BASE FORMING MATERIALS

FOR

AMALGAM RESTORATIONS

This thesis, based upon an original study by the author, is submitted to the University of Sydney in support of my candidature for the degree of Master of Dental Surgery.

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INTRODUCTION

The restoration of the single tooth with dental amalgam continues to occupy much of the chairside time of the "average" dentist.

While no restorative material perfectly satisfies all the demands made on it, amalgam can attribute its success and popularity to its many desirable physical and biological properties together with its ease of manipulation and relatively small cost to patient and dentist alike.

However, "a restoration can be no better than the sum of the components in its construction", (Hessing, 1956), "thus, a perfect filling must have a hard well placed lining overlying a healthy pulp, and be thick enough, in relation to its strength, to endure the force of mastication under all conditions". This is not to say that all amalgam restorations require a cement base; far from it. Indeed, the tendency in recent years has been towards the opposite; that is, bases should be kept to a minimum to allow maximum condensation of amalgam onto sound tooth structure and to ensure maximum bulk of amalgam (Markley, 1951, McCollochey, 1952 & Hessing, 1956). However, where bases are indicated, a certain amount of confusion exists in the selection of the most suitable material.
From the three principal types of base materials available — calcium hydroxide, zinc oxide-eugenol and zinc phosphate cements — which should be chosen? Since a choice must often be made between a material considered to be biologically superior yet physically inferior and one thought to be biologically inferior but physically superior, is one to be preferred to the other or are both, in fact, satisfactory, so that the decision is dependent solely on the dentist's personal preference? What is the desirable biological function of a base and do the available materials fulfill this need? Do the different materials satisfy the physical requirements of a base? Have they adequate strength and a suitable setting time? Do they provide thermal and electrical protection for the pulp?

Much has been achieved by clinical trials and laboratory research in an attempt to answer these and other issues related to the use of bases. Substantial evidence of the pulpal effects of base materials is now available, and, because of widespread consensus of opinion in this field, it is possible with some certainty to state the biological limitations and indications of the base forming materials, all other factors being equal.

Unfortunately, research directed at determining the strength of base materials has often been misleading and the cause of considerable confusion for the dentist. For many
years it was the one hour, one day or one week strength of the base materials that was compared, and although this was interesting information, it had little relevance to a clinical situation in which a base should possess adequate strength from six to seven minutes after mixing begins if it is to withstand the force exerted upon it during amalgam condensation. Hooley and Phillips (1949) found that fracture of amalgam restorations by masticatory forces was unlikely to be related to the base material. The ultimate compressive strength of the lining would therefore appear to be of little more than academic interest. Since very little information was available about the early strengths of accelerated zinc oxide-eugenol and zinc phosphate cements, and because of their high one week compressive strengths, it was inferred that the use of zinc phosphate type cements was essential to ensure adequate early strength of the base (Poffenbarger et al., 1934 and Tomor, 1940).

Even more misleading conclusions followed the comparison of unset, unaccelerated zinc oxide-eugenol cement with other base materials (Hoppenstand and McConnell, 1960 & Civjan and Deveau, 1964). The zinc oxide-eugenol cements, biologically preferable to the zinc phosphate type cements, have long been considered inferior and unsatisfactory because of the slow set and obviously low strength of the unaccelerated material.
Where an accelerated material was to be used, it was recommended that it should be covered by a layer of zinc phosphate cement because of "doubtful strength sufficiency" (Gardner, 1950, Kessing, 1958 & Phillips, 1966). If used alone "failure is likely . . . . . . if any attempt is made to pack amalgam into a Class II cavity, lined solely with accelerated zinc oxide-eugenol cement" (Kessing, 1958). As an alternative, Gardner (1950) & Lyell (1960) suggested leaving the modified zinc oxide-eugenol material as a temporary filling and, at the next appointment, removing excess cement before packing the amalgam, in the belief that the strength of the cement would then be adequate.

Only in the past seven to eight years has research been undertaken to compare the early strengths of various types of base materials and to ascertain the strength required of these materials at the time of clinical importance (Kessing, 1961, Colecan and Kirk, 1965 & Chong et al., 1967).

The aim of this research, entitled "Base forming materials for amalgam restorations", was to examine and compare the compressive and tensile strengths of some of the recently developed base materials, particularly at the time of clinical importance. It was hoped, in this way, to provide information which, when considered with the well-established biologic properties, would assist the dentist in the selection
of the most suitable material for a base beneath an amalgam restoration.

Twelve base forming materials were investigated. These included some calcium hydroxide, some accelerated zinc oxide-eugenol and some zinc phosphate type cements and, apart from one hand-mixed accelerated zinc oxide-eugenol material, consisted of commercial products available on the open market. A number of manipulative variables, within the control of the dentist, were studied by testing specimens in compression and tension, while particular interest was taken in the early strengths and setting times of the materials. To provide some reference to the clinical situation, a number of the base materials were subjected to amalgam condensation in cavities in extracted teeth, prior to sectioning and microscopic examination.

Although it was not possible to determine the exact clinical significance of this research, in view of the particular emphasis of this work, where materials were compared at times pertaining to the clinical situation, it was likely that some long held concepts, based on clinically unrelated findings, might require the reconsideration of the dentist.

Before detailing the experimental work, a review of the literature considered pertinent to the subject of this
thesis was included. In an endeavour to present a reasoned
exposition of the subject, it was thought necessary to begin
with a brief account on various aspects of dental amalgam
before proceeding to the base materials. The properties of
dental amalgam, cavity requirements for amalgam restorations
and manipulation of amalgam have been discussed but only in
so far as they were considered relevant to the following
investigation into base forming materials for amalgam
restorations.

For the purpose of this thesis, a base and a cement
lining were considered synonymous and distinct from a cavity
varnish. Because of its several implied meanings within the
literature, the term, cavity liner, was not employed.
REVIEW
OF THE
LITERATURE
Following years of controversy about the use of silver amalgam, fundamental research, conducted by G.V. Black in 1895 and ensuing years, firmly established amalgam as a dental restorative material of great importance.

Black listed the qualities of permanent restorative materials and considered the most desirable of these to be indestructibility in the oral fluids, adaptability to cavity walls, freedom from volume change after placement in the cavity, resistance to attrition and ability to withstand the force of mastication. Appearance, low thermal conductivity and convenience of manipulation were considered to be of secondary importance (Blackwell, 1955). From that day to this, a consideration of these qualities has been the basis for comparison of the ever increasing number of new materials.

Hollenbeck (1958) outlined objectives in the making of all single tooth dental restorations, namely —

1. to restore the damaged organ to complete anatomy and function,

2. to prevent the further ingress of the disease process to the remaining part of the organ,

3. to maintain the dental pulp and the investing tissues in a normal state of health and well-being, and
4. To restore the damaged organ to its normal beauty and colour.

By the careful use of modern dental amalgam and base materials, it is possible for the dentist to approach closely the fulfillment of these objectives.

I. Selected Properties of Dental Amalgam.

Four properties have been discussed, namely, the effect of amalgam on the dental pulp, the strength and thermal conductivity of amalgam and marginal adaptation. While, strictly speaking, corrosion of amalgam and the discolouration of tooth structure are not properties of amalgam, they are, nevertheless, frequently associated with amalgam restorations and have been mentioned here.

The effect of amalgam on the dental pulp.

Of the permanent restorative materials available, amalgam, par se, is one of the least irritating to the dental pulp. Attempts to evaluate its pulpal effect have very often proved to be inconclusive, a direct result of the difficulty experienced in distinguishing the reaction to the amalgam itself from the pulpal reaction to cavity preparation.

Silberstein et al (1955) recognized a definite localized injury to substantia odontoblasts and found that this
injury tended to increase with cavity depth. On the other hand, Lander (1959) and Shroff (1947) found little or no pulpal inflammatory reaction to the amalgam itself. While a cement-lined amalgam restoration produced little reaction, Henley (1936) observed that, where penetration of the base occurred, a slight change could be detected in the pulp opposite this area.

The possibility that the abovementioned reactions, where observed at all, might have been a result of thermal changes was generally acknowledged (Henley, 1942; Lander, 1959 & Selzer and Lander, 1963).

Strength.

Generally considered to be one of its major properties, the compressive strength of amalgam is a means of estimating the resistance to fracture in the mouth.

The design and shape of a typical amalgam restoration greatly complicate the distribution of stresses in function in comparison with the stress distribution in a test cylinder, for, while the principal stress during mastication may be compressive, - shear and tensile stresses are also acting (Rose, 1964 & Slinch and Phillips, 1967). For example, on the isthmus of a compound restoration, any compressive load on the adjacent restored cusp induces a shear stress which, in turn, produces a tensile stress in the isthmus region.
The minimum strength required by the analyst is not known. It is likely, however, that several factors, including the bulk of amalgam and the presence and type of base material used beneath the restoration, are related to this requirement by modifying the effective strength of the amalgam.

The American Dental Association Specification No. 1 for alloy for dental amalgam no longer requires a particular strength for amalgam but refers rather to its property of flow. The Australian Standards Specification No. 2.8. - 1949 for Dental Amalgam Alloy, on the other hand, specifies a one hour compressive strength for amalgam of at least 8,500 pounds per square inch (p.s.i.).

The one week compressive strength of amalgam has been variously described as between 45,000 p.s.i. and 62,000 p.s.i. (Phillips, 1949; Ding, 1961; Peyton et al, 1964; Mahler and Kitchen, 1964 & Skinner and Phillips, 1967).

Ding (1961, 1965) found the minimum one hour compressive strength to be 17,500 p.s.i. and, as a result of this low early strength, amalgam restorations require some early care. A range of from 7,900 p.s.i. to 10,000 p.s.i. has been reported for the one week tensile strength (Peyton et al, 1964; Mahler and Kitchen, 1964 & Skinner and Phillips, 1967), while Mahler and Kitchen found the one week shear or transverse strength to be between 15,000 p.s.i. and 19,000 p.s.i.
5. Thermal conductivity.

Algamon is a relatively poor thermal insulator when compared with tooth structure or dental cements, but a relatively good insulator compared with dental gold alloys. Craig and Peyton (1961) noticed considerable variation in the findings reported in the literature. They attributed this to different methods of measurement. They found the average thermal conductivity of algamon to be $5.4 \times 10^{-2}$ cal/sec/cm$^2$/°C/cm, which did not compare favourably with values obtained for tooth structure and a base material:

- Dentine: $1.56$
- Zinc phosphate cement: $3.1 \times 10^{-3}$ cal/sec/cm$^2$/°C/cm
- Algamon: $54.0$

Zander (1959) and Hanley (1942) suggested that the high thermal conductivity of algamon must be considered a likely cause of inflammatory pulpal changes. Furthermore, the thermal injury would be greater as the thickness of remaining dentine at the pulpal floor decreased. To prevent discomfort and damage due to thermal conductivity, Hanley (1942), Craig and Peyton (1961) & Selzer and Zander (1965) recommended the use of a non-irritating and non-conducting base material.
6.

Marginal adaptation.

No dental restoration perfectly seals the prepared cavity. Analges, particularly in the first few weeks after placement, exhibits a significant lack of marginal adaptation which permits the ingress of fluids and micro-organisms between the restoration and tooth structure (Barber et al., 1964 & Wing and Lyall, 1966). This lack of adaptation, permitting marginal leakage, may be related to the small proportion of analges failures evidenced by postoperative sensitivity, pulpal reactions, marginal deterioration, accumulation of debris and recurrence of caries (Phillips, Dental Clinics of North America, 1965).

Most attempts to prevent this leakage into the freshly cut tooth structure have been unsuccessful. Use of an expanding analges has been advocated, but Hollenback (1956) rejected this on the ground that due to the property of flow of dental analges it was "entirely impossible" for a restoration to exert continual pressure on the cavo surface. Wing and Lyall (1966) noticed that lack of adaptation was marked where attempts were made to pack mercury-rich analges into the line angles. They found that this space between tooth and restoration could be best reduced by good condensation, but even this never entirely eliminated it.
Nehler and Terkla (1965) were of the opinion that the difference in coefficients of thermal expansion or elastic modulus between tooth structure and amalgam could possibly account for the lack of adaptation.

Research using isotopes and dyes as tracers has established that, within 48 hours, the initially substantial marginal leakage is noticeably diminished, and, after one month, is only slight. After one year, there is virtually no penetration at all (Ging et al., 1960, Phillips et al., 1961 & Courts and Phillips, 1961). Pickard and Gayford (1965), having assessed marginal adaptation at varying intervals, suggested that the reduction in leakage with increasing age of the restoration was a result of the deposition of crystalline, amorphous and bacterial debris. On the other hand, Wing and Lyell (1966), found no evidence of a material responsible for sealing the space. A completely satisfactory explanation of this apparent sealing is not yet available.

"A significant volume of evidence (see Cavity Varnishes) has suggested that the penetration of salivary ions and bacteria into freshly cut dentine around an amalgam restoration can be minimized or prevented by the use of cavity varnishes."
Corrosion.

Corrosion may occur on both the inner and the outer surfaces of the amalgam restoration. Nechlin (1954), concerned with postoperative pain after the insertion of amalgam fillings, suggested that the cause was possibly the single tooth acting as both the anode and cathode of the galvanic cell with saliva as the electrolyte, while Bessler (1965) considered the ready oxidation of the amalgam surface and the subsequent tarnish and corrosion to be definite defects of the amalgam restoration. Not only might corrosion be partly responsible for postoperative pain, but it also might lead to recurrence of caries around a tarnished restoration because of the collection of debris.

Rickard and Gayford (1965) suggested that corrosion might serve a useful function. They observed "products of corrosion", along the walls of the restoration and especially at the cavo-surface margin, which, they claimed, were responsible for the "sealing" effect as the restoration aged. On the other hand, Wing and Lyell (1966), could not detect any material responsible for sealing.

There is general agreement that the surface condition of the amalgam is an important factor in determining corrosion potential. Thorough amalgamation and good condensation in the
absence of moisture are vital in the production of the smooth, homogeneous, self-cleansing surface necessary to prevent corrosion (Schoonover and Soudar, 1941; Sweeney, 1944; Ushchinn, 1954; Swartz et al., 1953 & Hardwick, 1960). Furthermore, Schoonover and Soudar (1944) suggested that the cavity must be completely sealed to prevent corrosion at the base of the amalgam.

To minimize the effects of galvanic action, Hassler (1965) recommended the placement of a base beneath the amalgam, although Ushchinn (1954) had found that reaction still occurred, despite the presence of a base, if the amalgam were moisture contaminated.

Discolouration of dentine.

This occurs frequently in teeth where galvanic action is associated with an amalgam restoration. Hassler and Barber (1955) concluded that the mechanism probably involved a slow diffusion of soluble metallic ions from the amalgam itself, under the influence of intermittent galvanic action, through the dentine and subsequent precipitation as dark metallic sulfides. It is generally believed the sulfide ions are derived from saliva and that mercury ions are involved, probably from a mercury-rich amalgam (Applebaum, 1925). The discolouration, an early description of which was given by
Applebaum, was more closely investigated by Kessler and Earber (1953). They used an electric current to reproduce dentine discolouration in amalgam-restored tooth models and observed that the staining penetrated in a rather diffuse and flake-like manner. It was found that the deepest colouring was closest to the amalgam and that the discoloured dentine was slightly softer than normal dentine and much more opaque than normal and carious dentine, when examined by translumination.

The use of a base beneath the amalgam has proved to be a successful means of limiting the discolouration (see Other Properties of Bases).

II. Cavity Requirements for Amalgam Restorations.

Upon completion of the cavity preparation for an amalgam restoration, the dentist must decide whether or not to line the finished, caries-free cavity with some type of base-forming material. He will be guided in his decision by the consideration of two factors, namely—(1) the need for adequate bulk of amalgam, and (2) the distance of the floor of the cavity from the dental pulp.
1. The need for adequate bulk of amalgam.

Amalgam, strong under compression, is relatively weak in tension. If there is adequate bulk of amalgam, then the inherent strength of the alloy need not be so great. Phillips (1949) noted that "a biting stress of one hundred pounds, which is not abnormal, placed on an area the size of a No. 556 bur, would mean an actual compressive strength of 60,000 p.s.i. on that area." Inadequate bulk, resulting from insufficient depth and breadth of the cavity might lead to fracture of the restoration (Tollett, 1958).

Cavity depth, rather than being the distance from the pulpal wall of the cavity to the pulp, is the depth of the cavity from the occlusal (or proximal) surface to the pulpal (or axial) wall. The ideal cavity depth has been variously described as being 0.5 mm. below the dentino-enamel junction (Eaker and Zuck, 1963, Nelsonson, 1965 & Attalla and Bibb, 1968), 0.5 to 1.0 mm. below (Ambrose, 1960) and 1.0 mm. (Hauspida) to 1.25 mm. (Tollett) below the junction (Hosteller, 1957). Apart from the likelihood of fracture of the amalgam, Ambrose (1960) warned that inadequate depth, as seen by failure to penetrate beyond the dentino-enamel junction, might result in either failure to remove remaining areas of carious dentine and/or hypersensitivity due to the increased innervation of the area.
Haehler and Tarkla (1965) warned against the indiscriminate removal of tooth structure in order to provide adequate bulk of amalgam. They pointed out that, due to the relatively low elastic modulus of the dentine, as much tooth structure as possible should be preserved to prevent the dentine bending away from the restoration or even fracturing during mastication. Poppenstand and McConnell (1960) & Skinner and Phillips (1967) also stressed the need to preserve tooth structure where this was feasible.

Retention of the amalgam should be obtained by the placement of definite undercuts and sharp line angles rather than by the roughness of the cavity walls (McCloskey, 1952). Further research, by Ireland (1951), indicated that fewer stresses were incorporated within the amalgam if the axial-pulpal line angle was rounded, while Haehler and Tarkla (1965) suggested that all internal angles should be slightly rounded to reduce internal stresses, but, at the same time, cautioned that increasing the bulk of amalgam by increasing the width of the cavity would not necessarily reduce stresses within that restoration.

When cement bases were used, Lankle (1951) advised that their bulk should be kept small in the interest of keeping amalgam bulk and strength at a maximum.

Whether there is adequate bulk of amalgam, therefore,
depends on a number of factors. The cavity should be deep enough to provide bulk, yet excessive removal of tooth structure might affect the prognosis of the restored tooth. An attempt should be made to reduce internal stresses. Discoloration use of certain bases is necessary to ensure maximum benefit to derived from the proposed amalgam cavity.

2. The remaining thickness of dentine.

While tooth size and age appear to be of relatively slight significance, the remaining dentine thickness between the floor of the cavity and the pulp chamber is the most important single factor in determining pulpal response to a given stimulus (Stenley and Goodnow, 1966). Due to variation in the thickness of the dentine in different teeth, this factor has no association with the more easily-measured cavity depth.

Dentine, being an efficient chemical and thermal barrier, protects the pulp against any types of insult. It is desirable, then, to maintain an optimal natural dentine barrier. If less than 0.2 mm of dentine remained, Attalla and Cuth (1960) believed that some form of pulp protection was mandatory and, as a guide, they suggested that an axial and pulpal depth of 0.5 mm beyond the dentine-canal junction would assure a desirable dentine barrier.
Richard (1934) summarized the position well. "Cavities also allow an adequate bulk of cement for insulation and of amalgam for strength, the insertion of a lining is a wise precaution."

III. Manipulation of amalgam.

To ensure adequate pulp protection, a base material should possess sufficient strength to prevent either fracture or displacement of the base during condensation of the amalgam.

4. The condensation of amalgam.

Habler (1967) considered that, of all the procedures involved in amalgam technique, condensation was the most important, for, while some errors in procedure up to this point could be corrected by optimum condensation procedure, "nothing can compensate for loss than optimum condensation procedure".

The objectives in condensing the amalgam (Hollenbeck, 1959 & White, 1961) are the removal of as much excess mercury as possible and the condensing of the particles into the closest possible physical contact with each other and with the walls of the cavity. Inadequate condensation predisposes to marginal failure, lowered resistance to tarnish and corrosion, increased expansion and reduced crushing strength (Hardsick, 1960).
"Packing Pressure". While the optimum pressure for
alginate condensation has been considered to be about 8,000
p.s.i. (Castellan, 1951 & Wing, 1961), there has been marked
uncertainty about the actual packing pressure applied by the
dentist, although it has been widely acknowledged that it was
considerably less than the optimum pressure.

Theoretically, heavy pressure is definitely very
desirable. Nadal (1962) pointed out that heavy pressures
were necessary to ensure a dense restoration, clinical residual
marginal and reduces compressive strength. Clinically, however,
the consistent use of heavy packing pressure appears to be most
unlikely. Castellan (1951) explained that to exert a packing
pressure of 8,000 p.s.i. on the surface of the alginate would
require a heavy ten pound thrust with a one millimetre diameter
condenser. To apply a ten pound thrust consistently would
require a concentrated effort by the dentist.

Realistically, then, a far more likely value for the
consistent packing pressure is between 4,000 and 6,000 p.s.i.
Gayler (1933) recommended a packing pressure of from 3,600
p.s.i. to 5,400 p.s.i., but was aware that the actual pressures
used by dentists could vary from 500 p.s.i. to 6,000 p.s.i.
She condemned the use of pressures lighter than 3,600 p.s.i.
because marked expansion was likely upon setting of the alginate.
After measuring the force applied by thirty practitioners,
Kahler and Hatchen (1965) concluded that forces of 3 to 4 pounds were most frequent. Forces in excess of 6 pounds were rare, while forces less than one pound were occasionally recorded.

**Factors involved in condensation.** In the light of these clinical observations it is indeed fortunate that condensation is not solely dependent on the applied force. Wing (1961 and 1965) listed a number of factors associated with condensation including force, the size of the condenser, the number of thrusts of the condenser on each piece of amalgam, the size of the increments and the time taken for condensation. Of these, Wing (1961, 1965) & Kahler (1967) singled out the increment size as the most important factor in ensuring good condensation. A small load might, in actual fact, be sufficient to condense completely through the whole thickness of the amalgam provided that the increment is small (Wing).

Often however, much of the force exerted at the point of pressure, having been dissipated in the condensation of the amalgam mass, would not be fully transmitted to the underlying cavity floor or base (Lyell, 1960 & Nassir, 1961). To compensate for this dispersion of the applied pressure, Wing (1961, 1965) suggested that "ideal condensation can probably be carried out using a fairly high load, very small
pieces and a large number of thrusts on a condenser which will move through the amalgam but will be resisted by the amalgam". In particular, Wing (1964, 1965) & Lehner (1967) stressed the importance of using several small pieces of amalgam, rather than one large increment, to fill the proximal portion during condensation for a proximo-occlusal restoration.

