capping. The rate then diminished with progressive decline in the rate of formation. This study did not substantiate the concept that calcium hydroxide exerts a persistent stimulating effect on reparative dentinogenesis resulting in pulp obliteration.

In 1977 Watts\textsuperscript{85} reported a capping study using different metallic compounds in rats. Among these materials were: barium sulfate, calcium carbonate, cupric oxide, magnesium oxide, aluminium oxide, ferric oxide, and stannic oxide. The animals were killed after 28 days. Histologic sections showed favorable results with barium sulfate, calcium carbonate, cupric oxide, ferric oxide, magnesium oxide and stannic oxide. A calcific bridge was observed.

In 1978 Starkey\textsuperscript{86} pointed out that it is generally agreed that calcium hydroxide is the material of choice for direct pulp therapy. He advocates limiting direct capping to those teeth which are evaluated to have little or no inflammation and infection. He considers that inflammation is limited to the exposure site and reversible when there is a small pulp exposure with no history of spontaneous toothache, the exposure is found in a clean environment with little or no hemorrhage, and surrounded by sound dentin.
Massler in 1978\textsuperscript{87} reported on the treatment of injured vital pulps. He pointed out that:

The results of thousands of empirical clinical trials and well controlled histologic animal experiments, leads to the current conclusion that there is no significant difference in healing between any of the medicaments.

Leakage and contamination from saliva are the principal causes of failure. Massler recommends direct pulp capping only for small, clean exposures made under the rubber dam during an operative procedure. Pulp capping has little chance of success when made through infected dentin.

Haskell\textsuperscript{88} in 1978 reported a long-term clinical study of pulp capping, using calcium hydroxide powder and penicillin crystals. The rubber dam was only used in anterior teeth. Of 149 cases that were recalled for more than five years, 130 cases (87.3\%) were successful; 117 of these were capped with calcium hydroxide and 13 with penicillin.

Brannstrom\textsuperscript{89} in 1979 evaluated a microbicidal cleaner and fluoride used in cavities with pulp lesions, for their effect on healing under calcium hydroxide capping. Thirty teeth in young patients and 24 teeth in two dogs were treated. Follow-up periods were from seven to 10 weeks. All but one of the pulps showed a favorable response. He concluded that neither the microbicidal cleaner nor the fluoride appeared to have any influence on the healing process.

**Calcium Hydroxyapatite Material Used as a Pulp Capping Agent**

Among the several different capping agents being tested in dentistry, tricalcium phosphate ceramics and a crystalline pure form of calcium hydroxyapatite are probably the latest materials under investigation.
Tricalcium phosphate ceramics have been tested primarily as bone implants.

In 1971 Bahaskar et al. implanted a biodegradable tricalcium phosphate ceramic in the proximal ends of rats tibias. Histologic examination showed that the ceramic was well tolerated. Within four days connective tissue buds were evident within the ceramic pores and at 14 weeks the cortex was completely repaired.

The Medical Research and Development Command, U.S. Army Institute of Dental Research also considered tricalcium phosphate as a useful bone implant material for treatment of avulsive type of maxillofacial combat wounds and in osseous periodontal defects. Periodontal defects filled with tricalcium phosphate showed bone regeneration after 12 months.

Heller in 1975 quoted Driskell who said,

The porous tricalcium phosphate ceramic most nearly approximates the ratio of calcium and phosphorous in the hydroxyapatite mineral phase found in natural bone and dentin.

Heller tested tricalcium phosphate ceramic powder as a direct pulp capping agent. Twenty-nine teeth in four adult monkeys were used. Calcium hydroxide (powder mixed with saline solution) was used as a control agent. Rubber dam was used. The animals were killed at 2, 3, 5, 8, 16 and 24-week periods. After two weeks a fibrous matrix was evident. At five weeks a calcific matrix was present and well defined. Tricalcium phosphate ceramic (TPC) particles were being phagocyrtized within the matrix compartments. Eight weeks later, calcific bridging was present and complete. Heller concluded that TPC stimulates formation of calcific bridging and maintains a non-inflamed, viable pulp.
In 1978 Strub\textsuperscript{92} reported formation of new bone and reattachment in periodontal pockets, if they were filled with tricalcium phosphate ceramic. However, he suggested that this material should be further investigated before its general use.

Sluka\textsuperscript{93} in 1979 studied the effect of bone matrix soaked in thyrocalcitonin on vitally amputated pulp in beagle dogs with light and electron microscopy. After eight weeks all treated teeth were vital, the area of inflammation was densely populated with cells, and formation of hard tissue differing from normal dentin had begun.

Boone and Kafrawy\textsuperscript{94} in 1979 investigated tricalcium phosphate ceramic in a powder form as a pulp capping material in monkeys. Forty-eight teeth were mechanically exposed without rubber dam and capped with one of the following materials: (1) polycarboxylate cement, (2) tricalcium phosphate ceramic powder with sterile saline solution, or (3) tricalcium phosphate ceramic powder applied over the pulp exposure. The teeth were extracted after 15 and 50 days. Approximately 45\% of the pulps capped with the tricalcium phosphate ceramic material were non-vital. Brown and Brenn staining of these necrotic pulps revealed the presence of bacteria in all of them.

