NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT **NBS REPORT**

311.05-20-3110560 December 31, 1964 8647

Progress Report

on

A Review of Zinc Oxide-Eugenol Type Filling Materials and Cements

By

Gerhard M. Brauer*

*Chemist, Dental Research Section, National Bureau of Standards, Washington, D. C.

This investigation is part of the dental research program conducted by the National Bureau of Standards, in cooperation with the Council on Dental Research of the American Dental Association; the Army Dental Corps; the Dental Sciences Division of the School of Aerospace Medicine, USAF; the National Institute of Dental Research; and the Veterans Administration.

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

Table of Contents

A Review of Zinc Oxide-Eugenol Type Filling Materials and Cements

by

Gerhard M. Brauer

Abstract

A review is given of the status of zinc oxide-eugenol type cements as well as modifications of these materials developed in this laboratory and elsewhere. The mechanism of the setting reaction and the physical, histological and clinical properties of these cements are discussed.

1. Introduction

Although oil of cloves has been used for the treatment of dental caries since the 16th century [1] zinc oxide-oil of clove cements were first reported in the dental literature by Chisholm [2] nearly a hundred years ago. Flagg [3] replaced the creosote oil used in the earlier formulations with oil of cloves. He found this cement very satisfactory and used it routinely in dried cavity preparations. Tomes [4] described a pulp capping procedure in which a concave platinum disc filled with thick zinc oxide-oil of cloves paste was placed over the exposure. Since oil of cloves contains about 85% eugenol the latter liquid was substituted in dental preparations. The first proprietary zinc oxide-eugenol (ZOE) cement was introduced in 1894 by Wessler in Sweden [5]. It was claimed to be "non-irritating, a poor conductor of heat, a powerful antiseptic and anodyne".

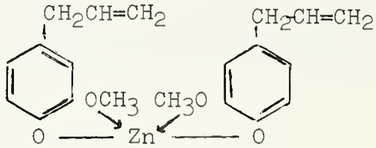
2. Dental Applications

The putty-like coherent mass formed on mixing zinc oxide and eugenol (ZOE) containing various additives has been found valuable in many phases of dentistry. As will be discussed later, this cement possesses much better compatibility than most dental materials with both the hard and soft tissues of the mouth, relieves pain and provides good marginal seal in tooth cavities. Hence, these materials are being widely employed as temporary fillings, sedative bases, cementing media for crown and bridge work, as a soft tissue pack in oral surgery, periodontics and certain phases of restorative dentistry, as root canal sealers in endodontics and with modifying agents as impression pastes. The greatest weaknesses of ZOE cement are: 1. its low strength which may not be large enough to resist the biting force transmitted to it through a restoration, 2. its lack of resistance to wear, and 3. disintegration under oral environment that limits the life of temporary fillings.

3. Setting Mechanism

Detailed studies of the setting mechanism of ZOE cements have been undertaken only during the last few years. Forster [6] in 1929 assumed that the hardening is a physicomechanical process in which the structure of the zinc oxide remains unchanged. Wallace and Hansen [7] showed that the phenolic group is essential for hardening. Harvey and Patch [8] demonstrated the greater activity of oxides prepared by the decomposition of zinc salts as compared to those prepared by combustion of the metal. The influence of the presence of small amounts of water was recognized but little evidence was found for the existence of a new crystalline species in the set mass.

These investigators assumed that a compound resembling zinc phenolate is formed and that the setting process is a combination of physical and chemical reactions. Copeland, Brauer, Sweeney and Forziati [9] showed by chemical, x-ray diffraction and infrared analyses that a zinc eugenolate chelate of the following structure is formed:



They deduced from electron photomicrographs that the set mass resulting from mixes of zinc oxide and eugenol consists of zinc oxide embedded in a matrix of long, sheath-like crystals of zinc eugenolate with any excess eugenol being sorbed by both the zinc eugenolate and the zinc oxide. Figure 1 shows the sheaf-like aggregation that is typical of the hardened mass. Similar conclusions were reached by Smith [10] and Vieillefosse, Vayson de Pradenne and Zumbrunn [11]. More recently Brauer and Wiedeman [12] have shown that solutions of zinc salts will give a change in the polarographic half-wave potential in the presence of eugenol, again indicating that zinc will form a complex with eugenol. More detailed x-ray diffraction studies of the crystal structure of zinc and magnesium eugenolates have been undertaken by Douglas [13]. A complete elucidation of the unit cell structure should aid in explaining and improving the mechanical properties of the cements.

4. Composition

Because simple mixtures of zinc oxide and eugenol harden slowly most commercial products contain additional ingredients. The composition of reasonably successful ZOE cements is given in Table 1 [7, 14] and a formula for a root canal sealer in Table 2 [14, 15]. The strength and mixing characteristics are improved by the incorporation of rosin or hydrogenated rosin. Many salts will accelerate the setting reaction but zinc compounds, especially zinc acetate, are very effective [7, 16]. Other compounds such as water, alcohol and glacial acetic acid also act as accelerators. It is likely that water or the hydrated salts react with zinc oxide in the following manner:

$$ZnO + H_2O \longrightarrow Zn(OH)_2$$

$$Zn(OH)_2 + 2OH\ C_{10}H_{11}O_2\ (\text{eugenol}) \longrightarrow Zn(O\ C_{10}H_{11}O_2) + 2H_2O$$

Thus, only a trace of water is necessary to start the reaction since the water liberated by the eugenolate formation will in turn react with additional zinc oxide.

5. Physical Properties

Setting Time - The setting time of zinc oxide eugenol is dependent on the following factors: (1) accelerators, (2) water, (3) process used in the manufacture of the zinc oxide, (4) particle size and surface area of the powder, (5) powder-liquid ratio, (6) method of mixing and (7) temperature. As has been mentioned above traces of water or a highly humid atomsphere generally speed up the setting reaction. Under conditions of high humidity the slurry may set before an adequate mix has been obtained. Zinc oxides made from carbonate are more reactive than those manufactured by oxidizing the metal, but addition of water to such powders has no marked effect [10]. D. C. Smith therefore, suggested use of zinc oxide made from carbonate by heating to 350-400° C for 20 minutes and cooling in air. On mixing with eugenol to a thick consistency such slurries will harden within 3 to 4 minutes.

Smaller particle size zinc oxides speed up the setting time. However, the setting time is more dependent on the method of manufacture than on the dimensions of the zinc oxide particles. On exposure to air, moisture absorption and formation of zinc carbonate may take place which will modify the reactivity of the particles. The amount of powder that will combine with the liquid to achieve a certain consistency is much greater than that of the zinc phosphate cements. The larger the amount of zinc oxide incorporated into the mix the shorter the setting time. High powder-liquid ratios are also desirable to increase strength. Trituration with a mortar and pestle or mixing for 30 seconds in a mechanical amalgamator using gelatin capsules has recently been suggested [18]. The rate and time of setting are somewhat affected by the length of spatulation. Within practical limits, the longer the mixing time, the shorter the setting time [19]. The lower the temperature of the mixing slab, the longer the setting time provided that the temperature is above the dew point.

Temperature Rise - The setting reaction is slightly exothermic. The temperature rise is dependent on the amount of slurry used, presence of modifying agents, powder-liquid ratio and degree of spatulation. However, the rise in temperature should not exceed 5° C under clinical conditions and hence, is much smaller than the temperature rise encountered during hardening of many other restorative materials.

Strength - Table 3 lists the 24-hour compressive, tensile and shear strengths as reported [18] for a zinc oxide-eugenol cement containing a powder-liquid ratio of 2.6 g/0.4 ml which is considerably higher than the ratio generally employed for commercial products. Compressive strengths as high as 385 kg/cm^2 have been reported when 8.5 g of powder were mixed with 0.4 ml of eugenol [20]. Such a stiff consistency is not often employed under clinical conditions where the resulting cements have compressive strengths of 40 to 240 kg/cm^2. Particle size does not seem to affect the strength of the mixtures, but has a pronounced influence when additive agents are employed [21]. A slight decrease in strength within 7 days occurs with ZOE cements. The 7 day specimens give, however, somewhat higher Knoop hardness values than those obtained at 24 hours. Inspection of Table 3 indicates that not only the compressive strength but also the tensile and shear strengths of ZOE cements are considerably lower than those of zinc phosphate cements. Using zinc oxide obtained by thermal decompositon of the carbonate does not increase the strength of the cements, but decreases the tackiness of the mix.

Solubility - The solubility of ZOE cements (0.02 to 0.1% after 24 hours) in water is considerably lower than that of silicate or phosphate cements. The rate of solution is essentially constant during the first week [22]. Cements prepared from large particle size zinc oxide (0.93 micron) exhibit an appreciably higher rate of disintegration in water both after 24 hours and 7 days [21]. This appears to be caused by disintegration rather than solubility since large particles of the cement were observed in the storage medium. In dilute acetic acid the solubility of all materials was increased and the influence of particle size proved negligible. Addition of zinc acetate accelerator results in a minor increase in water solubility. The cements are fairly soluble in lactic or acetic acid solutions (pH 4) (but less soluble than either zinc phosphate or silicate cements) and completely dissolve in citric acid within a week [23]. Specimens prepared with a lower powder-liquid ratio and stored in citric acid (pH 4.0) showed much less dissolution over the same 7-day period. Abrasion tests indicated the smallest particle (0.11 micron) zinc oxide to be slightly more resistant to the action of a toothbrush and water. Powder-liquid ratio also influenced abrasion resistance as less weight loss occured in specimens prepared with the higher powder-liquid ratios. Dynamic influences (such as suspending the specimen in a stirred solution or repeated brushing with a weighed toothbrush) greatly increase the disintegration [18]. Ultrasonic stirring was especially harmful. Sealing properties of ZOE cement when evaluated on the basis of their ability to prevent the penetration of Ca^{45} at the marginal areas are superior to those of either silicate or zinc phosphate cement [26].