Condensing the amalgam. Within the limited scope of this review, two other aspects, related to amalgam condensation by the dentist have been considered.

a) The lapse of time from the mixing of the base material until amalgam condensation begins.

While it is acknowledged that there would be considerable variation in this, it was, nevertheless, desirable to establish an approximate time interval so that the properties of the base materials could be investigated at this time of clinical importance. Naturally, many factors would affect this time interval; for example, the need to place a matrix band and some wedges or to position retentive pins or to adjust the cavity preparation after placement of the base.

Phillips (1966) suggested that it was the five or six
minute properties of the bases that were of special interest, because this was approximately the time taken by the dentist to mix, place and finish the base.  Iyall (1960) having allowed time for the placement of a matrix band and wedges, concluded that seven minutes was the approximate time lapse between the mixing of the base and initial acolgan condensation.  If the dentist has an assistant to mix the base material, then the time taken by him would appear shorter by one to one and a half minutes.

It seemed reasonable, then, to assume an interval of about six or seven minutes from initial mixing of the base to acolgan condensation.

b) The place in the cavity at which condensation commences.

This may appear to have little, if any, effect on any base material that may be present.  While it is important that the presence of a base should never be an excuse for less than maximum condensation, it is reasonable and certainly desirable to condense the acolgan in such a way as to support the base rather than tax its physical properties to the limit.  It was suggested by Attellin and Gibb (1965) that condensation should commence in the most inaccessible part of the cavity.  Tesing (1961) more fully expressed this view when he stated that "the initial portions of the acolgan, having been
condensed along the gingival steps and into the buccal and lingual embrasures, provide a buttress that gives support against dislodgement of the lining."

2. Finishing and polishing the amalgam.

No amalgam restoration is truly finished until its surface has been highly polished, a procedure which may be effected in a short time, providing that the surface is smooth and homogeneous.

Reasons advanced for the finishing and polishing of amalgam are numerous (Hardwick, 1960; Halter, 1967 & Attalla and Gibb, 1968). Proper polishing provides the restoration with maximum resistance to corrosion and tarnish, decreases food retention, prevents irritation of the adjacent soft tissues and enhances the appearance of the restoration. Although finishing must be delayed until the amalgam is fully set, usually about 24 hours after placement, Schoonover and Soudar (1944) pointed out that, if corrosion were to be prevented, it was essential that the amalgam be polished as early as possible and be kept polished.
"The function of a cement base that is placed under the permanent restoration is to encourage recovery of the injured pulp and to protect it against the numerous types of insults that may subsequently occur" (Phillips, 1966).

Mccluskey (1952) considered the incorrect use of a cement base to be a cause of amalgam failure. In earlier clinical study by Healey and Phillips (1949) in which over 1500 defective amalgam restorations were examined, concluded that amalgams apparently did not fail as a result of failure of the base. However, in their study, for amalgam failure to have been attributed to the base, or lack thereof, fracture of the restoration or dimensional change or recurrent caries or pulp involvement was a necessary prerequisite.

A later investigation, by Hosteller (1951), more closely concerned with bases, revealed that, of 300 patients questioned, approximately 75 per cent recalled that one or more of the several large amalgams in each patient had been sensitive to thermal changes after being filled, and this hypersensitivity had lasted from several days to some months. He attributed much of this postoperative sensitivity to failure to use a base beneath the amalgam.
1. The Functions of a Base.

Broadly speaking, the functions of a base are to encourage recovery of the pulp from irritation due to cavity preparation, to allow good amalgam condensation by resisting the pressure exerted upon it and to protect the pulp from irritants associated with the amalgam restoration.

1. The biological function of a base.

Biologically, an ideal base is expected to—

(i) Allow recovery of the pulp from injury sustained during cavity preparation, and

(ii) be non-irritating to the pulp.

(iii) A clinically normal pulp will show no clinical signs or symptoms indicative of pulp disease and will respond as expected to various tests. Selznick and Senker (1965), however, have observed that, histologically, a clinically normal pulp might exhibit pathology, and have indicated that pulpal irritation was cumulative in its effect so that the pulpal prognosis following a particular insult would be related to the severity and number of past insults and its degree of recovery from these.

The dental pulp is subjected to mechanical and thermal irritation in cavity preparation, and the degree of
injury is related to the following factors listed by Selzler and Bender (1965):

(a) The depth of the cavity preparation.
(b) The presence and formation of reparative dentine.
(c) The speed of rotation of the cutting instrument.
(d) The amount of pressure exerted on the tooth structure by the cutting instrument.
(e) The amount of heat produced by the cutting procedure and the use of coolants.
(f) The size and nature of the cutting instrument and

(g) The extent of the cavity preparation.

Although it is not intended to become involved in this subject, the importance of careful cavity preparation necessitates the mention of three factors. There is indubitable evidence of the need for an adequate water coolant to minimize pulp reaction at speeds such in excess of 6,000 revolutions per minute (Swardlow and Stanley, 1959; Langland, 1959 and 1961, Stanley and Swardlow, 1960 & Marrent and Hanau, 1963). Peyton (1959) stressed the importance of light pressure in cavity preparation and this was supported by Stanley and Swardlow (1960) who also pointed out that even intermittently applied heavy pressure evoked more pulpal response than light continuous pressure. Thirdly, the cutting of relatively uninvolved dentine renders
the involved odontoblasts more vulnerable to damage than those previously exposed to moderately deep caries, since the latter will have stimulated reparative dentine formation (Seltzer and Bender, 1965 & Stanley and Seward, 1959). Some treatment of the freshly cut dentinal tubules not lined by reparative dentine is therefore imperative prior to restoration (Seward and Stanley, 1962).

While injury to the pulp from mechanical preparation of the tooth is usually not severe, the future ability of the pulp to withstand insult will depend upon the protection afforded it by the placement of the base and restoration. It is essential, therefore, whether they be for a base or permanent restoration, that the restorative materials used allow the dental pulp to recover from injury due to cavity preparation.

(ii) A base material, if it is to allow pulp recovery and prevent further injury, must itself be non-irritating to the pulp.

In the past, it has been suggested (Bodecker, 1934) that a slightly irritating base material was preferable to a completely non-irritating cement because, whereas the former would stimulate the formation of secondary dentine, the latter would not. Furthermore, Bodecker reasoned that a slightly hyperaemic pulp, a common occurrence after cavity preparation,
would benefit from the effect of a mildly irritating base. Robinson (1954), commenting on the suggestion made by Bodecker, wrote - "Irritation is to be avoided, for while it admittedly may stimulate the formation of protective sclerotic and secondary dentine at certain levels, shortly beyond these levels it may produce inflammation and possibly pulpal necrosis. The optimal level of irritation is not predictable by available methods". In reply to earlier suggestions similar to Bodecker's, Costeller (1951) concluded that it was much safer to employ a non-irritating base, for while the production of secondary dentine might be slow beneath this material, there was little likelihood of further pulpal injury.

2. The strength of a base forming material.

A base material must possess sufficient strength to prevent displacement or fracture of the base during packing of the analges. The use of a base should never be an excuse for inadequate condensation.

Coleman and Kirk (1965) investigated the compressive strength property of base materials at both ten minutes and seven days. The early test was claimed to give an indication of the ability of the base to withstand the forces of condensation, while the one week compressive strength was claimed to be a measure of the pressure that the material would withstand.
under restorative forces. Rowe (1964) had observed that "the base exhibiting the greatest compressive strength also exhibited the greatest strength when superimposed by a restoration of silver amalgam." It is obvious that Rowe is referring to resistance to fracture of amalgam restorations rather than to the property of strength of the amalgam, which is inherent within the material. On the other hand, Phillips (D. Clin. N. Amer., March 1965 and J.A.D.A., March 1965) doubted if the strength of the base played any role at all in the clinical fracture of an amalgam restoration which, he claimed, was instead associated with incorrect occlusal relationships resulting in areas within the restoration of high stress concentration; the base itself was not a contributing factor. Phillips, however, did acknowledge the need for sufficient strength to prevent displacement or fracture during condensation. Inadequate strength at this early stage, he suggested, either could permit the amalgam to penetrate and contact the dentine, thereby eliminating the thermal protection afforded by the base or could even cause the amalgam to be forced into microscopic exposures in the pulp.

The exact strength required by a base material to resist condensation forces is not known, although the design of the cavity is unquestionably a critical factor (Phillips,

The clinical significance of the tensile strength of a base forming material is unknown, in fact, it is only recently that any real attempt has been made to measure this property (Civjan and Breuer, 1964 & Phillips et al, 1965). However, it is reasonable to assume that a base placed on the pulpal and axial walls of a Class II restoration would be subjected to tensile stresses in the isthmus region during condensation. Good initial condensation into the proximal portion (see "Condensing the amalgam") is likely to reduce considerably these stresses.

To summarize earlier discussion, while the optimum packing pressure is known to be about 8,000 p.s.i., it has been found that a clinically more usual packing pressure is between 4,000 p.s.i. and 6,000 p.s.i. Furthermore, since it is not yet possible to estimate the loss of effective pressure due to dissipation within the amalgam mass, it can only be concluded that the early compressive strength required by a base forming material is certainly less than 8,000 p.s.i. and probably considerably less than 6,000 p.s.i.
3. Protection of the pulp from future insult.

In addition to its abovementioned requirements, the ideal base for an amalgam restoration also provides thermal and galvanic protection for the pulp, it inhibits the penetration of mercury ions through the dentino, resists leakage around the amalgam restoration and possibly has some antibacterial action (Goings, 1964).

Dentine, being an efficient chemical and thermal barrier, protects the pulp against many types of insult. Removal of dentine below the ideal cavity depth is likely to lead to adverse effects upon the dental pulp unless a non-irritating base is used.

(1) Thermal protection of the pulp. The use of a base to eliminate or reduce discomfort and pulpal irritation resulting from thermal changes is widely recommended (see Thermal conductivity of amalgam), and Bessler (1965) pointed to this as the primary function of a base under a deep metallic restoration.

Thermal diffusion through metallic restorations is rapid. Phillips (1966) reported that since it took only three seconds for a thermal change to reach the floor of the prepared cavity after application to an amalgam restoration, it could be readily understood that unlined amalgam
restorations in deep cavities tended to be sensitive to heat and cold. The minimal thickness of base required for thermal insulation has not been determined. However, Phillips (1966) pointed out that, since reduction in temperature diffusion by a base 0.2 mm. thick beneath an amalgam was negligible, a "thin wash" of the cement applied to the cavity floor did not afford pulpal protection against thermal changes.

(ii) Galvanic insulation and inhibition of mercury ion penetration. There is some evidence to suggest that galvanic action may occasionally be a cause of postoperative pain following the insertion of an amalgam restoration (see Corrosion of amalgam). The use of a base has been advocated to provide galvanic insulation (Kessel, 1965). The use of cavity varnishes and bases has been suggested to inhibit the penetration of mercury ions beneath an amalgam restoration (Kessel and Barber, 1953, Fein, 1961, Kessel, 1965 & Saltor and Bender, 1965).

(iii) Resistance to marginal leakage around the restoration. The marked initial leakage around an amalgam restoration cannot be eliminated by varying the manipulation of the amalgam but will, after some weeks, become negligible (see Marginal adaptation of amalgam).

Not only may the initial ingress of fluids and debris around the amalgam irritate the pulp by way of the freshly cut
dental tubules and result in postoperative sensitivity, (Phillips, D. Clin. N. Am. 1965 & Dachi and Stiges, 1967) but Schoonover and Scudder (1944) associated this marginal leakage with cariogenic action on the pulpal side of the occlusion. There is very good evidence available that these undesirable effects can be minimized or even eliminated by the judicious use of cavity varnishes and bases.

(iv) The antibacterial activity of a base. Gain (1964) suggested that it would be desirable for a base material to have some degree of antibacterial activity so that it might "sterilize" the underlying dentine and the residual decay of deep carious lesions. However, he acknowledged that complete sterility was impossible to achieve on account of the necessarily long period of application. In fact, even if this could be obtained, marginal leakage and percolation would make any previous sterilization valueless.

Investigations by Sade (1943) cast real doubts upon the need for dentine sterilization. He observed that the carious process in dentine gradually appeared to cease and stop as soon as the lesion was isolated from the oral environment, whether or not micro-organisms remained alive. Salter and Bender (1965) compared a number of "dentine sterilizing agents" namely, phenol, silver nitrate, eugenolated paradichlorophenol and penicillin, crocoite and cetylal, and concluded that,
with the exception of eugenol, which mildly inhibited bacterial growth, the agents were either ineffective or potentially destructive to the pulp.

Therefore, while some antibacterial activity would certainly be desirable, it would appear that flushing the cavity with one of the many solutions and chemical agents should be avoided, as it does more harm than good (Ging, 1964).

II. Types of Base Filling Materials.

Broadly speaking, there are three main types of base materials, namely, zinc phosphate, zinc oxide-eugenol and calcium hydroxide. While some commercial products do contain a mixture of these basic types, it is nevertheless possible to discuss the three types independently and compare their properties.

Recently the extensive use of cavity varnishes has led many to suggest that they are capable of replacing the base materials. It is for this reason that some mention has been made of cavity varnishes with a view to outlining their uses and shortcomings.

At this stage, the principal uses, structure, recent developments and specific properties of the individual base materials have been outlined before comparing, in a more detailed fashion, their major properties.


1. Zinc phosphate type base materials.

Chalmers and Phillips (1967) described a zinc phosphate type cement primarily as a "luting agent for fabricated restorations". They suggested that its use as a temporary restorative material or as a thermal insulating base was of secondary importance.

Zinc phosphate cements continue to be very popular with the dental profession as a base material. This popularity is probably based upon the belief that other base materials, though they be less pulpal irritating, are too weak to withstand the forces of amalgam condensation. The validity of this belief has been questioned in a subsequent section.

A knowledge of the setting reaction of a zinc phosphate type product is of definite importance in any consideration of the pulpal effects of this material. On mixing a zinc oxide powder and phosphoric acid a solid substance is rapidly formed with considerable evolution of heat. The initial solution of the powder particles in the phosphoric acid is followed by reaction to form primary zinc phosphate which, it is thought, is in turn converted into the stable, water-insoluble tertiary zinc phosphate. At the moment the cement is placed in the dental cavity, the mixture is probably composed of undissolved powder particles and a solution of phosphoric acid and primary zinc phosphate; the reaction to form the


tertiary zinc phosphate probably taking place at a later stage (Harvey et al., 1944 & Skinner and Phillips, 1967). At the time of placement, there is marked acidity of the mix—pH 1.6 (Harvey et al.) to 3.5 (Skinner and Phillips). With the formation of the tertiary phosphate, the acidity decreases rapidly so that by one to two hours the pH is approximately 6.6 (Romer, 1948) and by 20 days is nearly neutral. It is this relatively rapid setting and acid neutralization that is responsible for less pulpal irritation and damage than is associated with silicate cements, although these also contain phosphoric acid (Kasser, 1965 & Selzer and Bender, 1969).

Colton and Ehrlich (1953) observed that while the zinc phosphate type cements did possess some antibacterial power in the wet, unset condition, when dry, there appeared to be no inhibition of bacterial growth. Attempts to incorporate antibiotics within the cement have met with little success (Swartz, 1965). While it was possible, then, that zinc phosphate cements did have some bacteriostatic property, Swarts considered that this was very limited.

The chemical combination of zinc oxide with an acid to form a zinc cement has been in use by dentists for a long time and the only major change made since the 1920's was the substitution of orthophosphoric acid for the highly injurious hydrochloric acid (Kasser, 1965). After observing the
prevalence of sensitivity in freshly filled teeth. Costeller (1951) suggested the use of a "sedative" zinc phosphate cement, in which the liquid contained equal parts of the commercial liquid and eugenol. Of more than 3,000 teeth examined in 600 patients only 6 teeth proved to be hypersensitive. He concluded that while there was some loss in compressive strength as a result of the incorporation of eugenol, the use of this mix was of definite value in reducing postoperative hypersensitivity, apparently due to the established sedative action of eugenol on the pulp.


Since 1898, when a Committee on Materia Medica reported on a "new" material, the chief ingredients of which were zinc oxide and eugenol, until present times, the zine oxide-eugenol type materials have been subjected to exhaustive investigation. Luckie (1898), Merritt (1914), Nowe (1919) & Black (1926) recognized the potential uses of this material. It was not until 1922 that the American Council of Dental Therapeutics announced the inclusion of zine oxide-eugenol cement in its list of Accepted Dental Remedies. Skinner and Phillips (1927) considered that the principal uses of this material were as a temporary restorative agent, as a thermal insulating base and as a pulp capping agent. The restoration
of the root canal was listed as a secondary use.

Although the material has been in use for 70 years, it is only quite recently that much understanding has been acquired of its setting reaction. Following a thorough examination using X-ray diffraction to investigate crystal structure during setting, Copeland et al. (1955) concluded that the reaction product appeared to be the relatively insoluble zinc eugenolate, crystals of which acted as a nucleus for the unreacted zinc oxide while unreacted eugenol remained and weakened the mass. Smith (1958) suggested that the setting involved concurrent sorption of the eugenol and formation of eugenolate (eugenate), the balance of these two processes depending upon the nature of the oxide.

If a zinc oxide-eugenol cement is to be used as a base beneath an amalgam restoration it must possess adequate early strength. However, two oft-quoted disadvantages of the material are its softness and slow setting time (Saltzur and Binder, 1965). As early as 1949, Howe suggested the use of a crystal of silver nitrate to accelerate the setting and over the last 50 years many attempts have been made to improve these properties of the material.

The principal factors affecting the setting time are the ambient conditions of temperature and humidity under which the set takes place, the type and condition of oxide employed.
and the presence or absence of accelerators (Wallace and Hansen, 1932, Smith, 1950 & Coleman and Kirk, 1965).

For a long time it has been known that the presence of moisture accelerates the setting process of zinc oxide-eugenol materials (Luckie, 1926, Copeland et al, 1955, Smith, 1950 & Coleman and Kirk, 1965). Since it has also been commonly observed that an increase in surrounding temperature or humidity tends to shorten the setting time, much research has been undertaken to control the other factors.

Some of the attempts to improve the properties of the zinc oxide-eugenol type materials are listed below.

(i) The manufacture of the zinc oxide. Zinc oxide produced by the direct oxidation of the metal will form a zinc oxide-eugenol product somewhat weaker than the zinc oxide derived from thermal decomposition of zinc carbonate at a temperature of about 300°c (Smith, 1950), possibly due to the greater absorption of eugenol by the zinc oxide manufactured by the latter process. Harvey and Fetch (1946) found that zinc oxide derived from zinc carbonate set "as fast as any of the present accelerated zinc oxide mixtures".

(ii) The particle size of the zinc oxide powder. A small particle size was observed by Harvey and Fetch (1946) to be important in promoting fast setting. Norman et al (1964) found the powder particle size to have considerable effect on
the setting time but only minor influence on the strength of a plain zinc oxide-eugenol material. The use of accelerators, however, led to greater increases in strength where the particle size was smaller.

(iii) The addition of zinc acetate to the zinc oxide powder. Zinc acetate is an "excellent accelerator" (Colmar and Skirner, 1942) and effectively accelerates the setting process (Harvey and Fetch, 1946 & Phillips and Love, 1961).

(iv) The addition of resin (resin) to the zinc oxide powder. Black (1936) noticed that the incorporation of resin would both hasten the setting and make the cement somewhat harder. While Wallace and Hansen (1939) & Colmar and Skirner (1942) confirmed that the setting time was reduced by resin, Harvey and Fetch (1946) found that resin retarded the setting of the zinc oxide-eugenol cements. Brewer and his co-workers (1962) possibly explained these conflicting findings when they observed that, above a critical concentration of resin, the compressive strength was considerably lowered.

(v) The addition of ortho-ethylbenzeneic acid (EBA) to the liquid. Brewer and his co-workers (1953 and 1967) have studied both clinically and in the laboratory the effect of mixing zinc oxide powder (with and without modifiers) with a liquid containing a high percentage of EBA. They attributed a reduction in setting time and a considerable increase in compressive strength
to the addition of the E D A. These findings have been confirmed by Phillips and Love (1961) & Norman et al (1964). After clinical tests, Civjan and Breuer (1965) recommended the use of E D A—containing zinc oxide-eugenol cement as a base and pulp capping material. While these materials do possess quite high strength, the incorporation of E D A does have the associated disadvantage of an increased solubility and disintegration (Phillips and Love, 1961; Breuer et al, 1956) which can be lowered to acceptable levels by the incorporation of hydrogenated resin within the zinc oxide powder (Skinner and Phillips, 1967). Although one commercial product, Opotow*, in which the liquid portion is 62.5 per cent E D A and 37.5 per cent eugenol, is at present available, the action of the E D A is not yet fully understood (Breuer et al, 1967 & Skinner and Phillips, 1967).

(vi) The addition of dicalcium phosphate to the zinc oxide powder. Roland et al (1959) found that the crushing strength of zinc oxide-eugenol cement was enhanced by the addition of increasing quantities of a dicalcium phosphate formulation.

(vii) The incorporation of 10 per cent polystyrene into the eugenol. The polystyrene-fortified zinc oxide-eugenol cement was found to give an optimum setting time and an increase in

* Opotow Dental Mfg. Corp., Brooklyn, N.Y., U.S.A.
compressive strength compared with a normal quick setting zinc oxide-eugenol cement, the increase being particularly noticeable in the early stages (Kaslow, 1961).

When a zinc oxide-eugenol cement was used, Holmer (1967) stressed the need for a thick mix to minimize the residual eugenol content. He pointed out that where free eugenol was present, even in small amounts, changes in tissue and tooth structure could be expected. Rothberg and de Shazer (1966) confirmed the need for a thick mix of cement and suggested that the eugenol was capable of chelating calcium ions, thereby removing calcium from dentine. Furthermore, they suggested that the lack of a dentine bridge at a pulp exposure where zinc oxide-eugenol was used and the softening of dentine around this material were results of this complexing action of eugenol with calcium.

The effect of capping the pulp with a zinc oxide-eugenol cement was examined by Cooke and Howbotham (1956) who found that, of 175 cases, 142 fulfilled their criteria for success. Further evidence of the direct effect on the pulp has been discussed in a later section of this review.

