THE DURABILITY OF AMALGAM RESTORATIONS

RELATED TO CAVITY LININGS

A Thesis submitted to the University of Sydney in support of my Candidature for the Degree of Master of Dental Surgery.

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The original work presented in this thesis has been carried out by me as an individual research project.

Clinical work has been conducted within my private practice and the laboratory investigation has been conducted in the research laboratory of the Department of Operative Dentistry, University of Sydney.

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PART ONE

A REVIEW OF THE LITERATURE
INTRODUCTION
INTRODUCTION

G. V. Black's definition of a "permanent restoration" demands critical evaluation by all who claim to provide their patients with permanent restorations; "permanent" he defines as "continuing in the same condition or state without marked change."

Whereas silicate cement restorations are accepted as being a short term measure, restorations using amalgam and most other restorative materials have come to be considered as being permanent. However, Moore and Stewart (1967), in a survey of 6,500 teeth, found that 45% of amalgam restorations were defective in some way; they found that of all operative procedures required for adults, 62% were due to primary caries, and 38% due to defective restorations. This means that more than one third of the operative effort was consumed by replacing previous restorations!

It is the responsibility of every practitioner to place more emphasis on his ability to provide durable restorations; to give his utmost attention to those factors which will increase the life expectancy of his amalgam restorations. Although the ideal restorative material is yet to be developed, it is the professional duty of every practising dentist to use techniques which will produce optimal results with the materials of choice.
The aspects of cavity preparation and physical properties of amalgam have been well explored and extensively investigated and documented. One aspect of the amalgam restoration, little investigated and about which controversy exists, is the part played by the cavity lining and its strength as a factor in the durability of the restoration. For example, Phillips (1965) doubts that the strength of the base is of great importance in the fracture of amalgams. Chong et al (1967) state that "the clinical significance of the compressive strength of the base material has not been defined," but Rowe (1964) states that "various bases modify the resistance to fracture of amalgam; bases with the greatest compressive strength give amalgams greater resistance to fracture."

The purpose of this investigation is to examine the relationship between the compressive strength of commonly used base materials and the durability and resistance to fracture of the restoration in service, and to attempt to clarify this controversial aspect of the amalgam restoration.
CHAPTER ONE

FACTORS AFFECTING THE DURABILITY OF AMALGAM RESTORATIONS

Healey and Phillips (1949) in a study of amalgam failures, grouped the types of failures into four categories:

1. Gross fracture
2. Dimensional change
3. Recurrent caries
4. Periodontal and pulpal complications

1. **GROSS FRACTURE**

The most important factor involving the amalgam material itself appears to be faulty manipulation of the amalgam, with occlusal trauma involved in a small percentage of cases only. The major cause of failures overall was found to be poor cavity preparation in the study done by Healey and Phillips (1949) but fracture of the restoration accounted for 398 failures, recurrent caries for 850 failures, and dimensional change for 300 failures. In this study, 325 out of the 398 fractured restorations were considered to fail due to faulty manipulation of the amalgam, 7 due to occlusal trauma, and 66 due to cavity preparation. Overall, this study showed that 40% of all failures were due to faulty manipulation of amalgam, and 60% were due to faulty cavity preparation.
Fracture of restorations can be said to be of two types:

A. Bulk fracture
B. Marginal fracture.

A. Bulk Fracture: The actual stress developed in the restoration in service depends on the shape of the amalgam mass and the nature of the applied force. Stresses can be compressive, tensile or shear, or any in combination. Amalgam, being a brittle material, is strong in compression but weak when subjected to tensile stresses - and cavity design must take this into account.

When bulk fracture does occur, the most common causes are failure to develop optimum physical properties in the amalgam, inadequate bulk of amalgam, or occlusal trauma. Bulk fracture of Class I amalgams is not frequently observed unless the restoration has been undermined by recurrent caries, as the resistance to the forces tending to fracture the restoration are more favourable than in the case of the Class II restoration. However, bulk fracture can result from inadequate depth of amalgam resulting either from insufficient removal of tooth structure or possibly careless placement of the cavity base.

The most commonly observed fracture of the Class II restoration occurs at the isthmus or part of the proximal box, where the amalgam is not supported entirely by tooth structure. Brodhurst (1964) in a survey of 1,364 first molars found ten instances of amalgam
fracture and attributed all these to failure to provide adequate depth for the bulk of amalgam and inadequate retention. Healey and Phillips (1949) also believed this to be the most common cause of failure of restorations which fractured in service.

Attalia and Gibb (1968) blamed inadequate condensation of the amalgam as being the underlying cause of the mechanical failure of restorations. However, an investigation by Nadal et al (1961) showed that amalgam with a narrow isthmus were no more prone to fracture than those with a very bulky isthmus; an investigation by photo-elastic methods showed that stress concentration was reduced by rounded line angles and shallow proximal cavities, Mahler (1958). Lampshire (1955) studied the effect of cavity design on the fracture of Class II restorations, and found that fracture could be minimised by ensuring an isthmus width of about one quarter of the bucco-lingual width of the tooth, rounding the pulpal floor and the axio-pulpal line angle. Further consideration of this aspect is considered to be outside the present purposes of this investigation, and the subject has been well documented in the literature.

It must be recognised that many of the factors involved with regard to the physical properties of the amalgam are also concerned in the fracture of amalgam restorations in service. However, it must also be emphasised that cavity design is the most important single factor, and cavity design must take into account the nature and properties of the material.
B. Marginal Fracture: "Marginal fracture" refers to the loss of integrity between the tooth structure and the restoration, allowing oral fluids to seep into the margin. Amalgam cannot withstand impact loading in small sections. Again, cavity preparation is most important, but marginal fracture can result from corrosion and inadequate physical properties of amalgam, and this type of failure is commonly observed by the practising dentist in varying degrees.

The term "edge strength" has been used in describing the physical properties of amalgam at the restoration margins. This term involves compressive strength primarily, but also includes shear strength and tensile strength as being important in the resistance of the amalgam to bending under load.

Marginal deterioration and fracture becomes progressively severe as the residual content of the mercury in the restoration increases. High mercury content also results in surface roughness, and dimensional change will be increased. Mercury analysis has shown that it is not uncommon to have a residual mercury content of up to 60% (Nadal et al, 1961). These investigators pointed out that even with the most meticulous technique, there is always some deterioration at the margins, but they found that surface roughness and deterioration became quite severe when the mercury content rose above 58%. The strength of the amalgam falls sharply when the residual mercury content rises above 55%. Nadal and his co-workers attributed most failures to this cause, and claimed that in their survey, no failures could be attributed to flow or dimensional change.
Baumgartner et al (1963) examined restorations that had been in service for five years or more, using both clinical, histological and isotope methods of investigation. All restorations showed marginal leakage and deterioration, the most frequent occurrence being at the gingival wall. However, they felt that the only basis for replacing a restoration was the presence of recurrent caries, and cautioned that in investigations of this nature, clinical evaluation alone was unreliable.

By contrast, Healy and Phillips (1949) felt that the most common cause of failure was the insufficient removal of tooth structure, insufficient bulk at the isthmus or elsewhere, and inadequate extension for prevention. Phillips admits (1966) that some failures have not been completely explained, particularly marginal deterioration and corrosion. Deflection of the margins under load may allow a small slit to develop between the cavity wall and the amalgam; then fracture, possibly undetected, may occur, allowing debris into the space resulting in further electrolytic corrosion and thus further deterioration of the margin. Two corrosion mechanisms exist: complex sulphides form along the cavity margin wall, and occlusal and proximal amalgam surfaces can be attacked, the fine grain alloy matrix becoming encircled, resulting in the dislodgment of small chips under stress.
Jorgensen (1965) described marginal fractures as being caused by either pressure or tensile forces, describing them as illustrated:

![Diagram of marginal fractures](image)

The fracture of type A was most predominant in practice, and these fractures predisposed to poor hygienic conditions along the margins of the restorations.

Jorgensen determined that the maximum load which could be withstood without failure of the amalgam was roughly proportional to the square of the wedge angle (Va and Vb in sketch). The maximum deflection of the amalgam will depend on the width of the slit between the amalgam and the cavity wall (see below). With a very small slit, the amalgam will deform elastically under load, but repeated application will cause a fatigue fracture. Wilkinson and Haak (1958) pointed out that in practice, amalgam restorations are subjected to fluctuating stresses, and the fatigue strength is thus
of greater importance than the static crushing strength. These investigators studied fatigue failures using a Sonnlaag Universal Fatigue Testing machine, and the results showed that whilst a restoration might withstand a static pressure of up to 63,000 psi or infrequent short duration stress applications of the same intensity, the highest fluctuating stress which the same amalgam may be expected to withstand is only 14,000 psi, only 22% of its maximum crushing strength.

However, all this presupposes that there is a slit between the amalgam and the cavity wall. "Micro-fractures" can indeed occur, but only "macro-fractures" are of clinical importance. Jorgensen (1965) believes that such slits are primarily caused by corrosion. Schoonover and Souder (1941) demonstrated that corrosion will consistently occur on the amalgam surfaces enclosed by the cavity walls, and that corrosion products can be found in these areas, together with a considerable loss of strength of the amalgam. Jorgensen has more recently (1965) demonstrated corrosion products up to 50 microns thick between amalgam and the enamel wall.

Jorgensen believes that the fracture of amalgam margins is due primarily to the deflection of the amalgam margin by the process of corrosion. The following sketch shows the margin (M) has bent away from the cavity wall and is porous due to the advancing corrosion; fracture is, therefore, likely to occur at the point illustrated.
Normally, the slit between M and the enamel E is not filled with corrosion products. The slit is not due to loss of amalgam, but is due to the deflection of amalgam. Jorgensen's explanation is that during corrosion mercury is set free; the amalgam against the cavity wall is anodic, whilst the free amalgam surface is cathodic. The corrosion attacks particularly the tin-mercury phase, and the mercury liberated diffuses into the amalgam from the cavity side causing this part of the amalgam to expand. This unilateral expansion causes the deflection of the margin. Although Jorgensen believes that the deformed amalgam margin is
always empty, others — such as Fisher and Mertensmeier (1965) — have suggested that this deformation is due to the thrust of corrosion products, and the exact nature of these mechanisms is controversial.

In addition to corrosion, Jorgensen also believes that delayed expansion is also a cause of marginal deterioration, and that this factor is greater when the cavity walls are very smooth, or when there are slightly diverging cavity walls in the marginal areas.

Type B was the more common, and was due to the slight divergence of the cavity walls in the marginal areas.
Faulty methods of condensation also contribute to the occurrence of marginal fractures. It is often easy to displace amalgam from areas already condensed, and this can result in slits of appreciable size developing.

The flow of amalgam was also considered to be a cause of similar slits; marginal excess can chip and crack after numerous temperature changes, and unsupported enamel can break off. However, Jorgensen believes that all these are of relatively infrequent occurrence.

Wolcott (1958) has also emphasised the importance of sharp, right-angled butt joints at the cavo-surface angles, and has demonstrated ditching of the amalgam due to the weakening of the margin by the bevelling of the preparation and the deep carving of the restoration. Overcarving of the amalgam can leave thin, acute-angled
sections at the cavity-surface margin that will encourage failure in this area. Phillips (1949) found some marginal deterioration in amalgams in a clinical survey, and found that both the number and severity of the failures increased as the residual mercury increased.

Jørgensen and Palbol (1965) found that under experimental conditions, fracture of the amalgam margins occurs earlier with reduction of the marginal angle, and the depth of the marginal fracture increased as the marginal angle was reduced.

It is interesting to note that non-zinc alloys may produce amalgams with a higher incidence of marginal deterioration than zinc-containing alloys. In a study carried out by Wilson and Ryge (1965), six different alloys were used to place 1,425 restorations which were evaluated over a period of at least one year. They found that non-zinc alloys gave greater marginal deterioration than alloys containing zinc, and that coarse-cut alloys gave poorer surface characteristics. However, they also emphasised that manipulative variables greatly influenced clinical success. Photographs taken during this study showed a much greater incidence of marginal breakdown than is recorded by clinical inspection, and they stated that marginal weakness is an intrinsic inadequacy of amalgam restorations.