Dickey, Kafrawy and Phillips\textsuperscript{2} in 1980 evaluated a crystalline form of pure calcium hydroxyapatite as a pulp capping material in three adult monkeys. Sixty teeth were mechanically exposed under rubber dam and capped. Calcium hydroxide compound was used as a control. Teeth were extracted at 15, 48, and 90 days after capping. Histologic results showed that the apatite was well tolerated by the dental pulp; however, the material was difficult to localize at the exposure site.
Bactericidal Properties of Chlorhexidine Gluconate Solution

It is well known that chlorhexidine solution applied topically reduces caries in animals and in humans. It has also been shown that the daily use of 0.2% aqueous solution of chlorhexidine as a mouthrinse results in reduction of plaque formation and gingivitis.95

Hennessey96 in 1973 described the antibacterial spectrum of chlorhexidine. He mentioned "A wide spectrum of activity with Gram-positive cocci being especially sensitive." Various bacterial species were exposed to chlorhexidine (0.02%) showing a reduction of viable organisms by about 99%.

In 1974 Asboe-Jorgensen97 studied the effect of chlorhexidine dressing on gingival healing after periodontal surgery. The results showed less gingival exudate from the chlorhexidine dressing site.

In 1977 Forsten and Karjalainen98 investigated the effect of a calcium hydroxide solution and chlorhexidine on the microbial activity of human carious teeth in vitro. Carious dentin was inhibited totally with the calcium hydroxide solution, whereas chlorhexidine had no effect.

Uptake and release of chlorhexidine has also been tested in bovine pulp and dentin by Parsons, Patterson, Miller, Katz, Kafrawy and Newton99 in 1980 to determine their subsequent acquisition of antibacterial properties. Forty specimens of dental pulp tissue from bovine teeth were used. Chlorhexidine 0.02%, and 1.0% solution was used. Specimens were evaluated immediately and after one week for antibacterial properties. They concluded that chlorhexidine is a potent antibacterial agent and its use as an irrigant solution in endodontics should be further evaluated.
METHODS AND MATERIALS
Preparation of Experimental Subjects

Two healthy male monkeys, which were kept at the Indiana University School of Dentistry animal facility, were used. One was a blue monkey from the Rhesus family, tattooed with number 10 on his chest for identification. The other was a Rhesus monkey, marked with number nine. The ages of the animals were estimated to be approximately five to six years since permanent cuspids and second molars were already erupted. Both animals had permanent dentition. Monkey number 10 was a smaller animal (eight pounds compared to 18 pounds in the other) and the teeth were also smaller. Monkey number nine had a missing first permanent molar in the lower right quadrant. A week before operative procedures were initiated, both animals were scheduled for prophylaxis. They were tranquilized with an intramuscular injection of 0.25 ml (20 mg per ml) of Ketamine Hydrochloride.¹ They were then brought to the operative room for oral examination and prophylaxis. Clinical examinations revealed no significant pathologic conditions in the oral cavities of either monkey. Some attrition was evident involving all the teeth in monkey number nine, but none in monkey number 10. Both animals showed generalized marginal gingivitis. Supra and subgingival calculus were removed and both animals were returned to their original cages.

¹Vetalar, Parke Davis and Company, Detroit, Michigan (veterinary use only).
Preparation of Materials for Capping

Calcium Hydroxide Powder

Pure calcium hydroxide powder\(^a\) was obtained from the graduate Pedodontic clinic at IUSD. It was stored in small bottles before it was used.

Synthetic Hydroxyapatite

The material was prepared in the Oral Health Research Institute at IUSD, in the following manner: concentrated stock solutions of calcium nitrate \((\text{Ca(NO}_3\text{)}_2\cdot4\text{H}_2\text{O})\)\(^b\) and dibasic ammonium phosphate \((\text{NH}_4\text{)}_2\text{HPO}_4\)\(^c\) were prepared by the method of Jarcho, O'Connor and Paris; 100 and 900 ml of 1.00 M \(\text{Ca(NO}_3\text{)}_2\cdot\text{H}_2\text{O}\) solution was transferred into a 2000 ml beaker and the pH was adjusted to between 11 and 12 with about 30 ml concentrated ammonium hydroxide.\(^d\) The final volume of this pH adjusted calcium nitrate solution was brought to 1.800 ml with distilled water.

In a separate 4000 ml beaker, 1500 ml of 0.600 M \((\text{NH}_4\text{)}_2\cdot\text{HPO}_4\) solution was poured and the pH was also adjusted to between 11 and 12 with about 750 ml concentrated ammonium hydroxide. The final volume was adjusted to 3,200 ml with distilled water.

The pH adjusted ammonium phosphate solution was added drop by drop into the pH adjusted calcium nitrate solution under continuous stirring at room temperature.

\(^a\)King's Specialty Company, Fort Wayne, Indiana.

\(^b\)Mallinckrodt Chemical Works, St. Louis, Missouri.