Apart from their use as a base forming material, zinc oxide-eugenol type cements have been employed as sedative dressings, for indirect pulp capping and as a temporary filling material.
As a sedative dressing the cement is thought to use its usefulness to its hygroscopic property whereby it removes moisture from the dentinal tubules, thereby relieving pressure on an inflamed pulp (Seltzer and Bender, 1965). The cement has been widely recommended for its sedative effect (Report of Committee, 1898, Herritt, 1914, Demar, 1958, Canby and Burnett, 1963 & Swartz, 1965). Hassler, 1965, partially attributed its sedative action to its sealing and bacteriostatic properties.

Hassler et al (1957) pointed to zinc oxide-eugenol as an ideal material for indirect pulp capping. The potential of the cement as a temporary filling material was soon realised (Luckie, 1938, Herritt, 1914 & Black, 1936) and, more recently, proof of its good marginal sealing has confirmed this indication for its use (Hassler and Ostrovsky, 1954 & Coing and Hassler, 1961).

Various authors have suggested that zinc oxide-eugenol cement has an antibacterial action (Report of Committee, 1898 & Hassler, 1965). Turkenheim (1953) compared the antibacterial action of a number of dental materials and observed that zinc oxide-eugenol retained its germicidal effect for longer than most of these.

Zinc oxide-eugenol cements are approximately neutral (Swartz, 1965). Harvey and Fetch (1946) determined that the cement had a pH range of from 6.8 to 8.0 and when zinc acetate
was added to the mix, the pH range was 6.8 to 7.2. For this reason, and because of their good seal, zinc oxide-eugenol cements have been suggested as ideal liners beneath zinc phosphate or silicate cements (Masalar and Mansukhani, 1960).

3. Calcium hydroxide type base materials.

For some years, increasing use has been made after cavity preparation of an application of calcium hydroxide mixed with distilled water. While this material is principally indicated for application to an exposed pulp (Skinner and Phillips, 1967), it has also proved to be satisfactory as an acid-neutralizing base (Seltzer and Zander, 1965) as it possesses a high alkalinity — pH from 11.5 to 13.0 (Skinner and Phillips, 1967) — and for indirect pulp capping and cases of possible pulp exposure.

Widespread evidence is available to substantiate the continued success of calcium hydroxide as a pulp dressing in pulp capping or pulpotomy procedures (Zander, 1939, Suthers, 1952, Slack, 1953, Patterson and Van Huysen, 1954, Levin, 1959, Shankle and Brauer, 1962 & Sapos, 1962) — for further discussion on the pulpal effects of calcium hydroxide, see Biological properties of base forming materials.

The use of a calcium hydroxide type material, either as an indirect pulp capping agent or as a base in deep
cavities where a possible exposure exists, has been a fairly recent development (Berk, 1957 & Mehlum, 1960). Damale (1961), after indirect pulp capping with calcium hydroxide, found that all the teeth tested remained asymptomatic and vital and that subsequent pulp exposure was unnecessary in 85 per cent of the cases.

Attempts have been made to improve the handling qualities of calcium hydroxide. Berk (1950) examined the effect on the pulp of a calcium hydroxide-methyl cellulose paste and subsequently (1957) recommended its use in deep cavities where an exposure was likely. Sander et al. (1950) reported that another liner, consisting of calcium hydroxide and zinc oxide suspended in a chloroform solution of polystyrene, had proved effective. More recently, two products became available which have markedly assisted in the handling of the calcium hydroxide. Delaney and Seyler (1966) tested the effect of Hydrex* on exposures and near exposures of the pulp and concluded that acceptable levels of success were obtained — 76 per cent success for direct pulp capping and 63 per cent success for indirect pulp capping. After a clinical and histological investigation, Sayegh and Reed (1967) reported complete success in 30 of 34 teeth treated by

* Kerr Mfg. Co., Detroit, Michigan, U.S.A.
either direct or indirect pulp capping with Hydrox. Gensach (1963) found by the application of Lycal that it was possible to achieve a relatively high percentage of success in cases of direct pulp capping. Furthermore, histological evidence indicated the ability of Lycal to form a dentine bridge over the exposed area.

Calcium hydroxide appears to be capable of stimulating and enhancing the production of sclerotic dentine in young teeth (Mjor et al., 1961 & Klein, 1961). Klein found that an area of marked dentine sclerosis could be detected roentgenographically in 93 per cent of the teeth beneath this base material. Mjor et al attributed this increased hardness to mineral deposition in the walls of the dentinal tubules, while Klein described it as a hypercalcification of the existing primary dentine rather than a recalcification of carious dentine.

4. Cavity varnishes.

For many years, cavity varnishes have been recommended for application to the walls of the prepared cavity (Bodocker and Applebaum, 1930), but only in relatively recent times have they been subjected to the detailed investigation necessary to place their use on a scientifically established basis. From

\[\text{\textcopyright L.D. Caulk Co., Milford, Delaware, U.S.A.}\]
the many types of cavity varnishes that have been tested, the 
copal varnishes, an example of which is the commercial product, 
copalite*, have emerged as the most effective (Going and 
Kassler, 1961), so that the majority of recent research has 
specifically investigated possible advantages and disadvantages 
of this type of varnish.

Suggested functions of a cavity varnish include 
prevention of the deleterious effects of marginal leakage, 
thermal and galvanic insulation beneath an amalgam restoration, 
prevention of acid penetration from silicate and zinc phosphate 
type cements and provision of an antibacterial agent at the 
floor of the cavity.

In its clinical application, Going (1964) recommended 
that the varnish should be applied generously to the walls of 
the cavity. Wing and Lysell (1966), on the other hand, suggested 
that the application of varnish lining be kept as thin as 
possible by the use of several thin coatings, thereby providing 
a layer of from 3 to 20 microns thick.

The effect of a cavity varnish on marginal leakage. 
Initially, there has been found to be significant leakage around 
an amalgam restoration, sufficient to allow the ingress of fluid 
and micro-organisms (see Marginal adaptation of amalgam

restorations). Reliable evidence has now suggested that
the application of a copal varnish to the walls of the cavity
preparation is effective in preventing the penetration of
debris and salivary ions into the freshly cut dentinal
tubules around an amalgam restoration (Going and Massler,
Barber et al. (1964), following experiments in which varnish
was placed on specific parts of the cavity preparation,
affirmed that complete sealing of the cavity was accomplished
when all surfaces of the cavity preparation were covered with
a copal varnish. It was observed by Swartz and Phillips
(1961) that the beneficial initial effects obtained by
application of the varnish did not interfere with the
excellent marginal seal which is a feature of amalgam some
months after placement.

Prevention of acid penetration. While varnishes
have markedly reduced the penetration of acid, from a
silicate or zinc phosphate type cement, into the dentinal
tubules, they have not completely inhibited it (Swarts, 1961
(1961) claimed that varnishes were ineffective in preventing
acid penetration. Varnishes, then, cannot be relied upon to
prevent acid penetration and some type of base material is
essential to achieve this.
Antibacterial property of varnishes. Cavity varnishes were shown by Harrison (1966) to be ineffective in inhibiting bacterial growth.

Galvanic insulation. Naselor (1965) suggested that for shallow cavities a copal resin varnish was the material of choice for galvanic insulation. Furthermore, the application of varnish inhibited the penetration of mercury ions through the dentine and thereby prevented discolouration.

Thermal insulation. Barkley (1951) claimed that the routine application of a varnish to cut dentinal tubules provided ample protection from thermal shock for 96 per cent of cavities. On the other hand, Phillips (D. Clin. N. Acad., 1965) pointed out that, although varnishes possessed a low thermal conductivity, they were usually not applied in sufficient thickness to provide adequate insulation under a metallic restoration. The ability of the varnish to reduce postoperative sensitivity to heat and cold was more likely to be associated with its effect on marginal leakage than its thermal insulation.

It may be concluded then, that the application of a copal varnish is an excellent means of controlling the effect of marginal leakage around an amalgam restoration. However, the ability of the varnish to inhibit bacterial
activity, to prevent acid penetration or to provide galvanic and thermal insulation cannot be relied upon.

III. The Properties of Base Filling Materials.

1. Biologic properties.

If it is to allow pulpal recovery and prevent further injury, a base material must itself be non-irritating to the pulp. So that a scientifically sound selection of base material may be made, it is important to know the effect on the pulp of the available preparations when placed in a cavity deeper than “ideal” depth. It has been shown that, in a very deep cavity, minute exposures, undetectable by the naked eye, occurred, and it is therefore desirable to know the pulpal reaction on direct contact with the different base materials.

It is proposed to discuss the direct and indirect effects of the base materials on the pulp and then to consider possible recommendations.

(1) Pulpal response to direct contact with base materials.

Of the three types of base materials, calcium hydroxide products unquestionably have the most desirable effect upon the exposed pulp. Initially, the calcium hydroxide has a necrotizing or coagulating effect on the superficial pulp tissue so that within an hour, definite zones of blood clot and debris,
necrotic pulp and small round cell infiltration may be detected progressively further from the calcium hydroxide. After three days, there are definite signs that organisation of the deeper blood clots is taking place, and by one week, two morphologically distinct barriers may be detected, the more superficial containing numerous calcified masses and the deeper consisting of sheets of fibres. After a period of three months, there is a well established dentine barrier (Easterton, 1966 & Serman, 1958). The formation of a definite hard tissue barrier was considered by Easterton to be evidence of permanent pulp healing and the ability of calcium hydroxide to form a dentine barrier (Cline and Zander, 1949, Zander et al., 1962 & Samusch, 1963) explains the popularity of this material as a dressing in pulp capping and pulpotomy procedures (see Calcium hydroxide type base materials).

Zinc oxide-eugenol materials, when placed directly on the pulp produce a marked inflammatory reaction (Seltzer and Sander, 1965). It was observed by Cline and Zander (1949) and confirmed by Naddan (1962) that a zinc oxide-eugenol material was a continuing source of irritation at the site of contact with tissue so that it seriously delayed the reparative process. Mohamed et al. (1964) found the material capable of destroying tissue and warned against the use of a potential irritant for pulp capping. Other research (Serman, 1958 &
Thanik et al. (1962) indicated that while a zinc oxide-eugenol material was more irritating than calcium hydroxide, the inflammatory reaction was relatively short-lived and after 28 days was often no longer evident. Berman, in fact, observed dentine bridge formation 21 to 28 days after application of the material.

Civjan and Drauer (1969) investigated the properties of a zinc oxide-eugenol E B A material and found that the five teeth pulp capped with the cement remained symptom free and responded normally to vitality tests after 2 to 10 months. A histological examination, by Rowe (1967), revealed that the modified zinc oxide-eugenol material produced little inflammation in coronal pulp tissue and even evidenced calcific bridge formation after 28 days in 22 of the 24 teeth tested.

Thanik et al. (1962) and Mohamed et al. (1964) were of the opinion that, of the three major types of materials, zinc phosphate cements were the most irritating. Application of this material directly to an exposed pulp was likely to result in severe pulp necrosis with massive destruction of pulp tissue. This material should not be allowed to contact the pulp.

(ii) Pulpal response to indirect contact with base materials. Calcium hydroxide materials, when applied to the
floor of a deep cavity, are non-irritating. Stewart and Kraser (1958) were unable to detect any significant difference in the pulpal response to calcium hydroxide and zinc oxide-eugenol. Even when the remaining natural dentine barrier at the floor of the cavity was reduced to less than 100 microns, Shand et al. (1962), having placed a calcium hydroxide base, observed only a slight pulpal change which was confined to the odontoblast layer.

Clinically and histologically it has been established that a zinc oxide-eugenol material placed on the pulpal floor of a deep cavity, was non-irritating to the pulp (Stanley, 1936, 1942, 1944; Harvey et al., 1944; Silberweitz et al., 1955; Stewart and Kraser, 1958 & Sander, 1959). Indeed, the very lack of pulpal irritation has been considered by some to be a disadvantage because of the possible lack of sufficient stimulation to induce secondary dentine formation (see Biological function of a base).

Olive and Freyman (1965) placed a zinc oxide-eugenol material on the floor of a deep cavity in a number of asymptomatic teeth and then completed the restoration. All teeth remained vital and lost their symptoms. Although much more clinical research is required, it appears that this modified zinc oxide-eugenol product may prove to be a satisfactory non-irritating base material.
A base of zinc phosphate cement on the floor of a deep cavity is likely to produce a marked pulp reaction in the form of moderate to strong cellular infiltration. The most severe changes are confined to the odontoblast layer (Hanley, 1944 & Brahnstrom and Nyborg, 1969). Subner and Stanley (1962) reported a reaction somewhat milder than the above but still much more marked than the response to a zinc oxide-eugenol material. The depth of the cavity and the thickness of the remaining natural dentine barrier determine the pulpal response to a zinc phosphate type material (Sander, 1959). Both Sander (1959) and Hassler (1965) observed that, where the cavity was relatively shallow, the pulp response was mild and a layer of reparative dentine was soon laid down. However, where little dentine remained between the base and the pulp, a severe inflammatory reaction and possible abscess formation ensued (Silberman et al, 1955, Sander, 1959, Chandil et al, 1962, Seltzer and Sander, 1965 & Hassler, 1965).

To summarize: very deep cavity preparations should always be treated as possible pulp exposures (Attalla and Gibb, 1968) and, whether visibly exposed or not, should be covered with a calcium hydroxide base material (Unbehr et al, 1961, Chandil et al, 1962 & Seltzer and Sander, 1965).
For deep cavities, the application of a zinc oxide-eugenol type material in the treatment of choice (Harvey et al., 1944; Schrott, 1947; Seltzer and Bender, 1969) although a calcium hydroxide product may be used (Usinger, 1965). Use of zinc phosphate type base materials should be avoided except in shallow cavities. Hanley (1944) and Heusing (1950) have recommended the use of a thin smear of zinc oxide-eugenol material beneath the zinc phosphate cement to limit the pulpal irritation of the latter and to provide a base with adequate resistance to marginal condensation.

2. The strength of base forming materials.

While fracture of an amalgam restoration by the forces of mastication is unlikely to be associated with the base forming material, the latter must possess sufficient strength to prevent its fracture or displacement during amalgam condensation.

The compressive and tensile strength values of a base material have been considered to be a fairly reliable indication of its ability to withstand the forces exerted in condensation, although the full significance of the strengths is not yet understood. The compressive strength required by a base material is unknown but it is probably considerably less than 6,000 p.s.i. (see Functions of a Base).
(1960) suggested that a strength somewhat less than 5,000 p.s.i. was possibly adequate. In 1965, Phillips (J.A.D.A.) reported that a 1,500 p.s.i. to 2,000 p.s.i. compressive strength might be adequate, while Chong et al. (1967) determined by investigation that the critical compressive strength lay between 100 p.s.i. and 170 p.s.i. This is a particularly low strength and, if it be the case, a material has virtually only to be set to have adequate strength.

Unfortunately, much of the past research has been more concerned with the one day or one week strengths than with the clinically important 6 or 7 minute strength.

1. The compressive strengths of base forming materials

Calcium hydroxide type materials. It is only with the advent of the quick-setting calcium hydroxide pastes that any real investigation of the strength properties of this type of material has been possible. Chong et al. (1967) determined the 7 minute compressive strength of Drycal to be 1,100 p.s.i. and of Hydrox to be 500 p.s.i. The 24 hour compressive strengths were 1,910 p.s.i. and 1,400 p.s.i., respectively. No other results have, as yet, been reported in the literature.

Zinc oxide-eugenol cement without accelerator. Although this material is of little use as a base material due to its softness and slow setting, its brief mention enables a comparison with the accelerated products. Kolmar and Skinner (1942)
reported an ultimate compressive strength of about 2,000 p.s.i. for this material. Because of its slow setting, Givens and Braun were unable to test this unaccelerated material for five hours at which time it possessed a strength of 5,000 p.s.i.; while at one week a value of 3,700 p.s.i. was recorded.

Accelerated zinc oxide-eugenol type materials. As previously mentioned, many attempts have been made to improve the physical properties of this type of product. Most of this research has been directed towards increasing the compressive strength and reducing the setting time.

One of the simplest, yet most effective, accelerators so far discovered has been zinc acetate. Using a mix containing 10 to 20 per cent zinc acetate, Chang et al. (1967) found the compressive strength to be rather low — a 7 minute strength of 600 p.s.i. and a 24 hour strength of 1,250 p.s.i. These low values were possibly a result of the high percentage of zinc acetate incorporated by Chang and his co-workers, which may have, in fact, weakened the mass.

A number of quick-setting zinc oxide-eugenol commercial products have been investigated. Kalsolyn® was found by Rossing (1954) to possess a 5 minute compressive strength of 1,600 p.s.i., a ten minute strength of 2,500 p.s.i.

and one week strength of 5,500 p.s.i. Swartz et al (1963) on testing four commercial products found that the 24 hour strength values ranged from 800 p.s.i. to 4,100 p.s.i. The strongest of the four, Zemrex®, was found by Chong et al (1967) to have a seven minute strength of 2,300 p.s.i. and a 24 hour strength of 3,500 p.s.i.

Mensing (1961) suggested the use of a polystyrene-fortified zinc oxide-eugenol cement. This material, with a five minute compressive strength of 5,050 p.s.i. and an ultimate strength of 7,000 p.s.i., appeared to be somewhat stronger than the normal quick-setting zinc oxide-eugenol materials, although Phillips (D. Clin. N. Amer., 1965) considered that the increase in strength was not significant.

Roland et al (1959) studied the effect on the crushing strength of adding dicalcium phosphate to zinc oxide-eugenol cement, and, although they observed some increase in strength with increasing quantities of the phosphate, all values obtained were very low, for, even when the powder contained 35 per cent dicalcium phosphate, the compressive strength was still below 1,500 p.s.i.

From a clinical viewpoint, it is interesting to observe that there was an apparent reduction in strength of some of the zinc oxide-eugenol type materials from one day to

* Interstate Dental Company, N.Y., U.S.A.
one week (Kessing, 1961, Swarts et al, 1963 & Civjan and Breuer, 1964). If a similar reduction were to occur clinically, it would appear to negate the suggestion (Gardner, 1950 & Lyell, 1960) that modified zino oxide-eugenol materials should be allowed to "harden" for a week before being cut back to allow placement of the permanent restoration.

Zinc oxide-eugenol-B B A cements. Possibly the most interesting attempt to improve the strength properties of zinc oxide-eugenol cements has been the development of the ortho-ethoxybenzoic acid (B B A) - fortified material. By slight alteration in the components, it has been possible to develop materials with ultimate compressive strengths ranging from 7,500 p.s.i. to 12,700 p.s.i. (Breuer et al, 1958, Phillips and Love, 1961, Breuer et al, 1962, Civjan and Breuer, 1964 & Coleman and Kirk, 1965). The addition of silice was found by Phillips and Love (1961) to produce no marked alteration to the strength, while Breuer et al. (1958) noticed a rise in strength from 10,600 p.s.i. to 11,600 p.s.i., when 30 per cent silica was employed. The early compressive strength of the material was found by Coleman and Kirk (1965) to be 4,500 p.s.i. to 6,800 p.s.i. after ten minutes and by Civjan and Breuer (1964) to be approximately 6,200 p.s.i., 15 minutes after mixing.
Phillips et al. (1960) examined the commercial product Opotow and, after mixing according to the manufacturer's specifications, found a 24-hour compressive strength of 5,500 p.s.i. This material, is, at present, recommended rather as a luting agent than as a base material. Zinc phosphate type materials. It is difficult to generalize about the compressive strengths of these materials. While Civjan and Breuer (1964) and Coleman and Kirk (1965) obtained one week values of about 17,000 p.s.i., Swartz et al. (1963) observed that the ultimate compressive strength could vary from 12,500 p.s.i. to 17,000 p.s.i. Even greater differences have been reported for the early strengths. While Coleman and Kirk (1965) found the ten minute compressive strength of a zinc phosphate type material to be about 10,000 p.s.i., Kessing (1961) obtained a five minute strength of about 10,500 p.s.i. and, with yet another material, the seven minute strength was only 1,000 p.s.i. (Chong et al., 1967). For a mix of Standard Testing Consistency zinc phosphate cement, Lyall (1960) reported a seven minute strength of approximately 1,300 p.s.i. and a ten minute compressive strength of 4,300 p.s.i.

The use of a "sedative" zinc phosphate cement has been suggested by Hostoller (1951). After mixing the powder with equal parts of commercial liquid and eugenol, he obtained
a cement which, he claimed, was only slightly weaker than the regular zinc phosphate cement. On the other hand, Swartz et al (1963) found a reduction of 5,000 p.s.i. to approximately 11,000 p.s.i. in the one week compressive strength after the addition of two drops of eugenol to the original liquid. Nevertheless, even with a reduction of this magnitude, this "sedative" mix might still possess adequate strength.

Of six zinc phosphate type materials tested after one week's storage by Swartz et al (1963), only three possessed a higher strength than at one day. One product remained relatively constant, while two showed a slight reduction in compressive strength after storage.

It is apparent, from a clinical point of view, that the zinc phosphate type materials must be considered individually and, even then, the dentist must make allowance for variations in manipulation and surrounding conditions.

(ii) The tensile and transverse (shear) strengths of base forming materials. Relatively little has been done to establish values for the tensile and shear strengths of base forming materials. This is probably related to the difficulty encountered in preparing suitable specimens and to the rather complex nature of many of the test methods.

Girjan and Kreuer (1964) employed two methods to determine tensile strength. One of these, termed the "grips"
method, used dumbbell-shaped specimens and, under these conditions, unaccelerated zinc oxide-eugenol cement had a 24 hour tensile strength of 200 p.s.i.; an E B A type material had a tensile strength of 800 p.s.i. and a zinc phosphate cement possessed a tensile strength of 700 p.s.i. The second method, termed "centrifugal", produced values approximately double those of the "gripa" method — the 24 hour tensile strength for unaccelerated zinc oxide-eugenol was 400 p.s.i., for E B A cement 1,300 p.s.i. and for the zinc phosphate material it was 1,600 p.s.i. Using the diametral compression test, Phillips et al. (1968) obtained a value of 600 p.s.i. for the 24 hour tensile strength of the E B A cement, Opatow, and, using a "pull" test similar to Civjan and Breuer's "gripa" test, recorded a value of 530 p.s.i. for the material.