In a clinical survey of 32 restorations, Matsumo and Fusayama (1970) used a photographic record at three monthly intervals to observe the marginal deterioration of Class I restorations. Within a year, all the restorations developed marginal defects, most of the
fauls being observed within the first six months, and taking the
form of ditching of the margin. There were no other types of
failures observed in this series. These investigators pointed
out that it is almost impossible to finish the amalgam margins per-
fectedly, and that the amalgam flash may not be readily observed upon
completion of the restoration; it was the fracture of this flash
that caused the defects described. Their recommendation was that
all restorations should be recalled and refinished six months after
insertion, when most defects will be observed and recurrent caries
will not yet have occurred.

McCrae et al (1962) found that the incidence of marginal
defects was significantly reduced by removing weakly supported cusps
and replacing them with amalgam. They also found that failure of
the amalgam itself was responsible for more failures than the break-
down of enamel. However, if weak cusps are removed, and pins are
used to support the restoration, it is important that the pins should
be of such a length that there is four to five mm. of amalgam above
the pin, for if the pin protrudes above the surface, galvanic corro-
sion can result and weaken the restoration in this area (Wing,
Feb., 1965).

In 1960, Ambrose claimed that the carving of the amalgam
surface was of importance in relation to the breakdown of both the
amalgam and the tooth structure. Poor carving would encourage
early breakdown as the forces of mastication are better resisted if
if anatomical contours are reproduced, and the forces needed for the mastication of food will be less when proper cutting and escape channels have been reproduced, rather than blocks of alloy sitting on the tooth. He also suggested that in many cases, reduction of the opposing cusps can be carried out, rather than reducing the bulk of amalgam to accommodate the cusps.

When polishing the restoration, care must be taken to avoid developing excessive heat in the restoration, as it has been claimed that this will draw mercury to the surface of the amalgam and result in a loss of strength at the edges of the filling and prevent a lasting polish (Atalla and Gibb, 1968).

The question of the marginal adaption of the amalgam to the cavity walls has been extensively investigated in recent years, and it is relevant to consider some of these investigations at this point, as they have a direct bearing on our understanding of the causes of marginal fracture as seen clinically.

No matter how carefully the amalgam is condensed, there will always be a slight space between the amalgam and the cavity wall. Wing and Lyell (1966) showed that spaces of up to 150 microns or more can be found, and that the width of the space became greater as the residual mercury content became higher. They found that the space between a well condensed amalgam and the cavity wall was between six and twenty-one microns, but a poorly condensed amalgam can have spaces of up to 21 to 45 microns. The spaces at the cavo-surface
area tend to be greater than those along the wall of the cavity; the reason suggested for this was that there was a higher mercury content in this area and the mass was less restricted. Lack of adaptation was most marked when attempts had been made to pack mercury-rich amalgam into line angles, and it was in these areas that the very large spaces were found. Although poorly condensed amalgam expanded up to 20 microns per centimetre, spaces were still much larger than in the case of well condensed amalgams which expanded only 5 microns per centimetre. It was suggested that the surface tension of mercury-rich amalgams causes a spheroiding of the amalgam than its subsequent expansion. Swartz and Phillips (1962) had earlier shown that expansion and contraction of the amalgam during setting did not appear to affect the adaptation of the amalgam to the cavity walls appreciably, and that expanding and contracting alloys showed similar leakage patterns.

Other attempts to measure the size of the space between the amalgam and the cavity wall have been made. Lees (1962) used an ultrasonic probe to measure the size of the space, and found that under ideal conditions the space was from fifteen microns down to one micron. This was considered to be quite large enough to permit large molecules and micro-organisms to penetrate along the interface. Although the freshly placed amalgam is penetrated readily, the aged amalgam was found to have a most efficient seal.
Hatt (1959) examined the space between the amalgam and the cavity wall in relation to the method used to condense the amalgam. The quality of the relationship of the amalgam to the cavity wall was assessed by the use of a Talysurf Analyser. Using a condensation pressure of 2,800 psi, which he regarded as being ideal, he found that the use of a condenser point that had an outline which enabled it to gain access to the line angles of the cavity and the angles formed by the cavo-surface angle and the matrix band was most satisfactory, and that the average size of the spaces resulting from such a procedure were 61 micro-inches (1.5 microns) between the amalgam and the wall, and 76 micro-inches (1.9 microns) along the cavo-surface angle. When a condensing point of circular outline was used, the figures were 66 and 140 micro-inches (1.7 and 3.9 microns respectively).

However, in addition to the force used and the shape of the condenser point, we must also consider its size, the number of thrusts on each increment of amalgam, the number and size of the increments, and the time of application of the force. Wing (1965) has pointed out that the condensation of the amalgam into the cavity is perhaps the most important single variable in the manipulation of amalgam. He regarded a force of from six to ten pounds on a condenser point of 1.5 mm. was necessary; the compressive strength continued to improve at loadings higher than ten pounds, but these forces were not practicable in the mouth. Wing also pointed out that there is
a relationship between the size of the cavity and the size of the condensing instrument required for optimal condensation. At low condensing loads, a point of approximately one quarter of the diameter of the cavity is most effective, whilst at higher condensation loads the ratio of the condenser width to the cavity is closer to 1:3. The most important factor of all, however, was the size of the pieces of amalgam introduced into the cavity. In clinical practice, where relatively low condensation loads are used, the size of the increments assumes even more importance, as a very small increment may be completely condensed through its whole thickness even by a small load. Ambrose (1960) has stated that if the initial condensation of alloy into the bucco-gingival and linguo-gingival line angles is inadequate, the subsequent condensation of further increments, even with very heavy condensation loads, will not rectify the problem of the uncondensed amalgam in these critical areas.

Peyton and Liatukas (1961) also investigated condensation forces, and found that light packing forces were associated with over-expansion, excessive flow and loss of strength in the restoration. They regarded a condensing force of eight to ten pounds on a 2 mm. plugger as being the maximum clinically acceptable, and showed that after one hour an amalgam packed with a pressure of two to four pounds would show a loss of strength of between 16% to 45%, and with six to eight pounds a loss of 5% to 20%, as compared to an amalgam packed
with a pressure of eight to ten pounds. The higher condensing force gave a lower residual mercury content, and thus better physical properties.

In recent years, new types of alloys have been introduced, notably "micro-cut" and "Spherical" alloys, with some claims of superior properties. Mitchem and Mahler (1969) investigated micro-cut alloys and found that they set faster and have very smooth carving characteristics, but they produce amalgams with 3% higher marginal mercury content and were less well adapted at the margins; the advantages of this type of alloy were, therefore, questioned. Wing (1970) investigated the properties of spherical amalgams; he found that although this type of amalgam has the ability to flow ahead of the condenser point into channels at right angles to the direction of condensation, and gives the appearance of superior adaptation to the cavity walls, in actual fact the best adaptation was found in well condensed lathe cut amalgams (ten pounds condensing pressure) where spaces in the order of 5 – 10 microns were found under experimental conditions. With all types of spherical amalgam tested, with a three pound load, spaces with an average width of 7 – 10 microns were observed. Again, low condensation loads were found to greatly affect the width of spaces with lathe cut alloys, spaces in the order of 25 – 30 microns being found with a three pound condensing force. However, if mercury has not been removed from a spherical amalgam during condensation, spaces of 10 – 15 microns were observed. It follows that
while spherical amalgams have similar properties to lathe cut amalgams when well manipulated, the use of spherical alloys may be advantageous in cases where there is some difficulty in proper condensation.

The burnishing of amalgam margins has long been discouraged, mainly on the grounds that it will raise the residual mercury at the margin and thereby increase the rate of corrosion and decrease the strength in the area. However, it has recently been claimed that burnishing will improve the marginal seal (Kato et al, 1965). Phillips (1953), while emphasising the importance of alloy manipulation, stressed that the amalgam must be carved within two minutes, and that the margin should not be burnished, as this would draw excess mercury into this area, thus weakening the amalgam and making it more susceptible to tarnish and corrosion. Sweeny (1944) also cautioned against stepping with small pluggers, or burnishing the amalgam during condensation and finishing. He felt that soft amalgam would be pushed ahead of the instrument, weakening the amalgam at the margins and sharp angles.

Ambrose (1960) also claimed that any burnishing of the amalgam margins was contra-indicated, as this will leave a mercury-rich surface which will contribute to early flow and pitting of the restoration.

However, Kanai (1966) claims that the opinions of Sweeny, Phillips and others were mainly based on speculation, and not supported by experimental evidence. Kanai investigated the effect of burnishing on the occlusal margins by measuring the area of residual grains of the micro-pores in the metallographic preparations. His
study showed that burnishing tends to decrease the residual mercury at the margins, especially when the cavities were not over-filled. Micro-pores were noticeably decreased by burnishing; thus the physical properties of the margins were improved.

Kato et al (1965) also claimed that burnishing the margins of restorations will improve the marginal seal. Specimens of clear plastic were packed, using conventional procedures but with varying degrees of burnishing of the margins. Then an aerosol dye – capable of penetrating a two-micron crevice – was used to assess the marginal leakage. The results of this study indicate that burnishing not only improves the marginal seal, but also decreases the residual mercury content and eliminates porosities, and provides a smoother surface for polishing. Best results were had by burnishing after condensation, and again after the carving of the restoration.

The use of varnishes prior to the insertion of restorations has also received some attention of late. Barber et al (1964) reported that copal resin varnish will effectively seal margins of amalgam restorations. A freshly placed amalgam will leak freely, but as the amalgam ages, the marginal defects are reduced or eliminated. This was attributed to corrosion products from the amalgam itself, or to products from the saliva, filling the interface between the amalgam and the cavity walls. In this study, leakage was assessed by immersing the restored teeth in dye and isotope tracers,
and after seven days these were sectioned and autoradiograms made to assess the degree of penetration of the tracers. The conclusion was that copal resin varnish would effectively seal the margins of Class II and Class IV cavities to the tracers when both the floor and the walls were covered by the varnish immediately before condensation of the amalgam. However, Harrison (1966) showed that varnishes are not bacteriostatic, nor do they prevent penetration of bacteria between the amalgam wall and the walls of the cavity. This was demonstrated by placing small sterile paper discs beneath restorations and then culturing these after seven days. A series of controls were used without varnish, and cultures taken immediately after the cavity preparation to determine the original bacterial status of the prepared surface. All teeth examined showed positive cultures. It was suggested that to be effective, a liner would have to be chemically bonded to the dentine. Wing and Lyell (1966) also pointed out that the use of varnishes does not reduce the space between the amalgam and the cavity wall, but that it may be effective in providing pulpal protection in the early stages after placement of the restoration. Lyell et al (1964) showed that the marginal interface between the amalgam and the cavity wall can be blocked against ingress of dyes and isotopes by chemical action of saliva and a solution of sodium sulphide. A marked decrease in marginal penetration was observed in specimens after two weeks' storage in
these solutions, and was similar to in vivo specimens placed six months prior to extraction and placing in the solution. Early research reported recently (O'Brien et al, 1969) has indicated that marginal leakage may be reduced by treating the tooth structure with hydrophobic compounds such as silicones or fluorcarbons.

From the above discussion, it appears that reduction of corrosion and the marginal fracture of restorations in service can be achieved by ensuring minimal dimensional change of the amalgam, good adaptation to the cavity walls, low residual mercury, parallel marginal walls, and a carefully polished marginal angle as close as possible to a right angle.