Methanol will extract some of the eugenol from the cement. Chloroform or acetone will remove nearly all the eugenol resulting in the complete disintegration of the cement.

Setting Shrinkage - The volumetric setting shrinkage is 0.9% in water[18]. This is little higher than the value for silicate cements, but considerably lower than the 6% shrinkage encountered in self-curing filling resins and should be of little clinical importance.

Coefficient of Thermal Expansion - The coefficient of linear thermal expansion is 35×10^{-6} per °C in the 25 to 60°C range [18]. This is about three times the value obtained for enamel.

Density - The density of different cements varies from 2.6 to 3.7 g/ml. The radiopacity of cements can be increased by incorporation of bismuth subcarbonate.

pH - The apparent pH value is 6 to 8 even at the time of contact with the tooth. The nearly neutral behavior of the cements may be responsible for their excellent tissue tolerance.

Heat Stability - The cements are stable at the temperatures encountered clinically [12].

Insulation - Phillips and coworkers [24, 25] showed that ZOE cement insulates against galvanic action both when wet or dry whereas zinc phosphate cements fail to do so when wet.

Eugenol inhibits the polymerization of methacrylates. Hence, ZOE cements should not be used as bases for acrylic fillings. Massler and Mansukhani [27] and Grossman [27a] using a dye penetration test to determine the in vitro sealing properties of different liners showed that fast-setting zinc oxide and eugenol mixtures most effectively prevented the penetration of acid from silicate and phosphate cements into the underlying area. The ZOE cements, however, have the disadvantage of discoloring the silicate cement.

6. Modified ZOE Type Cements

Low strength is unquestionably the main weakness of ZOE cements. To overcome this behavior a number of studies have been undertaken during the last decade to obtain cements showing improved physical properties. The following approaches have been used, 1. incorporation of fillers, modifying agents or resins, 2. study of the scope of the reaction of metal oxides with eugenol, 3. substitution or partial substitution of eugenol by other chelating agents, acids or acid derivatives. Each approach will be discussed below.

Incorporation of Fillers or Modifying Agents - Addition of rosin or rosin derivatives improves the working properties by reducing the friability and wear of the hardened cement. Generally, hydrogenated rosin is used since it is not readily oxidized and imparts better color stability to the cement. Addition of fused silica to the powder does not markedly alter strength, but improves the handling characteristics of the mixes when in concentrations of at least 10% in the powder [22]. The addition of alloy for dental amalgam is not very effective. Only slight improvement in strength is obtained on incorporation of glass or cotton fibers into the powder [28]. Somewhat more effective is the addition of about 5% dicalcium phosphate [29]. Ethylcellulose and powdered mica have been suggested as fillers and gum elemi is claimed to increase adhesion.

Incorporation of up to 20% polymer dissolved in eugenol to improve the physical properties was first suggested by Curtis [30]. Addition of 1 to 10% polystyrene or poly(methyl methacrylate) produces a modest increase in strength, adhesiveness and marginal sealing characteristics [22, 31, 32]. ZOE cements containing 10% dissolved polystyrene have a maximum 7-day compressive strength of 492 kg/cm^2 and appear to stand up to condensation of amalgam by manual and mechanical techniques.

Substitution of Other Metal Oxides - The oxides of group IIA of the periodic table (MgO, CaO, SnO, BaO) and group IIB (ZnO, CdO) react with eugenol to give a cement [11,33].

Modification of the Liquid - Clove oil which is approximately 85% eugenol, oil of bay or guaiacol may be substituted for eugenol. Olive oil and light mineral oil serve as plasticizers to improve the mixing and flow properties and to produce a milder tasting preparation by diluting the eugenol. Brominated olive oil may be added to regulate viscosity, chlorothymol to increase the bacteriostatic properties and bay oil to increase taste and odor [34]. Canada balsam gives tackiness to the mixed cement which is especially desirable for root canal sealers. ZOE surgical dressings contain greater quantities of mineral, peanut or almond oils to increase plasticity and to dilute the irritating eugenol. Asbestos or cotton fibers may be added to increase strength and tannic acid as a hemostatic agent.

Bergamot oil has been suggested as replacement of eugenol in gingival dressings [35]. Unlike eugenol, oil of cloves, linseed oil or thymol, bergamot oil has no hemolyzing or protein precipitating properties.

Isomers of Eugenol - The isomers of eugenol capable of forming chelates have been synthesized [36]. The effect of the position of substituents on the behavior of the isomers as evidenced by their ionization constants and reactivity with zinc oxide has been determined [37]. In the reaction of eugenol isomers with zinc oxide vicinal (1,2,3-trisubstituted) isomers do not react readily (Table 4) compared to the unsymetrically 1,2,4 or 1,2,5-trisubstituted ones indicating that the chelation reaction is greatly influenced by the steric hindrance of the bulky neighboring allyl groups. In addition to steric effects of the substituent groups, the chelation reaction may also depend to a lesser degree on the ionization constants. The more acidic chavibetol reacts somewhat faster than eugenol. Synthesis of new chelate cements should be directed towards derivatives with unsymetrically trisubstituted groups.

Substitution of Other Chelating Agents - Zinc oxide will react with a number of chelating agents to form cementitious products [33]. Among these, the product of the reaction of zinc oxide and o-ethoxybenzoic acid (EBA) has been studied in considerable detail. Mixes containing EBA and metal oxides of group II of the periodic table or lead oxide will harden within a few minutes even in the absence of accelerators. The products formed from EBA, eugenol and zinc oxide although showing much improved properties have too high a water solubility to be useful clinically. Substitution of 2-propoxy-5-methylbenzoic acid that is a higher, more hydrophobic homologue of EBA gives cements that show unexpectly high water solubility [38, 39]. However, on incorporation of hydrogenated rosin, monocalcium phosphate or heat-treated fused quartz 24 hour water solubility and disintegration is reduced to 0.04%. The compressive, shear and tensile strength (Table 3) are three to four times those of commercial ZOE cement formulations and approach the values obtained for zinc phosphate cements [18, 39, 40]. Thus, the 24-hour compressive strength is increased to 872 kg/cm^2 as compared to 210 kg/cm^2 for many commercial products. The addition of poly(methyl methacrylate) or polystyrene may improve these properties [22]. Particle size of zinc oxide and fused quartz does not affect greatly the physical properties of the cements [18, 21]. As will discussed later these cements are well tolerated by the tissues. Clinical results indicate their usefulness as bases, sedative restorations and for cementing media [41]. Fillings wore excessively under clinical conditions. This behavior of the EBA cements in the mouth showed no correlation with laboratory findings on solubility, disintegration and abrasion [18]. It appears likely that the excessive wear of EBA filling materials may be overcome by improved formulations. To aid such studies, the effect of the oral environment on the exposed surfaces should be studied by microbiological methods.

To determine the causes of the breakdown of fillings that could not be predicted from the physical properties of these materials, their heat stability, decomposition in organic solvents and mechanism of the setting reaction have been studied [12]. It has been shown that EBA forms an ionic complex with divalent metal ions such as Zn^{++} The EBA in the cements can be quantitatively extracted with methanol or chloroform whereas eugenol is held more firmly in the hardened cement. Since eugenol forms a five—membered chelate whereas EBA gives a six-membered ring, the determination of the EBA chelate formation and stability constants should indicate the relative stability of the two ring systems and thus assist in clarifying this unexpected behavior. Neilson [42] reported the reactivity of 39 liquid chelating agents with metal oxides to form cements that may be useful as root canal filling materials. The best cement was formed from 7-n-propyl-8-hydroxyquinoline (Oxol) when mixed with Bi_2O_3. Compared with ZOE cements it possesses greater hardness, fair expansion during setting and withstands the presence of bicarbonate.

Incorporation of various acids and esters into ZOE type preparations has also been suggested. A zinc oxide-fatty acid material is commercially available. It has the advantage of not affecting acrylic resin materials and is claimed to possess excellent tissue tolerance. The cement has lower physical properties (compressive strength 70 kg/cm^2) and higher solubility than ZOE cements [43]. The cement does not appear to be capable of withstanding the biting forces and there is a 95% failure rate within 6 months. Horn [44] has suggested addition of 1% Triamite (a mixture of benzoic acid and esters of hydroxysubstituted benzoic acids) to improve the fungicidal activity of ZOE type crown and bridge cements. Molnar and Skinner investigated the reactivity of 28 aromatic carboxylic acids with zinc oxide [45]. Hydrocinnamic, cyclohexane carboxylic, p-tertiary butylbenzoic, thiobenzoic and cyclohexane butyric acid gave cements having compressive strength varying from 32 to 532 kg/cm^2. Cements containing cyclohexane butyric acid had the lowest solubility (0.16%).