To obtain shear (or transverse) strength values, Civjan and Breuer (1964) used a "punch" and a "double shear" method. Fairly similar values were recorded provided that in the latter method the ends of the specimen were not braced. Unaccelerated zinc oxide-eugenol material possessed a 24 hour shear strength of 600 p.s.i., the E B A - accelerated cements varied between 700 p.s.i. and 1,800 p.s.i. depending upon their composition and a zinc phosphate type material was found to possess a 24 hour shear strength of 1,300 to 2,200 p.s.i.
3. Other properties of base forming materials.

(1) Setting time. The early strength of a base material is closely related to its setting time.

As previously mentioned, the surrounding conditions, the type and condition of oxide employed and the presence or absence of accelerators are the predominating influences on the setting rate. The dentist may control the amount of powder incorporated and the temperature of the mixing slab, for the greater the amount of powder incorporated and the higher the surrounding temperature and that of the slab, the more rapid will be the set (Skinner and Phillips, 1967).

Coleman and Kirk (1965) and Skinner and Phillips (1967) drew attention to the need for water to accelerate the setting of zinc oxide-eugenol products. It was observed by Coleman and Kirk that, while the presence of water did not appear to alter the setting time of a zinc phosphate cement, the setting times of two E B A - accelerated cements were shortened by ½ to 1½ minutes. Cizjon and Brenner (1964) found that in conditions of 37°C and 100 per cent relative humidity the setting time for unaccelerated zinc oxide-eugenol was 2 hours 20 minutes and for E B A - accelerated cement, 7 to 8 minutes. However,
when mixed and stored in conditions of 23°C and 50 per cent relative humidity (average clinical conditions) the E B A cement took 15 minutes to set and the unaccelerated zinc oxide-eugenol cement, 54 hours.

(ii) Thermal conductivity. Bases are effective thermal insulators beneath amalgam restorations (Seltzer and Bender, 1965; Phillips et al, 1954 & Pickard, 1954) and satisfactorily replace dentine in a deep cavity preparation (Craig and Peyton, 1961). The values expressed by different workers for thermal conductivity have been somewhat conflicting but there has been general agreement that the values for the base forming materials and dentine were approximately the same (Craig and Peyton, 1961 & Skinner and Phillips, 1967). Since thermal changes beneath the lining of an amalgam restoration are transient, Braden (1964) suggested that it was the thermal diffusivity rather than the thermal conductivity that was relevant. By measuring this property, he found that the zinc phosphate materials were slightly superior insulators to zinc oxide-eugenol cements although both possessed values close to dentine.

Braden (1964) suggested that since the differences in diffusivity between the base forming materials and tooth structure were only slight, they were of much less importance than variations in the lining thickness. Indeed, Craig and
Fayton (1961) claimed that the effectiveness of a cement base as an insulating medium was directly proportional to the thickness of the base.

(iii) Electrical insulation. Very little information is available about the electrical insulation afforded the pulp by a base. It is believed however, that galvanic currents are occasionally responsible for postoperative pain (see Corrosion of amalgam).

Phillips, L. et al (Aug. 1955) found that, with the exception of calcium hydroxide paste, all materials tested in a dry condition were adequate insulators. When exposed to moisture, in vitro, zinc phosphate cement became a poor electrical insulator while a zinc oxide-eugenol material maintained a high resistance.

When an attempt was made to simulate clinical conditions by placing the bases in cavities cut in extracted teeth, the insulating ability of all materials was greatly lowered (Phillips, L. et al, Dec. 1955). It seemed probable that, although in both wet and dry conditions a material was a good electrical insulator, clinically, its effectiveness was greatly reduced. Since prevention of initial marginal leakage was impossible even with the use of cavity varnishes, there appeared to be little likelihood of eliminating the irritation caused by short-circuiting of the
current around the amalgam and thence into the dentina. Phillips L. et al (Dec. 1955) were of the opinion that once the pulp had recovered from the trauma associated with cavity preparation, a previously irritating current would no longer be sufficient to produce a response.

(iv) Hardness. Swarts et al (1963) obtained values for the indentation hardness of two types of base materials. Knoop hardness values for zinc phosphate cement were between 42 and 48 after one day and, at one week, the values lay between 43 and 50. All Knoop hardness values for a zinc oxide-eugenol material were quite low — between 3 and 14 — although the one week values tended to be higher than one day values. It is not known what relevance the indentation hardness may have to base materials, but it is probable that values recorded only at one day and one week are clinically of little use, apart from giving a possible guide to early values.

(v) Retention of the base in the cavity. Adhesion refers to a bonding between unlike molecules. Although it would be most desirable, there is no true adhesion between the dental cement and tooth structure or any of the restorative materials with which the base is used (Skinner and Phillips, 1967). Corner (1940) found little or no adhesion to the cavity by a zinc phosphate cement, and
Seltzer and Bender (1965) observed that this was applicable also to zinc oxide-eugenol materials. The addition of EBA to the zinc oxide-eugenol was claimed by Breuer et al (1958) to increase the "adhesive properties". On a dry surface adhesion was considered by Griffith and Ware (1960) to be responsible for only 15 per cent of the retention of zinc phosphate cements, but on a wet surface, there was almost no adhesion. The remainder of the cement's retention was attributed to mechanical interlocking whereby the unset cement flowed or was compressed into all the irregularities of the cavity walls. The compressive, tensile and shear properties of the base materials were considered to play an important role in this mechanical interlocking (Faffenger at al, 1934 & Skinner and Phillips, 1967).

To summarize: the base materials provide good thermal insulation and protection of the pulp when there is ample thickness of material, but they are poor electrical insulators. The retention of the base is principally by mechanical interlocking into irregularities and undercuts in the cavity walls. The dentist has some control of the setting time of the materials and attempts are being made by manufacturers to further reduce the setting time particularly of the zinc oxide-eugenol materials.
IV. The Clinical Application of Base Forming Materials.

No single material is available which fulfills all the functions of a base. However, by the combination of a copal varnish with a zinc oxide-eugenol or calcium hydroxide type base forming material it is possible to satisfy all the principal requirements (Coing, 1964).

The use of a cavity varnish provides some protection of the pulp from acid-liberating cements and prevents the penetration of fluids and debris into the dentine that is associated with initial marginal leakage around the amalgam. Apart from its desirable effect upon the pulp, a suitable cement lining of accelerated zinc oxide-eugenol or calcium hydroxide, provides satisfactory thermal insulation and is probably sufficiently strong to meet the demands placed upon it in amalgam condensation.

When one of these two materials is used as a base it should be placed on the floor of the cavity. The bulk of material should be minimal with the proviso that there must be sufficient to provide thermal insulation and to resist the forces of amalgam condensation. Each of the materials should be covered by a varnish before placement of the amalgam. When a zinc phosphate type cement is used, the cavity varnish should be applied first, to provide some protection from the
acid-liberating base. The varnish should then be covered, in turn, by the zinc phosphate cement and amalgam.
THE

ORIGINAL

RESEARCH
MATERIALS AND METHODS.

Broadly speaking, the aim of this original research was "to examine and compare the compressive and tensile strengths of some modern base forming materials, particularly at the time of clinical importance".

The several manipulative variables investigated for their influence on the strength of the materials were:

1. The ambient temperature,
2. The powder-liquid ratio, and
3. The conditions of storage.

By the use of extracted teeth, an endeavour was made to relate the findings a little more closely to the clinical situation.

Standard Consistency.

Cement of "standard testing consistency" implied cement mixed in the powder/liquid ratio determined in the manner described in the Australian Standard Specification No. T 3 - 1949. Both the Australian and American specifications use a modified slump test in the determination of standard consistency for zinc phosphate cement. This standard testing consistency was in no way related to a mix of the cement which might be used in a clinical situation.
It was, however, in the opinion of the author, slightly thicker than a desirable consistency for the cementation of inlays and crowns.

Clinical Consistency.

For the results to be related to the clinical situation, it was necessary to establish a clinically desirable powder/liquid ratio for each material. For the purpose of this study, a certain mix of clinical consistency implied a powder/liquid ratio which, on mixing, resulted in a consistency considered, by the author, to be desirable for clinical use as a base beneath an amalgam restoration. Although it was impossible to examine the many different consistencies preferred by individual dentists, the general principles which governed the determination of clinical consistency were:

1. where the manufacturer gave directions, regarding the clinical use of a material, these were observed;

2. for other zinc oxide-eugenol and zinc phosphate materials, powder/liquid ratios were employed which allowed complete incorporation of the powder in the liquid within 12 minutes and produced a thick, "putty-like" yet "non-crunchy" mix.
The materials investigated are listed in Table 1 and have been classified into five categories:

I. Zinc Phosphate products
II. Accelerated Zinc Oxide-Eugenol materials
III. Zinc Oxide-Eugenol-ortho-ethylbenzene acid materials
IV. Calcium Hydroxide preparations.
V. A zinc oxide-eugenol type material containing a high percentage of calcium hydroxide.

Also, in Table 1, the powder/liquid ratio required by each material for a mix of clinical consistency has been mentioned.

Ambient conditions at the time of mixing the cement.

Cirjan and Brewer (1964) emphasized the importance of the ambient temperature and humidity in the setting of base forming materials. The Australian Specification states that "all mixing of cement for testing shall be carried out in a room in which the ambient atmospheric conditions are as follows:

a) Temperature 20-25°C.

b) Relative humidity 55-75 per cent."

In this investigation, these conditions were adhered to, except when temperature was the variable under examination.
<table>
<thead>
<tr>
<th>Category</th>
<th>Name of Base Material</th>
<th>Clinical Consistency gm. powder/0.5 ml. liquid</th>
<th>Manufacturer and/or Distributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>Zinc Oxide(1% Zinc Acetate)-Eugenol</td>
<td>2.25</td>
<td>Amalgamated Dental Trade Distributors, Ltd., London.</td>
</tr>
<tr>
<td></td>
<td>Kalsogen</td>
<td>2.70</td>
<td>Amalgamated Dental Trade Distributors, Ltd., London.</td>
</tr>
<tr>
<td></td>
<td>Kalzinol</td>
<td>2.70</td>
<td>Amalgamated Dental Trade Distributors, Ltd., London.</td>
</tr>
<tr>
<td></td>
<td>Caulk ZOE B&amp;T</td>
<td>1.65 *</td>
<td>L.D. Caulk Co., Milford, Del.; Toronto, Ont.</td>
</tr>
<tr>
<td>III</td>
<td>Opotow E B A Cement</td>
<td>2.50 +</td>
<td>Opotow Dental Mfg. Corp. Brooklyn, N.Y.</td>
</tr>
<tr>
<td>IV</td>
<td>Dycal</td>
<td>Equal lengths of base &amp; catalyst *</td>
<td>L.D. Caulk Co., Milford, Del., U.S.A.</td>
</tr>
<tr>
<td>V</td>
<td>Surgident's Hydro-Eugenol</td>
<td>2.40</td>
<td>Surgident, Ltd., Los Angeles, California</td>
</tr>
</tbody>
</table>

* Manufacturer's specifications
Manipulation of the material.

Relatively little apparatus was required for this project but care was observed to ensure the cleanliness of the spatula, glass slab and wound surfaces on all occasions.

The method whereby the powder and liquid were combined on the glass slab, varied slightly with the different base materials.

a) For zine phosphate type materials, the powder was routinely divided into eight portions and each portion added to the liquid at intervals of from ten to twelve seconds. This slow combination enabled the incorporation of a maximum quantity of powder within the liquid. Mixing over a large area of the glass slab, as suggested by Paffenbarger et al. (1953), ensured that the temperature rise was kept to a minimum thereby delaying the setting reaction and facilitating increased powder incorporation.

b) For the zine oxide-eugenol type materials, a considerable effort was required to incorporate the last portion of powder into the mix if a desirable thick, yet non-crunchy mass were to be obtained. It was observed that a satisfactory mix was secured when, initially, two-thirds of the powder was incorporated into the liquid — the remainder being added from 30 to 60 seconds later. All the zine oxide-
e) The calcium hydroxide preparations, LCQ and Libya, facilitated quite rapid mixing of the base and catalyst. It is timely however, to issue a caution on the mixing of Libya. Special care was required to ensure thorough combination of base and catalyst and failure to observe this invariably produced non-uniform mixes with irregular setting times.

The Mould.

According to the Australian specification, the cylindrical mould into which the mixed cement is placed should be of hard rubber, glass or other substance that is not corroded by the cement. Stainless steel moulds are now widely used.

There has been some variation in the actual size of the cylindrical mould used by different systems. Craig et al. (1961), having used fairly large specimens — 5/16 in. diameter and 1 in. length, observed that the strength values obtained appeared to be quite high. Vieg (1961), using cellulose, found that when the specimen had a length greater
then twice the diameter, the compressive strength was correspondingly reduced. For this reason, the two most popular moulds in present use for the testing of base materials have a diameter exactly equal to one half the length. Phillips et al. (1963) and Chang et al. (1967) both used moulds 12 cm. in length and 6 cm. in width. Using analysis, Taylor et al. (1969) found that the smaller 4 x 8 cm. specimens gave a 2 to 7 per cent increase in crushing strength over that of the 6 x 12 cm. cylinders, when prepared and tested under the same conditions. Since the Australian Specification requires the use of a 4 cm. x 8 cm. mould, a stainless steel split mould of these dimensions was employed in this investigation.

Before filling the mould with cement, its two surfaces were lubricated by a thin application of chloroform and wax to facilitate removal of the specimen.

Filling the Mould.

To eliminate a further variable, it was decided that all the materials should be placed in the mould in the same manner. Since it was impossible to fill the materials into the mould because of their thick consistency, ways of packing the mould were investigated. The use either of a packing instrument dipped in alcohol or of some moist cotton wool to tap the cement into position, either proved to be unsuitable for
all the materials or incorporated a further variable — water.
It was resolved that, after mixing was completed, the base
forming materials were to be packed into the mould by a flat
blended spade. Sufficient pressure was exerted on the
material to ensure that the mould was thoroughly filled through
to the glass plate on which it was resting. This procedure
proved to be satisfactory for all the materials tested.

The Storage of Specimens.

The Australian Standard Specification is concerned
only with the seven day compressive strength of nine phosphate
concretes. (The seven day strength is generally recognized as
an indication of the strength of these concretes than fully set.)
Three minutes after the commencement of mixing, the specifica-
tion requires the mould to be placed for about 30 minutes into
a 37°C, 95-100% relative humidity atmosphere and then into
distilled water at 37°C for 7 days.

It was observed by Urban (1940) that nine phosphate
concretes after one hour at 37°C and 100% R.H. were almost as
strong as they were after seven more days in distilled water
at 37°C. Furthermore, specimens kept for seven days in a R.H.
of 100% were generally 10-30% stronger than those immersed in
water for a similar period. It would appear then, that the
method of storage had some effect on the ultimate compressive
strength and, to investigate this, it was decided to store the specimens in two ways. Unless otherwise mentioned, the specimens were stored in a temperature controlled cabinet where the relative humidity was 50-70% and the temperature, 37°C. To observe the effect of moisture on the setting time and strength, most specimens were also tested after storage in water at 37°C and, in those tests, the mould was placed into water immediately after it had been filled with cement.

The Time of Testing:

Observations of dentists in a clinical situation have indicated that it would be desirable to know the strength of the base forming materials approximately six or seven minutes after mixing (see Condensing the Amalgam), for it was at this time that the base material was subjected to the forces of amalgam condensation. With very few exceptions, it was possible to test all the materials at or before this time.

For the duration of this thesis, the terms "set", "initial set", "setting time" and "first set" have been used to refer to a mix of cement which appeared to be clinically set.

Some specimens of each material were removed from the mould as soon as the initial set had occurred. By the time removal was complete, these specimens were ready to be
tested approximately 30 seconds after the initial set. As an
indication of this, for each material, mention is made of the
"time of first testing".

However, the earliest values were usually recorded
approximately 30 seconds after this "time of first testing", that is, approximately one minute after the initial set had
occurred. It was found that the considerable moisture of
specimens when the mould was separated at the time of initial
set, could be significantly reduced if removal from the mould
were delayed by a further 30 seconds. A similar finding has
been reported by Chong et al. (1967) who also noticed a slight
variation in the setting times of individual mixes of the
materials.

All strength values obtained at times up to and
including one hour after mixing were tested at the time
indicated. One day and one week values however, were
recorded within 15 minutes of the 24 hours or seven days
indicated.

To prepare them for testing, the Australian
Specification requires that the axis of the specimen be
"surfaced plane at right angles to the axis by drawing the
mould back and forth across a plate coated with wet carbon-
union paste". While this might be satisfactory for 7 day
specimens it was felt to be too time consuming to be
practical where interest was in the early strength. For this investigation, the ends of the specimens were planed by the use of sharp blades which provided smooth surfaces in a short time. The specimens were now ready for testing.

The Tests.

This present investigation was confined to the compressive and tensile strength properties of the base materials. For this reason, procedures for shear and transverse strength have not been discussed.

a. The testing for compressive strength.

The exact significance of the compressive strength of a base material is unknown. Generally however, the compressive strength has been considered to be a good indication of the ability of the material to withstand packing pressures.

A Universal Tester was used to test both compressive and tensile strengths. For the determination of compressive strength the load was applied axially along the cylindrical specimen (Figure 1(a)).

TESTING FOR COMPRESSIVE STRENGTH

TESTING FOR TENSILE STRENGTH

FIGURE 1
The rate of movement of the crushing head in testing the specimens was found by Hohier and Kitts (1964) to influence values for the compressive strength but to have little or no effect on the transverse or tensile strength values. Wing (1961) observed that amalgam specimens loaded at a faster rate required a greater load before fracture under compression occurred. It would be desirable, therefore, if the rate of testing were standardised. Unfortunately, such is not the case, so that some care is needed to interpret accurately the results obtained by different workers. Craig et al. (1961) employed a cross-head speed of 0.01 in./min., Phillips et al. (1968) a cross-head speed of 0.035 in./min., and Chong et al. (1967) used a speed of 0.015 in./min. The Australian Specification states that "the crushing head shall be moved at a rate of 0.25 mm. (0.01 in.) per minute". For this investigation, the strain rate was controlled by maintaining a constant cross-head speed of 0.015 in./min.

b. The testing for tensile strength.

While its full significance is unknown, the tensile strength of a base forming material is probably of some importance where the base covers both the axial and pulpal walls of a Class II cavity, particularly during condensation of amalgam in the isthmus region.
A number of methods have been used to test the tensile strength of base forming materials. Citzen and Dreiser (1964) used both a "Grips" method where the specimens were dumbbell in shape and the ends held in steel grips during testing and a "Centrifugal" method, using cylindrical specimens in which a rapidly spinning specimen was stressed primarily in tension along its entire length by centrifugal forces. Both of these methods were, however, quite complex.

Recently, use has been made of the Diametral Compression test (Indirect Tension test, Brazilian test) to determine the tensile strength of base forming materials. This test has been used principally in the testing of concrete, coal and rock.

In its simplest form, cylindrical specimens identical with those used in compression tests are compressed diametrically between two flat plates (or cushions) by the testing machine (Figure 1(b)). Under proper conditions, tensile stresses cause the cylinder to fracture along the diametral plane joining the points of contact of the specimen with the plate (Mitchell, 1961 & Lindhick et al, 1963).

The cushion material affects the distribution of stresses within the specimen in three ways. It promotes a uniform distribution by "Ironing out" slight surface irregularities, it reduces the magnitude of the maximum
compressive and shear stresses and reduces the amount of
material subjected to the maximum tensile stresses (Rubinick
et al., 1963). The type of cushion used has been shown by
Addinall and Hackett (1964) to influence considerably the
value obtained for tensile strength. Mitchell (1961)
observed that "cardboard plates seemed to provide the necessary
load and stress distribution".

Various types of failure are possible when a specimen
is tested in this fashion and Rubinick et al. (1963) stressed the
importance of distinguishing between these if the value for
tensile strength is to be valid. Crushing of the specimen and
an irregular fracture pattern are indicative of failure due to
compressive and shear stresses respectively. A valid tensile
fracture may be simple, where a single fracture occurs across
the loaded diameter, or triple clef, where the specimen
splits symmetrically about the loaded diameter into four pieces.
Figure 2 depicts examples of valid (a & b) and invalid (c)
tensile fractures.

The tensile strength may be calculated from the load
at fracture by using a formula outlined by Addinall and Hackett
(1965) & Rubinick et al. (1963). Mitchell (1961) observed that
this test had many good features including the ease of testing
and the simplicity of the specimen and that results from this
test were in good correlation with other more complex methods
Valid Tests for Tensile Strength

i. Longitudinal section

ii. Cross section

Figure 2 (a)
Valid tests for tensile strength

i. Longitudinal Section

ii. Cross Section

Figure 2 (b)
Shattering of specimen

Excessive flow
Invalid tests for tensile strength

Figure 2 (c)
of tension testing. On the other hand, Addis and Hackett (1965) felt that the values obtained tended to be fairly low and Seefried et al (1967) questioned the validity of this test for non-linear, inelastic materials like concrete.

The diametral compression test has been applied to dental materials by Eden and Waterstrat (1967) using alginate, by Barnshaw and Smith (1967) for the testing of dental plaster and stone, by Southan (1968) for the testing of ceramic porcelain and by Phillips et al (1968) for base forming materials.

Using the Housefield Tensometer the diametral compression test was used in this present investigation. Soft cardboard (0.225 cm. thick) was chosen as the cushion material. As previously mentioned, the specimens for this test were identical with those used in the compression test.

Statistical method.

Although all values listed represented the mean of at least five specimens, more frequently six or seven readings were taken before the mean value was calculated.

The standard deviations were calculated by use of
the formula:

\[ S.D. = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}} \]
where \( x \) was the value for a single specimen
\( \bar{x} \) was the mean value for \( N \) specimens and
\( N \) was the number of specimens.

The statistical significance of the difference between two results was determined using the "t" test (Spiegel, 1961), where

\[
t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}} \times \frac{N_1 + N_2}{N_1 N_2}}
\]

\( S \) was the standard deviation, and the numbers 1 and 2 represented the two values being compared.

For the purpose of this research, the difference between two values has been termed "statistically significant" when the "t" test indicated that a difference occurred at the 99\% confidence level or greater.

Practical Application in Extracted Teeth.

To relate them more closely to the clinical situation, eight base forming materials were placed into Class I or Class II cavities prepared in extracted teeth, to determine the effect of packing pressure on the base. In this way it was hoped to examine the possibility either of fracture of the base
or of its displacement along the walls of the cavity to the occlusal surface.