\(^c\)Allied Chemical, General Chemical Division, Morristown, New Jersey.

\(^d\)Matheson Scientific, Chicago, Illinois.
A milky and somewhat gelatinous precipitate was then stirred at room temperature for 24 hours, at which time the mixture was left at room temperature without stirring to settle the precipitate for an additional 24 hours.

The supernatant was carefully decanted and the remaining mixture was then centrifuged at 3000 rpm for 20 minutes. The precipitate was then thoroughly washed with distilled water and centrifuged again. This procedure was repeated five times until the pH of the suspension was brought to 7.95, and the precipitate was washed once more and recentrifuged for the end product. The creamy precipitate was placed on a Petri glass container and allowed to dry under a hood at room temperature for approximately 18 hours. The precipitate dried to a ceramic like material.

X-ray diffraction was done to confirm the crystallographic structure of the material. As shown in Figure 1, the x-ray diffraction pattern indicated a typical hydroxyapatite crystal configuration. The material was ground to a powder with a clean mortar and pestle and stored in a clean glass bottle.

Distilled water and one percent chlorhexidine gluconate solution were used as mixing vehicles.

Experimental pulp capping materials were prepared as follows: One hundred mgs of either synthetic hydroxyapatite or calcium hydroxide were weighed using an analytical balance and placed in a small crystal bottle. The synthetic hydroxyapatite and calcium hydroxide were sterilized by

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\(^a\) Obtained from Oral Health Research Institute, Indiana University School of Dentistry, Indianapolis, Indiana.

\(^b\) Analytical Balance, Christina Becher, Clifton, New Jersey.
dry heat at 160° C for 20 minutes, mixed with 50 microliters\(^a\) of 1.0 percent chlorhexidine solution and distilled water, and then subjected to testing.

Pulp Capping Procedures

The monkeys were anesthetized using an I.V. injection of sodium pentobarbital.\(^b\) Dosages of 4.2 mg and 6 mg, respectively, were used, for monkey number 10 and monkey number nine. The syringe containing the anesthesia was taped to the arm. Profound anesthesia was obtained. Additional amounts of the anesthesia were injected as needed. All teeth were used except cuspids and third molars due to the difficulty of extraction in the case of the cuspids and poor access in the case of the molars. Each monkey was placed in a supine position with its head tilted back. A plastic mouth prop was used to keep the mouth open. Two pieces of clean gauze were placed in the posterior part of the mouth to prevent any debris from reaching the throat. Sterile surgical sheets were placed. All operative work was done under septic conditions. All materials and instruments used, were previously sterilized.

A total of 47 pulp exposures were made. Sterile rubber dam was placed for each individual tooth. Clamps number 211, 212, and 00\(^c\) were used, according to the size and configuration of each tooth. Teeth were cleaned with an antiseptic solution before cavity preparation. A Class V preparation was made on the facial surface of each tooth. A number 35

\(^a\)Glass disposable micro-sampling pipet.

\(^b\)Nembutal solution I.V. or I.M. use. Abbot Laboratory, North Chicago.

inverted cone carbide bur was used at high speed with continuous dripping of sterile saline solution from a plastic syringe, to avoid overheating. The bur was used to make the preparation until pink dentin showed that pulp exposure was imminent. A number five explorer was then used to mechanically expose the pulp. No attempt was made to place the exposure at the center of the preparation. After the exposure was made, a sterile cotton pellet was used to arrest hemorrhage and to clean the floor of the cavity in case some remaining chips of dentin or enamel were present (Figure 2).

Immediately after the exposure one of the following preparations was applied using a dental applicator:

(1) Hydroxyapatite mixed with chlorhexidine.
(2) Hydroxyapatite mixed with distilled water.
(3) Calcium hydroxide mixed with chlorhexidine.
(4) Calcium hydroxide mixed with distilled water.

The capping material was placed directly over the exposure site only. Then small squares of gold foil sheet #4\(^a\) approximately .5 mm in size, and previously sterilized by dry heat were gently placed over the capping material and the complete floor of the preparation. IRM cement\(^b\) was mixed and placed with a torno instrument over the gold foil. Copalite varnish\(^c\) was then applied and amalgam\(^d\) was prepared and inserted (Figure 3).

\(^a\)Gold Foil sheets #4, Williams. M.H. Williams Gold Refining Company, Incorporated, Buffalo, New York.

\(^b\)IRM cement, L.D. Caulk Company, Incorporated, Milford, Delaware.

\(^c\)Copalite Intermediary Varnish, Cooley and Coley, Ltd., Houston, Texas.

\(^d\)Dispersalloy, dispersed phase alloy, Johnson & Johnson Company, East Windsor, New Jersey.
Capping procedures were done at two week intervals from one quadrant to another, in order to give the monkeys a recuperative period between the successive operative procedures.

Surgical Procedure

The teeth of monkey number 10 were removed 14 days after the pulp capping. For monkey number 9, the teeth were extracted 90 days after the capping. Extractions were also scheduled from one quadrant to another at two-week intervals as was done with the capping procedures.