2. DIMENSIONAL CHANGE

Healey and Phillips (1949) claimed that 16.6% of the failures they observed were due to excessive expansion, and 2.5% were due to excessive contraction, even though the residual mercury contents were up to 62% in some cases. The main factors involved in excessive dimensional change are moisture contamination and a high mercury content. Phillips (1955) has shown that the main factor in delayed expansion in amalgams is moisture contamination. The zinc in the alloy reacts with water releasing hydrogen; this gas so formed can produce pressures between 1600 and 2200 psi within the restoration, resulting in protrusion of the restoration from the cavity, pain from pressure on the pulp, and blister formation on the surface of the filling.
The part played by flow of the amalgam after placement is much debated. Ward and Scott (1935) implied that flow was responsible for marginal failures, but other investigators have felt otherwise. Nadal and Swartz (1961) did not believe that the flow of amalgam was of clinical significance. Phillips (1953) defined "flow" as the measure of the ability of the restoration to retain its shape under constant load. He believed that a high flow value would lead to overhanging margins, flattened contact points, and protrusion from the cavity preparation. It has been claimed that delayed expansion will cause deterioration of the margins of the restoration, with the possibility of marginal fracture resulting (see discussion on Page 9). Terkla and Mahler (1964) pointed out that whilst the exact clinical significance of extrusion may not yet be well defined, it is reasonable to assume that such a condition is deleterious to the integrity of the restoration.

Baumgartner et al (1963) examined restorations that had been in service for five years or more, using both clinical, histologic and isotope methods of testing. All restorations showed marginal leakage, the most frequent occurrence being at the gingival floor. They found that in the case of Class V restorations, that a better seal was obtained by condensing the amalgam against all walls, rather than simply condensing against the axial wall. These investigators also cautioned that their studies had shown that clinical investigation and evaluation alone was unreliable.
Mahler and Van Eysden (1969) have recently investigated the deformation characteristics of amalgam (termed "dynamic creep") when subjected to test conditions approximating those found in clinical usage, in order to investigate the clinical phenomenon of the extrusion of restorations from the cavity. They found that amalgams conforming to A.D.A. Specification No. 1 showed differences in dynamic creep by as much as four times or more. An increased mercury content increases the dynamic creep; the dynamic creep of an amalgam with a mercury content of 53% was found to be one and one-half times greater than that of an amalgam with 48% mercury. Trituration had little effect, but it was found that excessive trituration tended to increase the dynamic creep. It was found that amalgams made from alloys with high creep properties showed a significantly higher incidence of marginal fracture after one year's service. Extrusion of amalgam was observed when Class II restorations in brass dies were subjected to occlusal force cycling between 5 and 25 pounds compression. It was, therefore, suggested that the property of dynamic creep may well play a greater role in the clinical behaviour of amalgam than has been believed in the past.

The manipulative variables, therefore, will influence the clinical success of the restoration in regard to dimensional change, and it will be recognised that some aspects of the previous discussion of marginal fractures could possibly be considered as failures due to dimensional change.
3. RECURRENT CARIES

Failures due to recurrent caries are due either to poor oral hygiene, aggravated by marginal deterioration, or by inadequate extension for prevention in the design of the cavity. The latter is squarely the operator's responsibility, as is the former to some extent. In the study of Healey and Phillips (1949) recurrent caries was by far the greatest cause of failure (850 out of 1,548 restorations). Broadhurst (1964) found that caries recurrence is directly related to caries activity, and is more frequent around restorations replacing extensive caries originally. In many cases, secondary caries appeared to be an extension of the original caries attack. He pointed out that recurrent caries is not a property of the restoration per se, but depends on the occurrence of three factors:

1. Non removal of all caries;
2. Susceptibility of adjacent enamel - determined by the level of caries and the pattern of caries attack;
3. The physical condition of the restoration as they predispose to recurrent caries.

In his survey of 1,364 first molars, Broadhurst felt that more adequate extension for prevention should be made in relation to both the degree of the original carious destruction and the pattern of the carious attack, and that the careless removal of caries was a major factor in failures. Amalgam manipulation, condensation and finish-
ing appeared to have little or no bearing on the success of the restoration (Page 74 of thesis). Marginal deterioration was present to varying degrees, but only when severe and associated with marked corrosion, did caries occur. Initial marginal deterioration resulted from chipping of the excess of amalgam at the margin in many cases.

There have been very few studies done on the magnitude of marginal crevices that can be tolerated without recurrent caries developing. Jorgensen and Wakumata determined the figure to be 50 microns (1968). Defects of this order can be easily detected by clinical examination, and they also emphasised that the presence of marginal excess plays an important part in increasing the frequency of recurrent caries, as these extensions fracture in time to create an open margin. Baumgartner et al (1963) believed that although marginal defects were quite common and could be extensive, recurrent caries did not necessarily follow, and that restorations should not be replaced unless recurrent caries had actually occurred.

Some investigators have examined the use of fluoride-containing cavity liners and varnishes as a possible deterrent to the recurrence of caries around the restoration. A clinical study by O'Brien et al (1969) showed that dentine solubility can be reduced by contact with a calcium hydroxide-polystyrene cavity liner to which fluoride compounds have been added. A clinical study showed a lower
incidence of recurrent caries after one year around restorations when a 30% stabilised stannous fluoride solution was used as a varnish. The report was preliminary only, and more research is needed into this possibility. Soremark et al (1969) also advocate a similar procedure. They incorporated calcium mono-fluoride phosphate and potassium fluoroazirconate into chloroform, with zinc oxide and calcium hydroxide. The addition of the fluoride did not appear to affect the physical properties of the liner. Under experimental conditions, the solubility of dentine was reduced and a continuous release of fluoride was observed for a three week period. It was recommended that the liner should be used to cover all prepared enamel and dentine surfaces, and for deep cavities applied on top of calcium hydroxide. This liner will reduce thermal diffusion from the metal restoration to the pulp, but this effect is limited due to its necessary thinness.

4. PERIODONTAL AND PULPAL COMPLICATIONS

A. Periodontal Failure: Quite apart from recurrent caries beneath an overhanging margin, the typical localised gingivitis, with possibly pocket formation and bone loss that follows, can surely be regarded as a failure of the restoration to restore the patient's dental health to an optimum level. The vast majority of matrices MUST be wedged to prevent this, and previous overhanging margins detected and corrected, or the restoration replaced. The relationship
between operative dentistry and periodontal disease has been well
documented (Mosteller, 1953; Stibbs, 1952).

Proper contour and contacts are essential. Instability
of the matrix will not only result in a distorted restoration, but
will invite gross marginal excess and undercondensed amalgam, with
resultant loss of adequate physical properties. It is never safe
to assume that the condensation of the plastic mass will push or
stretch the matrix into the form desired. It is most important
that in the packing of Class II restorations the proximal box
portions be filled with small increments of amalgam, and that each
one be carefully condensed (Wing, 1965). Attempts to fill a prox-
imal box with large increments can result in a restoration that is
almost completely uncondensed at the gingival margin and which will
be porous at the proximal surface. Porosity in this region would
not be eliminated during polishing and may give rise to galvanic
corrosion and general poor hygiene in this area with subsequent
recurrence of caries and possible periodontal problems. Ambrose
(1960) pointed out that if the initial condensation of the amalgam
into the bucco-gingival or linguo-gingival line angles is inadequate,
the subsequent condensation of further increments, even with heavy
condensing loads, will not rectify the problem of the under-condensed
amalgam in these critical areas.

A study by McCrae et al (1962) showed that gingival margin
overhangs were second only to marginal faults in a survey of defects
in Class II restorations. The importance of an adequate matrix technique cannot be over-emphasised. Phillips et al (1956) in an evaluation of the various matrix techniques for the restoration of proximal contour, found that with teeth of all shapes, wedging was imperative in order to prevent cervical flash of amalgam; for ovoid or square-shaped teeth, contouring of the matrix was also necessary. Their data showed that removal of the flash by the operator was unreliable, and contouring and wedging was always needed for optimal results. None of these techniques, however, gave a perfect reproduction of the original surface contours. Ambrose (1960) also claimed that some form of gingival wedging was always necessary, and that such wedging must be carried out with reasonable force to afford some slight separation of the teeth, which will contribute to the establishment of a sound contact point or area. Ambrose also pointed out that attention must be given to the proximal surface of the matrix in order that the proper contour will be restored, ovoid teeth being the most difficult in this respect. Class V restorations must also be contoured with respect to gingival contour and the effect the restoration will have on the impact of food on the gingiva.

5. POST-OPERATIVE PAIN

Thermal diffusion is the most commonly observed factor involved in the occurrence of pain following the placement of the restoration. The thickness of the liner seems to be more important
than its composition (Phillips, 1966). All thermal change can be transferred from the surface of the restoration to the base within three seconds. A lining must be reasonably thick, for if it is 0.2 mm or less, it is of no value at all. Attala and Gibb (1968) have proposed that post-operative pain can be caused by the bending of the elastic dentine by the forces of condensation, causing irritation to the confined pulp tissue. A very rigid base is, therefore, necessary, and their recommendation was that zinc phosphate cement should always be used as a lining, with calcium hydroxide under the cement where necessary. Gilmore (1970) also emphasises the importance of a rigid base and thick dentine support in the prevention of irritation by the forces of condensation, and agrees with Stanley and Swerdlow (1964) that it is not the amalgam per se that causes pulpal irritation, but the condensation of the amalgam causes injury from the pressure applied to the dentine floor. The biological advantages of high speed instrumentation, with minimal pulpal response, can be modified or lost altogether if the restorative material is placed directly over freshly cut dentinal tubules not lined with reparative dentine of a protective base material.

It must not be overlooked that pulpal irritation can follow the injudicious use of cutting tools, and thus cause post-operative pain. In their study of pulpal responses to operative treatment, Swerdlow and Stanley (1962) found "burn lesions" resulting from the use of high-speed instruments; with an air-water spray, these lesions
were confined to the cut dentinal tubules, but if air alone was used, or no coolant at all, the resulting burn lesion could extend completely across the pulp chamber. They found that about 23% of the burn lesions developed into intra-pulpal abscesses, the rest being reversible with the formation of reparative dentine.

A third factor in the appearance of post-operative pain is the possibility of irritation from medicaments or cavity bases used. In the past, it has been common practice to "sterilise" the prepared cavity before condensing the amalgam with such agents as peroxide, creosote, phenol or silver nitrate. Going (1964) has cautioned against the use of any type of medicament; he claimed that the flushing of dentine with chemical agents does much more harm than good, and that they cause irritation to the pulpal tissue, and increase the permeability of the dentine. A more common offender, however, is the use of zinc phosphate cement in deep cavities. This material can still have a pH of 6 at 24 hours (Phillips, 1965) and its use can cause considerable post-operative pain. Most other lining materials are either mildly sedative to the pulp or are at least neutral in their effect. This subject will be considered in more detail in the next chapter.
IN SUMMARY:

The durability of the amalgam restoration will depend on three factors:

1. Care with the cavity preparation:
   - adequate bulk;
   - adequate extension;
   - removal of all caries.

2. Careful manipulation of the amalgam to develop optimum physical properties.

3. The restoration of anatomical contour.
CHAPTER TWO

TYPES OF CAVITY BASES

There are three basic requirements for a material intended for use as a cavity base:

1. It must encourage the recovery of the pulp from irritation resulting from the cavity preparation;
2. It must allow good condensation of amalgam, by resisting the pressure on the base during condensation;
3. It must protect the pulp from irritation associated with the amalgam restoration.

The three basic types of cavity bases available to the practitioner will be evaluated from the recent literature in relation to the above requirements.

1. PULPAL RECOVERY

   A. Zinc Phosphate Cements: Zinc Phosphate, with its ultimate crushing strength in the region of 16,000 psi is by far the strongest base available. However, at the time the amalgam is condensed, the strength is somewhat lower; Bryant (1968) gave the seven minute strength of zinc phosphate cements as being between 8,000 and 9,000 psi, the strength at seven minutes being taken under laboratory
conditions as being an indication of the ability of the material to withstand clinical packing pressures. These figures were determined for mixes of the consistency normally used when zinc phosphate is employed as a cavity base; when mixed to a thinner consistency for use as a cementing medium, the strength is much lower. Lyell (1960) found that cements had strengths of 2,000 to 3,000 psi at three minutes after mixing when mixed to standard consistency, which is between the consistency of inlay cement and clinical base forming cement. Unfortunately, zinc phosphate is very irritant to the pulp. It has been shown (Massler, 1965) that the cement can still contain free acid after twelve hours from the time of placement. When placed over old or sclerotic dentine, it can stimulate secondary dentine formation; however, in most cases the material is placed over freshly cut and highly permeable dentinal tubules and this can result in acute pulpal damage, possibly haemorrhage, with pain and discomfort being experienced by the patient. Massler has suggested that the acidity of this material is not without deleterious effect on the amalgam as well.