7. Histological Studies

Many investigations have shown that zinc oxide-eugenol cements are well tolerated by the tissues. Since the hardened cement is essentially neutral the ZOE cement offers unusual pulpal protection. The eugenol is an obtundent; however, the clinical significance of this is not known. In addition to these qualities ZOE cement is superior to other cements in its initial adaptation to the cavity walls, at least during the first few days or weeks (26, 46, 47). The extremely mild effect on the pulp may be related to the ability of the cement to prevent ingress of fluids and organisms that might produce a pathologic condition in the pulp during the time when the pulp is injured. The palliative effect of ZOE cement has long be recognized. Sensitivity on cementation is unusual, even in preparations in mouths having past history of gross caries. Eugenol is relatively non-toxic as indicated by an LD_{50} of 0.50 gm/kg determined for white mice [48]. It is a substance that is generally recognized as safe for use as a food additive [49].

However, free eugenol has some inflammatory characteristics. Schilder and Amsterdam injected eugenol in the abdominal integument and eyes of rabbits and observed severe inflammation at both test areas [50].

Torneck [51] studied the reaction of hamster tissue to drugs used in root canal sterilization. The method employed consisted of surgical implantation of punctured polyethylene capsules containing the medicaments into the dorsum of the test animal. Within 48 hours eugenol produced a localized reaction; suppuration and a moderate inflammatory infiltration of the surrounding tissue were noted.

Coolidge [52] sealed various drugs in the root canals of dogs for a period of 21 days. Of the essential oils tested, oil of cloves seemed to produce the least irritation. Eugenol, however, produced extensive leukocytic infiltration with bone resorption. Similar observations were reported by Feldman [53].

Pohto and Scheinin [54] observed the effect of oil of cloves and eugenol on the circulation of the pulp in the lower rat incisor. In these experiments oil of cloves or eugenol was applied either directly on the exposed tissue or on a thin dentinal layer remaining over the pulp. Total thrombosis of the entire pulpal circulation developed within a few minutes. In cases where the opening made through the dentin was a slit, stasis and thrombosis occured within a radius of 200-400 microns from the site of the perforation. In the group where a thin dentinal layer had been left over the pulp the two liquids produced hyperemia. This condition was revealed through an increase of the velocity of the blood flow and through capillary dilation. Aggregates of red and white cells were observed in some of the cases. Thrombosis developed only in a few instances. The pulpal changes were limited, however, to hyperemia and cell aggregates when using a zinc oxide-eugenol paste.

Schach [35] suggested substitution of bergamot oil for eugenol, oil of cloves, linseed oil or thymol in gingival dressings since only bergamot oil showed no hemolyzing, protein precipitating properties in in vitro tests. He considers the previously used oils as possible tissue damaging agents.

Hardened ZOE cements, however, appear to be well tolerated by the tissues. Mitchell [55] studied the irritational qualities of dental materials by implanting them directly into the connective tissues beneath the skin of rats and by leaving them there for an "acute" period or a chronic period of approximately two weeks. The tissues around the materials were then studied microscopically. ZOE or ZOE cement containing zinc acetate were very mild irritants whereas calcium hydroxide had moderate irritational properties, but no heterotropic bone formation occurred around ZOE cement implants in the dermis of the rat [56,57]. Schaad, Carter and Myers [58] in similar studies detected a moderate reaction for ZOE cement. On the other hand, Roydhouse and Weiss [59] injected ZOE cement immediately after mixing and before setting into the fascial layers of the belly wall of rats and a severe initial irritation and necrosis resulted. After 30 days, inflammation was still present around the implant. On the basis of the reaction of the chorio-allantoic membrane of the chick embryo Colman [60] suggests that ZOE cement has a toxic action on cells. Probably unreacted eugenol which was in contact with the tissues in the latter studies is responsible for the reactions. ZOE fillings and cements usually harden shortly after being placed and the residual eugenol content which may come in contact with the pulp is small. However, periodontal packs or non-setting ZOE pastes containing a high percentage of eugenol may perhaps not be the "ideal" remedy they were originally considered to be.

Silberkweit, Massler, Schour and Weinmann [61] prepared incisors of albino rats and filled them with a variety of filling materials to determine their effect on the young pulp and odontoblasts. Animals were sacrificed 2,7 and 8 days after operation and the effects on the odontoblasts were evaluated primarily from alterations in the quality (calcification and structure) and quantity of the dentin formed after the operation. ZOE cement brought about a reduction in the acute operative injury to the odontoblasts and accelerated the postoperative recovery as evidenced by the formation of a less prominent calcio-traumatic band and a return of the postoperative incremental pattern to normal. No morphologic changes were observed in the pulp or odontoblasts. In moderately deep cavities the reaction to ZOE cement was slightly more pronounced than was the effect of the cavity preparations per se. The reaction was less pronounced than in the specimens covered with gold plate. The stratification was slightly more prominent than that seen under the cavities of equivalent depth with connective tissue, but significantly less than under the cavities covered with gold plate. The odontoblasts and calcification of the post-operative dentin appeared normal even in very deep cavities (30 microns from the pulp). These findings indicate that ZOE cement has a definite palliative effect on the odontoblasts and tends to nullify the effects of the cavity preparation.

Manley [62] found that removal of the fillings in dogs' teeth after 10 to 12 weeks showed that ZOE cement gave no pulpal reaction and only a slight change in the odontoblasts was observed.

Manley also used patients between 10 and 16 years of age in whom extraction of premolars was required for orthodontic purposes [63]. After extraction the teeth were fixed and decalcified. He observed that the use of amalgam and silicate or phosphate cements is attended by a marked reaction in the pulp and dentin. With ZOE cement, however, no significant reaction in the pulp was reported. Even under a very deep cavity, changes were confined to the odontoblastic layer that had lost its close contact with the dentin margin by the breaking of the cell collars. The pulp tissue under the odontoblasts was normal. Odontoblasts were shrunken and some had lost their fibrils. Others had been drawn up close to the mouth of the tubules by contraction of the cut fibrils. Comparison of these histologic observations with those seen under the cavities used as controls indicated that these changes may have been due to the effect of cutting the fibrils by the burs. These changes were observed only in the sections under the deepest part of the cavity whereas with all other cements it occurred in all types of cavities. A thin layer of ZOE cement base was sufficient to prevent the severe localized reactions of the pulp observed on using acid cements.

Similarly, Gurley and Van Huysen [64, 65], from experimental work on the teeth of dogs, concluded that reaction of the pulp may be prevented by filling or lining cavities with ZOE cement. These authors estimated that it required 40 days for the pulp to recover from the inflammation caused by cutting a cavity half way through the dentin unless that cavity was filled with ZOE cement. ZOE cement produced a very mild reaction in the pulp compared to that of gutta percha, silicate or phosphate cements. Teeth in which cavities had been filled with ZOE cement for 6 months showed reticular atrophy histologically.

James and Diffenbach [66] observed the changes in the dentin and the pulp of young dogs following deep cavity preparations when the cavity was allowed to remain open. The deeper the cavity, the more marked and extensive were the reactions of the dentin and pulp to the trauma of the operation. When deep cavities were either filled or lined with ZOE cement beneath other types of filling materials protection was afforded the pulp and dentin.

Mitchell, Buonocore and Shazer [67] filled Class V cavities of varying depth with ZOE cement and other filling materials. Histological studies of the extracted teeth indicated that a decrease in floor thickness increased the pulp reaction except in the case of ZOE cement which gave a mild response irrespective of cavity depth.

Human teeth extracted after 22 minutes to 37 hours were studied by James and Schour [68]. Specimens sacrificed within the first hour showed a disruption of the pulpodentinal membrane, a reduction of the number of odontoblasts and edema. The edema was prominent and appeared to have pushed the odontoblasts into clumps. Some of the odontoblastic nuclei were seen within the tubules of the predentin. The layer of Weil was invaded by fibroblasts and many capillaries contained cellular debris. In specimens sacrificed after two weeks, the odontoblastic layer began to assume a normal appearance. Recovery of the odontoblasts and Weil layers appeared to be complete in the later survival periods (up to 39 days). Under gutta percha there was found in the longer survival periods a persistent chronic inflammation and formation of reparative dentin. Under cavities filled with ZOE cement the pulp showed only minimal inflammation. There was concurrently an absence of reparative dentin. Similar histologic observations in 116 cuspid teeth of young dogs showed mild inflammation in 88% and moderate inflammation in 12% [69]. There was not a single specimen with severe inflammation and no incidence of pathologic response. In comparison, silicate cements showed 55% mild, 39% moderate and 6% severe inflammatory responses with a 28% incidence of pathologic response of dentin. The inflammation under ZOE cement decreased after the first week and probably represented the pulpal response to the cutting of the odontoblastic processes during the cavity preparation. ZOE cement apparently did not add to the pulpal injury produced by the operative procedure. These authors classified dental restorations in order of the increasing irritating effect on the dentin and pulp as follows: ZOE cement, calcium hydroxide, amalgam, zinc phosphate cement, gutta percha, silicate cement and gold foil.