The animals were anesthetized as described previously and were placed in the supine position. Before extraction the oral cavity was examined closely to determine if any pathological condition was present. Amalgam restorations were observed to be in place.

A curette was used to separate the attached gingiva. In one quadrant (lower right, monkey number 9) the facial gingiva and alveolar mucosa were reflected to facilitate extraction. Straight elevators\(^a\) were used to luxate the teeth until they were mobile. Forceps number 22\(^a\) and 203\(^b\) were used to remove the tooth from the socket. A piece of gauze was placed immediately afterward to promote hemostasis. Monkey number nine had a local infection in the socket of the upper left central incisor, one day after extraction. Three hundred units of penicillin G procaine was administered daily for four days.

After extraction, the apical third of the roots was cut off with a number 701 carbide bur, using high speed and water spray. The specimens

\(^a\)Hu-Friedy, 3118 North Rockwell Street, Chicago, Illinois 60618.

\(^b\)Hu-Friedy, 3118 North Rockwell Street, Chicago, Illinois 60618.
were placed in labeled bottles containing 10% formalin. Four teeth were fractured during extraction and they were excluded from the study.

**Laboratory Procedure**

Before teeth were taken to the laboratory, each tooth was ground in one of the proximal surfaces until approximation of the pulp was evident. This was done under a water spray and care was taken not to expose the pulp.

The teeth were decalcified with 5% formic acid for approximately three weeks, after which they were dehydrated and embedded in paraffin blocks. Semiserial sections 7 microns in thickness were prepared and stained with hematoxylin and eosin. From each tooth 10 to 25 slides were prepared and each slide had four or five sections.
RESULTS
The histologic sections of each tooth included in this study were screened. The sections showing the area of the exposure were studied in detail. Pulp reactions were classified as satisfactory or unsatisfactory. A satisfactory reaction showed no pulp inflammation or mild inflammation with scattered leukocytes at the area of the exposure or around particles of the material which had been introduced inside the pulp, with or without complete dentin bridging of the exposure. Pulps which showed dense leukocytic infiltration of the pulp or pulp necrosis were considered to have responded unsatisfactorily. The presence of capping material or dentin chips inside the pulp and the reaction which they elicited were recorded.

Findings at 14 Days

Hydroxyapatite Mixed with Chlorhexidine

A total of six teeth were examined in this group. Five specimens showed a satisfactory pulp reaction with mild inflammation at the exposure site (Figures 4, 5). Particles of the capping material and dentin chips were present inside the pulp in these five specimens. The capping material appeared as angular spaces within the pulp tissue due to dissolution of the material during decalcification of the specimens. Onset of dentinogenesis was evident around the capping material and around the dentin chips in all specimens. The exposures appeared to be small.

The sixth tooth showed an unsatisfactory pulp reaction. In this tooth, the exposure was unintentionally made with the bur. The exposure was extensive, and a bur indentation was evident on the pulpal wall opposite to the exposure. Destruction of pulp tissue at the exposure
site was evident. Considerable capping material was introduced inside the pulp, and was associated with a moderate inflammatory reaction with macrophages and lymphocytes predominating. There was no evidence of reparative dentinogenesis either at the exposure site or around the particles of the capping material that were introduced inside the pulp. The exposure appeared to be large (Figure 6).

Hydroxyapatite Mixed with Distilled Water

A total of six teeth were examined in this group. Satisfactory pulp reaction with mild inflammation at the exposure site was observed in five specimens (Figures 7, 8). Particles of the capping material and dentin chips were inside the pulp in all the specimens (Figures 9, 10). Onset of dentinogenesis was evident around the capping material in three specimens (Figures 11, 12); and around dentin chips in five specimens. Aspiration of odontoblasts was observed in one specimen at the middle third of the root due to extraction. In the sixth specimen unsatisfactory pulp reaction with moderate inflammation was observed. The exposures appeared to be small in all specimens.

Calcium Hydroxide Mixed with Chlorhexidine

Six teeth were examined in this group. Satisfactory pulp reaction with mild inflammation at the exposure site was observed in all specimens. Four teeth showed evidence of a thin calcific bridge formation which was incomplete (Figures 13, 14). Necrotic tissue was observed above the bridge. Two specimens showed no evidence of bridging. Dentin chips were present inside the pulp tissue and reparative dentinogenesis was evident around them in all specimens. Exposure size was considered to
be small. In one specimen root fracture occurred during extraction; however, the area of exposure and underlying pulp were unaffected, and the specimen was included within histologic evaluation.

Calcium Hydroxide Mixed with Distilled Water

Six teeth were examined in this group. The exposure site was not evident in the histologic sections of two specimens which were excluded from the evaluation. The remaining four teeth showed satisfactory pulp reaction with mild inflammation at the exposure site. Two specimens showed a thin calcific bridge; however, examination of the serial sections showed that thin bridge to be incomplete. Necrotic pulp tissue was observed above the calcific bridge (Figure 15). No evidence of calcific repair was present in the other two specimens. Dentin chips were present inside the pulp in three specimens, with evidence of reparative dentinogenesis around them. Exposures were considered small in all instances.