Thanik et al (1962) found that zinc phosphate was very irritating to the pulp, and when placed over a small exposure, was associated with massive destruction of pulpal tissue. Mohammed et al (1961) found that if zinc phosphate was forced through a microscopic exposure, severe pulpal necrosis resulted. However, if there is a reasonable thickness of dentine between the pulp and the base, little
adverse effect has been noted, and it has been claimed that if the cement is mixed slowly to a thick, putty-like consistency, it may be safely used in deep cavities (Mesling, 1958).

It has been suggested that the addition of eugenol to zinc phosphate may provide some sedative effect on the pulp, Monstélar (1951). The addition of one drop of eugenol to each drop of phosphoric acid reduced the setting time, and reduced the strength from 16,000 psi to 11,000 psi. However, when one remembers the ease with which the base material can be forced through a microscopic exposure (Mohammed et al, 1961), the use of this mixture must be regarded with caution as the prospect of pulpal necrosis would remain. However, it may be of some benefit where there is a reasonable thickness of dentine, as the possibility of injury is then remote.

The use of varnishes applied to the dentine has been shown (Phillips, 1965) to effectively seal the margins against ionic and molecular tracers, and it has been suggested that the use of these varnishes will reduce the penetration of irritants from the cement lining to the base. Massler and Manaukhani (1964) devised a simple method for testing liners in vitro, with a glass tube, thus:

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Material - e.g. Zinc Phosphate
Liner - e.g. Copal Varnish
Plaster mixed with dye to show acid penetration
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These investigators tested materials such as zinc oxide and eugenol, Pulpdent and Cavitec, and the varnishes, and found that copal resin and silicone liners were least effective in preventing acid penetration, with zinc oxide best. They also made the observation that uncontrolled clinical tests of a new material tend to be subjective, and rarely detect pulpal damage, since any such damage rarely becomes evident before one or two years; the pulp may degenerate over a very long period.

It, therefore, appears that zinc phosphate cements should be used with caution, and when it is used, varnish or preferably zinc oxide and eugenol should be used beneath it; Going (1964) has stated that zinc phosphate cement satisfies only one of the requirements for a satisfactory cavity base in that it does provide protection from thermal shock.

B. Zinc Oxide and Eugenol Preparations: Zinc oxide and eugenol is only mildly irritant to the pulp (Going, 1964) and is destructive to the pulpal tissue to a small extent only (Mohommed et al, 1961). It has also been claimed that this material is the best available as regards cavity seal (Coleman and Kirk, 1965). Canby and Burnett (1965) found that when placed over deep caries, zinc oxide and eugenol gives a pulpal response which is most satisfactory, and they suggested that it may be preferable to place zinc oxide and eugenol over a minimal amount of caries and restore immediately rather than continue to excavate to solid dentine and risk
an exposure, provided that the prognosis is good. Going (1964) claims that zinc oxide and eugenol is the most satisfactory base in most respects, but it does not reduce marginal leakage. Massler (1965) also advocates the use of a modified zinc oxide and eugenol base, followed by a varnish of polystyrene (10% - 20%) dissolved in eugenol.

In an earlier study, Massler (1955) found that free eugenol, when left in contact with a thin layer of carious dentine for a week or more, may effectively sterilise the dentine and will sedate the inflamed pulp. After ten to fourteen days, the odonto-blasts will differentiate and form a protective layer of secondary dentine. After three to four weeks, the cavity can be re-opened and the carious dentine removed with much less risk of an exposure. In their suggestion that zinc oxide and eugenol can be placed over deep caries and the restoration be completed, Canby and Burnett (1963) emphasised the importance of minimal trauma in the removal of deep caries, and avoided the use of excavators as it was believed that these instruments increased the risk of an exposure being made accidentally.

Zander (1962) stated that although eugenol was a potent germicide, it is palliative to the pulp and it is the only material available for use as a base that will inhibit bacterial growth over a long period. He found that it will sterilise dentine up to 1 mm. in depth in 24 to 48 hours, and that it was the base of choice in all
deep but unexposed cavities due to its soothing effect on the inflamed pulp. However, the concept that eugenol will sterilise dentine has been challenged by Turkenheim (1955). He inoculated sterile slices of dentine with bacteria normally found in carious lesions, and exposed these to zinc oxide eugenol for various periods. All were sterile within 48 hours. Under similar circumstances, however, natural decay was exposed to zinc oxide and eugenol and in no single case was the dentine sterilised. Molnar also cautioned (1967) that when this material was used, free eugenol was always present, even in small amounts, and changes in the tooth structure and tissue can be expected. The final amount of free eugenol was determined to be about 5%, sufficient to cause discomfort to the patient and possibly pathological effects on the pulp if placed on either an exposed or near-exposed pulp. Furthermore, Ralberg and De Shazer (1966) have shown that eugenol has the ability to remove calcium from the dentine at a rather rapid rate. Both free eugenol and zinc oxide and eugenol compounds were observed to progressively remove calcium from dentine; this was seen clinically as softening of the sound dentine beneath clinically applied zinc oxide and eugenol. The complexing action of eugenol with calcium prevents the mineralisation of the collagen matrix formed beneath the site of a pulp exposure, thus preventing any dentine bridge formation. There was histological and clinical evidence of tissue inflammation, haemolysis and protein precipitation being caused by eugenol.
C. Calcium Hydroxide Preparations: Calcium hydroxide is the least irritant of the base forming materials available, and will satisfactorily encourage the formation of secondary dentine. Mahomed et al (1961) have recommended that it should be used as a matter of routine in all deep cavities, to take care of the situations where the base material contacts a microscopic exposure. The high pH of the material favours the action of alkaline phosphatase, which appears to be necessary for the formation of secondary dentine. Although calcium hydroxide will not sterilise dentine as eugenol will, it has been suggested that it is bacteriostatic to some extent (Southan, 1964).

The ability of calcium hydroxide to stimulate the formation of secondary dentine has well been documented. Massler (1955) found that when this material was placed over small exposures, complete closure of the exposed site resulted in 65% of cases after four to six weeks; he recommended the placement of calcium hydroxide mixed with distilled water over the exposure, then a thick mix of zinc oxide and eugenol, then zinc phosphate cement. Southan (1964) felt that all cavities should be lined with calcium hydroxide, with zinc phosphate cement applied over a coating of varnish. The practice of lining all cavities as a matter of routine with calcium hydroxide does seem to have a sound clinical and histological basis. Ratzlaff and Castaldi (1969) have recently expressed the opinion that the concept held by most practitioners as to exactly what constitutes
an exposure should be revised, pointing out that the appearance of
a minute amount of bleeding from a "pin-point" exposure constitutes
in actual fact a fairly large exposure. Van Rysen (1955) claimed
that many teeth with radiographic evidence of apical granuloma, when
removed and sectioned for histological study, were found to have
minute mechanical exposures. It follows that, therefore, the routine
use of calcium hydroxide will encourage pulpal recovery in many cases
where minute exposures pass unrecognised by the operator.

The use of calcium hydroxide mixed with distilled water has
been largely replaced by commercial products with more satisfactory
handling properties. In a comparative histological evaluation of
two calcium hydroxide cements and a paste, Phaneuf et al (1968) found
that the paste (Pulpdent) was superior, as it consistently produced
early pulp organisation and dentine bridge formation. With Dycal
cement, secondary dentine formation was slower and more irregular,
but bridging did occur in most cases. Results with Hydrex cement
were somewhat less satisfactory; there was little evidence of
secondary dentine formation and superficial necrosis and inflammation
occurred in many instances. The reason given for the superiority
of Pulpdent paste was that it is a more pure form of calcium hydroxide
(52.5%) in a methyl cellulose base. The other products, whilst more
easily handled, were less reliable due to the other ingredients which
seemed to reduce the effectiveness of the calcium hydroxide content.
These workers pointed out that whilst dentine bridge formation was
desirable, viable and intact pulps were observed histologically in a
significant number of teeth where bridge formation was incomplete.

In an examination of the effect of Dycal as a pulp capping material, Sawusch (1963) found a relatively higher percentage of success, histological evidence showing that dentinal bridge formation followed the application of Dycal to the exposure within one month in most cases. It was also found that the percentage of successful pulp cappings varied directly with the extent of the pre-operative carious lesion as viewed radiographically, and that most failures became evident six to twelve months after the treatment. However, Brosch (1965) has claimed that the presence of a dentinal bridge is not a criterion of pulp healing; bridging occurred in the form of osteo-dentine, secondary dentine, proliferation of connective tissue, or all three combined. He believed that adequate sealing of the pulpal exposure against the ingress of oral fluids and bacteria was essential for pulp healing, and that clinical and radiographical findings were not always supported by histological findings. The study done by Brosch found that the use of a compound consisting of calcium phosphate, Neomycin and hydrocortisone resulted in a better rate of success than calcium hydroxide, although some have suggested that internal resorption may be associated with the use of this compound.

In a clinical survey of 354 restorations, Delaney and Seylar (1966) evaluated the success of restorations placed over Hydrex
(20% calcium hydroxide, 80% zinc oxide) used as a sole base, as a deep cavity liner, and as a pulp capping agent. They found that 93% of the restorations where Hydrex was used as a deep cavity liner were successful; when used as an indirect pulp capping agent, 88% success was achieved; and when used as a pulp capping agent, 76% were successful. These were regarded as acceptable levels of success, and the reduction of bulk by using a single material, thus providing greater bulk of amalgam, was an advantage in many cases, especially in pedodontics.

The use of calcium hydroxide as an indirect pulp capping agent has also been reported as being successful. Aponte et al. (1966) found that residual carious dentine, following the application of calcium hydroxide as an indirect pulp capping agent, was free of micro-organisms when examined at periods ranging from 5 to 46 months (average time was 28 months) after treatment in 93% of primary molars included in their study. They found that the dentine was hard and shiny in appearance, and evidence of reparative dentine was seen radiographically. Ninety-three percent of the capped teeth were found to be sterile.

In recent years, much has been written concerning the use of corticosteroid preparations on exposed pulps. The application of these drugs to dentistry has been based on rather empirical grounds.
Schroeder (1968) advocates the treatment of pulpitis with corticoid antibiotic preparations, leaving a pellet beneath a zinc oxide and eugenol dressing in contact with the cariuous dentine in the immediate vicinity of the pulp. On subsidence of the symptoms (3 - 5 days) the dressing is removed and an indirect cap of calcium hydroxide is then placed. This procedure was claimed to give a much better success rate than the use of calcium hydroxide or zinc oxide and eugenol alone. Research by Everett and Kirk (1969) and Baker and Ehrmann (1969) has indicated that corticosteroid preparations will depress both the inflammatory response and the formation of secondary dentine. Although these drugs do give very good symptomatic relief, they can mask a degenerating pulp, as there is a poor correlation between clinical observation and the histological state of the pulp. Everett and Kirk found that loss of vitality was common when materials such as Ledermix were used, and suggested that when Ledermix is used, the teeth concerned should be recalled and checked periodically for vitality; they point out that the fact that a treated tooth is symptom free is encouraging, but that this is no guarantee of success. Failures are rarely evident in the first few months, and the tooth may remain symptom free as long as the corticosteroid remains chemically active.