Glass and Zander [70] reported no microscopic evidence of true healing of healthy pulps mechanically exposed under sterile conditions and capped with zinc oxide and eugenol. At the end of eight weeks the site of exposure was still walled off with chronic inflammatory cells although the pulps remained clinically vital. Less inflammation was found when a paste of calcium hydroxide and water was applied under the ZOE cement. At the end of four weeks, pulps capped in this manner demonstrated complete healing with the original site of the exposure completely walled off by a new odontoblastic layer and a new dentin barrier. This work was done on exposed pulps and the tests were conducted to determine the influence of ZOE cement on the healing process of the pulp rather than on its nonirritating and palliative effect when used as a covering for freshly cut dentinal tubules.

From their data Zander and Glass [71] suggested that ZOE cement might be irritating and may delay the formation of a calcified bridge when in direct contact with freshly amputated pulp. These authors, however, do not feel that the material is irritant to the pulp when used in cavity preparations where the pulp is not exposed.

Massler's studies [72] clearly indicate that ZOE cement is not irritating to the pulp. To the contrary, this material quickly reduces the inflammatory reaction in human pulps exposed by dental caries. These studies also indicate only a mild inhibitory effect on the rate of secondary dentin formation during the first week. This inhibition disappears after three weeks.

On the other hand Bodecker [73] objects to the use of ZOE cement as a pulp capping material because it is too bland and does not irritate the pulp enough to cause the formation of a calcified bridge of secondary dentin as do the more irritating materials such as zinc phosphate cement [73]. He recommends ZOE cement only for cavities in teeth with pulpitis.

On insertion of ZOE cement into standard cavities cut into young human premolars the hardness of the dentin increased beyond that of unaffected dentin in.the same teeth [74]. The average increase in hardness is smaller than that caused by calcium hydroxide, but larger than that caused by amalgam covered dentin. This increase in hardness indicates an increase in the mineralization of the dentin between the pulp and the cavity preparation; an advantage in operative dentistry. With ZOE cement the formation of secondary dentin is delayed until the cleaning up process is completed.

The o-ethoxybenzoic acid containing cements have also been studied for inflammatory reaction by subcutaneous placement of specimens in the back and abdomens of rats [22]. The rats were sacrificed at 2, 16 and 32 days, and the connective tissue reaction around the implants was studied microscopically. All formulations containing EBA and polystyrene, methyl methacrylate, silica or zinc acetate did not increase the mild reaction of unmodified ZOE cements. Compared with zinc phosphate the tissue tolerance is superior. Similar results for ZOE were obtained by Bhaskar [75] and Coleman, Kirk and Pickard [40].

8. Bacteriocidal and Palliative Effects

Turkheim [76] inocculated sterile slices of decalcified dentin with micrococcus pyogenes var. aureus, Lactobacillus acidophilus odontolyticus, Escherichia coli and Candida albicans and exposed them to a ZOE cement in vitro for 1-48 hours. E coli was the most sensitive. The cement exerted a bacteriostatic and bactericidal action on the other microorganisms and all the inocculated slices were sterile within 24-48 hours. Under similar conditions, natural decay obtained from extracted carious teeth was resistant and in no case was the dentin sterilized Artifically infected, previously sterile slices of human dentin were rendered sterile in vitro within 3 hours of direct contact with a ZOE cement containing, among other things, ammonium chloride and thymol [77]. In most cases it was possible within 10 to 20 hours to sterilize natural decayed dentin obtained from freshly extracted human teeth by close contact with this cement. Clinical trials showed that the vitality of the healthy pulp was preserved. Turkheim [78] also claims that zinc oxide itself is antiseptic. He showed that discs of ZOE cement placed on seeded agar plates showed a prolonged germicidal action even after 14 months and 130 transfers, in contrast to other materials such as silver amalgam, copper amalgam, zinc phosphate, copper phosphate and silicate cements which showed germicidal action and produced bacteria-free zones in the agar plate only when inserted during the period of mixing and setting.

Studies of Coleman [60] indicate that of the antimicrobial agents used in oral surgery, ZOE cements had the broadest antimicrobial range.

Microorganisms vary in their sensitivity toward eugenol or oil of cloves [79]. E typhi and Monilia albicans were affected to a greater extent than the other microorganisms tested. B pyrocyaneus was the most resistant. Zinc oxide had no apparent antibacterial effect, but ZOE paste possesses definite inhibitive properties.

Terramycin and chloramphenicol are best suited for inclusion in ZOE pastes [80]. Penicillin is affected by either eugenol or ZOE cement [81-83]. Low unit dilutions lose most or all of their inhibitory bactericidal action, whereas the higher-unit concentrations, though affected, still possess definite growth restraining action.

To improve the antiseptic properties of eugenol Gurney [83a] recommends addition of 0.1% nitromethylfurfuryl ether to eugenol. This antiseptic is claimed to be equal in therapeutic effect to parachlorophenol-eugenol solutions and with almost no increase in toxicity.

ZOE cement possesses significant inhibitory power on the rate of acid production by oral bacteria in vitro but looses this ability rapidly, possibly due to the loss of free eugenol during the setting of the cement [84]. A good correlation can be obtained between decreased acid production and decreased counts of Lactobacilli.

ZOE cement acts as a local anesthetic or anodyne, a mild non-irritant antiseptic, and promotes healing by reducing the inflammatory reaction in the connective tissue. Whether the latter is specific or the result of its antiseptic action is not clear.

9. Clinical Studies

ZOE cement exerts a palliative effect on the pulp. It is at present the material of choice for use over recently injured pulps since it is unquestionably the least irritating of any of the dental cements. ZOE cement is preferred over other materials as a temporary sedative filling after pulpal injuries caused by deep and extensive operating procedures. This is especially true in the teeth of children in whom secondary dentin has not yet formed a protective barrier within the pulp chamber. Since ZOE cement is superior to other cements in its initial adaptation to the cavity walls, its extremely mild effect on the pulp may be related to its ability to prevent ingress of fluids and organisms that might produce a pathologic condition during the time when the pulp is injured.

The main purpose of a temporary filling is sedation and protection of the tooth from irritants and decay. Despite the wide use of ZOE cement as a temporary filling no detailed study has been made on how long this material will last under clinical conditions. Civjan and Brauer [41] placed ZOE cement fillings in maxillary first molars requiring mesio-occlusal restorations. The cavities were prepared to receive ultimately amalgam restorations. The cement (2.6 g ZnO per 0.4 ml eugenol- a powder-liquid ratio considerably higher than that used in commercial formulations) was mixed in a mortar and pestle and the paste was tamped into the dry cavities, using a wedged matrix when contact was to be restored. Slight lubrication of the matrix band and added care were needed to remove the band without disturbing the restoration which was finished and the occlusion adjusted by the normal operative procedures. The patients were instructed not to eat for 2 1/2 hours. Although some of the ZOE cement fillings chipped at their margin, they all remained serviceable for two to ten months of observation. No exposure of the dentinoenamel junction by fracture or wear of the restoration was observed during this time. EBA containing cements, despite their improved physical properties, failed within 1 1/2 months. These results seem to indicate that properly placed ZOE cement fillings containing a high powder-liquid ratio and with no zinc acetate accelerator may last considerably longer than previously expected. Further investigation to determine the durability of ZOE cement fillings is needed.

A ZOE-fatty acid material was employed in 41 Class I and Class II restorations [43]. Within six months 95% of the restorations had failed as compared to failure of 47% of the zinc phosphate cement and 14% of the silicate cement restorations.

It is good practice in mixing ZOE cements to incorporate the maximum amount of powder into the liquid consistent with a usable consistency so that the powder will be present in a large excess in the set cement. Preparing the cavity involves cutting perhaps millions of dentinal tubules. Therefore, cavity surfaces should be coated to protect and to insulate the pulp against the irritating action of filling and/or thermal shock. This is especially true with silicate cement and amalgam fillings. A ZOE cement base reduces the sensitivity of large excavations, ameliorates and sometimes prevents pulp inflammation and acts as a protective insulation for the pulp [85].

Pulp damage due to cutting heals in about 2 weeks. It takes about 40 days to lay down 0.1 mm of secondary dentin. Compared to a calcium hydroxide underfilling, the more bland ZOE cement base will cause the formation of less secondary dentin (which reduces the effect of external irritation and protects the pulp effectively). Cavities in young patients are sometimes filled with a ZOE cement filling and after a waiting period the final restoration is placed. Most dentists, however, insert the permanent restoration at the same sitting. A satisfactory base should possess not only the sedative qualities of ZOE cement, but should also have sufficient strength to provide a substantial foundation for the immediate insertion of a well condensed amalgam restoration. According to Gayler [87] the variation in the pressures used in hand-packing amalgam ranged from 21 to 420 kg/cm^2. Regular ZOE cement will not withstand the maximum packing pressure if this is exerted on a cylindrical specimen, but should stand up to the average packing pressure in four-walled cavities. A study of the mechanical failure of amalgam restorations with zinc phosphate and ZOE cement bases has been reported by Hoppenstand and McConnell [88]. They reported that a deep Class I restoration does not have appreciable strength when amalgam is condensed upon a layer of ZOE cement and this type of restoration might fail in clinical practice. When ZOE cement is used in a small excavation immediately above the pulpal chamber and the principal mass of amalgam is supported by the tooth structure, the strength can approach that of a base of zinc phosphate cement or that of amalgam. For large Class 1 restorations, there appears to be a decrease in strength which accompanies the increase in depth of the cavity preparation even for amalgam alone. This reduction in strength becomes extreme with the use of ZOE cement. It should be noted that the ZOE cement used did not set to a rigid condition within 48 hours, so that failure occurred under comparatively small loads.