Findings at 90 Days

Hydroxyapatite Mixed with Chlorhexidine

Six teeth were examined. All showed satisfactory pulp reaction. Reparative dentin was evident on the pulpal walls adjacent to the exposure, and around dentin chips and particles of the capping material which were introduced inside the pulp (Figure 16). The latter appeared as angular spaces within the reparative dentin, due to dissolution of the material during decalcification of the specimens. All specimens showed calcific bridging of the exposure; however, examination of the serial sections showed the bridges to be incomplete in five specimens and complete in only one specimen. The vital pulp tissue that was present above the
incomplete bridges, showed mild inflammation (Figure 17). In one specimen pieces of gold foil were observed over the floor of the cavity preparation. Pulp exposure was considered small in all specimens.

**Hydroxyapatite Mixed with Distilled Water**

Five teeth were examined in this group. Two specimens were excluded from the evaluation due to fracture during extraction. The remaining three teeth showed satisfactory pulp reaction with no inflammation. Two specimens showed incomplete calcific bridging of the exposure with reparative dentin around dentin chips and particles of capping material and on the pulpal walls adjacent to the exposure. The third specimen showed a complete calcific bridge. The exposures were considered small in all three teeth. Pieces of gold foil were present in the cavity preparation in one specimen (Figure 18).

**Calcium Hydroxide Mixed with Chlorhexidine**

Six teeth were examined in this group. All specimens showed a satisfactory pulp reaction with complete bridging of the exposure and no pulp inflammation. Necrotic tissue was evident at the exposure site above the reparative dentin bridge. Reparative dentin formed below the exposure site, and around dentin chips, which were incorporated within the bridge (Figure 19). Pulp exposure appeared to be small in all specimens.

**Calcium Hydroxide Mixed with Distilled Water**

Six teeth were examined in this group. One tooth was excluded from the evaluation due to fracture during extraction. Of the remaining five teeth, pulp reaction was satisfactory in four. Three specimens
showed no inflammation and one specimen showed mild inflammation at the exposure site. In all four reparative dentin was evident below the exposure site and around dentin chips (Figure 20). Three specimens showed complete calcific bridging of the exposure, and one showed incomplete calcific bridge.

The fifth specimen showed total pulp necrosis (Figure 21). Pulp exposure appeared to be small in all five specimens.
TABLES AND FIGURES
<table>
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<th>Hydroxyapatite Mixed with Chlorhexidine</th>
<th>Hydroxyapatite Mixed with Distilled Water</th>
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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

a = + satisfactory reaction
- unsatisfactory reaction

b = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

c = p present, complete or incomplete
np not present

d = p present
np not present

e = s small
L large
TABLE III

SUMMARY OF THE MICROSCOPIC FINDINGS AT 14 DAYS OF SPECIMENS CAPPED WITH HYDROXYAPATITE MIXED WITH DISTILLED WATER

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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

a = + satisfactory reaction  
- unsatisfactory reaction

b = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

c = p present, complete or incomplete  
np not present

d = p present  
np not present

e = s small  
L large
**TABLE IV**

**SUMMARY OF THE MICROSCOPIC FINDINGS AT 14 DAYS OF SPECIMENS CAPPED WITH CALCIUM HYDROXIDE MIXED WITH CHLORHEXIDINE**

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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

<sup>a</sup> = + satisfactory reaction  
- unsatisfactory reaction  

<sup>b</sup> = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis  

<sup>c</sup> = p present, complete or incomplete  
np not present  

<sup>d</sup> = p present  
np not present  

<sup>e</sup> = s small  
L large
### Table V

**SUMMARY OF THE MICROSCOPIC FINDINGS AT 14 DAYS OF SPECIMENS CAPPED WITH CALCIUM HYDROXIDE MIXED WITH DISTILLED WATER**

<table>
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<th>Tooth Number</th>
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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

- **a = +** satisfactory reaction
  - - unsatisfactory reaction

- **b = 0,** none; 1, mild; 2, moderate; 3, severe and 4, necrosis

- **c = p** present, complete or incomplete
  - np not present

- **d = p** present
  - np not present

- **e = s** small
  - L large
### TABLE VI

**SUMMARY OF THE MICROSCOPIC FINDINGS AT 90 DAYS OF SPECIMENS CAPPED WITH HYDROXYAPATITE MIXED WITH CHLORHEXIDINE**

<table>
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<tr>
<th>Tooth Number</th>
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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

- **a** = + satisfactory reaction
  - - unsatisfactory reaction

- **b** = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

- **c** = p present, complete or incomplete
  np not present

- **d** = p present
  np not present

- **e** = s small
  L large
### TABLE VII

**SUMMARY OF THE MICROSCOPIC FINDINGS AT 90 DAYS OF SPECIMENS CAPPED WITH HYDROXYAPATITE MIXED WITH DISTILLED WATER**

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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

a = + satisfactory reaction  
- unsatisfactory reaction

b = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

c = p present, complete or incomplete  
np not present

d = p present  
np not present

e = s small  
L large
### TABLE VIII

**SUMMARY OF THE MICROSCOPIC FINDINGS AT 90 DAYS OF SPECIMENS CAPPED WITH CALCIUM HYDROXIDE MIXED WITH CHLORHEXIDINE**

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Teeth are identified as follows: 1, central incisor; 2, lateral incisor; 4, first bicuspid; 5, second bicuspid; 6, first molar and 7, second molar.