The role of these agents compared to other pulp capping agents, therefore, appears to be questionable; if pulpal injury is
slight, resolution can occur, but in most cases where these agents are considered to be indicated, the pulps are often of questionable recuperative ability. Lees (1970) is also doubtful that the dramatic relief from pain afforded by corticosteroid agents should alone justify the use of these drugs in general pulp therapy, pointing out that they inhibit the differentiation of mesenchymal cells into odontoblasts, with the result that dentine bridging will not follow. The suggestion was also made that the depression of the inflammatory response allows bacteria into the vascular system of the pulp, with the result that there may be a risk of bacterial endocarditis, but the exact significance of this aspect seems doubtful.

It is important to realise that all materials used as cavity bases will cause some pulpal inflammation. Langland (1968) has demonstrated a marked reduction in inflammation when all caries is removed from deep cavities and no drug applied; however, in clinical practice, some degree of inflammation persists, whether caused by caries or the operative procedures, despite application of anti-inflammatory agents. Inflammation was observed with both calcium hydroxide and Ledermix, and Langland emphasises the complete removal of caries with placement of the restoration over a very thick mix of zinc oxide and eugenol, with excess eugenol removed with a squeeze cloth.
2. THE STRENGTH OF THE CAVITY BASE

Introduction: How strong must the base be?

The early strength of the cavity base is important in that it must have sufficient strength to resist fracture or displacement when the amalgam is condensed, to prevent the amalgam packing through the base, thus reducing or eliminating its benefits, (Phillips, 1966). There is also the risk of displacing the base, resulting in uneven thickness with the likelihood of fractures in areas of uneven thickness (Chong et al, 1967).

N.B. Can be forced into small exposures

Chong and his co-workers suggested that the minimum compressive strength required to resist distortion during condensation is about 170 psi; bases under test conditions showed displacement. The figures
below were given for some of the popular base materials. (Note that times given are for laboratory conditions – the set is accelerated in practice.)

<table>
<thead>
<tr>
<th>Base Material</th>
<th>7 mins.</th>
<th>30 mins.</th>
<th>24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVITEC</td>
<td>400</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>TEMREX (zinc oxide and eugenol)</td>
<td>2,300</td>
<td>3,100</td>
<td>3,500</td>
</tr>
<tr>
<td>ZINC OXIDE-EUGENOL-ACETATE</td>
<td>600</td>
<td>1,200</td>
<td>1,250</td>
</tr>
<tr>
<td>HYDREX</td>
<td>500</td>
<td>1,000</td>
<td>1,400</td>
</tr>
<tr>
<td>DYCAL</td>
<td>1,100</td>
<td>1,000</td>
<td>1,100</td>
</tr>
<tr>
<td>TENACIN (zinc phosphate)</td>
<td>1,100</td>
<td>12,600</td>
<td>16,900</td>
</tr>
</tbody>
</table>

(NOTE: The figure of 170 psi as a minimum was arrived at by using "Tempbond", a proprietary material, the strength of which can be varied by the use of a modifier.)

The comparatively low strength required by the cavity base is due to the fact that the actual pressure exerted by the packing instrument is not transferred directly to the liner (Iyell, 1960). It is interesting to note that the strength required under spherical
amalgam would be even less; it has been shown that in addition to having comparable adaptability to conventional alloys, the spherical alloys show little loss of strength at relatively low condensation loads (approximately two pounds). Lathe-cut alloys should be condensed at loads from six to ten pounds, and show a marked loss of strength when less than optimal condensation is employed (Eden and Waterstat, 1967).

Bryant (1969) claims that the fracture of the base forming material per se is unlikely to significantly alter the capacity of the restoration to fulfil its functional requirements. Fractures of the cavity base were found to be unlikely to occur unless the base collapses around a void in the material. Extrusion of the material at the margin of the cavity and its subsequent loss provides gross leakage and the prospect of recurrent caries quickly following. Bryant considered that both Dycal and Hydrex have sufficient strength to withstand the condensation of amalgam, provided that voids in the material are minimised; if voids were present, amalgam can be packed through the base to the dentine or the base can be dislodged to a margin of the cavity, possibly without the operator's knowledge.

The significance of the ultimate strength of the cavity base in clinical service is controversial. Phillips (1965) doubts that it is significant at all, or that it is a contributing factor in the failure of the restoration. Rowe (1964) claims that amalgams
packed over stronger bases have greater resistance to fracture than those packed over weaker bases. Hoppenstad and McConnell (1960) claimed that when a small amount of base is used, there is no difference so far as the strength of the base is concerned, but when a large base is used, a stronger base will give a stronger amalgam restoration.

The purpose of the present paper is primarily an attempt to resolve this question.

A. Zinc Phosphate Cement: Mechanically the strongest of the base materials, zinc phosphate cement can have an ultimate crushing strength varying from 12,000 psi (Phillips, 1965) to 17,000 psi (Mosteller, 1961). The strength at three to seven minutes has been given as 1,100 psi (Chong et al, 1967) to 2,000 psi (Iyell, 1960). When mixes of clinical consistency are used, rather than the standard consistency used for testing purposes, considerably higher early strengths (in the vicinity of 8,000 psi) can be obtained. Bryant (1969), in considering the strength of cements, considered the five to seven minute strengths as being an indication of the ability of the base to withstand condensation pressures. He found zinc phosphate to have a clinical strength of 8,000 to 9,000 psi at this time after mixing, roughly twice the strength of the next strongest base material.
B. Zinc Oxide and Eugenol Preparations: There are now so many of these preparations available consisting of zinc oxide and eugenol with additives to alter the material's properties, that the operator's choice is largely governed by handling ease. Most of the commercially available products have similar physical properties, with compressive strengths in the vicinity of 3,000 psi. Claims of compressive strengths of up to 8,400 psi have been made (Guzmann et al, 1969), the strength in this instance being attributed to the addition of 20% methyl methacrylate to surface treated zinc oxide, and the addition of 1% acetic acid to the eugenol. The addition of 10% silica and 0.3% zinc acetate to the powder, and 47.5% EBA (see below) to the liquid is claimed to give a compressive strength of 7,300 psi. Zinc stearate, titanium oxide, hydrogenated rosin, fused quartz and various other modifiers have all been advocated as means of improving the qualities of zinc oxide and eugenol cements, (Mohammed et al, 1961; Brown and Semon, 1962; Massler, 1955).

The use of EBA (Ethoxy-benzoic acid) added to the eugenol (50% each) decreases the setting time and gives substantial increase in the compressive strength (Phillips and Love, 1961) but the solubility of the set material is increased. Polystyrene has a similar effect.
In a recent investigation of the strengths of cavity bases, Bryant (1969) showed that the strength of zinc oxide and eugenol preparations showed a considerable increase in the first 30 minutes, then remained relatively constant before a significant fall in strength from one day to one week after mixing. However, both zinc phosphate and Dycal showed a steady rise in strength; some examples from Bryant's figures are given below:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>7 mins.</th>
<th>one hour</th>
<th>one day</th>
<th>one week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dycal</td>
<td>800</td>
<td>1,450</td>
<td>2,020</td>
<td>2,860</td>
</tr>
<tr>
<td>Zinc Oxide–Eugenol with 1% zinc Acetate</td>
<td>4,300</td>
<td>4,750</td>
<td>5,100</td>
<td>3,750</td>
</tr>
<tr>
<td>Zinc Phosphate (clinical consistency)</td>
<td>8,200</td>
<td>12,900</td>
<td>13,640</td>
<td>15,200</td>
</tr>
</tbody>
</table>

Bryant's conclusion was that there is no point in following the practice of leaving zinc oxide dressings in place for a week or more, then recalling the patient to restore the preparation after removing the set material to an ideal depth. Bryant considered that a very thick mix of zinc oxide and eugenol was essential to
obtain a high early strength and rapid set, and in clinical use amalgam could be condensed over a freshly-placed base quite satisfactorily.

Civjan and Brauer (1964) found that the physical properties of cements of EBA were close to those of zinc phosphate cements but for the thermal co-efficient of expansion, which was too high. The addition of heat-treated fused quartz to the powder improved the dimensional stability and strength, and gave properties superior in clinical use to those of zinc phosphate. Coleman and Kirk (1965) compared fortified zinc oxide and eugenol cements to zinc phosphate, and found that the fortified zinc oxide preparations were superior as regards cavity seal, and no more irritant to the pulp than normal zinc oxide and eugenol. Canby and Burnett (1963) also believed that the practice of condensing amalgam over freshly-placed zinc oxide and eugenol cavity bases was a satisfactory procedure.

C. Calcium Hydroxide Preparations: The use of calcium hydroxide with distilled water as a pulp capping agent obviously involves the use of another base material placed over the mixture on which the amalgam can be condensed. Although the calcium hydroxide cements are considerably lower in their compressive strengths than the other base materials, it appears that they do possess sufficient strength to enable amalgam to be condensed soon after placement.
Delaney and Seylar (1966) found that by using these cements as a sole base, a reduction in the thickness of the cavity base was achieved, and this was considered to be an advantage in addition to the obviously easier procedure than the use of two mixes of different materials. Bryant (1969) found that Dycal has a four minute strength of 800 psi, rising steadily to 2,860 psi at one week. He pointed out that the tensile strength of Dycal and Hydrex was only slightly lower than the weaker examples of zinc oxide and eugenol bases he tested. However, he found that these materials were prone to the formation of voids in clinical use, and these may collapse under condensing loads allowing the amalgam to contact the dentine, or perhaps be dislodged to a margin of the cavity. It has also been conjectured that the condensing forces may force the relatively weak material through an exposure. However, even if this did occur to some extent, it would be unlikely to be clinically significant; Thanik et al (1962) found that a pulp can be exposed and displaced centripetally without any ill effects when calcium hydroxide is used. Chong et al (1967) found Dycal to have a seven minute strength of 1,100 psi which remained virtually constant thereafter; Hydrex was only 500 psi at seven minutes, but rose to 1,400 psi at 24 hours. They found Cavitec to be the weakest of the materials they tested, with a seven minute strength of 400 psi, rising to 750 psi at 24 hours.
However, even this figure is above the minimum compressive strength required, which they determined to be 170 psi (See Page 45).

Whilst it appears that from the mechanical point of view the use of calcium hydroxide cements is quite satisfactory, one must bear in mind that their effect on the pulp is not as favourable as the use of more pure forms of calcium hydroxide (see discussion on pages 35 and 36 above). However, it is seen from the above discussion that the response is superior to either of the alternatives materials when employed in close proximity to the pulp.

NOTE: In the figures given by Chong et al, the strength of Dycal at seven minutes (1,100 psi) was the same as the strength of Tenacin, one of the zinc phosphate cements tested.

3. PROTECTION OF THE PULP FROM IRRITANTS

All the materials under consideration will protect the pulp from thermal irritation, provided that they are of adequate thickness. The matter of irritation from the materials themselves has been discussed above. In their work previously mentioned, Massler (1960) found that all bases examined (this did not include zinc phosphate) prevented acid penetration; zinc oxide and eugenol was the most satisfactory, Cavitec and Pulpdent and similar materials were quite good, and the varnishes, such as copal resin and silicone, were the least adequate. Wing and Lyell (1966), however,
claimed that the use of copal resin varnish, although it does not reduce the space between the amalgam and the cavity wall, may be effective in providing pulpal protection in the early stages after placement of the amalgam. They also emphasised that the varnish lining should be kept to a minimal thickness. Soremark et al (1969) recommended that cavity varnish be used on all prepared surfaces under all restorative materials at present in use.

Massler (1969) states that the penetration of salivary ions and bacterial products into the underlying dentine can be halted by the placement of a base under the restoration. As well as insulating the pulp from thermal shock, the bases also prevent galvanic action and the penetration of mercuric ions from the restoration into the dentine. Zinc phosphate tends to be porous and a non-acid fast setting fortified zinc oxide and eugenol cement is to be preferred.

It may be appropriate at this point to list Going's criteria for a satisfactory cavity base (1964):

1. The base must protect the pulp from thermal shock.
2. It must insulate against galvanic action inherent in amalgam.
3. It should inhibit the penetration of mercury into the underlying dentine to prevent discolouration of the tooth.
4. Provide an anodyne effect on the pulp.