Mosteller [89] suggests the addition of an equal part of eugenol to the liquid used in conventional zinc phosphate cements. It is claimed that this formulation reduced postoperative sensitivity in over 3000 cavities due to the established sedative action of the eugenol on the pulp. The compressive strength of this cement is 770 kg/cm^2. No histologic study of this material on the pulp is reported. Although patient sensitivity to acid might be masked by the eugenol, it is improbable that the actual effect of the phosphoric acid would be greatly reduced.

Polystyrene fortified ZOE cements handle well clincially when used as a temporary filling or a base under amalgam fillings [31, 32]. Sealing properties and adhesiveness are excellent, while hardness, edge strength and friability are comparable to that of the zinc phosphate cements. An in vitro test indicated that the ZOE or ZOE fortified cement base does not break down under the forces applied during the condensation of amalgam. Incorporation of a few fibers of cotton-wool into the mix increased resistance to masticatory stress and facilitated subsequent removal of the filling. The cavity should be completely dry and 4-5 minutes should elapse before placing the silicate cement or amalgam filling. Otherwise free eugenol discolors the silicate cement restoration and the strength of the base may not be high enough to resist the forces applied during packing of the amalgam.

Cements containing EBA seem to be well suited as a one-step base in deep cavities for gold, silicate cement and amalgam fillings. When this cement was placed in 32 vital, but symptomatic teeth, symptoms subsided within two days [41]. The cavity preparations were then completed and permanent restorations placed, leaving part of the EBA cement as a base. The teeth remained vital and non-symptomatic. No histological findings are available.

Since for all types of ZOE temporary fillings or bases excess of liquid is undesirable, excess eugenol can be removed by squeezing [90]. A ZOE paste of putty like consistency can be prepared and stored in a glass jar over anhydrous calcium chloride [91]. Such paste will remain usuable for several weeks. The consistency at the time of placement does not appear to influence the sealing characteristics [92].

Sensitivity to ZOE cement is unusual. For this reason the cementation of inlays, crowns or fixed bridges with ZOE is a frequently used procedure. This is generally considered a temporary measure to provide the patient greater comfort while the pulp heals. Often a bridge is later cemented permanently with zinc phosphate cement. Dentists, when employing ZOE as a temporary cement, have invariably found sound tooth structure and no evidence of leakage on removing the casting for permanent cementation. Therefore, there has been increasing interest in the use of ZOE cement for permanent cementation.

The relative retentive properties of various luting agents have been obtained by measuring the tensile forces necessary to remove cast gold, occlusal inlays or crowns seated with different cements [93, 94]. Inlays cemented with commercial ZOE cement required less force to remove than when the restorations were luted with phosphoric acid cements. However, the retention of inlays cemented with zinc phosphate cement was not affected by placing a ZOE cement base in a depression in the floor of the cavity. The shear resistance and compressive strength of ZOE cement are also somewhat low for cementing restorations, particularly for long span bridges where the cement is subjected to unusually high biting stress. The surfaces of both the casting and the tooth structure are somewhat rough and the plastic cement is forced into these irregularities during cementation. After the cement hardens such extensions may assist in providing mechanical retention of the casting [95]. If the compressive or shear strength of the cement is low, the particles of the cement may fracture and reduce the retentive tendencies. The minimum strength and retention values for dental cements are not known. Possibly a cement with lower compressive strength, but higher ductibility might be more satisfactory. At the present time it is probably wise to restrict commercial ZOE cement for permanent cementation of restorations not unduly subjected to stress or where retention is not greatly dependent on the cementing medium. For example, ZOE cement might be indicated for the full-cast crown or the simple inlay, but contraindicated for cementing a long-span bridge with MOD inlays or three-quarter crowns as abutments.

Cementation of fixed bridges with commercial ZOE cement is, however, a means of coping with a variety of exigencies that may arise in conjunction with the use of a fixed bridge regardless of the length of its span [96]. Heavily denuded abutment teeth are less sensitive to thermal changes when ZOE cement is used than where zinc phosphate cements are employed. Furthermore, the teeth do not have to be completely dry when ZOE cements are employed since the setting time is reduced in the presence of moisture. The working time is generally less critical than that of zinc phosphate cement which also has poor flow characteristics. However, ZOE cements can and do wash out. The patient should be advised that loosening of an abutment may be accompanied by (1) sensitivity to thermal changes and to biting forces in the area where the cement has washed out and (2) a bad taste. In many cases the washout may go unnoticed by the patient unless the bridge is notably loose. Loosening of the bond on an abutment may be detected by applying an unseating force with an instrument beneath the soldered joint between the abutment and the adjacent pontic. "Bubbling" of saliva at the gingival margin of the tooth and an "oozing" sound indicate a break of the seal. The loosening of the bond is most commonly observed on a lone terminal abutment that is the only distal support for a span of two or three pontics. To help overcome the weakness of the bond, the lone terminal abutments may be cemented with zinc phosphate cement to take advantage of its greater strength and the remainder of the prothesis can be cemented with ZOE cement. The rationale of using the "temporary cement" on the intermediate abutment is that, despite the fact that one or two terminal abutments may be permanently cemented, removal of the bridge is still possible.

Messing [32] states that the polystyrene fortified ZOE cement due to its increased toughness and crushing strength is an ideal material for the setting of temporary crowns of aluminium, acrylic resin or cellulose acetate. The tooth surface should be lightly lubricated before applying the crown form, thus, facilitating complete eradication of the cement when the temporary crown is removed.

Due to their much improved physical properties, EBA mixtures have been studied clinically over a two-year period using 186 full cast crown bridge retainers and 205 full cast crowns [97]. The span of the bridges cemented with this material was limited to a maximum of two consecutive pontics of bicuspid width. Nineteen of the full cast crown bridge retainers were associated with a cantilever type of bridge. Abutment teeth that were too short or of questionable taper were not involved in this study. Powder-liquid ratio used was approximately 1.4 g powder per 0.2 ml liquid. Resin veneers were protected from the excess EBA cement by coating them with silicone grease. Abutment teeth were dried gently with cotton until no evidence of moisture was visible. No cavity liners or medicaments were applied. The crowns were not completely filled with the cement, but a coating was applied to the internal surfaces and then a small amount was flowed into any crevices or depressions on the teeth prior to insertion. All restorations were tapped with a mallet and orangewood stick after initial seating. Dryness was not maintained after the restorations were seated. The cement has good flow characteristics which allows easy manipulation and gave minimum resistance to complete seating during the insertion of fixed restorations. The EBA cement set in the mouth in 2 to 3 minutes, but remained plastic on the cooled mixing slab for 10 minutes. Excess cement is difficult to remove. After cementation abutment teeth are not painful and marginal relationships are not unduly disoriented. In selected cases, tests with ice-cold water seemed to indicate excellent insulation. Although this effect may be due to the ability of the cement to obtund pain, the fused quartz component is known to be a good insulator. The low abrasion resistance observed for fillings does not appear to be very significant when the material is used under full crown castings and no restorations loosened prematurely.

For certain temporary cementations of multiple unit fixed prostheses a non-setting anodyne ZOE type cement would be desirable [98] that retains its original consistency over an extended period and is insoluble in the oral fluids. Such a cement will facilitate removal of the restoration. Final cementation may be postponed until evidence of the success of the restoration can be evaluated. Although such a cement may provide little retention it would give a marginal seal against the ingress of saliva and bacteria and may have therapeutic value. An example of a non-setting formulation is as follows[97]:

Zinc oxide (USP) with 1% Propyl Paraben	0.2 g
Eugenol (USP)	0.25 ml
Silicone grease	0.57 g

Approximately 1% of methyl or propyl paraben (neutral esters of parahydroxybenzoic acid) is added to improve the plasticity and antibacterial properties.

A neutral orthodontic cement that is resistant to attack under oral conditions and that will strip cleanly from enamel on removal of the band is also needed. After removal of bands cemented with zinc phosphate cement from the teeth of children the enamel in contact with the cement is sometimes of a slightly different appearance from the unprotected enamel. This has been attributed to the decalcifying action of the phosphoric acid used in the preparation of the cement [99,100]. However, only abnormally thin mixes of zinc phosphate or silicate cements are likely to attack the natural surface of sound tooth enamel [101]. Bands cemented with zinc and zinc silico-phosphate cements show better retention than those cemented with commercial ZOE materials [102]. Addition of EBA markedly improves retention. There appears to be some correlation between compressive strength and the ability to retain the orthodontic bands under a tensile load.

ZOE cementing media require good flow characteristics and film thickness of less than 40μ, a value generally considered to be the maximum limit acceptable for cementation.

ZOE cement or calcium hydroxide are recommended for vital pulp therapy [103]. Massler and Manuskhani report the following stages in the pulp healing of rats under a zinc oxide-eugenol covering [104].

Stage 1 Acute inflammatory reaction.

3 days: Massive infiltration of polymorphs concentrated in the site of amputation. Pulp below is normal.

7 days: Localization of inflammatory zone by fibrous band. Inflammatory cells at site of amputation tend to degenerate. Engorged vessels under the fibrous band. Pulp below is normal.