After the cavities were cut to a depth considered to be deeper than "ideal depth" both on the axial and pulpal walls, each cavity was in turn restored. Base material was placed on both of these walls, excess cement was removed and a mechanical matrix band placed on the tooth. Seven minutes after mixing the base, amalgam condensation began in a manner similar to that which would be used in a clinical situation. A load of approximately 7 pounds was applied by varying sized condenser points. Condensation commenced at the floor of the proximal box and progressed towards the occlusal, care being taken to remove excess mercury. When the cavity had been overfilled, the matrix band was removed and the surface of the amalgam carved. The tooth was then placed into water for at least one week to ensure complete setting of the base forming material and the amalgam.

The ability of each base to withstand the pressure of amalgam condensation was recorded as it appeared to the operator at the time of packing. Where it was apparent that the base was too soft, the "filing" of the cavity was completed, although condensation, as such, was not possible.

Before sectioning for microscopic examination, specimens were mounted in pieces of one inch diameter lucite
rod using small amounts of self-polymerizing resin. A hole was drilled in the rod, soft acrylic was poured into the hole and the restored tooth placed in the resin in such a position that subsequent sectioning would allow investigation of significant areas of the base forming materials and the amalgam.

In Class I and Class II restorations mesio-distal sections were prepared so that examination of the nature of the pulpal wall was possible in Class I restorations. In Class II restorations it was possible to examine the pulpal wall, axio-pulpal line angle, axial wall and gingival wall areas.

Technique of sectioning. Because of the considerable variation in hardness of the materials present a technique of sectioning had to be employed which cut each of these materials at approximately the same rate without a tendency to flow or smear some of the materials. The technique employed was the metallographic polishing technique, using diminishing grades of abrasives, outlined by Samuel (1955, 1967).

(i) The specimen was ground until the area of tooth, base forming material and amalgam was exposed for examination and the surface was flat. This stage of the specimen preparation, carried out using Silicon Carbide papers 220, 400 and 600 grades on a flat glass disc left a considerable layer of disturbed material to be removed in subsequent stages. A constant stream
of cold water was used to prevent overheating.

(11) The specimen was ground with light hand pressure on an "alumina-jax" lap to produce a flat specimen.

(iii) The specimen was then ground on a slowly revolving cloth-covered wheel charged with diamond paste. Two grades of diamond paste were used. A paste with 4-8 micron particles was followed by a paste containing 0-1 micron diamond particles.

After the completion of specimen preparation, microscopic examination was carried out at magnifications ranging from 10X to 50X using reflected light on a Zeiss Neophot II metallographic microscope.

A photographic record at magnification of 2X was made.
III. DISCUSSION

Standard and Clinical Consistency.

This investigation was primarily concerned with the compressive and tensile strengths of clinical consistencies of base forming materials at the time of clinical importance. As a starting point, the compressive strength of a clinical consistency zinc phosphate cement (Z.P. White Zinc Cement Improved) was compared with that of the standard consistency cement.

See Figure 3 and Table 2.

Griffith and Teres (1960) determined that the powder/liquid ratio for a standard consistency mix of this cement required 1.55 gms. powder/0.5 ml. liquid. A mix of clinical consistency was found to require 2.50 gms. powder for 0.5 ml. liquid. The standard consistency mix was quite thin and, because of its high acid content could be unacceptable for use as a base in a deep cavity.

The effect of this difference in consistency was most easily demonstrated in the time of first testing. For the clinical consistency cement, first testing was possible at 4½ minutes, but, for the standard consistency mix, removal from the mould and testing of the specimen was not possible before seven minutes.
Table 2.

S.S. WHITE ZINC CEMENT IMPROVED

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.) at 0 Times after beginning of Mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>7 min.</td>
<td>8 min. 14 min. 22 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>1.35 gm. powder/0.5 ml. liquid.</td>
<td></td>
<td>3,750 (150)* 6,720 (265) 6,960 (185) 7,100 (510) 9,700 (945) 9,730 (1,890)</td>
</tr>
<tr>
<td>Clinical</td>
<td>4½ min.</td>
<td>5½ min. 12 min. 20 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>2.30 gm. powder/0.5 ml. liquid.</td>
<td></td>
<td>8,200 (420) 10,600 (1,420) 12,150 (1,300) 12,900 (1,160) 13,640 (1,700) 15,200 (3,200)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

© Storage in air.
SS. WHITE ZINC CEMENT IMPROVED

COMPRESSIVE STRENGTH P.S.I. $\times 10^3$

CLINICAL CONSISTENCY ★
STANDARD CONSISTENCY ▽

TIME

FIGURE 3
Values for compressive strength, up to one hour after mixing, were plotted and a "curve of best fit" drawn. Subsequent values up to one week have also been plotted. Both standard and clinical consistencies showed a rapid rise in compressive strength during the first thirty minutes so that after one hour, both consistencies had attained at least 75\% of their one week strengths and the subsequent increase in strength was gradual. Statistically, the clinical consistency mix was significantly stronger than the standard consistency mix at all times of testing. A characteristic of the readings obtained for the compressive strengths of most of the tested base materials was their wide distribution so that rather large standard deviations were quite common (see Table 2). This was probably related both to the difficulty experienced in eliminating small voids from the specimens and to the slight variations in mixing, although every attempt was made to standardize this procedure.

The Compressive Strength of some Base Forming Materials of Clinical Consistency.

To examine and compare the compressive strengths of a few base forming materials, 3 commercial products (G.S. White Zinc Cement Improved, Kalsinol and Dycal) and one non-commercial material (Zinc Oxide + 4.3 Zinc Acetate and Lugano) (ZnOAc5) were selected.
See Figure 4, Table 3.

In the mixing of Dycal, the manufacturer's directions were adhered to, while the clinical consistencies of the zinc phosphate material and the commercial accelerated zinc oxide-eugenol material were determined by a "trial and error" method. The non-commercial product was prepared by the author and every effort was made to ensure that the crushed zinc acetate crystals were thoroughly incorporated within the zinc oxide powder before determining the clinical consistency.

After placing the materials into the mould, the specimens were stored in air - at 37°C and at 50 to 70% relative humidity.

Dycal quite closely possessed the fastest setting rate although all materials were set within five minutes. In general, more difficulty was experienced in removing the zinc phosphate type materials from the mould than specimens of a zinc oxide-eugenol or calcium hydroxide type. Specimens of this last-mentioned type showed the least evidence of surface irregularities and voids, possibly due to the thinner consistency of the mix when placed into the mould. Any specimen with gross surface deficiency was discarded.

On statistical examination it was revealed that the difference in the values expressed for all four materials up to at least ten minutes was highly significant. Thereafter there was only an apparent difference between the two zinc
### Table 3.

**Compressive Strength of Some Base Materials of Clinical Consistency.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.) at Times after beginning of Mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5½ min.</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved</td>
<td>4½ min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(420)*</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate)-Eugenol.</td>
<td>4 min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4,300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(110)</td>
</tr>
<tr>
<td>Kalszinol</td>
<td>5½ min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2,770</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(370)</td>
</tr>
<tr>
<td>Dycal</td>
<td>3½ min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(145)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

° Storage in air.
oxide-eugenol materials. However, since it is the strength of these materials six or seven minutes after mixing that is of clinical importance, the initial difference in strength has added importance.

Referring again to Figure 4, with the exception of Eycal, the materials showed a considerable increase in strength during the first thirty minutes. Thereafter, while the compressive strengths of Eycal and the zinc phosphate cement material continue to increase slowly with time, the strengths of the two accelerated zinc oxide-eugenol materials remain relatively constant before a significant fall from one day to one week. The relative flatness of the strength—time curves for both Zinc Oxide (1/3 Zinc Acetate) — Eugenol and Ecalginol would indicate that, from a clinical viewpoint there was no evidence to support the practice of leaving a quick-setting zinc oxide-eugenol material as a temporary filling until a future appointment to enable it to gain additional strength.

One week specimens of Zinc Oxide (1/3 Zinc Acetate) — Eugenol were quite crusty so that considerable variation resulted upon testing as evidenced by a large standard deviation.
The Tensile Strength of some Base Forming Materials of Clinical Consistency and Standard Consistency Zinc Phosphate Cement.

The same four materials, examined above for compressive strength, were compared for their tensile strength together with standard consistency zinc phosphate cement. (See Figure 9, Table 4).

Although the "curves of best fit" for tensile strength were much lower in value, they did approximately parallel those for compressive strength. The values for Dycol and clinical consistency zinc phosphate cement still increased gradually with time, while the curves for the two zinc oxide-eugenol based materials remained relatively flat. There was, then, the suggestion of a possible relationship between the compressive and tensile strengths of a material. (This has been discussed in a subsequent section).

As it was with compressive strength, the tensile strength of standard consistency zinc phosphate cement showed a greater relative increase between one hour and one day than the clinical consistency mix. This was probably associated with the slower setting rate of this material and was a good indication of the need to have zinc phosphate materials mixed thickly to minimize the time during which free acid is present in the material.
### Table 4.

**TENSILE STRENGTH OF SOME BASE MATERIALS OF STANDARD AND CLINICAL CONSISTENCY.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Tensile Strength (p.s.i.) at Times after beginning of mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.S. White Zinc Cement Improved, Standard Consistency.</td>
<td>7 min.</td>
<td>8 min. 14 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>1.35</td>
<td></td>
<td>500 650 755 1,205 1,320</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(55) * (30) (85) (50) (25)</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved.</td>
<td>4½ min.</td>
<td>5½ min. 12 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>2.30</td>
<td></td>
<td>860 930 1,230 1,360 1,380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(40) (30) (95) (55) (95)</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate) - Eugenol</td>
<td>4 min.</td>
<td>4 min. 6 min. 14 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>2.25</td>
<td></td>
<td>330 310 300 350 380</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(40) (30) (40) (65) (50)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(100)</td>
</tr>
<tr>
<td>Kalzinol</td>
<td>5½ min.</td>
<td>7 min. 12 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>2.70</td>
<td></td>
<td>415 450 370 4.10 355</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(25) (75) (40) (30) (40)</td>
</tr>
<tr>
<td>Dycal</td>
<td>3½ min.</td>
<td>4 min. 10 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Equal lengths of base &amp; catalyst</td>
<td></td>
<td>200 215 215 235 405</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(15) (12) (25) (35) (15)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

* Storage in air.
A feature of the tensile strength tests was the great similarity in values recorded for each material at each time of testing so that the standard deviations tended to be quite small. There was good evidence to suggest that the dinocral compression test for tensile strength was less susceptible to surface irregularities than the compression test due, probably, to the use of a cushion material between the specimen and the crushing head. Up to at least twelve minutes after mixing commenced, the values for the tensile strengths of the four materials of clinical consistency were all significantly different from each other.
Zinc Phosphate Type Materials.

Two materials of this category, Delton's Zinc Phosphate Cement and S.J. White Zinc Cement Improved, have been investigated at clinical consistency. For each of these materials, a standard consistency mix was found by Griffith and Waro (1960) to require 1.35 gm. powder/0.5 ml. liquid. However, for the purposes of this study, clinical consistency was found to require 2.25 gm./0.5 ml. (S.J. White material) and 2.50 gm./0.5 ml. (Delton's cement). As far as it was possible to discern, these powder/liquid ratios produced mixes of a similar consistency. Due to the thick nature of mixes of clinical consistency, a considerable effort was required to fill the moulds with these materials.

Results obtained for the compressive and tensile strengths of the two products have been listed in Table 5 and plotted in Figure 6.

Both materials were able to be first tested at 15 minutes, indicating an initial setting time of approximately 4 minutes from the beginning of mixing.

Statistically, there was not a significant difference between the values obtained for the compressive strengths of the two materials at times up to and including the first hour after mixing. The strengths of the two materials were
Table 5.
TWO COMMERCIAL ZINC PHOSPHATE MATERIALS OF CLINICAL CONSISTENCY.

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.) at Times after commencement of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5(\frac{1}{2}) min. 12 min. 20 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved. 2.30</td>
<td>4(\frac{1}{2}) min.</td>
<td>8,200 (420)* (1,420) (1,300) (1,160) (1,700) (3,200)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 min. 12 min. 20 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Dalton's Zino Phosphate Cement. 2.80</td>
<td>4(\frac{1}{2}) min.</td>
<td>7,470 (1,120) (1,030) (1,720) (1,680) (2,300) (1,850)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

\(\text{\textdegree}\) Storage in air.

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Tensile Strength (p.s.i.) at Times after commencement of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5(\frac{1}{2}) min. 12 min.</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved. 2.30</td>
<td>4(\frac{1}{2}) min.</td>
<td>860 (40) 930 (30) 1,230 (95) 1,360 (55) 1,380 (95)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 min. 12 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Dalton's Zino Phosphate Cement. 2.80</td>
<td>4(\frac{1}{2}) min.</td>
<td>820 (70) 980 (35) 1,260 (110) 1,335 (180) 1,650 (155)</td>
</tr>
</tbody>
</table>
significantly different at one day and one week but, clinically, these values are probably of very little importance when the material is used as a base. The difference between the two materials in tensile strength was not significant until after one day from the time of mixing.

In the review of the literature it was noticed that it was difficult to generalize about the values obtained for either the early or late compressive strengths of these materials. It was observed that the early compressive strengths varied from a 7 minute strength of 1,400 p.s.i. to a 5 minute strength of 10,000 p.s.i. (See Strength of Base Materials). The values obtained in this investigation lay within these extremes (Table 5).

The 5' minute compressive strength values obtained for the two products varied from 7,500 p.s.i. to 6,200 p.s.i., while 7 minute values were 6,200 p.s.i. and 9,000 p.s.i., respectively for the Dalton's and S.S. White products. These values were not significantly different. The one week compressive strengths recorded in the literature for zinc phosphate type materials varied from 12,500 p.s.i. to 17,000 p.s.i. The S.S. White material used in this investigation was found to possess a seven day compressive strength of approximately 15,000 p.s.i., while a significantly higher value of 25,000 p.s.i. was obtained for the one week strength of Dalton's Zinc Phosphate cement.
The 7 minute tensile strength of both materials
was approximately 800 p.s.i., while the one week tensile
strength recorded for S.S. White Zinc Cement Improved was
1,200 p.s.i. and that for the Dalton's product 1,650 p.s.i.
These values, obtained by the diametral compression test,
lay between tensile strength values reported by Ovijan and
Brewer (1966) for a zinc phosphate type material. Using two
other different techniques to test tensile strength they found
a 24 hour strength of 700 p.s.i. with one method and 1,600
p.s.i. using the other. This further emphasized the need to
name the method of testing when quoting a tensile strength.

The most striking feature of the compressive
strength curves shown in Figure 6 for the two zinc phosphate
type materials, was the rapid increase in strength of the
Dalton's cement from one hour to one week compared with the
relatively gradual increase shown by the other material.
The compressive strength of the former material increased by
a highly significant 10,300 p.s.i. from 12,700 p.s.i. at one
hour to 23,000 p.s.i. at one week. The 3,300 p.s.i. rise of
the S.S. White product over the same period of time was not
statistically significant.

Both materials displayed a gradual and similar rate of
increase in tensile strength from five minutes to one day.
Thereafter, as with compressive strength, the Dalton's Cement
showed a more rapid increase in tensile strength.
Again it was apparent (Figure 6) that, while the tensile strength curves for the zinc phosphate materials were only a fraction of the value of those for compressive strength, they did resemble the shape of the other curves and suggested the possibility of some relationship between values for compressive and tensile strength.
Accelerated Zino Oxide-Eugenol Based Materials.

Four accelerated commercial zino oxide-eugenol based materials — Kolsoon, Kalsinel, S.C. White Cavity Lining or Calk 281 B2 — were examined and compared with the non-commercial Zino Oxide (13% Zino Acetate) — Eugonal material.

Because of competition on the market between different materials, the manufacturers, understandably, are reluctant to release much information on the exact composition of the base materials. For example, S.C. White Cavity Lining is "based on the well-known properties of zino oxide and eugenol. To these essential constituents are added chemical stabilizers ...". Personal communication with research laboratories has revealed that Kolsoon consists of an activated zino oxide powder and unmodified eugenol. The catalyst is basically acetic acid and is added to the powder in a "special" manner. Kalsinel appears to contain an activated zino oxide powder and a high molecular weight polymer dissolved in a liquid with eugenol. Calk 281 B2, is apparently similar in composition to Kalsinel. On the basis of the generally vague information available, it is impossible to assess the differences observed in the strengths of various materials to the inclusion of a particular activator, accelerator or chemical stabilizer.
The directions supplied with each material emphasized the need for a thick, non-sticky mix. Only one of the materials — Gaul: 203 R2 — was accompanied by a specified powder/liquid ratio applicable to clinical use of the material. The clinical consistency powder/liquid ratios for the other products were determined in the normal way. All materials of this category were relatively easy to mix, pack into the mould and separate from the mould after the initial set.

By way of introduction to the investigation of accelerated zinc oxide-eugenol based materials, it was decided that the unaccelerated material should first be examined. This simple zinc oxide-eugenol material was mixed to a thick consistency using 2.55 g. powder/0.5 ml. liquid. The setting time in air at 37°C. and 50-70% rh. — was between three hours and eighteen hours.

It is unlikely that results with this material can be considered valid. After removal of the specimen from the mould, there was evidence of an apparent cross-sectional fracture of the specimen within the mould (Figure 7(a)) which was thought to be due to an exaggerated contraction of the material associated with its very slow setting. Furthermore, this "setting fracture" line tended to delineate two zones of the material — one, a white shorter area and the other a more
"Setting fracture" line in a specimen of unaccelerated Zinc Oxide and Eugenol.

Figure 7 (a)
Specimen of unaccelerated Zinc Oxide and Eugenol after testing for compressive strength.

N.B. Only the material to one side of the setting fracture line has been crushed.

Figure 7 (b)
yellow, longer area. Then subjected to loading under compression one day after mixing, fracture of the material occurred at values between 550 p.s.i. and 1,350 p.s.i., but only the material on the "white" side of the "setting fracture" line had been crushed (Figure 7(b)). Tensile strength tests were also not valid. Specimens examined for tensile strength provided a normal fracture on the yellow, longer side of the "setting fracture" line but the white zone disintegrated into fine particles. One week specimens fractured in a similar fashion to those of one day, although by one week some of the specimens had actually fallen apart at the "setting fracture" line.

Some difficulties with the unaccelerated material were apparently not encountered by Citjens and Dresser (1966) — non-Strength of Some Materials.

The setting time of each of the accelerated zinc oxide-eugenol materials was no longer than five minutes from the commencement of mixing (Table 7). None of the materials — S.S. White Cavity Liner, Caudle 500, R.E. and Zinc Oxide (1%) Zinc Acetate — Eugenol — were able to be tested at a time earlier than the two previously-discussed zinc phosphate type materials.

Some difficulty was experienced in obtaining certain
values for two of the products. S.S. White Cavity Lining proved to be too brittle at one week to yield valid results, for, whether the test was compressive or tensile, the one week specimens invariably shattered at very low values.

All early specimens of Camil 20E DE2, while appearing to be set and enabling easy removal from the mould, exhibited a very considerable amount of flow prior to fracture, so that the early strength values obtained cannot be regarded as valid. A 7 minute specimen under compression required fifteen minutes of testing before fracture took place and by this time the length of the specimen had been reduced from 8 cm. to approximately 5 cm. However, tests for the 7 minute compressive and tensile strengths of S.S. White Cavity Lining and the ultimate strengths of Camil 20E DE2 were valid and have been included in subsequent discussion.

The compressive and tensile strengths of the three materials for which a full range of values was able to be obtained have been listed in Table 6 and the "curves of best fit" shown in Figure 6.

All three materials showed an early rise in compressive strength with time. This was more noticeable with the commercial products. All three materials showed a tendency to decline in compressive strength from one day to one week and this statistically significant fall was approx-
Table 6.
ZINC OXIDE-EUGENOL BASED MATERIALS OF CLINICAL CONSISTENCY.

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.) at * Times after beginning of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Oxide (1% Zinc Acetate)-Eugenol 2.25</td>
<td>4 min.</td>
<td>4 min. 6 min. 14 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td>4 min. (110)*</td>
<td>4.300 4.50 4.750 4.750 5.100 3.750</td>
</tr>
<tr>
<td></td>
<td>6 1/2 min. 10 1/2 min.</td>
<td>1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Kalsogen 2.70</td>
<td>5 1/2 min.</td>
<td>2.060 3.200 4.370 2.940 1.770</td>
</tr>
<tr>
<td></td>
<td>260 (260)</td>
<td>(340) (190) (320) (300)</td>
</tr>
<tr>
<td></td>
<td>7 min. 12 min.</td>
<td>1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Kalsinol 2.70</td>
<td>5 1/2 min.</td>
<td>2.770 3.520 5.600 5.050 4.000</td>
</tr>
<tr>
<td></td>
<td>370 (370)</td>
<td>450 (100) (610) (600)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.
* Storage in air.

---

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Tensile Strength (p.s.i.) at * Times after beginning of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Oxide (1% Zinc Acetate)-Eugenol 2.25</td>
<td>4 min.</td>
<td>4 min. 6 min. 14 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td>4 min. (40)</td>
<td>330 310 300 350 380 350</td>
</tr>
<tr>
<td></td>
<td>6 1/2 min. 10 1/2 min.</td>
<td>1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Kalsogen 2.70</td>
<td>5 1/2 min.</td>
<td>300 365 280 255 2.45</td>
</tr>
<tr>
<td></td>
<td>60 (60)</td>
<td>(50) (40) (25) (50)</td>
</tr>
<tr>
<td></td>
<td>7 min. 12 min.</td>
<td>1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Kalsinol 2.70</td>
<td>5 1/2 min.</td>
<td>4.15 4.50 3.40 4.10 3.55</td>
</tr>
<tr>
<td></td>
<td>25 (25)</td>
<td>(75) (40) (30) (40)</td>
</tr>
</tbody>
</table>
imutely equal for each material. Although Kalaogen at no
time possessed a strength equal to the non-commercial
material, Kalsinol, at one hour, had a significantly higher
compressive strength than the other two materials.

The tensile strength values were very low and
showed very little change with time. Once again, the
tensile strength "curves" appeared to resemble closely the
general shape of those for compressive strength.

Table 7 has listed the compressive and tensile
strengths of all five accelerated zinc oxide-eugenol based
materials after storage for seven minutes and one week. The
7 minute values are of definite clinical importance.