5. Have some anti-bacterial effect to sterilise the dentine and residual caries in deep cavities.

6. Should reduce marginal leakage, limiting the diffusion of bacterial toxins and soluble ions of all types into the underlying dentine and pulp.
CHAPTER THREE

THE RELATIONSHIP BETWEEN CAVITY BASES AND THE DURABILITY OF THE RESTORATION IN THE LITERATURE

There have been many opinions voiced, but little research has been reported in this area; the work that has been done has shown conflicting results. Rowe (1964) cut preparations in ivorine teeth, duplicated these in Ney's technical metal, then packed these preparations with cavity bases and amalgam. The cavity design was similar to a typical deep cavity as found in a deciduous second molar involving one proximal surface. The specimens thus prepared were tested using a specially constructed device to measure the force necessary to fracture the amalgam. The results were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Lead</th>
<th>psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (all amalgam)</td>
<td>171 pd.</td>
<td>35,115</td>
</tr>
<tr>
<td>Zinc phosphate base</td>
<td>130 pd.</td>
<td>21,560</td>
</tr>
<tr>
<td>Calcium hydroxide and zinc cement</td>
<td>105 pd.</td>
<td>16,696</td>
</tr>
<tr>
<td>Zinc oxide and eugenol</td>
<td>87 pd.</td>
<td>17,862</td>
</tr>
</tbody>
</table>

The conclusion drawn by Rowe was that the strength of the restoration was proportional to the strength of the cavity base used.
Hoppenstand and McConnell (1960) also cut preparations in ivorine teeth, and then used various bases and amalgam to restore the cavity. The preparations were cut in a jig, using a surveyor, and a template used to check the cavity dimensions for uniformity. Two types of cavity were prepared thus (both being Class I cavities).

They found that in the case of preparation of type A, fracture occurred at 480 pd. with a zinc phosphate base, and at 460 pd. with zinc oxide and eugenol. A control (all amalgam) fractured at 500 pd. In the case of the preparation type B, the specimen with a zinc phosphate base fractured at 355 pd., and the zinc oxide base at 125 pd. The control fractured at 380 pd. Their recommendation was that a class one amalgam does not have appreciable strength when the amalgam is condensed over a layer of zinc oxide and eugenol, and that this type of restoration may well fail in practice. However, if zinc oxide and eugenol
is used under a small excavation only, and the mass of the amalgam is supported by tooth structure, the strength of the restoration is adequate.

It is significant that in this study, the examination of the specimens after fracture indicated that the zinc oxide had behaved essentially as a non-rigid material, and the forces of loading had been resolved against the cavity wall in such a way that the failure of the restoration was related to the strength of the ivorine tooth; zinc phosphate behaved as a rigid material.

In his discussion of cavity liners and dentine treatment, Going (1964) stated that the use of zinc oxide and eugenol or calcium hydroxide cements was satisfactory provided that the base at no time covered the entire dentine surface, since the metal restoration was then "denied the additional strength gained in condensing on solid dentine." However, no experimental evidence was put forward to substantiate this view.

It, therefore, appears that the exact nature of the relationship between the strength of the cavity base and the durability of the restoration in service is in considerable doubt.
PART TWO

THE ORIGINAL INVESTIGATION
CHAPTER ONE

THE SCOPE OF THE INVESTIGATION

In an attempt to investigate the relationship between the clinical durability of the restoration and the cavity base used, both theoretical testing, using metal dies, and a clinical survey of restorations with known bases taken over a period of up to 54 months' service were carried out.

Four types of cavity base materials were employed throughout the study.

a. Zinc Phosphate cement
b. Zinc oxide and eugenol cement
c. Calcium hydroxide cement
d. Temporary stopping.

The base forming materials are shown in Table 1.

The bases were chosen as being representative of their groups, and were routinely used in the author's practice. Most of the zinc phosphate cements available have very similar physical properties, and the cement chosen (Odus) has a compressive strength of approximately 15,000 psi when mixed to clinical consistency and
when fully set. Temrex was chosen as the zinc oxide and eugenol cement to be used; this is a modified zinc oxide, but the manufacturers (Interstate Dental Supply Co., New York) have not published the modifiers used. Possibly a little stronger than most similar materials when fully set, Phillips (1965) gave a compressive strength of 4,200 psi for this cement. Dycal has been well documented as a calcium hydroxide composition (see discussion on pages 38 - 41), and has a compressive strength of approximately 2,020 psi when fully set (Bryant, 1969). The temporary stopping material chosen was Plastor (Unident Inc., New York) which contains some calcium hydroxide and will set under moisture. This material was used under some restorations, being a putty-like consistency, and the amalgam condensed over the unset material with much care to avoid displacing the base. This is fairly easily done in Class I restorations, but is difficult in Class II restorations, and the use of spherical amalgam is necessary as packing pressure is of necessity somewhat limited. This material will not set under the amalgam; the range of base materials used, therefore, had claimed compressive strengths from 15,000 psi to virtually nil.

Because the data in Table 1 has been taken from a number of sources where tests will have been carried out using a number of different sized specimens, different types of testing machines and different cross-head speeds at the time of test, it was decided that values for the compressive strength at seven minutes and when fully
### TABLE 1

**BASE MATERIALS INVESTIGATED**

<table>
<thead>
<tr>
<th>Base</th>
<th>Class of Material</th>
<th>Fully Set Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>O dus Zinc Cement</td>
<td>Zinc Oxy-phosphate</td>
<td>14,500 psi (i)</td>
</tr>
<tr>
<td>Temrex</td>
<td>Zinc oxide/eugenol accelerated</td>
<td>4,200 psi (ii)</td>
</tr>
<tr>
<td>Dycal</td>
<td>Calcium hydroxide cement</td>
<td>2,020 psi (iii)</td>
</tr>
<tr>
<td>Plastor</td>
<td>Temporary stopping</td>
<td>Does not set</td>
</tr>
</tbody>
</table>


set would be obtained under uniform conditions. Cement specimens were made and tested using the method of Bryant (1969). Cylindrical specimens 4 mm x 8 mm were used, made in a split stainless steel mould and tested when fully set in the Hounsfield Tensometer using a cross-head speed of 1/64" per minute.

The aim of the laboratory investigation was to collect data on the forces required to fracture the specimen restorations constructed, and to attempt to correlate the figures obtained with the strength of the base materials employed. Both Class I and Class II restorations were investigated.

A clinical survey was undertaken in an attempt to find some correlation between the failure rate of amalgams through fracture and the strength of the base materials used. A total of 412 restorations were observed over periods ranging from six months to 5½ months. The degree of marginal deterioration was also assessed and recorded.
CHAPTER TWO

THE EXPERIMENTAL METHOD

1. LABORATORY STUDY ON AMALGAM FRACTURES

Metal dies, of chrome-cobalt alloy, were constructed. The dies represented Class I and Class II cavities as may be typically found in practice, with extensive excavation as would be found in the case of near pulpal exposure.

The cavity preparations were cut in ivorine teeth (Fig. 1 and Fig. 2). A distinct line was made in the preparation to enable precise duplication of the thickness of the bases and amalgam. Cusps were removed for two reasons:

a. To provide a reproducible flat surface of amalgam after carving;

b. To provide a standard surface on which physical properties could be evaluated.

No proximal retention grooves were cut, principally to simplify procedures, but also in the light of recent investigations (Terkla and Mahler, 1967) these may well be of doubtful benefit.

The dies were mounted on a stem, cast integrally with the die, to fit into an adapter constructed of mild steel, which was
Fig. 1

The Class I cavity prepared in an ivorine tooth, before removal of cusps.

Fig. 2

The Class II cavity prepared in an ivorine tooth, before removal of the cusps.
then fitted to one ram of the Hounsfield Tensometer (Fig. 3). The dimensions of the prepared dies were recorded (Figs. 4 and 5).

The base material was placed in the cavity to the previously described line. The cavity was then packed to excess with a spherical amalgam (Shofu) and excess was removed with a sharp razor blade to provide a flat surface of amalgam confluent with the flat surface of the die. Spherical amalgam was used for all test specimens to minimise variations in condensing procedures. Standardized dispensing, mixing and condensing procedures, as recommended by the manufacturer, were used in each case. It may be confidently expected that these procedures would produce amalgams with compressive strengths of approximately 55,000 psi when fully set (Wing, 1970). After packing, the specimens were stored at 37° C. (See Figs. 6 and 7).

The dies were tested in a Hounsfield Tensometer under compression at times varying from 2½ to 72 hours, when the material may be considered to be fully set. The load was applied with a Brinell ball, at the rate of 1/64" per minute, using the motor drive of the Hounsfield Tensometer. Construction of the die allowed orientation so that the Brinell ball was applied to the centre of the amalgam specimen (Fig. 8). The load was applied until:
Fig. 3

Mild steel adapter and chrome-cobalt die.
**Fig. 4**

- \(a = 3\, \text{mm}\)
- \(b = 5.3\, \text{mm}\)
- \(c = 3.5\, \text{mm}\)
- \(d = 6\, \text{mm}\)

**Fig. 5**

- \(a = 4\, \text{mm}\)
- \(b = 5\, \text{mm}\)
- \(c = 2.2\, \text{mm}\)
- \(d = 3.5\, \text{mm}\)
- \(e = 5\, \text{mm}\)
- \(f = 3\, \text{mm}\)
- \(g = 4.3\, \text{mm}\)
Fig. 6
Die with cement lining in place.

Fig. 7
Packed and flattened amalgam ready for testing.
Fig. 8

Class I specimen after testing, showing orientation of the Brinell ball. Note that specimen has not been distorted or fractured (load 750 pounds).
a. the restoration fractured;
b. amalgam extruded from the preparation;
c. 750 pounds was reached without fracture or extrusion,
(load well above clinically possible).

The force required to fracture the restoration, or cause the amalgam to extrude from the preparation, was recorded in pounds. Class I and Class II specimens were tested in a similar manner. Five specimens of each type of cavity for each type of base forming material were tested.

Fractured Class II restorations, and Class I restorations which had been subjected to a load of 750 pounds without apparent fracture were sectioned metallographically with the amalgam and base in position in the chrome-cobalt die, using the technique described by Samuels (1952, 1967) (Fig. 9). It was possible, even where Class II restorations had fractured completely to retain the portions in the die during sectioning. Some Class II restorations which had obviously fractured, as evidenced by extrusion of amalgam at the proximal gingival margin but where no fracture line was visible on the occlusal surface, were included in this portion of the study (Fig. 10).

To attempt to determine the load required to fracture amalgam and tooth structure, five Class I restorations in natural teeth were prepared for each type of cavity base material used, and
Fig. 9

A Class II specimen mounted in resin and sectioned for examination of the microstructure of the fracture.
Fig. 10

Class II restoration in chrome-cobalt die, after testing in the Hounsfield Tensometer, demonstrating extrusion of the amalgam on the proximal aspect. The Brinell indentation can be seen on the occlusal surface.
were tested in a similar manner to that of the chrome-cobalt dies. The cavities were prepared to resemble the dies as closely as possible, using a periodontal probe to copy the dimensions of the die.

2. THE CLINICAL SURVEY

In the clinical survey, a total of 412 restorations were observed over periods ranging from six months to 5½ months, in the hope that some pattern would emerge as to the marginal deterioration and failures of restorations packed over different cavity bases.

To make this comparative survey as accurate as possible, restorations were only included when the following conditions were met:

1. Good oral hygiene.

2. Restorations opposing natural teeth in complete, or almost complete, dentitions.

3. Standardised dispensing and mixing of amalgam, using a "Dentomat" amalgam dispenser and mixer in the case of fine grain amalgams, and in the case of spherical amalgams, the manufacturers' pre-set dispensers, with trituration in a Wig-1-bug mixer for fifteen seconds.

4. Absolute exclusion of moisture.
5. Overheating of the restoration avoided during polishing. (All restorations were polished as evenly as practicable.)