Stage 2 Calcification of fibrous band (defense reaction).

14 days: The number of inflammatory cells becomes greatly reduced. Cells at the surface are necrotic. Formation of dense fibrous layer with encapsulated cells (scar tissue) under zone of inflammation. The fibrous capsule becomes calcified, forming a temporary bridge. Vascularization of pulp under temporary bridge. Pulp below is normal.

Stage 3 Reparative dentin formation.

14 days: Secondary dentin formation by old odontoblasts just lateral to site of amputation. Reparative dentin formation under temporary bridge of calcified fibers by new odontoblasts.

21 days: Lateral and central reparative dentin formation well advanced.

28 days: Bridging and coalescence of lateral and central reparative dentin complete.

Use of ZOE cement between pulp capping medicament and amalgam markedly decreased the incidence of pulpal necrosis and increased the incidence of healing [104]. When this sealer was omitted degenerative changes in the pulp followed swiftly. Whether this result was due to the sealing action of the material and the prevention of marginal leakage along the amalgam filling or to some action by the eugenol is not clear.

Tananbaum [105] reported clinical studies using ZOE cement or calcium hydroxide as pulp capping materials. A total of 135 teeth were observed. No failures occurred with either calcium hydroxide or ZOE cement treated primary teeth during 5 to 39 months. Pulp capping of permanent teeth was 91% successful with calcium hydroxide and 86% with ZOE cement. Only 4% of the ZOE cement group showed roentgenographically a secondary dentin barrier after 2 years, while 89% of the calcium hydroxide group showed this barrier within one year.

Bonsack [106] claims that removal of the carious dentin layer next to the pulp chamber is not advisable. Following a hermetic filling of ZOE cement over the last layer of decayed dentin, the latter becomes harder by some yet unknown remineralization process. The decayed dentin should be carefully removed 1 to 1 1/2 mm beyond the dentinoenamel junction and only left on an area 2-3 mm in width and 1 mm in thickness from the pulp chamber. Best results were obtained by covering this area with a layer of ZOE cement.

Prader [107] in his extensive review also recommends ZOE cement for indirect pulp capping. Spreter von Kreudenstein [108] recorded 95% successful results after capping with zinc oxide-clove oil cement and 77% after capping without medication. He also observed that softened dentin will harden after a few days or weeks if covered with this cement. Pulps which had been exposed in the course of normal operative procedures in five nonsymptomatic teeth were capped using the EBA containing cement and the cavities were filled [41]. Within a week part of the material was removed and permanent restorations placed leaving part of the previous cement filling as a base. None of the patients reported any symptomatology. None of the teeth showed any radiographic changes and all responded normally to vitality tests within the two to ten months observation period.

Schach [35] has recommended substitution of bergamot oil for eugenol in the field of indirect and direct capping.

Endodontic therapy and immediate root resection employing ZOE cement as filling material has been suggested by Hamilton [109], Becker [110] and Prior [111]. These investigators reported remarkable clinical success with this form of therapy.

ZOE cement has also been widely used in the treatment of dry sockets. This treatment not only relies upon the palliative effect of the eugenol, but also upon its bacteriostatic properties. Radden [112] questions the advisability of using ZOE cement since it may damage the tissues. He found that ZOE cement packs in monkey tooth sockets resulted in polymorphonuclear response that was a continuing source of irritation, killed the tissues it contacted, and in many cases seriously delayed reparative processes.

The toxic character of eugenol can also be used to advantage in situations where chemical necrosis is desired, such as in the treatment of a vital pulp scheduled for endodontic therapy [83a].

During the last twenty years, the use of ZOE cement as a periodontal dressing prior to gingivectomy has become universal since these cements reduce inflammation and swelling of hyperemic gingivae and reduce the bacterial count. Ward advocated ZOE paste with rosin as a postoperative dressing following gingivectomy. Some patients, however, object to the lingering eugenol taste and odor. Commercially available surgical pastes containing zinc oxide and weak organic acid derivatives can be applied to the tissue with no sensation of burning, and with no unpleasant flavor or odor [113].

Uses of ZOE impression materials are beyond the scope of this review. These pastes are used in making the final impression for 46% of all upper and 48% of all lower dentures.

10. Summary

Zinc oxide-eugenol cement is decidedly superior to other materials in its palliative effect on the pulp and in patient comfort. Whereas, solubility is low and initial adaptation to the cavity walls unusually good, its low strength and lack of resistance to abrasion confine its use to restorations not involving high stress or attrition. Properly formulated, it is the cement of choice for selected restorations.

ZOE preparations often contain an accelerator such as zinc acetate, rosin and an antiseptic, e.g., thymol. ZOE cements are successfully employed as filling materials, cementing media, cement bases, pulp capping agents, anodyne pastes and periodontal packs.

Recent investigations have explored the possibilities of improving the desirable physical properties. Incorporation of <u>o</u>-ethoxybenzoic acid has led to materials that appear promising as bases and cementing materials for inlays and crowns. Further studies should lead to stronger, more adhesive and more permanent restorative materials that are impermeable to moisture.

References

1. Molnar, E. J. Cloves, oil of cloves and eugenol. The medico-dental history. Dent. Items of Interest (June-Oct. 1942).

2. Chisholm, E. C. In proceedings of the Tenn. Dent. Association, 7th annual meeting, Nashville, October 1873. Discussion, Dent. Register 27, 517 (1873).

3. Flagg, J. F. Dental pathology and therapeutics. Dent. Cosmos 17, 111-118, 465-469, 617-621 (1875).

4. Tomes, J. and Tomes, C. A System of Dental Surgery 3rd ed., London 1887, pp 414,417.

5. Wessler, J. Pulpol, ein neues medicamentoses cement. Deutsche Monatschr f. Zahnheilk. 12, 478-484 (1894).

6. Forster, E. Il cemento provisorio all' ossido di zinco ed il carattere fisico-mecanico della sua presa. Stomatologia 27, 217-221 (1929).

7. Wallace, D. A. and Hansen, H. L. Zinc oxide-eugenol cements. J.A.D.A. 26, 1536-1540 (1939).

8. Harvey, W. and Patch, N. J. Acceleration of the setting of zinc oxide cements. Brit. Dent. J. 80, 1-8, 35-41 (1946).

9. Copeland, H. I., Jr., Brauer, G. M., Sweeney, W. T. and Forziati, A. F. Setting reaction of zinc oxide and eugenol. J. Res. Natl. Bur. Stand. 55, 133-138 (1955).

10. Smith, D. C. The setting of zinc oxide-eugenol mixtures. Brit. Dent. J. 105, 313-321 (1958).

11. Vieillefosse, R., Vayson de Pradenne and Zumbrunn, J. P. A study of combinations of types of oxides of zinc-eugenol cements and phenol plastics. Rev. Franc. odonto. stomatol. 5, 488-494 (1958).

12. Brauer, G. M., Wiedeman, W. H. Unpublished data.

13. Douglas, W. H. Studies of crystal structure of zinc and magnesium eugenolates (Abstract). J. Dent. Res. 42, 1108 (1963).

14. Accepted Dental Remedies, 29th ed., 1964. American Dental Association, Chicago, Illinois 1964, pp 177-178.

15. Dixon, C. M. and Rickert, U. G. Histologic verification of results of root-canal therapy in experimental animals. J.A.D.A. and Dent. Cosmos 25, 1781-1803 (1938).

16. Molnar, E. J. and Skinner, E. W. A study of zinc oxide-rosin cements. I. Some variables which affect the hardening time. J.A.D.A. 29, 744-751 (1942).

17. Smith, D. C. A quick-setting zinc oxide-eugenol mixture. Brit. Dent. J. 108, 232 (1960).

18. Civjan, S. and Brauer, G. M. Physical properties of cements based on zinc oxide, hydrogenated rosin, o-ethoxybenzoic acid and eugenol. J. Dent. Res. 43, 281-299 (1964).

19. Vieira, D. F. Factors affecting the setting of zinc oxide-eugenol impression pastes. J. Pros. Dent. 9, 70-79 (1959).

20. Paffenbarger, G. C. and Caul, H. J. Dental cements. Proc. Dent. Cent. Celebration, March 1940, pp 232-237.

21. Norman, R. D., Phillips, R. W., Swartz, M. L. and Frankiewicz, T. The effect of particle size on the physical properties of zinc oxide-eugenol mixtures. J. Dent. Res. 43, 252-262 (1964).

22. Phillips, R. W. and Love, D. R. The effect of certain additive agents on the physical properties of zinc oxide-eugenol mixtures. J. Dent. Res. 40, 294-303 (1961).

23. Norman, R. D., Swartz, M. L. and Phillips, R. W. Additional studies on the solubility of certain dental materials. J. Dent. Res. 38, 1028-1037 (1959).

24. Phillips, L. J., Schnell, R. J. and Phillips, R. W. III. Measurement of the electric conductivity of dental cement: Effect of increased contact area and thickness: Values for resin, calcium hydroxide, zinc oxide-eugenol. J. Dent. Res. 34, 597-607 (1955).

25. Phillips, L. J., Phillips, R. W. and Schnell, R. J. Measurement of the electric conductivity of dental cement. In vivo test. J. Dent. Res. 34, 839 (1955).