Statistically, there was not a significant difference
in compressive strength either between Kalaogen and Kalsinol,
or between S.S. White Cavity Lining and Zinc Oxide (\textsuperscript{+3} Zinc
Acetate) – Eugenol at seven minutes, although the difference
between these two groups was significant. Similarly, although
there was not a significant difference at seven minutes in
tensile strength either between Kalsinol and S.S. White Cavity
Lining or between Kalaogen and the non-commercial material,
the difference between these two groups was significant. It
followed then that at seven minutes, Kalsinol had a relatively
good tensile strength and Zinc Oxide (\textsuperscript{+3} Zinc Acetate) –
Eugenol, a relatively good compressive strength. S.S. White
<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.)</th>
<th>Tensile Strength (p.s.i.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc Oxide (1% Zinc Acetate) - Eugenol</td>
<td>4 min.</td>
<td>7 min. 1 week</td>
<td>7 min. 1 week</td>
</tr>
<tr>
<td>Kalsogen</td>
<td>5.2 min.</td>
<td>4,500 (approx.) 3,750 (approx.)</td>
<td>310 (approx.) 350 (approx.)</td>
</tr>
<tr>
<td>Kalzinol</td>
<td>5.2 min.</td>
<td>2,200 (approx.) 1,770 (approx.)</td>
<td>300 (approx.) 245 (approx.)</td>
</tr>
<tr>
<td>S.S. White Cavity Lining</td>
<td>3.2 min.</td>
<td>2,770 (approx.) 4,000 (approx.)</td>
<td>415 (25) 355 (40)</td>
</tr>
<tr>
<td>Caulk ZOE B&amp;T</td>
<td>4 min.</td>
<td>4,200 (705) Not Valid</td>
<td>4,800 (50) Not Valid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4,800 (approx.) 7,920 (approx.)</td>
<td>Not Valid 960 (40)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

Storage in air.

Note: 1. 7 minute strengths for Zinc Oxide (1% Zinc Acetate) – Eugenol and Kalsogen were not determined and these values (approximate) have been derived from Figure 5.

2. S.S. White Cavity Lining material at one week was too brittle to test accurately — see discussion.

3. Caulk ZOE B&T possessed too much flow at 7 minutes to test accurately — see discussion.
Cavity filling was the strongest material and contained the
vacuum.

The one week values, although clinically not very
important, did highlight the possibilities of the 
Compo. 200
B5 material were it feasible to reduce its early flow,
because at one week this material possessed a compressive
strength of almost 6,000 p.s.i. which was double that of
Kalcosrol.  Its one week tensile strength of 960 p.s.i. was
more than double that of the other zinc oxide-eugenol
materials and approached the one week tensile strength of the
zinc phosphate products.

Discussion.  Some of the more recently developed
materials have not yet been discussed in the literature.  A
brief comparison has been made here of the aforementioned
findings with previous research.

1.  Chong et al. (1967) obtained a 7 minute compressive strength
of 600 p.s.i. and a one day strength of 1,250 p.s.i. for a zinc
acetate accelerated zinc oxide-eugenol material.  Results from
this present investigation indicated substantially higher
values — 4,500 p.s.i. at seven minutes and 4,750 p.s.i. at one
day. Although the powder/liquid ratio might have played a
part, it was probable that a raised difference in the quantity
of accelerator employed adequately explained this discrepancy.
While the present investigation used \( \text{ZnO} \) zinc acetate in the zinc oxide powder, Chang and his co-workers incorporated slightly more than 20\% accelerator and this large quantity has apparently weakened the case quite markedly.

2. The early values obtained for Calsocon in this study tended to confirm the work done by Hessing (1961). On the other hand, Hessing apparently observed no marked loss of strength with time as he referred to a one week compressive strength of 5,500 p.s.i. for the material.

3. Four commercial products tested by Swarts et al. (1963) possessed a one day compressive strength of from 800 to 4,100 p.s.i. Two of the three materials tested at one day in this present investigation — Calsocon (5,050 p.s.i.) and Zino Oxide (15 Zinc Acetate) — Eugonol (5,410 p.s.i.) — considerably exceeded the upper limit observed by Swarts et al.

4. The strongest commercial product tested by Swarts et al. (1963), Calson, was examined by Chang et al. (1967) at seven minutes and was found to possess a compressive strength of 2,700 p.s.i., a strength considerably below values obtained for accelerated zinc oxide-eugenol products in this investigation — S.S. White Cavity Lining (4,200 p.s.i.), Zino Oxide (15 Zinc Acetate) — Eugonol (4,500 p.s.i.) and Calsocon (2,770 p.s.i.). Calsocon (2,200 p.s.i.), alone, possesses a similar strength to the strongest material investigated by Swarts et al. (1963).
5. The significant reduction in compressive strength from one day to one week found, in this present investigation, for the three materials in Figure 3, supported similar observations made by Kassing (1961), Quarts et al. (1963) and Civjan and Frenor (1964).

6. At present, there has been no report in the literature of the tensile strength of simply accelerated zinc oxide-eugenol based materials although the tensile strengths of a more complex material containing ortho-ethylbenzole acid (EBA) and an un-accelerated zinc oxide-eugenol cement have been investigated.
Sino Oxide-Cugenol Based Material containing ortho-ethoxybenzoic acid.

Research by Drury, Givjan and others has led to the development of the commercial ortho-ethoxybenzoic acid-containing cement, Opotex. The manufacturer has listed its contents as follows:

<table>
<thead>
<tr>
<th>Powder</th>
<th>Sino Oxide</th>
<th>76.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrogenated Resin</td>
<td>63.2</td>
</tr>
<tr>
<td></td>
<td>Fused Quartz</td>
<td>20.3</td>
</tr>
<tr>
<td>Liquid</td>
<td>0-Ethoxybenzoic Acid</td>
<td>62.51</td>
</tr>
<tr>
<td></td>
<td>Cugenol</td>
<td>37.51</td>
</tr>
</tbody>
</table>

While the principal use of Opotex has been claimed to be for the final cementation of bridges and crowns, its suitability as a base under amalgam has also been suggested by the manufacturer. Phillips et al. (1968) observed that a mix of recommended consistency — four drops of liquid to one level scoop of powder — was in fact, 2.50 ml. powder for 0.5 ml. liquid. Opotex, it was found, (Phillips et al., 1968) has a film thickness of 50 microns which was a little above the requirement laid down by the Australian Standard Specification for a luting material.

For this investigation, the recommended powder/liquid
ratio was adhered to and the setting time of Opowax in air, at 37°C and 50-70% R.H., was found to be slightly less than 15 minutes. This lengthy setting time would appear to preclude the use of Opowax as a base forming material. It was observed, however, that when the mould was exposed to contact with water (see later results), or when a small bulk of the material was allowed to set out of the mould, the setting time was considerably reduced. This confirmed the manufacturer’s advice that delayed set on the glass slab was of no significance because “the cement is formulated to set appropriately in the oral environment.”

All early specimens exhibited marked flow, during testing under compression, so that little significance can be attached to the 15 minute values for compressive strength. Because of the degree of flow the tensile test was considered to be non-valid. Specimens of Opowax, subjected to compression fifteen minutes after mixing, remained intact after ten minutes of testing, although it was noticed that after a certain strength had been attained and in the absence of a fracture, further loading only increased the flow and produced no rise in the recorded value for compressive strength above approximately 4,360 p.s.i. (Table 6). The dimensions of the specimen after ten minutes testing were 5.5 cm. in length (initially 8 cm.) and about 4.5 cm. in diameter (initially 4 cm.). Figure 9
<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength p.s.i.</th>
<th>Tensile Strength p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15 min. 1 hour 1 week</td>
<td>15 min. 1 hour 1 week</td>
</tr>
<tr>
<td>Opotow</td>
<td></td>
<td>4,360 (370) 5,770 7,900</td>
<td>740 1,040</td>
</tr>
<tr>
<td>1 Scoop : 4 drops</td>
<td>15 min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.50</td>
<td></td>
<td>4,120 (120) 6,400 (660)</td>
<td>430 525</td>
</tr>
<tr>
<td>Hydro-Eugenol</td>
<td>3 min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.
* Storage in air.
* See discussion on early strength of Opotow.
Cylindrical Opotow specimen before testing

After testing for compressive strength

Marked flow with a 15 minute Opotow specimen.

Figure 9 (a)
Before testing

After testing for tensile strength

Marked flow with a 15 minute Opotow specimen.

Figure 9 (b)
Coplets flow with the 15 minute Coplet specimens.

Specimens tested one hour and one week after mixing showed minimal flow. Coplet's one week compressive strength of 7,900 p.s.i. and one week tensile strength of 1,040 p.s.i. (Table 6) were very similar to those of the Cemil 203 KF material and significantly higher than the one week compressive and tensile strengths of the other zinc oxide-eugenol type materials included in this investigation. While the one week strength of Coplet was much less than that of the zinc phosphate type materials (Table 5) it did indicate a significant development in zinc oxide-eugenol type materials. However, the clinical significance of Coplet's improved strength is open to conjecture as far as its use as a base material is concerned, as indeed is the use of Cemil 203 KF. Both these materials evidenced marked flow at times soon after the initial set had been reached, so that the possibility of displacement of these base forming materials by amalgam cannot be overlooked.

Very little research has so far been conducted on PDA-containing cements. Phillips et al. (1968) reported values of 5,500 p.s.i. for compressive strength and 600 p.s.i. for tensile strength (using the diametral compression test) of Coplet, 24 hours after mixing. These values appeared to be slightly lower than those observed in this present investigation, although the differences may not be significant.
Calcium Hydroxide Type Materials.

Two commercial calcium hydroxide type materials, Dyocel and Hydrex, were investigated. Each material has been particularly recommended by its manufacturer for use as a base in deep-seated cavities, while the content of calcium hydroxide has been recommended for the maintenance of vitality in cases of exposure or near-exposure of the pulp.

The components of both Dyocel and Hydrex were supplied in two tubes—a base paste and a catalyst paste. The manufacturers recommended the use of equal lengths of base and catalyst. These should be thoroughly mixed to ensure uniform dispersion of the ingredients. In this investigation, it was noticed particularly with Hydrex that complete mixing was essential if a uniform setting rate was to be obtained.

The results have been presented in Table 9 and "curves of best fit" shown in Figure 10.

It was at once evident that there was a marked difference in the setting times of the two materials. While Dyocel, under the conditions of testing, was set in approximately three minutes, Hydrex required fifteen minutes to reach its initial set. Under conditions more closely resembling the clinical situation however, Hydrex was found to be a satisfactory quick-setting material (see subsequent results).
**Table 9.**

**TWO COMMERCIAL CALCIUM HYDROXIDE TYPE MATERIALS.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Compressive Strength (p.s.i.) at Times after beginning of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4 min. 10 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Dyocal</td>
<td>3 1/2 min.</td>
<td>800 970 1,450 2,020 2,860 (145)* (175) (55) (235) (335)</td>
</tr>
<tr>
<td>Equal lengths of base &amp; catalyst.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrex</td>
<td>16 min.</td>
<td>575 (30) 760 1,600 1,700 (60) (120) (185)</td>
</tr>
<tr>
<td>Equal lengths of base &amp; catalyst.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.

e Storage in air.

w See discussion.

<table>
<thead>
<tr>
<th>Material</th>
<th>Time of First Testing</th>
<th>Tensile Strength (p.s.i.) at Times after beginning of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4 min. 10 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Dyocal</td>
<td>3 1/2 min.</td>
<td>200 (15) 215 (12) 215 (25) 235 (35) 405 (15)</td>
</tr>
<tr>
<td>Equal lengths of base &amp; catalyst.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrex</td>
<td>16 min.</td>
<td>135 (10) 135 (12) 175 (13) 175 (16)</td>
</tr>
<tr>
<td>Equal lengths of base &amp; catalyst.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 10

Graph showing compressive and tensile strength over time for two materials, DyCal and Hydrex.

- Compressive strength for DyCal increases significantly over time.
- Tensile strength for Hydrex remains relatively stable over the first hour, then increases over time.

Time axis: 10 minutes, 1 hour, 1 day, 1 week.
When compared with zinc phosphate and zinc oxide-eugenol type materials, the values for the compressive strengths of Hydrex and Dycal were very low (see Figure 3). The tensile strengths were only slightly inferior to those of the weaker zinc oxide-eugenol materials (Tables 7 and 9). When the materials were tested soon after they had reached an initial set, Dycal, with a compressive strength of 800 p.s.i., was appreciably stronger than Hydrex (575 p.s.i.) and this superiority was maintained for values recorded at times up to and including one week after mixing when Dycal (2,860 p.s.i.) was significantly stronger than Hydrex (1,700 p.s.i.). The initial tensile strength values were 260 p.s.i. for Dycal and 155 p.s.i. for Hydrex, while the one week tensile strengths were 405 p.s.i. and 175 p.s.i. respectively.

Statistically, Dycal was significantly stronger than Hydrex at all times of testing, under the prevailing experimental conditions, for both compressive and tensile values.

While both Dycal and Hydrex displayed a gradual increase in compressive strength with time after mixing, the tensile strength curves were relatively flat (Figure 10). There was a greater relative increase in compressive strength of Dycal during the first hour than of Hydrex although between one hour and one day Hydrex showed the greater rise. Between one day and one week neither the compressive nor tensile strengths of Hydrex showed a significant change. On the other hand, both the
compressive and tensile strengths of Dycal evidenced a significant rise in this interval.

From the above discussion and from the results shown in Table 9 and Figure 10, there was good evidence to suggest a relationship between the compressive and tensile strengths of each material.

Results obtained by Chong et al (1967) conflicted with some of these findings. While they also observed a gradual rise in the compressive strength of Hydrox with time, they found no increase in the strength of Dycal from seven minutes to 24 hours. The method of storage may possibly have explained this. Specimens tested after thirty minutes by Chong et al were removed from the mould at one hour and placed into water for the remainder of the period.
A Sino Oxide-Eugenol Cement containing a High Percentage of Calcium Hydroxide.

Surgident's Hydro-Eugenol has been placed in a category of its own because of its 20% calcium hydroxide content. Hydro-Eugenol has been claimed by its manufacturer to be useful as an "analgesic base over which a permanent restoration can be placed immediately", for therapy in cases of pulp exposure and as a durable temporary filling. When used as a base, a thick quick-setting mix was recommended by the manufacturer although a thin, slower setting mix might be used if desired. For the purpose of this investigation, a clinical consistency mix was found to require 2.40 g. powder/0.5 ml. liquid.

Directions for the use of Hydro-Eugenol pointed out that the mix sets quickly. This investigation certainly confirmed this for the material appeared to be set 2/4 minutes after mixing began (Table 8). In fact, it proved to be the most rapidly-setting material tested and would require immediate application following completion of mixing, when used in a clinical situation.

Seven minutes after mixing, Hydro-Eugenol had a compressive strength of 4,120 p.s.i., and a tensile strength of 450 p.s.i. (Table 8). Both these values were within the
range normally expected for a zinc oxide-eugenol based material. The one week compressive strength of 6,400 p.s.i. and tensile strength of 525 p.s.i. were both somewhat above the values for a simple accelerated zinc oxide-eugenol material and did show the tendency of the more complex materials to increase in strength with time.

Hydro-Eugenol can possibly attribute its rapid setting to the calcium hydroxide content and its good early strength to the acceleration of a basic zinc oxide-eugenol reaction. It is an interesting material and one which opens up new horizons for future development.
The Relationship between the Compressive and Tensile Strengths of Base Forming Materials of Clinical Consistency.

The possibility of a relationship between the compressive and the tensile strengths of a material has been noticed on numerous occasions in the preceding discussion. All materials, where both the compressive and tensile strengths had been obtained at identical times after mixing, were used to investigate this relationship more closely.

For each material, at every time of testing, a ratio of compressive strength : tensile strength (C.S.:T.S.) was obtained by dividing the compressive strength (p.s.i.) by the tensile strength (p.s.i.). When values obtained at similar times for materials within the same category were nearly identical, a mean value was calculated and the results expressed as one. This was possible for the two zinc phosphate type materials (Salton’s and S.S. White), for the two commercial zinc oxide-eugenol type materials, Kalsinol and Kalsogen, and for Dycal and Hydrex, the two calcium hydroxide type materials. However, when ratios obtained for materials within the same category differed appreciably, the results were expressed separately. For this reason, the values obtained for the zinc oxide (15 Zinc Acetate) – Eugenol material were not incorporated with those for Kalsinol and Kalsogen.
While for many materials a full range of values was possible, for four materials — Hydro-Suganol, Opotex, G.S. White Cavity Lining and Gbulk 302, 635 — only one or two ratios have been listed. As mentioned in preceding discussion, the last two materials allowed complete testing only at seven minutes or one week respectively. Opotex possessed too much flow at fifteen minutes and Hydro-Suganol was only tested at seven minutes and one week.

The diagram in Figure 11 has illustrated the values obtained as outlined above and listed in Table 10.

NOTE: A high ratio of compressive strength to tensile strength was an indication of either a relatively good compressive strength or poor tensile strength and in no way indicated the actual strength values.

The zinc phosphate type materials showed a slight increase with time in the G.S.:T.S. ratio. During the first hour, the value was approximately 10:1 but with further time the compressive strength increased at a slightly greater rate than the tensile strength so that the one week G.S.:T.S. ratio was 12.5:1.

The zinc oxide-eugenol materials showed some variation in the G.S.:T.S. ratio at different times of testing. As seen in Table 6, a feature was the similarity in the values for tensile strength at various times. The greatest range in
<table>
<thead>
<tr>
<th>Category and Material(s)</th>
<th>Ratio of Compressive : Tensile Strength of Base Materials at times tested</th>
<th>Ratio at 7 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong> Zinc Phosphate Type</td>
<td>5-5½ min. 12 min.</td>
<td>1 hour 1 day 1 week</td>
</tr>
<tr>
<td>Zinc Oxide-Eugenol</td>
<td>4 min. 6 min. 14 min.</td>
<td>13.0:1 14.3:1 15.8:1</td>
</tr>
<tr>
<td>2 Commercial Products</td>
<td>6½-7 min. 11-12 min.</td>
<td>6.8:1 8.5:1</td>
</tr>
<tr>
<td>S.S. White Cavity Lining</td>
<td>7 min.</td>
<td>8.7:1</td>
</tr>
<tr>
<td>Caulk ZOE B&amp;T</td>
<td>7 min.</td>
<td>Not Valid</td>
</tr>
<tr>
<td><strong>III</strong> Opopow</td>
<td>15 min.</td>
<td>Not Valid</td>
</tr>
<tr>
<td><strong>IV</strong> Calcium Hydroxide Preparations</td>
<td>4 min. 10-16 min.</td>
<td>4.0:1 4.4:1</td>
</tr>
<tr>
<td><strong>V</strong> Hydro-Eugenol</td>
<td>7 min.</td>
<td>9.5:1</td>
</tr>
</tbody>
</table>

* Approximate – since no reading was taken at exactly 7 minutes.
tensile strength values in either of the three materials was the 120 p.s.i. range of Halsegen. In contrast, Kolzinol had a range of 2,630 p.s.i. in compressive strength values. It might have been expected, therefore, that graphs of the C.S.:E.S. ratio for these three materials would resemble the compressive strength curves shown in Figure 8. This was, in fact, revealed in Figure 11.

The early values for Opalow, because of the excessive flow, were not valid. One hour (7.9:1) and one week (7.6:1) values, however, indicated the possibility of a fairly steady relationship between compressive and tensile strength.

The combined C.S.:E.S. ratio for Lycobl and Hydrox gradually increased with time indicating a greater relative increase in compressive strength. All C.S.:E.S. ratios for these two materials were quite low, indicating a relatively higher tensile strength or lower compressive strength than was the case with the majority of the other base forming materials.

Some interesting aspects of Surgident's Hydro-Eugenol have already been noted. With a 7 minute ratio of 9.5:1 and a one week ratio of 12.5:1, Hydro-Eugenol lay within the range of values expected of a zinc oxide-eugenol base material. Yet it even more closely paralleled values for the
zinc phosphate type materials, although the lack of intermediary values was possibly misleading.

In summary:— Although there was some deviation, there did appear to be a fairly steady relationship between the compressive and tensile strengths of each material or group of materials. Different products, however, had different C.S.:T.S. ratios.

The two zinc phosphate materials had an approximate C.S.:T.S. ratio of 11:0:1 while Zinc Oxide (1:5 Zinc Acetate) — Eugenol possessed the highest average ratio of about 13.5:1. Hydro-Eugenol had an approximate ratio of 11.0:1 and Ryconal and Hydrox, the two calcium hydroxide preparations possessed the lowest C.S.:T.S. ratio of 6.0:1 indicative of their low compressive strengths. The remainder of the zinc oxide—eugenol based materials had approximate values between 7.5:1 and 10.5:1.
The Effect of a Variation in Storage Conditions on the Compressive Strength of Base Forming Materials.

When a base forming material is placed into a prepared cavity in a tooth, it is invariably subjected to contact with moisture despite every effort to ensure a dry cavity before amalgam condensation. Moisture, normally present on the surface of freshly cut vital dentine, may be introduced in the application of moist cotton wool to the cement base or may enter the cavity as saliva. It was therefore considered important to study the effect of this contact with moisture on the compressive strength of the base materials and to compare these results with those obtained following storage of the material in air.

The effect of water storage on the compressive strength was examined using eight base materials of clinical consistency (see Table II) and, in each case, the mould was placed in water at 37°C immediately after specimen formation had been completed. The mould was removed from the water to facilitate removal of the specimens. With this single exception, the material remained in water until the time of testing.

All eight materials were tested ten minutes, one hour and one week after the incorporation of powder in the
Liquid (or catalyst in the base). While ten minutes was considerably longer than the clinically significant time interval, it was chosen to enable all materials to be examined and to allow a minimum of five minutes contact with water before testing of the early specimens.

The ten minute values listed in Table 11 for air-stored specimens of 0.2. White and Dalton's zinc phosphate cements and Kalzinol were approximate only, having been estimated from the curves drawn in Figures 5 and 8, because no results were obtained for these three materials at this particular time. When stored in air, specimens of Opotor and Hydrex were not set sufficiently at ten minutes to enable testing. Specimens of Cerlik 205 127 exhibited excessive flow at ten minutes and one hour regardless of the method of storage. A ten minute water-stored specimen of this material had still not fractured after thirteen minutes of testing despite a recorded loading indicating a compressive strength of approximately 5,000 p.s.i., but had markedly altered its dimensions which were now 5.2 mm. length (initially 8.0 mm.) and 4.5 mm. diameter (initially 4.0 mm.).