6. Careful records were kept of the base used in each case.

At subsequent visits, any relevant observations concerning the condition of the restoration were recorded. Failures were examined for the probable cause, and a photographic record kept of cases considered to be typical. Marginal deterioration was recorded as being excellent, good or poor, according to the author's judgment. (Typical assessments of deterioration are recorded in the results.)
CHAPTER THREE

RESULTS OF THE INVESTIGATION

1. LABORATORY STUDY

The results of the physical property tests of amalgam restorations are shown in Table 2. Fig. 11 shows a typical Class II specimen after testing and fracture.

Testing of the Class I restorations was abandoned upon failure to fracture at 750 pounds, as this represents an occlusal force far above any that could be produced by masticatory musculature of human subjects.

A comparison of the forces required to fracture Class II amalgam specimens, using the "t" test, revealed that there was no significant difference between the forces required to fracture restorations placed over zinc phosphate cement, zinc oxide (accelerated) cement, or calcium hydroxide cement at the 99% confidence level. The difference between the values for the above three cements and Plastor was significant at a level above the 99% confidence level.

Further tests were carried out using Class I cavities in natural teeth as described in the method (page 68), in an
TABLE 2

THE RELATIONSHIP BETWEEN LOAD REQUIRED TO FRACTURE AMALGAM RESTORATIONS AND THE BASE MATERIALS USED FOR CLASS I AND CLASS II RESTORATIONS

<table>
<thead>
<tr>
<th>Base</th>
<th>Load at Fracture under Brinell Ball (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class I Rest'n.</td>
</tr>
<tr>
<td>Odus Zinc Cement (Zinc Phosphate)</td>
<td>750 *</td>
</tr>
<tr>
<td>Temrex (Zinc Oxide)</td>
<td>750 *</td>
</tr>
<tr>
<td>Dycal (Calcium Hydroxide)</td>
<td>750 *</td>
</tr>
<tr>
<td>Plaster (Temporary Stopping)</td>
<td>750 *</td>
</tr>
</tbody>
</table>

* No Class I restorations fractured at loads of 750 pounds or less.

** Standard deviations in brackets.
endeavour to relate the results obtained with Class I dies to the strength of actual teeth. Twenty specimens were tested, and the results shown in Table 3. Using the "t" test, it was established that the values for the fracture of teeth and Class I restorations did not produce differences that were significant at the 99% confidence level. The large standard deviations which may be noted are due to differences in support of cusps by sound dentine, variations in the strength of individual teeth and the subjective factors in cavity preparation.

The overall strength of the restorations in Class II dies was calculated in terms of psi. The load required to fracture the restoration was related to the cross-sectional area of the restoration. The results obtained are shown in Table 4.

It is interesting to note that there is a significant difference between "restoration strength" for Plastor and the other three base forming materials, but no significant difference between the values obtained for Odus cement, Temrex and Dycal. The calculated "restoration strength" is approximate only, since the cross sectional area of the restoration could not be accurately determined. The values in Table 4 fall far below the fully set compressive strength for the amalgam used in this study (see discussion).

The results of the compressive strength tests at seven minutes and 24 hours of the base forming materials used in this study
Fig. 11

Typical failure of Class II specimen, showing both fracture and extrusion from the preparation.

Fig. 12

Typical fracture of Class I amalgam restoration and natural tooth after loading. A small number of specimens showed longitudinal splitting.
TABLE 3

FORCE REQUIRED TO FRACTURE CLASS I AMALGAMS
IN NATURAL TEETH WITH DIFFERENT BASES

<table>
<thead>
<tr>
<th>Base</th>
<th>Force Required to Fracture Tooth and Restoration (Pounds)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odus Zinc Cement</td>
<td>480 (55) **</td>
</tr>
<tr>
<td>Temrex</td>
<td>400 (85) **</td>
</tr>
<tr>
<td>Dycal</td>
<td>440 (65) **</td>
</tr>
<tr>
<td>Plastor</td>
<td>340 (80) **</td>
</tr>
</tbody>
</table>

* In no case did the restoration fail or extrude from the preparation prior to the fracture of the tooth.

** Standard deviations in brackets.
### TABLE 4

**The Relationship Between Fracture Load and Calculated "Restoration Strength" for Class II Restorations Placed Over Different Base Forming Materials**

<table>
<thead>
<tr>
<th>Base</th>
<th>Fracture Load (Pounds)</th>
<th>Calculated Restoration Strength (psi) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odus cement</td>
<td>200</td>
<td>35,200</td>
</tr>
<tr>
<td>Temrex</td>
<td>180</td>
<td>31,200</td>
</tr>
<tr>
<td>Dycal</td>
<td>170</td>
<td>29,900</td>
</tr>
<tr>
<td>Plaster</td>
<td>105</td>
<td>18,480</td>
</tr>
</tbody>
</table>

* Cross sectional area of the Class II restoration is 1/176 sq. ins. approximately.
are given in Table 5. It can be seen that the values obtained for the 24 hour strength are slightly lower than those claimed by other workers for Odus and Temrex cements. Plastor gave a zero result, as the material will not set in the absence of moisture. Dycal gave results similar to those obtained by Bryant, as it was tested under similar conditions of specimen size and cross-head speed.
<table>
<thead>
<tr>
<th>Base</th>
<th>Compressive Strength (psi) 7 minutes</th>
<th>Compressive Strength (psi) 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odus</td>
<td>9,000</td>
<td>13,000</td>
</tr>
<tr>
<td>Temrex</td>
<td>3,100</td>
<td>3,000</td>
</tr>
<tr>
<td>Dycal</td>
<td>900</td>
<td>2,050</td>
</tr>
<tr>
<td>Plastor</td>
<td>Did not set</td>
<td>Did not set</td>
</tr>
</tbody>
</table>
The Microstructure of a Fracture of a Class II Amalgam Restoration

Fig. 13 shows photomicrographs of a typical Class II amalgam restoration which has fractured without the fracture reaching completion. This amalgam packed in a chromium cobalt die has been subjected to a loading of approximately 200 pounds under a Brinell ball indenter.

Fig. 13a, at a magnification of 10X shows the relationship of the amalgam to the chromium cobalt die and the cement base which has been placed. It can be seen that the amalgam is supported on chromium cobalt material at point A and B and the area of cement lies between these points. The area which has been subjected to the loading under the Brinell ball can be seen on the occlusal surface at C and the fracture lines originating at the pulpal wall of the amalgam restoration adjacent to the cement can be seen at C.

Fig. 13b, at a magnification of 50X is a higher magnification view of the area indicated within the frame in Fig. 13a. In Fig. 13b the fracture lines originating in the amalgam from the pulpal aspect and proceeding towards the occlusal aspect under the Brinell ball indentation can be seen very clearly. A very small fracture line can also be seen on the occlusal surface of the amalgam adjoining the Brinell ball indentation at point B. From Fig. 13b it is obvious that the large fracture lines towards the pulpal wall
have originated there and are further opening up on this aspect despite the application of the force with the Brinell ball indenter on the opposing surface.

Figs. 13c and 13d are higher magnification views, 200X, of the areas 1 and 2 in Fig. 13b. In Fig. 13c the relationship of the two relatively large cracks can be seen to the cement base. A small fracture line between the two large fracture lines can be seen in the region A. Fig. 13d shows a small fracture line which has originated on the occlusal surface and is proceeding in a downward direction towards the pulpal wall of the amalgam. The relationship of the fracture line originating on the occlusal surface to the end of the Brinell indentation can be seen very clearly. In Fig. 13d it becomes obvious that deformation or abrasion of the spherical particles on the surface under the influence of the Brinell ball load has taken place. The end of the indentation line quite clearly occurs at point B.

Figs. 13e and 13f at magnification 500X show higher power views of the areas outlined in Figs. 13c and 13d respectively. It can be seen that fracture has occurred through the spherical particles as well as through the matrix of the amalgam in both figs. 13e and 13f. In Fig. 13e it is obvious that good amalgamation has taken place and that there is no preferential fracturing of matrix away from spherical particles where it meets them, and subsequently through
Fig. 13a.

10X Magnification of Fractured Specimen

50X Magnification of Fractured Specimen
Fig. 13c

200X Magnification of the Fractured Specimen

Fig. 13d

200X Magnification of the Fractured Specimen
Fig. 13e

500X Magnification of the Fractured Specimen

Fig. 13f

500X Magnification of the Fractured Specimen
the silver mercury matrix. (This confirms observations made by Wing (1966) on the fracture paths through dental amalgam.) Although the beginning of the fracture line may be related to the inherent roughness of the surface of the amalgam against the cement, from a study of all the fracture lines observed in Fig. 13, it is obvious that fracture has occurred in relationship to the applied from the Brinell ball indenter, and although the load applied is of a compressive nature, the fractures that occurred are apparently due to bending and tensile stresses, (see conclusions and discussion).
2. CLINICAL SURVEY

The results of the clinical survey are shown in Table 6. The assessment of gross fracture of the restoration is self-explanatory, and typical examples are shown in Fig. 14. The assessment of marginal failure, however, is more subjective, and actual failure must be distinguished from what must be considered to be a normal degree of deterioration. Fig. 14 also shows a typical instance of marginal failure.

The restorations considered to have undergone normal marginal deterioration were also assessed as to the degree of deterioration of the margins, and the results are shown in Table 7. The deterioration was assessed as being excellent, good or poor without regard to the period of service of the restoration, and typical examples are shown in Figs. 15, 16, and 17, together with illustrations of these restorations at time of placement. Restorations showing a degree of deterioration which, in the author's opinion, required replacement at the time examined, were regarded as showing "Marginal Failure" and were recorded accordingly.
Fig. 14

Typical Examples of Gross Fracture (top) and Marginal Failure (bottom)
Fig. 15

Restoration at time of placement (top) and after 52 months' service. Margins were assessed as being excellent, and were exceptional for this period of time.
Fig. 16

Restoration at time of placement (top) and after 36 months of service. Margins were assessed as being good.
Fig. 17

Restoration at time of placement (top) and after 48 months of service. Margins were assessed as being poor.
### Table 6

The relationship of the base material used in conjunction with cavity type and fracture of the restoration.

<table>
<thead>
<tr>
<th>Base</th>
<th>Time in Service (Months)</th>
<th>Cavity Type</th>
<th></th>
<th>Cavity Type</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class I</td>
<td></td>
<td>Class II</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>M.F.</td>
<td>G.F.</td>
<td>N.F.</td>
<td>M.F.</td>
</tr>
<tr>
<td>Zinc Phosphate</td>
<td>6 - 12</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>12 - 18</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>18 - 24</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>24 - 36</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
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<td>36 - 48</td>
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*** M.F. - Marginal Failure
G.F. - Gross Failure
N.F. - No Failure
### Table 7

**Relationship of the Base Material Used and Assessment of Marginal Deterioration of the Restoration**

<table>
<thead>
<tr>
<th>Base</th>
<th>Period of Service (Months)</th>
<th>Cavity Type</th>
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CHAPTER FOUR

DISCUSSION AND CONCLUSIONS

1. LABORATORY STUDY

From the laboratory data presented, it appears that for Class I restorations, fracture does not occur which can be attributed to the lining, even when very high loads, up to 750 pounds, were applied with a Brinell ball indenter (which can be likened to a cusp applying a load over a small area). Even when unset Plastōr was used, Class I restorations did not fracture. No failures occurred where set linings were used, whether these were of the weak calcium hydroxide cement type, slightly stronger accelerated zinc oxide type, or the much stronger zinc oxy-phosphate cements.

For Class II amalgam restorations there was a significant difference between the load required on the Brinell ball to fracture amalgams placed over set bases, whether Dycal, Temrex or Zinc Phosphate cement, compared with the load required to fracture amalgams placed over an unset base (Plastōr). No significant difference was noted between the set bases, despite the considerably lower strength of Dycal and Temrex compared with the strength of the Odu zinc phosphate cement. The forces required to fracture Class II amalgams placed over these three types of bases are in the order of
180 pounds, which appears to be considerably higher than forces possible in the mouth (see later discussion).