26. Norman, R. D., Swartz, M. L. and Phillips, R. W. Studies on film thickness, solubility and marginal leakage of dental cements. J. Dent. Res. 42, 950-958 (1963).

27. Massler, M., and Mansukhani, N. Testing liners under cements in vitro. J. Pros. Dent. 10, 964-975 (1960).

27a. Grossman, L. I. A study of temporary fillings as hermetic sealing agents. J. Dent. Res. 18, 67-71 (1939).

28. Swartz, M. L., Phillips, R. W., Norman, R. D. and Oldham, D. F. J.A.D.A. 67, 367-374 (1963).

29. Roland, N., Kutscher, A. H. and Ayers, H. D. Effect of dicalcium phosphate on the crushing strength of zinc oxide and eugenol. N. Y. State Dent. J. 25, 84-86 (Feb. 1959).

30. Curtis, D. U. S. Patent 2,413,294 Dec. 1946.

31. Weiss, M. B. An improved zinc oxide and eugenol cement. Ill. Dent. J. 27, 261-271 (1958).

32. Messing, J. J. A polystyrene-fortified zinc oxide-eugenol cement. Brit. Dent. J. 110, 95-100 (1961).

33. Brauer, G. M., White, E. E., Jr., and Mashonas, M. G. The reaction of metal oxides with o-ethoxybenzoic acid and other chelating agents. J. Dent. Res. 37, 547-560 (1958).

34. Molnar, E. J. U. S. Patent 3,028,247 April 3, 1962.

35. Schach, H. Experimentelle Untersuchungen zu einigen ätherischen Ölen, die in der Zahnheilkunde Verwendung finden, unter besonderer Berücksichtigung des Nelkenöls als Bestandteil gewisser Zahnfleischverbände. Deut. Zahnärtztl. Z. 18, 325-336 (1963).

36. Brauer, G. M., Morris, R. W. and Howe, W. B. Synthesis of isomers of eugenol. J. Res. Natl. Bur. Stand. 67A, 253-257 (1963).

37. Brauer, G. M., Argentar, H. and Durany, G. Ionization constants and reactivity of isomers of eugenol. J. Res. Natl. Bur. Stand. 68A, 619-624 (1964).

38. Brauer, G. M. and Simon, L. Synthesis of 2-propoxy-5-methylbenzoic acid. J. Res. Natl. Bur. Stand. 66A, 313-315 (1962).

39. Brauer, G. M., Simon, L. and Sangermano, L. Improved zinc oxide-eugenol type cements. J. Dent. Res. 41, 1096-1102 (1962).

40. Coleman, J. M., Kirk, E. E. J. and Pickard, H. M. Investigation of a fortified zinc oxide cement (Abstract) J. Dent. Res. 43, 950 (1964).

41. Civjan, S. and Brauer, G. M. Clinical behavior of o-ethoxybenzoic acid-eugenol-zinc oxide cements. J. Dent. Res. 44, 80-83 (1965).

42. Nielsen, T. H. The ability of 39 liquid chelating agents to form cements with metal oxides, respecting their usability as root-filling materials. Acta Odont. Scand. 21, 159-174 (1963).

43. Wolcott, R. B., Shiller, W. R. and Kraske, L. M. A clinical evaluation of temporary restorative materials. J. Pros. Dent. 12, 782-790 (1962).

44. Horn, H. R. Improved cementation. J.A.D.A. 63, 813-829 (1961).

45. Skinner, E. W., Molnar, E. J. and Suarez, G. Reactions of zinc oxide with carboxylic acids - physical properties (Abstract) J. Dent. Res. 43, 915 (1964).

46. Swartz, M. L. and Phillips, R. W. Influence of manipulative variables on marginal adaptation of certain restorative materials. J. Pros. Dent. 12, 172-181 (1962).

47. Massler, M. and Ostrovsky, A. Sealing qualities of various filling materials. J. Dent. Children 21, 228-234 (1954).

48. Caujolle, F. and Meynier, D. Toxicité du méthyleugenol des méthylisoeugénols et au méthyldihydroeugénol. Comp. rend. 250, 1148-1149 (1960); ibid 248, 2907-2908 (1959).

49. Anon. Food additives - Substances that are generally recognized as safe. Fed. Register 26, 3991 (March 9, 1961).

50. Schilder, H. and Amsterdam, M. Inflammatory potential of root canal medicaments. A preliminary report including nonspecific drugs. Oral Surg., Oral Med., and Oral. Path. 12, 211-221 (1959).

51. Torneck C. D. Reaction of hamster tissue to drugs used in sterilization of the root canal. Oral Surg., Oral Med., and Oral Path. 14, 730-747 (1961).

52. Coolidge, E. D. Reaction of dog tissue to drugs used in root canal treatment. J.A.D.A. 19, 747-759 (1932).

53. Feldman, G. Experimental investigation on the action of eugenol, thymol and decomposition products of the pulp on the periodontium. Dent. Magazine 45, 492-496 (1928).

54. Pohto, M. and Scheinin A. Microscopic observation on living dental pulp. The effect of oil of cloves and eugenol on the circulation of the pulp in the lower rat incisor. Suomen Hammaslääk. Toim. 55, 185-195 (1959).

55. Mitchell, D. F. The irritational qualities of dental materials. J.A.D.A. 59, 954-966 (1959).

56. Mitchell, D. F. and Shankwalker. Osteogenic potential of calcium hydroxide and other materials in soft tissue and bone wounds. J. Dent. Res. 37, 1157-1163 (1958).

57. McDonald, R. E., Zawawi, H. A. M. and Mitchell, D. F. Rat connective tissue reactions to implants of pulp capping materials (Abstract). J. Dent. Res. 38, 738 (1959).

58. Schaad, T. D., Carter, W. J. and Myers, H. I. Reaction of abdominal connective tissue in rats to dental base materials (Abstract) I.A.D.R. 34th General Meeting 1956, p. 11.

59. Roydhouse, R. H. and Weiss, M. E. Tissue reactions to restorative materials (Abstract) J. Dent. Res. 43, 807 (1964).

60. Colman, G. A study of some antimicrobial agents used in oral surgery. Brit. Dent. J. 113, 22-26 (1962).

61. Silberkweit, M., Massler, M., Schour, I. and Weinmann, J. B. Effect of filling materials on the pulp of the rat incisor. J. Dent. Res. 34, 854-869 (1955).

62. Manley, E. B. A preliminary investigation into the reaction of the pulp to various filling materials. Brit. Dent. J. 60, 321-331 (1936).

63. Manley, E. B. Pulp reactions to dental cements. Proc. Roy. Soc. Med. 36, 488-499 (1936).

64. Gurley, W. B. and Van Huysen, G. Histologic changes in teeth due to plastic fillings. J.A.D.A. and Dent. Cosmos 24, 1806-1816 (1937).

65. Gurley, W. B. and Van Huysen, G. Histologic response of teeth of dogs to operative procedures. J. Dent. Res. 19, 179-192 (1940).

66. James, V. E. and Diffenbach, G. B. Prevention of histopathologic changes in young dogs teeth by the use of zinc oxide and eugenol. J.A.D.A. 29, 583-592 (1942).

67. Mitchell, D. F., Buonocore, M. G. and Shazer S. Pulp reaction to silicate cement and other materials: Relation to cavity depth. J. Dent. Res. 41, 591-595 (1962).

68. James, V. E. and Schour, I. The effects of cavity preparations and zinc oxide and eugenol upon the human pulp. (Abstract) J. Dent. Res. 34, 698-699 (1955).

69. James, V. E. and Schour, I. Early dentinal and pulpal changes following cavity preparations and filling materials in dogs. Oral. Surg., Oral Med. and Oral. Path. 8, 1305-1314 (1955).

70. Glass, R. L. and Zander, H. A. Pulp healing. J. Dent. Res. 28, 97-107 (1949)

71. Zander, H. A. and Glass, R. L. Healing of phenolized pulp exposures. Oral Surg., Oral Med. and Oral Path. 2, 803-810 (1949).

72. Massler, M. Effects of filling materials on the pulp. N. Y. J. Dent. 26, 183-198 (1956).

73. Bodecker, C. F. Zinc oxide-eugenol too bland as a filling material. N. Y. Dent. J. 20, 207-216 (1954).

74. Myör, I. A. The effect of zinc oxide and eugenol on dentin evaluated by microhardness testing. Arch. Oral Biol. 7, 333-336 (1962).

75. Bhaskar, S. N. Unpublished data.

76. Turkheim, H. J. Bactericidal effect of zinc oxide-eugenol cement on bacteria-containing dentin. J. Dent. Res. 34, 295-301 (1955).

77. Turkheim, H. J. A study of the bactericidal effect of zinc oxide eugenol cement. Dent. Record 75, 29-35 (1955).

78. Turkheim, H. J. Bacteriological investigations on dental filling materials. Brit. Dent. J. 95, 1-8 (1953).

79. Bartels, H. A. The effect of eugenol and oil of cloves on microorganisms. Am. J. Orthodont.,(Oral Surg. Sect.) 33, 458-465 (1947).

80. Urzua, S. and Gilmour, M. Antibacterial effect of essential oils and antibiotics in zinc oxide pastes. Abstracts 35th Meeting I.A.D.R., Atlantic City 1957, p. 103.