Results obtained for the zinc phosphate type materials (Table 11, Figure 12) indicated a tendency for the water-stored specimens to possess a higher ten minute strength but a lower one hour and one week compressive strength than the
Table 11.

EFFECT OF STORAGE CONDITIONS ON COMPRESSION STRENGTH.

<table>
<thead>
<tr>
<th>Material and Consistency, gm. powder/0.5 ml. liquid</th>
<th>Compressive Strength (p.s.i.) at times after beginning of mix.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage in air</td>
</tr>
<tr>
<td></td>
<td>10 min. 1 hour 1 week</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved 2.30</td>
<td>10,100 (1,160) (3,200)</td>
</tr>
<tr>
<td>Dalton’s Zinc Phosphate Cement 2.80</td>
<td>9,000 (1,680) (1,850)</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate)-Eugenol. 2.25</td>
<td>4,580 (100) (310)</td>
</tr>
<tr>
<td>Kalzinol 2.70</td>
<td>3,250 (600)</td>
</tr>
<tr>
<td>Caulk ZOE B&amp;T 1.65</td>
<td>No value due to flow.</td>
</tr>
<tr>
<td>Opotow 2.50</td>
<td>Not set (460) (1,500)</td>
</tr>
<tr>
<td>Dycal</td>
<td>970 (175) (355)</td>
</tr>
<tr>
<td>Hydrex</td>
<td>Not set (60) (185)</td>
</tr>
</tbody>
</table>

* Approximate.

Standard Deviations in brackets.
Figure 12

Graph showing the compressive strength of Dalton's and S.S. White cement under different storage conditions.

- **Compressive Strength (P.S.I. x 10^3)**
  - Y-axis: 8 to 24
  - Scale: Linear

- **Time**
  - X-axis: 0 to 1 week
  - Scale: Linear
  - Markings: Minutes and Hours

Legend:
- **Storage in Air** (solid line)
- **Storage in Water** (dashed line)
- **Dalton's Cement** (squares)
- **S.S. White Cement** (stars)

Graph indicates a significant increase in strength over time for both types of cement, with storage in water leading to higher strength values compared to storage in air.
air stored material. It was not possible to determine the significance of this tendency because values for air-stored specimens were approximate only. However, it was unlikely that any actual difference existed. The difference between the one week compressive strengths of air and water stored specimens of the C.S. White product was not significant at the 95% level of confidence. Only in the case of one week specimens of Dalton's Zinc Phosphate Cement was the air-stored specimen significantly stronger. Of the water-stored material tested, the C.S. White product appeared to be slightly stronger than the Dalton's cement at all times of testing. This difference however was not significant.

It was impossible to generalize on the results obtained for the zinc oxide-eugenol based materials (Table 11, Figure 13). The compressive strengths of water-stored specimens of Zinc Oxide (7% Zinc Acetate) - Eugenol tended to be slightly lower than the strength of those stored in air at all times of testing although the differences were not statistically significant. As was the case with the dry specimens, there was a noticeable loss in strength with time.

When stored in air the compressive strength of Eulzinol decreased after one hour but under conditions of water storage there was a significant rise in compressive strength from 3,970 p.s.i. at one hour to 5,250 p.s.i. at one
week. It was rather surprising, therefore, that at ten minutes and one hour, the water-stored specimens were significantly weaker than specimens stored in air.

At ten minutes and one hour, the effect of varying the storage conditions of Conik 2091227 could not be determined because of the marked early flow exhibited by both water- and air-stored specimens. After storage in water for one week, the compressive strength of the material was significantly lower than the one week air-stored material.

The E D A product, Opow, rather surprisingly appeared to gain strength more slowly under water than in air although it set more rapidly under water. (Table 11, Figure 15). After ten minutes storage in air, the material had not yet set, but after water storage for ten minutes, it had a compressive strength of 3,375 p.s.i. The one week values — 7,900 p.s.i. (air storage) and 7,550 (water storage) — were not significantly different although such a difference did exist at one hour.

The storage of specimens in water before testing had a definite effect upon the compressive strength of Dycal and Hydros, when compared with results obtained following air-storage. Water-stored Dycal had a ten minute strength similar to the air-stored material but showed very little increase in compressive strength with time (Table 11,
Figure 14). The one hour and one week values after water storage were significantly lower than values obtained from air-stored specimens. On the other hand, Hydrex, which did not appear to be set in air for about fifteen minutes, had a ten minute compressive strength of 780 p.s.i. when stored in water. At one week, values obtained by air and water storage were very similar. This is in contrast with the one week values for Lycal. When the specimens were stored in air, then, Hydrex set slowly and Lycal had a significantly higher one week strength. Under conditions of water storage, the early values of Hydrex and Lycal were almost identical while at one week Hydrex was significantly stronger.

Water-stored specimens of unmodified zine oxide-eugenol set a little more quickly than in air but still exhibited a "setting fracture" line (see Accelerated Zine Oxide-Eugenol Based Materials). Many one day specimens fell apart as they were being positioned for testing, and one week specimens, on testing, tended to shatter following storage in water. Results obtained after water storage for one day ranged from 800 p.s.i. to 3,700 p.s.i. After one week, the recorded values were approximately 600 p.s.i. although it would be misleading to describe any of these values as the actual compressive strength.
In summary:-

1. Zinc phosphate type base materials tended to be slightly stronger at ten minutes but this improvement was not significant. There was very little increase in strength after one hour so that at one week the water-stored specimens were appreciably weaker than those stored in air. Womer (1940) observed that zinc phosphate cements after one hour in air were almost as strong as they were after seven more days in distilled water at 37°C. The present investigation certainly supported Womer's finding (see Figure 12). Womer also suggested that specimens kept seven days in air were generally 10 to 30% stronger than those immersed in water for a similar period. Again, the present investigation was in agreement with Womer who, in an attempt to explain this, suggested that "certain bonding constituents" were leached out by long contact with water at mouth temperature and that this was responsible for the reduction in strength after water storage.

2. Storage of the specimens in water, markedly accelerated the setting of Lydraz and Opalow, two of the most slowly setting materials when stored in air.

3. Water storage appeared to have little effect on the early strength of the materials. While the ten minute
Compressive strength of water-stored zine phosphate materials tended to be slightly higher than when stored in air; the difference was not statistically significant. The ten minute strengths of Dyocal and Zino Oxide (1:5 Zino Acetate) — Eugenol were slightly lower when stored in water, but again, this was not significant. The reduction in the early strength of Kalsinol after storage in water probably was significant. Water storage did not appear to eliminate the excessive flow observed at ten minutes and one hour with Camlik 208 B.W.T. Surprisingly, although water storage accelerated the setting of Opotow, the one hour strength was significantly lower.

4. With the exception of Kalsinol, all tested materials exhibited a lower one week compressive strength with water storage than with air storage. This was possibly related to the leaching effect described by Simons (1940).

Of three materials — Dalton's Zinc Phosphate Cement, Camlik 208 B.W.T and Dyocal — showed a significant reduction with water storage. For four materials — S.S. White Zino Cement Improved, Zino Oxide (1:5 Zino Acetate) — Eugenol, Opotow and Hydrex — there was a tendency (not significant) for the one week water-stored strength to be lower. Of the base forming materials investigated, only Kalsinol possessed a significantly greater one week compressive strength under conditions of water storage.
The Effect of Variation in the Powder/Liquid Ratio.

Biologically, for a zinc phosphate type material it is desirable that as much powder as possible be incorporated within the liquid to accelerate the formation of the tertiary zinc phosphate and thereby minimize the exposure of dentino and pulp to acid. A thick mix of a zinc oxide-eugenol type material is recommended to minimize the percentage of residual, unreacted eugenol thereby reducing the possibility of removal of calcium ions from dentino by the chelating action of the eugenol. For these reasons it was considered important to determine the effect of different powder/liquid ratios on the strength properties of these two types of base materials.

Four consistencies of 3.6. White Zine Cement Improved were studied — 1.10, 1.35, 1.90 and 2.50 gm. powder/0.5 ml. liquid. The first mentioned powder/liquid ratio represented a consistency suitable for luting purposes. 1.35 gm./0.5 ml. was "standard testing consistency" and the remaining two consistencies represented possible clinical mixes. Zino Oxide (1:3 Zinc Acetate) — Eugenol was selected to represent the zinc oxide-eugenol type materials and three consistencies were tested — clinical consistency (2.25 gm./0.5 ml.) and two thinner mixes (2.00 and 2.15 gm./0.5 ml.).

The results have been shown in Tables 12, 13 and 14.
and Figures 15, 16, 17 and 18. Until one hour after mixing, the compressive strengths of the four consistencies of 0.8 White Zinc Cement Improved were significantly different and the thicker the mix, the greater was the compressive strength. Over a period of a week, the compressive strength of each consistency continued to increase. Due to a large spread in results the values obtained at one week for the four consistencies were markedly but not significantly different. Since the compressive strength of the luting consistency (1.40 gm./0.5 ml.) was tested at only three times, it was not possible to draw a "curve of best fit" (Figure 15).

The tensile strengths of the three thicker consistencies of zinc phosphate material were significantly different until at least one hour after mixing but, at one week, the strengths were almost identical (Table 12, Figure 16). At one week, the luting consistency mix was significantly weaker than the other three consistencies.

In summary, all values obtained for these four consistencies of 0.8 White Zinc Cement Improved indicated a continual increase in compressive strength and tensile strength until one week after mixing. The early strengths, either compressive or tensile, were significantly higher as increasing amounts of powder were incorporated within the liquid.

The values obtained for the early compressive
Table 12.
EFFECT OF POWDER/LIQUID RATIO - S.S. WHITE ZINC CEMENT IMPROVED.

<table>
<thead>
<tr>
<th>Test</th>
<th>Powder/Liquid Ratio (gm. powder/0.5 ml. liquid)</th>
<th>Time of First Testing</th>
<th>Strength (p.s.i.) at times after mixing, after storage in air.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 min. 20 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2,150 5,050</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(190) (875)</td>
</tr>
<tr>
<td>Compressive</td>
<td>1.10 (Inlay Consistency)</td>
<td>10 min.</td>
<td>8 min. 14 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,750 6,720 7,100 9,700 9,730</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(150) (265) (510) (945) (1,890)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7 min. 12 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6,980 7,980 9,600 11,900 12,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(480) (525) (1,130) (715) (2,730)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>52 min. 12 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8,200 10,600 12,900 13,640 15,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(420) (1,420) (1,160) (1,700) (3,200)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52 min.</td>
<td>10 min. 20 min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.30</td>
</tr>
</tbody>
</table>

Standard Deviations in brackets.
Table 13.

EFFECT OF POWDER/LIQUID RATIO - ZINC OXIDE (1% ZINC ACETATE) - EUGENOL.

<table>
<thead>
<tr>
<th>Test</th>
<th>Powder/Liquid Ratio gm. powder/0.5 ml. liquid</th>
<th>Time of First Testing</th>
<th>Strength (p.s.i.) at times after mixing, after storage in air.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 min.</td>
<td>5 1/2 min. 16 1/2 min. 1 hour 1 day 1 week.</td>
</tr>
<tr>
<td>Compressive</td>
<td>2.00</td>
<td>5 min.</td>
<td>3,770 (430)* 4,450 (530) 3,630 (590) 3,650 (1,200) 3,530 (650)</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td></td>
<td>5 min. 15 min. 1 hour 1 day 1 week</td>
</tr>
<tr>
<td></td>
<td>2.15</td>
<td>4 1/2 min.</td>
<td>4,300 (130) 4,600 (310) 3,900 (500) 4,100 (760) 3,300 (1,030)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 min. 10 min. 1 hour 1 day 1 week</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.25</td>
<td>4 min.</td>
<td>4,300 (110) 4,580 (310) 4,750 (300) 5,100 (290) 3,750 (1,030)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.
S.S. WHITE ZINC CEMENT IMPROVED

COMPREHENSIVE STRENGTH (PSI x 10^3)

GM. POWDER / 0.5 ML. LIQUID

2.30  *
1.90  ▽
1.50  ⊙
1.10  ○

TIME

MINUTES  HOUR  DAY  WEEK

FIGURE 15
S.S. WHITE ZINC CEMENT IMPROVED

TENSILE STRENGTH (P.S.I. x 10^2)

GM. POWDER / 0.5 ML. LIQUID
2.30 *
1.90 ▼
1.35 ⊕
1.10 ◊

TIME

FIGURE 16
ZNOXACE

2.00 GM. POWDER / 0.5 ML. LIQUID
2.15
2.25

COMPRRESSIVE STRENGTH P.S.I. x 10^3

TIME

FIGURE 17
strengths of the three consistencies of Zino Oxide (1:3 Zino Acetate) - Eucarol material indicated a significant difference between the 2.00 gm./0.5 ml. consistency and the two thicker mixes. There was very little difference in the 5 to 10 minute strengths of the 2.15 and 2.25 gm./0.5 ml. consistencies although the thicker mix did tend to be slightly stronger. The two thinner mixes tended to lose strength from fifteen minutes to one hour (Table 13, Figure 17) while, for the same period, the compressive strength of the thickest consistency tended to remain relatively constant. From one day to one week, the compressive strengths of all three consistencies tended to decrease but only for the most thickly mixed material (2.25 gm./0.5 ml.) was the reduction significant.

From a clinical point of view, it was found that there was no advantage to be gained from the use of a 2.25 gm./0.5 ml. consistency in preference to a mix of 2.15 gm./0.5 ml. to achieve greater strength. There was, however, definite value in using either of these powder/liquid ratios in preference to the significantly weaker 2.00 gm./0.5 ml. consistency.

To investigate the effect of varying the powder/liquid ratio on the compressive strength of materials stored in water, two consistencies of each of the above two base forming materials were selected and examined (Table 14, Figure 18).
Ten minutes after mixing, clinical consistency
(2.30 gm./0.5 ml.) S.S. White Zinc Cement Improved was
significantly stronger than a slightly thinner mix containing
only 1.90 gm. powder/0.5 ml. liquid. This latter consistency,
which had a ten minute compressive strength of 8,100 p.s.i.,
after water storage, was still a much thicker mix than either
the luting or the standard consistency, and would no doubt be
considered suitable for clinical use by many dentists. At
ten minutes though, it was approximately 3,200 p.s.i. weaker
than a consistency of 2.30 gm./0.5 ml.

A relationship similar to this existed between two
consistencies of Zinc Oxide (1:1 Zinc Acetate) - Eugenol. At
ten minutes, a mix of 2.25 gm. powder/0.5 ml. liquid was
significantly stronger than a mix containing only 2.00 gm.
powder. After storage for either one hour or one week, there
was virtually no difference in the compressive strength of the
two materials. (Figure 18).

For both materials, a "thick" mix is not only
desirable for biologic reasons but also necessary to ensure
maximum early strength.
**Table 14.**

**EFFECT OF POWDER/LIQUID RATIO ON MATERIALS STORED IN WATER.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Powder/Liquid Ratio gm. powder/0.5 ml. liquid</th>
<th>Compressive Strength (p.s.i.), at times after mixing, after storage in water at 37°C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10 min.</td>
</tr>
<tr>
<td>S.S. White Zinc Cement</td>
<td>1.90</td>
<td>8,100</td>
</tr>
<tr>
<td>Improved</td>
<td></td>
<td>(1,530)*</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate) Eugenol</td>
<td>2.00</td>
<td>11,330</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1,010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(260)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(410)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.
\[ \text{TIME} \]

- \( \star \) S.S.WHITE ZN PO\(_4\) 2.30
- \( \odot \) S S WHITE ZN PO\(_4\) 1.90
- \( \nabla \) ZNOXACE 2.25
- \( \oplus \) ZNOXACE 2.00

\[ \text{STRENGTH} \] P.S.I. \( \times 10^3 \)

- 12
- 12
- 10
- 8
- 6
- 4
- 2

\[ \text{COMPRESSION} \]

- 0 10 20 30
- 0 1 1 1

**Figure 18**
The Effect of Ambient Temperature at the time of mixing on the Compressive Strength of Base Filling Materials.

The room temperature at which base materials are mixed in a dental practice is likely to fluctuate and will depend to some extent upon seasonal conditions. It was decided, therefore, to investigate the effect, if any, of room temperature on the compressive strengths of base filling materials. This study was confined to the early values of two base materials of clinical consistency — S.S. White Zinc Cement Improved and Zinc Oxide (1/3 Zinc Acetate) — Eugonol. The materials were mixed within three temperature ranges — 16-18°C, 21-23°C and 26-28°C — which represented cold, average and hot conditions respectively. Immediately after filling with material, the mould was moved into a temperature controlled cabinet at 37°C. In this way it was hoped to simulate the clinical situation at least in so far as the temperature change was concerned.

See Table 15 and Figure 19.

Seven minutes after mixing, the 16-18°C S.S. White material possessed a compressive strength of 3,200 p.s.i. and was significantly weaker than the 21-23°C material (9,700 p.s.i.) and the 26-28°C material (10,300 p.s.i.). The difference between the strengths of the two higher temperature
Table 15.

EFFECT OF AMBIENT TEMPERATURE AT TIME OF MIXING ON COMpressive STRENGTH.

<table>
<thead>
<tr>
<th>Material and Consistency</th>
<th>Ambient Temperature at Mixing</th>
<th>Compressive Strength (p.s.i.), at times after mixing, after storage in air (37°C).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7 min.</td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved</td>
<td>16-18°C.</td>
<td>8,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(775)*</td>
</tr>
<tr>
<td>2.30 gm. powder/0.5 ml. liquid.</td>
<td>21-23°C.</td>
<td>9,700</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(610)</td>
</tr>
<tr>
<td></td>
<td>26-28°C.</td>
<td>10,300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(775)</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate) - Eugenol.</td>
<td>16-18°C.</td>
<td>4,950</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(195)</td>
</tr>
<tr>
<td></td>
<td>21-23°C.</td>
<td>4,700</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(360)</td>
</tr>
<tr>
<td></td>
<td>26-28°C.</td>
<td>4,300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(310)</td>
</tr>
</tbody>
</table>

* Standard Deviations in brackets.
Figure 19

Compressive Strength $\times 10^3$ vs. Time (minutes)

- S.S.White Zinc Cement Improved
- Znoxace
ranges was not significant. In direct contrast with the zinc phosphate material, the 16-18°C specimens of Zinc Oxide (13 Zinc Acetate) + Eugenol possessed the greatest compressive strength at seven minutes = 4,950 p.s.i. Although this was only slightly higher than the 21-23°C material, it was significantly higher than specimens from material mixed at 26-28°C which possessed a compressive strength of 4,300 p.s.i. Considerable difficulty was experienced in mixing both the zinc phosphate and zinc oxide-eugenol materials at 26-28°C. At times, a decided effort was required to fully incorporate all the zinc phosphate cement powder in the liquid. When the temperature was within this range there was a tendency for the accelerated zinc oxide-eugenol material to set almost immediately after the completion of mixing.

The zinc phosphate material mixed at 16-18°C was significantly weaker than material mixed at 21-23°C at both fourteen and twenty minutes after the commencement of mixing. At twenty minutes, the 21-23°C material tended to be stronger than the 26-28°C material which, in turn, tended to be stronger than the 16-18°C material, although none of these differences in compressive strength were statistically significant at the 95% level of confidence.

Zinc Oxide (13 Zinc Acetate) + Eugenol mixed at 16-18°C possessed a 14 minute compressive strength of 5,100
p.s.i. which was significantly stronger than the 26-28°C material. At twenty minutes, differences between mixes made at the three temperature ranges were not statistically significant.

Broadly speaking then, the ambient temperature during mixing appeared to have only a slight effect upon the early compressive strengths of the two base forming materials tested. When mixed at 16-18°C a zinc phosphate material was significantly weaker than when mixed under "average" conditions (21-23°C). Zinc Oxide (17 Zinc Acetate) - Eugenol mixed at 16-18°C was slightly stronger at seven minutes than mixes at 21-23°C and 26-28°C although it was noticed that the setting of the material was most rapid at the highest temperature range.
The Compressive and Tensile Strengths of Base Forming Materials at Seven Minutes.

By way of summarizing the results, and in view of the particular emphasis of this research, the seven minute compressive and tensile strengths of the base forming materials tested have been listed in Table 16. The values for these materials were obtained after storage in air at 37°C and 50-70% relative humidity.

A number of the materials were not specifically tested at seven minutes because particular interest was taken in the strength immediately after the initial set was obtained. For these materials use was made of previous tables and graphs to approximate 7 minute strengths and these estimates have been indicated in Table 16 by a symbol. Standard deviations for the materials actually tested at seven minutes have been stated in previous tables and were not included here.

At the time of clinical importance, the compressive strengths of the two zinc phosphate cements were 8,200 p.s.i. and 9,000 p.s.i. These two materials had approximately double the strength of the next strongest group of base forming materials tested. This group, consisting of Surgident's Hydro-Eugenol, S.S. White Cavity Lining and the
Table 16.

<table>
<thead>
<tr>
<th>Material &amp; Consistency</th>
<th>Compressive Strength (p.s.i.) at 7 minutes</th>
<th>Tensile Strength (p.s.i.) at 7 minutes</th>
<th>Time of first testing (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gm. powder/0.5 ml. liquid.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved.</td>
<td>9,000 *</td>
<td>880 *</td>
<td>4½</td>
</tr>
<tr>
<td>Dalton's Zinc Phosphate Cement.</td>
<td>8,200 *</td>
<td>880 *</td>
<td>4½</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate)-Eugenol. 2.25</td>
<td>4,500 *</td>
<td>310 *</td>
<td>4</td>
</tr>
<tr>
<td>Kalaogen.</td>
<td>2,200 *</td>
<td>300 *</td>
<td>5½</td>
</tr>
<tr>
<td>Kalzinol.</td>
<td>2,770</td>
<td>415</td>
<td>5½</td>
</tr>
<tr>
<td>S.S. White Cavity Lining. 2.40</td>
<td>4,200</td>
<td>480</td>
<td>3½</td>
</tr>
<tr>
<td>Caulk ZOE B&amp;T. 1.65</td>
<td>Too much flow</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Opotow E B A Cement.</td>
<td>Not yet set</td>
<td></td>
<td>15 *</td>
</tr>
<tr>
<td>Dycal. Equal lengths of base and catalyst.</td>
<td>880 *</td>
<td>210 *</td>
<td>3½</td>
</tr>
<tr>
<td>Hydrex. &quot; &quot; &quot;</td>
<td>Not yet set</td>
<td></td>
<td>16 *</td>
</tr>
<tr>
<td>Surgident's Hydro-Eugenol. 2.40</td>
<td>4,120</td>
<td>525</td>
<td>3</td>
</tr>
</tbody>
</table>

* Storage in air.