- a = + satisfactory reaction
  - - unsatisfactory reaction

- b = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

- c = p present, complete or incomplete
  - np not present

- d = p present
  - np not present

- e = s small
  - L large
TABLE IX

SUMMARY OF THE MICROSCOPIC FINDINGS AT 90 DAYS OF SPECIMENS CAPPED WITH CALCIUM HYDROXIDE MIXED WITH DISTILLED WATER

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   - unsatisfactory reaction

b = 0, none; 1, mild; 2, moderate; 3, severe and 4, necrosis

c = p present, complete or incomplete
   np not present

d = p present
   np not present

e = s small
   L large
FIGURE 1  X-ray diffraction sample of a typical crystallographic structure of synthetic hydroxyapatite.
FIGURE 2  Typical mechanically exposed pulp under the rubber dam.

FIGURE 3  Amalgam restoration used after capping procedure.
FIGURE 4 Photomicrograph of a maxillary right lateral incisor. The pulp was capped with hydroxyapatite mixed with chlorhexidine for 14 days before extraction. A satisfactory pulp reaction is evident. (Hematoxylin and eosin stained, original magnification X35).

FIGURE 5 Higher magnification of the same pulp shown in Figure 4. Mild inflammation is evident at the exposure site. Dentin chips were introduced inside the pulp and are associated with reparative dentinogenesis. There is no evidence of calcific bridge of the exposure. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 6  Unsatisfactory reaction in a pulp of a maxillary right central incisor capped with hydroxapatite mixed with chlorhexidine for 14 days before extraction. The exposure was accidentally made with the bur during cavity preparation. Notice the bur indentation on the pulpal wall opposite the exposure. Destruction of pulp tissue in the area of the exposure is evident. Considerable capping material was introduced inside the pulp and appeared as angular spaces. The capping material is associated with a moderate inflammatory reaction. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 7 Photomicrograph of a mandibular right central incisor. The pulp was capped with hydroxyapatite mixed with distilled water for 14 days before extraction. A satisfactory reaction is evident. Dentin chips are present. The angular spaces represent voids that were occupied by particles of capping material before decalcification. (Hematoxylin and eosin stained, original magnification X35).

FIGURE 8 Higher magnification of the same pulp shown in Figure 7. Reparative dentin formation around capping material and dentin chips can be observed. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 9 Photomicrograph of a mandibular right lateral incisor. The pulp was capped with hydroxyapatite mixed with distilled water for 14 days before extraction. Capping material has been forced into the pulp. (Hematoxylin and eosin stained, original magnification X35).

FIGURE 10 Higher magnification of the same pulp shown in Figure 9. Capping material has been forced inside the pulp and is associated with mild inflammation. There is no evidence of reparative dentinogenesis around the capping material. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 11  Photomicrograph of a mandibular right first molar. The pulp was capped with hydroxyapatite mixed with distilled water for 14 days before extraction. Mild inflammation is evident at the exposure site. (Hematoxylin and eosin stained, original magnification X35).

FIGURE 12  Higher magnification of the same pulp shown in Figure 11. Reparative dentin is evident on the pulpal walls adjacent to the exposure and around particles of capping material inside the pulp. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 13  Photomicrograph of a maxillary left central incisor. The pulp was capped with calcium hydroxide mixed with chlorhexidine for 14 days before extraction. Calcific repair is evident at the exposure site. (Hematoxylin and eosin stained, original magnification X35).

FIGURE 14  Higher magnification of the same pulp shown in Figure 13. Reparative dentin is evident at the exposure site and around dentin chips accidentally introduced inside the pulp. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 15  Photomicrograph of a mandibular left first bicuspid. The pulp was capped with calcium hydroxide mixed with distilled water for 14 days before extraction. A thin calcific bridge is evident at the exposure site, with necrotic tissue above it. (Hematoxylin and eosin stained, original magnification X100).
FIGURE 16  Photomicrograph of a maxillary right central incisor. The pulp was capped with hydroxyapatite mixed with chlorhexidine for 90 days before extraction. Incomplete calcific bridge is evident, with vital pulp tissue above the bridge. Notice reparative dentin on the pulpal walls adjacent to the exposure and around dentin chips. The angular spaces within the bridge represent areas that were occupied by the capping material before decalcification of the specimens. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 17 Photomicrograph of a maxillary right first molar. The pulp was capped with hydroxyapatite mixed with chlorhexidine for 90 days before extraction. Notice the incomplete calcific bridge, with vital pulp tissue above the exposure. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 18  Photomicrograph of a mandibular right central incisor. The pulp was capped with hydroxyapatite mixed with distilled water for 90 days before extraction. Calcific bridging of the exposure is evident. Some capping material and dentin chips served as a nidus for reparative dentin formation. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 19  Photomicrograph of a maxillary left central incisor. The pulp was capped with calcium hydroxide mixed with chlorhexidine for 90 days before extraction. Bridging of the exposure is complete. Notice dentin chips within the calcific bridge. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 20  Photomicrograph of a mandibular left central incisor. The pulp was capped with calcium hydroxide mixed with distilled water for 90 days before extraction. Notice bridging of the exposure site and dentin chips within the calcific bridge. (Hematoxylin and eosin stained, original magnification X35).
FIGURE 21 Photomicrograph of a mandibular left lateral incisor. The pulp was capped with calcium hydroxide mixed with distilled water for 90 days before extraction. Pulp necrosis is evident. (Hematoxylin and eosin stained, original magnification X35).
DISCUSSION
Pulp capping has been and probably still is a controversial issue in pulp treatment. It has been variously stated that diagnosis, history of the tooth, exposure size, presence of rubber dam, capping material, restorative material and follow-up are the key factors which determine whether the treatment will be successful.