81. Bartels, H. A. Effect of zinc oxide-eugenol cement on penicillin. Am. J. Orthodont. and Oral Surg. (Oral Surg. Sect.) 32, 344-350 (1960).

82. Buchbinder, M. Laboratory and clinical study of penicillin in root canal therapy. J.A.D.A. 34, 108-114 (1947).

83. Shaw, F. E., Sprawson, E. and May, H. B. Use of penicillin in dental pulp canal therapy. Brit. Med. J. 1, 551 (1945).

83a. Gurney, B. F. Eugenol: Utility versus toxicity. Oral Hygiene 55, 74-82 (February 1965).

84. Suthers, W. D. and Parfitt, G. J. The effect in vitro of some materials used in restorative dentistry on the rate of acid production by oral bacteria. Dent. J. Australia 27, 216-220 (1955).

85. Mumford, J. M. and Ferguson, H. W. Temporary restorations and dressings. Dent. Pract. and Dent. Record 9, 121-124 (1959).

86. Langeland, K. Histologic evaluation of pulp reactions to operative procedures. Oral. Surg., Oral Med. and Oral Path. 12, 1235-1248, 1357-1369 (1959).

87. Gayler, M. L. V. Some factors affecting the setting of a dental amalgam. Brit. Dent. J. 54, 269-288 (1933).

88. Hoppenstand, D. C. and McConnell, D. Mechanical failure of amalgam restorations with zinc phosphate and zinc oxide-eugenol bases. J. Dent. Res. 39, 899-905 (1960).

89. Mosteller, J. H. An evaluation of intermediate base materials. J.A.D.A. 34, 571-577 (1951).

90. Kanterman, C. B. Manipulation of ZOE cement. Dent. Survey 33, 40 (1957).

91. Paskow, H. A. Ever-ready storage for zinc oxide-eugenol cement. Dent. Survey 19, 54-55 (1943); ibid 33, 321-322 (1957).

92. Hampel, A. T. and Hill, A. J. Marginal penetration studied with Ca^{45}. North-West Dent. 42, 114 (March-April 1963).

93. Oldham, D. F., Swartz, M. L. and Phillips, R. W. Retentive properties of dental cements. J. Pros. Dent. 14, 760-768 (1964).

94. Kaufman, E. G., Colin, L. and Coelho, D. H. Comparison studies of the retentive ability of temporary cements. (Abstract) J. Dent. Res. 39, 759 (1960).

95. Phillips, R. W. Dental cements: A comparison of properties. J.A.D.A. 66, 496-502 (1963).

96. Baraban, D. J. Cementation of fixed bridge prosthesis with zinc oxide-rosin-eugenol cement. J. Pros. Dent. 8, 988-991 (1958).

97. Horn, H. R. The cementation of crowns and fixed partial dentures. The Dental Clinics of North America. W. B. Saunders Co., Philadelphia, Pa. 1965 pp 65-81.

98. Horn, H. R. Non-setting zinc oxide and eugenol cements. (Abstract) J. Dent. Res. 40, 775 (1961).

99. Lefkowitz, W. Histologic evidence of the harmful effect of cement under orthodontic bands. J. Dent. Res. 19, 47-55 (1940).

100. Costello, I., Massler, M., Montellone, U. and Suher, T. The effect of zinc oxyphosphate cements on enamel. Am. J. Orthodont. 34, 271-277 (1948).

101. Docking, A. R., Newbury, C. R., Donnison, J. A. and Storey, E. The effect of orthodontic cement on tooth enamel. Dent. Record 72, 243-256 (1952).

102. Swartz, M. L., Williams, J. D. and Phillips R. W. Retention of orthodontic bands as influenced by the cementing media. (Abstract) J. Dent. Res. 43, 915-916 (1964).

103. Mitchell, D. F. Pulp reaction to commonly used capping materials. J. Dent. Child. 28, 150-153 (1961).

104. Massler, M. and Mansukhani, N. Effect of formol-cresol on the dental pulp. J. Dent. Child. 26, 277-297 (1959).

105. Tananbaum, N. I. Pulp capping with zinc oxide and calcium hydroxide. Clinical studies on 135 patients. J. Dent. Child. 18, 16-20 (3rd quarter 1951).

106. Bonsack, C. Le coiffage naturel ou indirect. Schweiz. Monatsschr. Zahnheilk. 62, 219-242 (1952).

107. Prader F. Conservative treatment of the floor of the carious cavity. Carious dentin near the pulp. Int. Dent. J. 8, 627-638 (1958).

108. Von Keudenstein, S. Die Behandlung des pulpanahen Kavitätenbodens. Zahn-Mund und Kieferheilk. in Vorträgen 13, 137, Verlag C. Hauser, München.

109. Hamilton, R. E. Endodontic therapy and immediate root resection employing zinc oxide and eugenol as a filling material. Texas Dent. J. 81, 11-13 (Jan. 1963).

110. Becker, B. M. One sitting root canal therapy employing immediate root resection and zinc oxide and eugenol as a root canal filling material. J. Phillipine Dent. Assn. 13, 6-11 (June 1960).

111. Pryor, J. J. Surgical endodontics. Dent. Survey 37, 29-35 (1961).

112. Radden, H. G. Mouth wounds. Brit. Dent. J. 113, 112-119 (1962).

113. Molnar, E. J. Eugenol - no longer a dental panacea. Cal 26, 18-20 (June 1964).

Table 1

Composition of Typical ZOE Cements

Powder	Composition %				
Zinc oxide	99.8	70.2	70.0	69.65	95
Zinc acetate	0.2	0.4	0.5	0.5	-
Zinc sterate	-	-	1.0	-	-
Rosin	-	-	28.5	-	-
Hydrogenated rosin	-	29.4	-	29.85	-
Thymol iodide	-	-	-	-	5
Liquid					
Eugenol	100	85	85	82.1	46
Olive oil	-	15	-	-	-
Cottonseed oil	-	-	15	-	-
Corn oil	-	-	-	17.9	-
Rosin	-	-	-	-	40
Oleic acid	-	-	-	-	9
Menthol	-	-	-	-	5
References	[7]	[7]	[7]	[14]	[14]

Table 2

Composition for a Root Canal Sealer [15]

Powder	Composition
Zinc oxide	41.2 g
Precipitated silver	30.0 g
White rosin	16.0 g
Thymol iodide	12.8 g
Liquid	
Clove oil	78.0 ml
Canada balsam	22.0 ml

Table 3

Physical Properties of Zinc Oxide-Eugenol Type Cements

	ZOE Cements		EBA Cements[b]
	Experimental cements[a]	Range for commercial cements	
24 hr. compressive strength	337 kg/cm^2	140-385 kg/cm^2	872 kg/cm^2
7 days compressive strength	260	-	893
24 hr. tensile strength	14-28	-	56-91
24 hr. shear strength	-	-	-
punch test method	42	-	127
double shear, specimen ends braced	148	-	319
24 hr. linear setting shrinkage	-	-	-
dry	0.85%	-	0.24%
wet	0.31		0.12
Coefficient of thermal expansion			
25-60 °C	$35X10^{-6}$ per °C		$64X10^{-6}$ per °C
at 37 °C	$35X10^{-6}$		$60X10^{-6}$
Density	3.6-3.7 g/ml	2.6-3.7 g/ml	2.9-3.0 g/ml
24 hr. solubility, distilled water	0.4%	0.02-0.1%	0.04%
8 days solubility, distilled water	0.10	-	0.09
24 hr. solubility, 0.1 NH_4OH	0.35	-	0.33
pH range of cement	-	6.0-8.0 pH	-
Heat stability			
24 hr. loss on heating to 62°C	0.32%	-	0.32%
14 days loss on heating to 62°C	0.50%	-	0.60%

[a] Values are given for a ZOE cement containing no accelerator and powder-liquid ratio of 2.6 g/0.4 ml which is considerably higher than that generally employed in commercial products.

[b] Composition: Powder: 74% zinc oxide, 6% hydrogenated rosin, 20% fused quartz
Liquid: 62.5% o-ethoxybenzoic acid (EBA), 37.5% eugenol.

Table 4

Reactivities of Eugenol Isomers with ZnO

Powder[a]	Liquid[a]	Setting Time Initial Set[b] hr.	Setting Time Final Set hr.
ZnO	Eugenol	3.5	23
ZnO + 1% $Zn(Ac)_2$	Eugenol	0.18	0.35
ZnO	Chavibetol	6.5	22
ZnO + 1% $Zn(Ac)_2$	Chavibetol	0.15	0.19
ZnO	o-Eugenol	[c]	[c]
ZnO + 1% $Zn(Ac)_2$	o-Eugenol	[c]	[c]
ZnO	3-Allyl-2-methoxyphenol	[c]	[c]
ZnO + 1% $Zn(Ac)_2$	3-Allyl-2-methoxyphenol	~90	~170

[a] Powder-liquid ratio: 1.3 g powder per 0.4 ml liquid

[b] Initial setting time in hours is the time elapsed from starting the mix to the time when the point of a Gilmore needle makes only a slight but visible indentation after placing the needle on the material for 5 seconds.

[c] Did not harden within 10 days

Figure 1. Electron micrograph of a zinc oxide-eugenol mixture showing the small, rounded particles of zinc oxide and the thin, elongated crystals of zinc eugenolate.