* Approximate - see accompanying discussion.
non-commercial Zino Oxide (Zinc Oxide Acetate) — Eugenol cements, had 7 minute compressive strengths of from 4,100 p.s.i. to 4,500 p.s.i. Two other quick-setting zinc oxide-eugenol cements, Kelsoind and Kelseogen, possessed 7 minute compressive strengths of 2,700 p.s.i. and 2,200 p.s.i. respectively, while Bycoil had a strength of 680 p.s.i. Since Hydex and Opotow were not set at seven minutes and Gaulin 1200 LDT possessed too much flow at this time, no values were available for inclusion in Table 16. It had been observed, however, that at least one of these, Hydex, was capable of setting by seven minutes provided that a relatively thin layer was exposed to contact with moisture.

At seven minutes, the tensile strengths obtained by the diametral compression test tended to be related to the compressive strengths. For example, the zinc phosphate cements had a tensile strength markedly greater than any of the other cements and, of the materials able to be tested, Bycoil had the lowest tensile strength at seven minutes.
Practical Application in Extracted Tooth.

Eight different base forming materials and ten extracted teeth were used in this short investigation.

The results have been listed in Table 17. The type of cavity into which the base material and amalgam were placed has been indicated and mention has also been made of the opinion of the operator as to the satisfactory (or unsatisfactory) nature of the condensation procedure. This opinion was recorded immediately after each material had been packed. After sectioning, the base forming materials were examined microscopically for evidence of fracture and/or displacement. The appearance of voids was also noted.

Finally, an overall assessment was given, based on this research, as to the apparent adequacy of each material for use as a base beneath amalgam.

(4) 3.3. White Zinc Cement Improved.

See Figure 29.

This zinc phosphate product gave evidence of a slight fracture approximately midway up the axial wall. There was no displacement of the base. In two places, a very slight space was detected between the base and either the dentine or the amalgam.
<table>
<thead>
<tr>
<th>Base Forming Material</th>
<th>Type of Cavity</th>
<th>Opinion of the operator on the condensation procedure.</th>
<th>Microscopic Examination After Sectioning.</th>
<th>Overall Assessment of the Strength of the base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fracture</td>
<td>Displacement</td>
<td>Voids</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fracture</td>
<td>Displacement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.S. White Zinc Cement Improved,</td>
<td>Cl. II</td>
<td>Good</td>
<td>+</td>
<td>**</td>
</tr>
<tr>
<td>Zinc Oxide (1% Zinc Acetate) - Eugenol</td>
<td>Cl. II</td>
<td>Good</td>
<td>+</td>
<td>Nil</td>
</tr>
<tr>
<td>Unaccelerated Zinc Oxide-Eugenol (Unset)</td>
<td>Cl. II</td>
<td>Very</td>
<td>Nil</td>
<td>+++</td>
</tr>
<tr>
<td>Unaccelerated Zinc Oxide-Eugenol (Set)</td>
<td>Cl. II</td>
<td>Poor</td>
<td>Nil</td>
<td>+++</td>
</tr>
<tr>
<td>Kalzinol</td>
<td>Cl. II</td>
<td>Good</td>
<td>+</td>
<td>Nil</td>
</tr>
<tr>
<td>Caulk ZOE B&amp;T</td>
<td>Cl. II</td>
<td>Good</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>Opotow</td>
<td>Cl. II</td>
<td>Good</td>
<td>Nil</td>
<td>++</td>
</tr>
<tr>
<td>Dycal</td>
<td>Cl. II</td>
<td>Good</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Dycal</td>
<td>Cl. I</td>
<td>Good</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Hydrex</td>
<td>Cl. II</td>
<td>Good</td>
<td>Nil</td>
<td>++</td>
</tr>
</tbody>
</table>

* + Mild  
++ Moderate  
+++ Severe
S.S. White Zino Cement Improved

Figure 20.
Sino Oxide–Eugenol Based Materials.

2. Unaccelerated Sino Oxide–Eugenol.

This unaccelerated material required between three and eighteen hours to set in air and, even when in contact with moisture, its setting was very slow.

Gross displacement of the base forming material resulted when an attempt was made to pack amalgam onto unset single sino oxide–eugenol (Figure 21A). Condensation of the amalgam was impossible. Sino oxide–eugenol unset was not only grossly incorporated within the amalgam, but was also extruded from the cavity at the margin (see Figure 21A). In two places, it was observed that amalgam had penetrated the “lining” and was in direct contact with the dentine in spite of the fact that normal condensation pressure was not even approached during packing into the cavity.

In contrast with the unset material, unaccelerated sino oxide–eugenol, when allowed to set for one week before condensation, possessed adequate strength to resist displacement (Figure 21B). Some lines indicating fracture of the base were observed on the axial and pulpal walls and there was a tendency, in one area, for the material to leave a slight space between itself and the amalgam. It did, however, allow good condensation and certainly evidenced
Unset, unaccelerated zinc oxide and eugenol

Set, unaccelerated zinc oxide and eugenol

Figure 21.
none of the gross displacement so apparent with the unset material packed at seven minutes.

b. Zinc Oxide (1:3 Zinc Acetate) + Eugenol.

There was no evidence of displacement of this material by the forces exerted in condensation (Figure 22). Small voids could be detected throughout the material. At one point in the cavity, a large void was evidence of failure to place the material adequately into contact with the cavity preparation, in spite of the fact that considerable care was taken in an attempt to prevent such occurrences. This large void apparently did not weaken the base sufficiently to allow condensation forces to crush the unsupported material.

c. Kelainol.

As was the case with the above non-commercial accelerated material, Kelainol appeared to allow good condensation of the amalgam. Microscopic examination revealed neither fracture nor displacement of the base forming material (Figure 23).

d. Cemik 205 RST.

See Figure 24.

No displacement of the base occurred during condensation of amalgam onto this zinc oxide-eugenol based
Zinc Oxide (1% Zinc Acetate) - Eugenol

Figure 22.
Kalzinol

Figure 23.
Caulk ZOE B&T

Figure 24.
product. Numerous small voids were found to be scattered through the material.

a. Opotow.

Particular interest was taken in this material as it had been found to have a quite slow setting rate in air. Cross displacement of the base, however, did not occur despite normal condensation procedures (Figure 25). It was noted at the time of packing (seven minutes after the start of mixing) that the material had virtually reached a set. The irregular outer surface of the material along the pulpal wall of the cavity was possibly caused by a slight displacement. The fact that the axially placed aspect of the lining was of relatively even width and showed no signs of displacement suggested that it was more likely that this irregular appearance was attributable to the virtual lack of any "trimming" of the Opotow prior to amalgam condensation. Any "trimming" was made difficult by the material's slow setting rate and "tacky" nature. There was no evidence of fracture of the material.

(131) Calcium Hydroxide Type Materials.

a. Dycal.

Two methods of applying Dycal were investigated:— A thin layer of Dycal was applied to the axial and
Opotow

Figure 25.
pulpal walls of a Class II cavity. Subsequent examination revealed relatively large voids within the lining along the axial wall and on the pulpal wall at the end farthest from the proximal box (Figure 26A). It was apparent that fracture of the Dycal had taken place, at least in the region around the latter of these two voids.

Before placement of the amalgam shown in Figure 26B, several layers of Dycal were applied to the floor of the Class I cavity and the lining was reduced by use of a bar to provide a clinically flat pulpal wall. In the opinion of the operator, condensation was normal onto the Dycal base.

Examination of the section revealed marked displacement, fracture, and crushing of the base at one end of the floor. The remainder of the lining was intact. It was possible that the displacement of the base was associated with a subsurface void in that region, so that the application of pressure during amalgam condensation was sufficient to fracture the relatively unsupported layer of Dycal and allow intrusion of the amalgam.

If this explanation did, in fact, account for the appearance in Figure 26B, it would suggest that great care should be taken in the mixing of Dycal not only to ensure uniform mixing and rapid setting but also to minimize voids, if the material were to be used as a base. However, it
Dycal

Figure 26.
would also cast considerable doubt upon the choice of Busal as a base beneath anaigum.

b. Hydrex.

Rather surprisingly (in view of its slow setting rate in air), Hydrex was found to be one of the most satisfactory materials tested. There was no evidence of either fracture or displacement of the base (Figure 27).

Further discussion of these results has been included in the relevant section of the general conclusions.
Hydrex

Figure 27.
CONCLUSIONS.

The results obtained in this investigation have already been discussed at some length and comparisons have been made with previous work in the various fields. It was considered desirable at this stage to draw together some general conclusions.

1. Setting time.

Of the twelve base forming materials investigated, cloven appeared to have set seven minutes after the beginning of mixing when placed in a simulated clinical situation in extracted teeth.

When allowed to set under normal room conditions — 50-70% R.H. and 20-25°C — Hydro-Eugenol, Dycal and S.3. White Cavity Liner had an initial setting time of 2½-3 minutes. Zinc Oxide (1:1 Zinc Acetate) — Eugenol, Caulk 205, Dycal, Dalton's Zinc Phosphate Cement and S.3. White Zinc Cement Improved reached an initial set 3½-4 minutes after the beginning of mixing while Kalzinol and Kalugen required 5 minutes. The setting times of both Spotex (15 minutes in air) and Hydrex (16 minutes in air) were markedly reduced when the materials were allowed to set under water. When used in a situation simulating clinical conditions, by placing them into moist extracted teeth,
both Opalow and Hydrex had set seven minutes after mixing. A mix of unaccelerated zinc oxide and eugenol required between three and eighteen hours for it to appear clinically set.

2. Early Strength.

In this thesis, particular emphasis has been placed on the early strengths of the base forming materials. Values for the compressive and tensile strengths of many of the materials were frequently recorded at times between four and seven minutes after mixing. For purposes of comparison, the seven minute strength was taken as the indication of the ability of the base forming material to withstand occlusal packing pressures.

a. Compressive strength (storage in air) —

The two zinc phosphate type products — Dalton's and S.S. White — were the strongest materials tested and had 7 minute compressive strengths of 8,200 p.s.i. and 9,000 p.s.i., respectively. Zinc oxide-eugenol based materials were significantly weaker. Zinc Oxide (1:1 Zine Acetate) — Eugenol, Guggenheim's Hydro-Eugenol, and S.S. White Cavity Lining possessed 7 minute strengths of between 4,100 p.s.i. and 6,500 p.s.i., while Kaisinol (2,700 p.s.i.) and Kalsogen (2,200 p.s.i.) were still
Dycol, a calcium hydroxide preparation had a compressive strength of only 630 p.s.i. at seven minutes.

Gauld 1962; 1965; Hyndez and Gatoz were unable to be tested satisfactorily at seven minutes following storage in air.

Because it did not set in air or water until seven hours after mixing, it was not possible to determine the early compressive or tensile strengths of unaccelerated zinc oxide-eugenol.

b. Tensile strength (storage in air) —

Once again, the two zinc phosphate cements were the strongest (600 p.s.i.), and Dycol, the weakest — 7 minute tensile strength of 210 p.s.i. Other materials possessed values of from 500 p.s.i. to 525 p.s.i. at seven minutes. A feature was the quite low tensile strength of Zinc Oxide (15% Zinc Acetate) — Eugenol at seven minutes.

It is not at all certain exactly what strength is required by a base forming material to ensure resistance to the forces exerted during amalgam condensation. Cheng et al (1967) suggested that the critical compressive strength lay between 100 p.s.i. and 170 p.s.i. If this be the case, then the eleven base forming materials, which have set by the time the amalgam is ready to be condensed, would possess more than adequate strength.

The compressive and tensile strengths of the two zine phosphate cements investigated continued to increase up to one week after mixing. When tested at or before one hour, the difference in either compressive or tensile strength between these two materials was not significant at the 95% level of confidence.

At one week, after storage in air, the compressive and tensile strengths of Dalton's Zine Phosphate Cement were significantly greater than values recorded for C.S. White Zine Cement Improved. Both materials had quite high one week strengths when compared with the one week strengths of the other materials investigated.


Unaccelerated zine oxide-eugenol sets very slowly. Unless air-drying condensation is delayed until a subsequent appointment, this material is of little use as a base. Valid results could not be obtained for the compressive and tensile strengths of the material at any time of testing.

Many of the accelerated zine oxide-eugenol materials investigated appeared to be considerably stronger at seven minutes and one day than products studied by Chong et al. (1967) and Swarts et al. (1963).
Zinc Oxide (Zinc Acetate) - Eugenol, Kalsinal and Kalsogen, three quick-setting materials, showed a statistically significant reduction in compressive strength from one day to one week. This evidence supports similar observations made by Messing (1961), Swarts et al (1963) and Civjan and Brener (1964). The suggestion that modified zinc oxide-eugenol materials should be left until a subsequent appointment to enable them to gain sufficient strength to resist anaesthetic packing pressures has not been substantiated.

Very little information has been made available about the exact content of the commercial quick-setting zinc oxide-eugenol products. Variations in composition probably accounted for the peculiarities observed in particular materials. Smith 202 RM possessed too much flow at seven minutes and one hour to enable a valid test, but at one week, it was the strongest zinc oxide-eugenol type product tested. While it had a good 7 minute compressive strength of 4,200 p.s.i. and the highest measurable 7 minute tensile strength for a zinc oxide-eugenol product, 5,3. White Cavity Lining shattered almost on touching after one week's storage in air.


This investigation confirmed the slow setting rate of this material in air (on a glass slab) -- a desirable
feature for a luting material. Subsequent examination of the effect of water storage suggested that Opotex could be successfully used as a base forming material.

Opotex was found to have high one week compressive and tensile strengths of 7,900 p.s.i. and 1,040 p.s.i., respectively. Although significantly weaker than the zinc phosphate materials, Opotex and Castil 502 IC were markedly stronger at one week than other zinc oxide-eugenol based materials.


The compressive and tensile strengths of Dycal and Hydrex continued to increase with time after mixing. After storage in air, the compressive and tensile strengths of Dycal were significantly higher than corresponding values for Hydrex, at all times of testing.

While the compressive strengths of these two materials were very low, the tensile strengths were only slightly less than for the weaker zinc oxide-eugenol based materials.

Rapid setting of Dycal and Hydrex required considerable care during mixing to ensure thorough blending of the base and catalyst.
7. Surpfluent's Hydro-Eugenol.

This product, based on zinc oxide and eugenol and containing 20% calcium hydroxide, was the most rapidly setting material investigated.

Unlike most quick-setting zinc oxide-eugenol materials, the one week compressive and tensile strengths were significantly greater than the seven minute values. This tendency to increase in strength with time was possibly related to the calcium hydroxide content of the Hydro-Eugenol.

The effect of this material upon direct contact with pulpal tissues would be of definite interest. Further development of products of this type — containing both a zinc oxide-eugenol and a calcium hydroxide portion — would seem to depend to a large extent upon their use as relative linings in cases of near and frank pulpal exposures.

8. The Relationship between Compressive and Tensile Strength.

The results indicated a fairly steady relationship between the compressive and tensile strengths of each material. Different materials, however, possessed different C.S./T.S. relationships.

Zinc Oxide (50% Zinc Acetate) — Eugenol had the
highest 6.0:2.5:6.0 ratio of approximately 13.5:1 and Dyecal and Hydrex, the lowest — approximately 6.0:1. The remaining materials of the zinc phosphate and zinc oxide-zinc acetate variety possessed approximate values between 6.0:1 and 11.0:1.

9. The Effect of Water Storage on Compressive Strength.

Storage in water after mixing, markedly accelerated the setting of Hydrex and Opotov (two of the most slowly setting products when stored in air).

Water storage had very little effect on the early strength of each tested material with the exception of Kolceinol which indicated a significant reduction in early compressive strength when exposed to moisture.

At one week, all materials with the exception of Kolceinol, possessed lower compressive strengths under conditions of water storage. Dalton's Zinc Phosphate Cement, Camel 205 Res and Dyecal showed a significant reduction. S.S. White Zinc Cement Improved, Zinc Oxide (4.5 Zinc Acetate) — Eugonol, Opotov and Hydrex had a modest lower one week water-stored strength, but the reduction was not significant. Kolceinol's one week water-stored strength of 5,230 p.s.i. was significantly greater than a corresponding value after storage in air.

The general reduction in one week strength following
water storage was possibly associated with the leaching effect described by Vernon (1940).

10. The Powder/Liquid Ratio.

a. Air Storage.

(i) 0.9. White Zinc Cement Improved — The compressive and tensile strengths of all four consistencies increased with time after mixing.

The ten minute strength was found to increase directly as the powder/liquid ratio was increased. Correspondingly, the setting time decreased with the addition of increased amounts of powder.

(ii) Zinc Oxide (1/3 Zinc Acetate) — Eugenol — The ten minute compressive strengths of the two mixes of higher powder/liquid ratio were not significantly different. Each of these was however significantly stronger than the mix of lowest powder/liquid ratio.

As with the zinc phosphate material, the setting time was shorter for a mix of higher powder/liquid ratio.

b. Water Storage.

After storage in water both the zinc phosphate and zinc oxide-eugenol materials were significantly stronger at ten minutes when mixes of higher powder/liquid ratios were employed.
At all other times of testing of either material type, the differences in the compressive strengths of the two tested consistencies were not significant.

To attain rapid setting and high early strength of the base forming materials, results indicated the need for a thick mix.

11. The Effect of Ambient temperature on the Compressive Strength.

Broadly speaking, variations in ambient temperature did not have a marked effect on the compressive strengths of the materials investigated.

Average room temperatures (21-25°C) were generally more desirable than cold or hot extremes in the attainment of high early strengths for both zinc phosphate and zinc oxide-eugenol type materials.

12. Test Procedures.

The method adopted to pack the base forming material into the mould proved to be satisfactory for all consistencies investigated.

Results obtained for the compressive strength of the base forming materials possessed large standard deviations
regardless of the care taken to ensure uniform mix of material and accurate placing of the ends of the specimen.

The use of the axial compression test to determine the tensile strengths of base forming materials yielded valid results (see Materials and Methods). A study of the different compressive strength - tensile strength relationships for various materials made it apparent that this test was measuring a property other than compressive strength.

13. Practical Application in Extracted Teeth.

The ability of the base forming material to resist fracture or displacement has been widely used as an indication of the adequacy of the cement's strength.

The pressure of voids in a mix not only lowers the density of the material but also renders it more susceptible to fracture and/or displacement. Large voids, in particular, are likely to result in fracture and crumbling of the overlying unsupported material when subjected to pressures likely to be exerted in amalgam condensation.

Displacement of the base forming material by packing forces (as seen, for example, with the unaccelerated zinc oxide-eugenol cement — Figure 21A) is likely to (1) result in contact between amalgam and dentin. In this
way the insulatory effect of the base is lost and the likeli-
hood of postoperative hypersensitivity to heat and/or cold
is increased;

and (ii) lead to eventual marginal failure of the
restoration. The extrusion of material at the margin of the
cavity and its subsequent loss provides a site for recurrence
of caries.

Fracture of the base forming material, per se, is
unlikely to significantly alter the capacity of the restora-
tion to fulfill requirements. In the absence of voids it is
unlikely that the forces exerted in analogy condensation are
sufficient to crush the cement lining. However, the majority
of the base forming materials are unable to be mixed without
the incorporation of air voids. Fracture of the material and
subsequent crumbling around a relatively large void then
renders the material liable to failure for similar reasons as
were mentioned above in reference to a displacement of the
material.

Zinc phosphate products have been widely acknowledged
as satisfactory base forming materials, at least in so far as
their resistance to fracture and displacement was concerned.
With this in mind, it can be deduced from this investigation
that slight fracture of the base and the presence of small
voids within and around it do not constitute a threat to the
satisfactory functioning of the lining. Displacement of the base, on the other hand, is likely to seriously affect the prognosis (see unset, unaccelerated zinc oxide-eugenol — Figure 21A).

On the basis of this clinically related segment of the investigation, it can therefore be concluded that clinical consistencies of S.C. White Zinc Cement Improved, Zino Oxide (as Zino Acetate) — Eugenol, Polished, Castile; Z.O. RX, Ormol, and Hydrox do possess sufficient strength to be used as bases beneath amalgam. In the light of earlier results, it can be inferred that Dalton's Zinc Phosphate Cement, Kalsogen, S.C. White Cavity Lining and Surgeon's Hydro-Eugenol similarly fulfill the necessary requirements. A knowledge of the early strengths of Lyocel and Hydrox indicates that Lyocel is a satisfactory material if voids can be minimised. If this is not possible, then the inadequacy of this material is open to conjecture. Unaccelerated zinc oxide-eugenol cement is of little use in a clinical situation. In the unset condition, its use is contraindicated.

Clinically, should the dentist observe—

(i) tendency for the base to become incorporated within the amalgam and/or

(ii) the base extending at the margin of the cavity and/or

(iii) postoperative hypersensitivity to heat and/or cold,
he should suspect the use of a base forcing material not yet
set at the time of amalgam condensation and/or the use of a
material possessing inadequate strength at this time of
clinical importance.
1. Biologically, the use of a zinc oxide-eugenol or calcium hydroxide type base seating material is most desirable. Zinc phosphate cements should be avoided except in relatively shallow cavities and, when used, should be separated from underlying dentine by a layer of a copal varnish.

2. The compressive and tensile strength properties of twelve base seating materials have been investigated.

3. Variables considered likely to affect the early strengths and setting rates of the materials have been studied.

4. By the use of extracted teeth, the results have been related to a simulated clinical situation.

5. The results indicated the need for a thick mix to ensure rapid setting and high early strength of the base seating materials.

6. The minimum strength required by a base seating material has not been established.
analgesic condensation was found to be contraindicated.

7. Although they had relatively low early strengths, the calcium hydroxide preparations probably possessed adequate strength in the absence of large air voids within the material.

8. The results of this investigation suggest that all base forming materials, which are clinically set at the time of analgesic condensation, possess adequate strength to withstand applied forces.
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