A crystalline form of pure hydroxyapatite has been tested in a previous study, and was well tolerated by the dental pulp. However, complete bridging was infrequent with the material, apparently due to the difficulty of localizing it to the area of exposure during capping.

In this study synthetic hydroxyapatite in a paste consistency was used as an experimental capping agent, to observe pulp reactions and to determine if there was any improvement in localizing the material over the area of exposure during capping.

Calcium hydroxide was used as a control material since it has been shown that it induces pulp healing and bridge formation. It was used in its pure form, to be consistent with the experimental material which did not have any other component.

Distilled water and chlorhexidine were used as mixing vehicles for the capping agents. Chlorhexidine has been shown to be taken up and slowly released by enamel. It was thought that if chlorhexidine was incorporated in hydroxyapatite, the material might acquire antiseptic properties and might slowly release the antiseptic at the exposure site. This might enhance pulp recovery if the exposure had been contaminated.
However, the study was done on uncontaminated pulps to determine if the addition of chlorhexidine to the apatite would have any adverse effect on the pulp.

Rubber dam was placed on each individual tooth that was capped. Quadrant placement was desired, but was impossible due to the position of the teeth in the arch and difficulties in clamp retention.

In all instances cavity preparations were done with extreme care and with constant examination of the depth of the cavity. Pulp exposures were carefully made with an explorer. In only one instance was the exposure unintentionally made with the bur, during cavity preparation. No difficulties were encountered during placement of the capping agents. In all instances, cavity depth was adequate for the placement of the capping materials, gold foil, IRM and amalgam restoration. Small pieces of square sheets of gold foil were used to isolate the capping material from the IRM cement bases, which were placed because a hard setting base was desired for amalgam condensation.

Histologic findings at 14 days after capping, with hydroxyapatite mixed with either vehicle, showed only two instances of unsatisfactory pulp reaction with moderate inflammation. The unsatisfactory reaction in one specimen occurred in association with extensive exposure of the pulp by the bur. Capping material was introduced inside the pulp in most instances, indicating the difficulty of localizing the material at the area of exposure. Lack of a setting reaction of the material probably contributed to its lack of localization at the site of the exposure. In addition, pressure exerted during condensation of the restorative materials could have forced the capping material inside the pulp. Particles of the
Capping material appeared as angular spaces in the histologic sections due to dissolution of the material during decalcification of the specimens. Reparative dentinogenesis in association with the particles was noticed in 8 out of 12 specimens examined at this study period.

Dentin chips were present inside the pulp in every specimen, and reparative dentin was observed around them in all cases. Thus dentin chips and capping material served as a nidus for reparative dentinogenesis.

The onset of a calcific bridge at the exposure was not evident in any specimen capped with hydroxyapatite at 14 days irrespective of the mixing vehicle. On the other hand, specimens capped with calcium hydroxide at the same interval showed a thin calcific bridge in about 60% of cases, regardless of the mixing vehicle used. Specimens capped with calcium hydroxide showed necrotic tissue at the area of exposure as a result of the alkaline pH of the material. Dentin chips were present inside the pulp in all instances, and reparative dentin was observed around them. The dentin chips contributed to the formation of a thin bridge, since they were localized at the exposure site.

Histologic findings at 90 days after capping with hydroxyapatite, regardless of mixing vehicle used, showed incomplete bridging of the exposure in 75% of the specimens. Vital pulp tissue was evident above the incomplete bridges. The infrequent occurrence of complete bridging appeared to be related to lack of localization of the material to the area of exposure. Particles of the capping material as well as dentin chips served as a nidus for reparative dentinogenesis, and were incorporated inside the reparative dentin which had been deposited. The capping material appeared as angular spaces within the reparative dentin due to
dissolution of the material during decalcification of the specimens. The atubular reparative dentin formed around the capping material was observed to be identical to that formed around dentin chips, in agreement with previous findings by Dickey, Kafrawy and Phillips. ²

Specimens capped with calcium hydroxide mixed with either vehicle at 90 days showed complete bridging in 85% of cases. In these specimens the bridge formed below the exposure site due to necrosis of the superficial pulp tissue caused by the capping material. Dentin chips introduced inside the pulp served as a nidus for reparative dentinogenesis and were found to be incorporated within the calcific bridge. Reparative dentin formed around dentin chips was found to be atubular and identical to that formed in the calcific bridge at the exposure site.

The findings of this study indicate that hydroxyapatite is well tolerated by the pulp, as has been shown previously. ² Also, although the consistency of the material was different, the same difficulty in localization at the area of the exposure was apparent. With these results in mind, it is suggested that some component should be added to it, to improve its handling properties and obtain a hard setting reaction which will facilitate its placement.

The efficiency of calcium hydroxide as a pulp capping agent was again substantiated.

The findings also indicate that one percent chlorhexidine used as a mixing vehicle had no adverse effect on the pulp with either capping material.
SUMMARY AND CONCLUSIONS
The present investigation evaluated pulp reactions to a synthetic hydroxyapatite in a paste consistency, using one percent chlorhexidine and distilled water as a mixing vehicle. Pure calcium hydroxide also mixed with both vehicles was used as a control.

Two monkeys with healthy permanent dentitions were used in the investigation. The animals were anesthetized using an IV injection of sodium pentobarbital. Sterile rubber dam and sterile instruments were used. Class V cavities were prepared using high speed in a total of 47 teeth. The pulps were mechanically exposed with an explorer and capped with either hydroxyapatite mixed with one percent chlorhexidine, hydroxyapatite mixed with distilled water, calcium hydroxide mixed with one percent chlorhexidine or calcium hydroxide mixed with distilled water. After capping, small pieces of gold foil were placed over the cavity floor to isolate the capping material. A base of IRM was placed and the cavities were restored with amalgam.

The teeth were extracted at 14 and 90 days after capping. The specimens were fixed in 10% formalin and decalcified in 5% formic acid. Serial sections 7 microns thick were prepared and stained with hematoxylin and eosin.

Findings at 14 days after capping showed a satisfactory pulp reaction in 10 specimens out of 12, when hydroxyapatite mixed with either vehicle was used. Particles of capping material and dentin chips were evident inside the pulp in all specimens. No evidence of calcific bridging was
observed at the exposure site in any of the specimens. Teeth capped with calcium hydroxide showed a thin calcific bridge in six specimens out of 10, at the area of exposure. Dentin chips were present inside the pulp in all specimens.

Findings at 90 days after capping showed incomplete bridging formation in seven specimens out of nine, when hydroxyapatite was used. Particles of capping material and dentin chips served as a nidus for dentinogenesis. Teeth capped with calcium hydroxide showed complete bridging formation in 9 out of 11 teeth.

Histologic examination showed that the synthetic hydroxyapatite mixed with either vehicle was well tolerated by the dental pulp. Complete bridging occurred infrequently in the specimens capped with the hydroxyapatite, compared to those capped with calcium hydroxide, which usually showed complete bridging at the area of the exposure.

It was concluded:

(1) Synthetic hydroxyapatite material mixed with either one percent chlorhexidine or distilled water was well tolerated by the dental pulp.
(2) One percent chlorhexidine gluconate solution did not produce any adverse effect on the dental pulp.
(3) Incomplete bridging under hydroxyapatite was related to the difficulty of localizing the material to the areas of exposure.
(4) Dentin chips present inside the pulp served as a nidus for reparative dentin formation.
(5) The reparative dentin that formed around hydroxyapatite was morphologically identical to that formed around dentin chips.
(6) Pulps capped with calcium hydroxide showed a high incidence of complete bridging formation.

(7) Further investigation in the use of synthetic hydroxyapatite as a capping material is necessary.
REFERENCES


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PULP REACTIONS TO A SYNTHETIC HYDROXYAPATITE AND CHLORHEXIDINE IN MONKEYS

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The study compared pulp reactions to a synthetic hydroxyapatite and to calcium hydroxide with either one percent chlorhexidine or distilled water as a mixing vehicle. Forty-seven permanent teeth of two monkeys were mechanically exposed under aseptic conditions. The pulps were then capped with one of the following: synthetic hydroxyapatite mixed with chlorhexidine; synthetic hydroxyapatite mixed with water; calcium hydroxide mixed with chlorhexidine; calcium hydroxide mixed with water.

Small square sheets of gold foil were then placed over the capping material. A base of IRM was placed and the cavities were restored with amalgam. The teeth were extracted at 14 and 90 days after pulp capping. The specimens were fixed in 10% formalin and decalcified in 5% formic acid. Serial sections 7 microns thick were prepared and stained with hematoxylin and eosin.

The synthetic hydroxyapatite mixed with one percent chlorhexidine or water was well tolerated by the dental pulp. Complete bridging occurred infrequently in the specimens capped with the hydroxyapatite, compared
to those capped with calcium hydroxide, which usually showed complete bridging of the exposure.