The forces required to fracture Class II restorations placed over non-setting Plastor were significantly lower than for the three set materials tested, being approximately 100 pounds. Again, this may appear to be above the force possible in the mouth by the forces of mastication, but this is not necessarily so (see later discussion).

Class I restorations placed in cavities prepared in sound natural, extracted teeth fractured at loads approximately 400 pounds for all types of bases. Restorations placed over non-setting Plastor tended to fracture on the application of a slightly lower load. This is clearly a measure of the forces required to fracture tooth structure. Failure of the restoration had not commenced, as evidenced by fracture lines or extrusion of the restoration, before complete failure occurred. Immediately the tooth fractured, the restoration also demonstrated total failure. This situation is similar to that produced by Hoppenstand and McConnell (1960) where failure of ivorine teeth preceded fracture of Class I restorations.

The attempt to relate the load applied to the Brinell ball and the cross sectional area of Class II restorations in terms of "Restoration Strength" probably does not produce a meaningful guide to the strength of the restoration. There is, however, a definite
indication of the greater strength of amalgam packed over set bases than over unset bases.

Considering the complexity of the stresses within a Class II restoration subjected to load, it appears that the load as applied in this investigation bears a closer relationship to a transverse test as described by Mitchem and Mahler (1964) than to a compressive strength test, or tensile strength test.

A study of the photomicrographs presented of a fractured Class II restoration indicated that fracture is initiated because of bending within the amalgam restoration, allowing failure to take place in directions related to tensile forces, (Fig. 18). This supports the observations made by Granath (1965) on photoclastic studies on Class II restorations.

The situation illustrated in Fig. 18 is similar to that occurring in the three point loading transverse test of Mahler and Mitchem (1964) (Fig. 19). Although no direct calculation of the transverse strength of an irregular solid such as a Class II amalgam can be made, it is likely that the "Restoration Strengths" given in Table 4 will be more closely related to the transverse strength of amalgam than the compressive strength, which is considerably higher than the calculated "Restoration Strength". (At the same time the calculated Restoration Strength is higher than the tensile strength.) The results of a study carried out by Mitchem and Mahler showed that
the amalgam specimens (see Fig. 19) had transverse strengths of 18,000 to 19,000 psi; they also stated that compressive, tensile and transverse strengths of amalgams all show decreasing values as the residual mercury content rises above 54%, but that although the rate of loading of specimens will influence the compressive strength figures obtained, this does not influence the figures for either tensile or transverse strength measurement.

It must be realised that the forces exerted on the test specimens have been single applications of large loads to produce fracture. The dynamic situation where smaller loads are applied over long periods intermittently may produce fracture at somewhat lower loads.

It may appear that human subjects rarely if ever exert forces of even 100 pounds, suggesting that an unset lining such as Plastor may be adequate in service; however, it must be remembered that not all Class II restorations have cross-sectional areas as great as the test cavity, and that it is rarely, if ever, that a restoration has a perfectly flat occlusal surface at right angles to an opposing force. The cuspal inclines of teeth and restorations may enable weaker tensile forces to play a more dominant role in the fracture of Class II restorations, even when bending is not likely to take place (see further comments and discussion on the clinical use of Plastor).
Support on chromium–cobalt

C Compressive stresses.

T1 Tensile stresses giving rise to fracture, beginning on occlusal surface adjoining Brinell ball.

T2 Tensile stresses giving rise to fracture against cement, resulting from bending of the restoration.

Fig. 18
Specimen thickness 1 mm.
(Width 4 mm.)

Specimen length between supports 10 mm.

Fig. 19

Diagramatic representation of the three-point loading transverse strength test of Mahler and Mitchem (1964).
2. CLINICAL SURVEY

A. Gross Fracture of Restorations:

All the set base materials at the time of condensation appeared to be very similar with regard to possessing satisfactory physical properties for the condensation of amalgam; all seemed to resist the forces of condensation equally well. However, Plastor, being unset (but putty-like) made the condensation of amalgam difficult since there was a tendency for the material to be displaced by the applied force. In the case of Class I cavities in chromium-cobalt dies using spherical amalgam, Plastor could be used with a minimum of distortion, but in the case of Class II cavities in the dies, this became more difficult. Observations made on the fractured specimens showed evidence of distortion in Class II restorations. Fig. 20 shows a typical example of a Class II die in which amalgam has been condensed over Plastor and the material removed after testing to demonstrate the distortion of the base. In the clinical survey it became obvious that it is much more difficult in clinical practice to use an unset base than in the case of the test dies.

Clinically, it is difficult to determine whether a distorted base was in fact distorted by the forces of condensation, or if the base material was placed in the cavity in such a way as to provide insufficient bulk of amalgam. Such a situation arises because of
the impossibility of completely controlling the placement of a non-setting base. Fig. 21 shows a typical case of an isthmus fracture in which insufficient bulk of amalgam, resulting from the above factors, was undoubtedly a contributing factor in the failure of the restoration.

No cases of actual extrusion of the base material to the cavo-surface of the restoration were observed in the clinical survey where set base materials were used. In a few cases where Plastor was used, extrusion to the margins was seen. One case (Fig. 22) shows clearly the futility of condensing a large Class II amalgam over a soft base. In this case, Ledermix paste had been placed over a pulp with a poor prognosis, and Plastor then placed to an ideal depth and amalgam condensed into the cavity. The amalgam was thought to have been fairly well condensed, and the result shown was entirely unexpected. Although a better result may have been obtained with a spherical alloy, this procedure, in Class II cavities at least, can only be regarded as one inviting failure. Even the use of low condensation loads required for spherical amalgam alloys may be sufficient to cause the displacement of unset bases with all the resultant problems.
**Fig. 20**

Class II die with Plaster base material removed after testing, showing distortion of the base by the forces of condensation of the amalgam.

**Fig. 21**

Isthmus fracture, showing base material providing insufficient restoration thickness.
Fig. 22

Result of extrusion of Plastor to the gingival margin by the forces of amalgam condensation.

Fig. 23

Class I restoration showing gross failure due to collapsing of amalgam condensed over a base of Plastor.
A number of failures were observed in Class I restorations that could be considered to be due to the use of Plastor as a base, but some cases involved excessively thin amalgam in the centre of the surface of the restoration with the resultant collapsing of the restoration (Fig. 23).

There did not appear to be any significant difference in the durability of the restorations with the set base materials. There does not seem to be any evidence that the low compressive strength of Dycal results in a restoration which is more likely to fail in service; indeed, the evidence of the excellent pulpalm response of this material in the literature would indicate that materials of this type will give a restoration which is more likely to fulfil its biological requirements, and adequately fulfil mechanical requirements. As the results of this study indicate that a restoration placed over a zinc phosphate cement base is no stronger and no more durable than those placed over the weaker materials, it raises the question as to whether, in the light of the pulpal effects of this material, it has any place at all in regard to its use as a cavity base for amalgam.

Mechanically, much the same could be said in regard to the zinc oxide bases. The compressive strength tests carried out on Temrex cement to determine the strength of this material as used for cavity bases failed to obtain figures as high as those given by others
(Phillips, 1965, gave 4,200 psi.) and it must be remembered that this type of material will lose strength slowly over a longer period (see discussion on pages 48, 49). Even so, the results of the present study do not show any significant difference in the strength of the restoration or its durability compared with restorations condensed over Dycal or zinc phosphate cement. However, the "sterilising" effect of eugenol preparations on dentine may be considered by many to be a sound reason for advocating the routine use of these materials. Against this must be weighed considerations as to the possibility of minute exposures or detrimental effects of eugenol on the tooth structure as discussed on pages 36 and 37.

It must be remembered that in practice, the loading of restorations in service is very different to the manner in which the tests were carried out on the metal dies, which served only as a means of comparison of "restoration strength" rather than any attempt to find absolute values. In function, all dentitions operate according to the principles of shear, rather than simple vertical crushing strokes (Brodie, 1969). There are great variations in chewing patterns, with corresponding distribution of stresses on the amalgam. Chewing patterns vary from those with broad lateral grinding movements, together with a mesio-distal movement, which will place tensile as well as compressive forces on the restoration, to those with almost vertical movement only, which will have a higher compressive component over a smaller area of the restoration.
The results of the tests carried out indicate that the properties of the restoration in service do not seem to vary according to the compressive strength of the base material used; rather, these properties are dependent on other factors, all of which are under the operator's control. Most failures in the clinical survey could be attributed to factors other than the simple fact that some bases are stronger than others. The exception found was in the case of Plastor, but even here most of the failures in Class I amalgams were attributed to the displacement of the material to the margins of the restorations, or to the centre of the occlusal surface resulting in a thin section of amalgam which subsequently failed in service. Failure of Class II restorations with Plastor bases could be accounted for to a large extent by the fact that the easily compressible material under the amalgam at the isthmus allowed the restoration to collapse under the occlusal forces applied to the amalgam, whereas the other materials, even those relatively weak, were sufficiently incompressible to adequately support the amalgam in this area.

It is important to note that in the Class II test specimens utilising Plastor, the early fracture was not due to the displacement of the base material at the isthmus with subsequent reduction of thickness of amalgam, but rather the inherent weakness of the material when used to support a restoration which is not itself supported by four rigid walls as in Class I restorations. All the set base materials
were equally satisfactory from the standpoint of "restoration strength"; the operator's choice of set base material should, therefore, be governed solely by biological factors.

The tests carried out on natural teeth were conducted in an effort to relate the values obtained with the metal dies to clinical conditions. Little data for biting forces on natural teeth are available. As long ago as 1908, G. V. Black listed values for occlusal forces obtained by use of an instrument he called a "Gnathodynamometer." He found enormous variations in forces applied by different patients. The minimum given for an adult was 50 pounds or less, and the highest figure given was 350 pounds. The forces actually used for chewing varied from 129 pounds for rock candy to 39-60 pounds for various meats, and almost nil for soft foods. Most subjects in his study stopped applying further pressure because of pain in the periodontal membrane rather than reaching their maximum muscular effort.

O'Rourke (1949) stated that man has much greater power in his masticatory muscles than is needed for the chewing of foods, or can be tolerated by the supporting tissues. He showed that subjects showed 21% increase in biting force when maxillary and mandibular blocks were given. Masticatory function is usually maintained at a level in harmony with physical comfort; the natural tendency is not only to avoid pain, but to masticate in a subconscious or reflex manner to remain below the threshold where pressure would give rise to
apprehension. O'Rourke gave figures of 3–30 pounds for chewing meats, using trituriation movements, and up to 103 pounds for direct crushing movements.

Manley and Schiere (1950) measured maximum biting forces with a Howell–Manley oral force meter. A rubber cushioning device was placed over the bite element, and the meter centred over the cusps of the molar and premolar teeth. Average forces found for 20–29 year old males was 91 pounds, and for females in the 30–39 year old group, 31 pounds. Other age groups were between these figures. Baker et al (1940) used a 2 mm steel ball held between the arms of an instrument, one of the arms holding a standardised aluminium plate of known Brinell hardness, to determine biting forces, but no figures were given. Ralph (1969) has suggested a simple device using two arms with strain gauges attached and suitably calibrated to give figures for occlusal forces, but has not as yet published figures for complete natural dentitions, this study being concerned with prosthetic problems. Anderson (1956) used electrical strain gauges placed in a cavity cut in gold inlays in lower molars, the position of the cavities being arranged so that the cusp of the occluding tooth contacted the centre portion of the gauge unit. Anderson found peak loadings were 10–15 pounds, and demonstrated that jaw muscles in practice do not exert the much higher forces that static measurements have shown. (Wire strain gauges are used
in many industrial applications to accurately measure very small
deflections, such as, in this case, the deflection of an inlay under
functional stress - McKay, 1968.) In a second study in 1959,
Anderson used a similar arrangement on several different subjects,
and found that chewing forces for different foods did not vary to
a great extent in the same subjects, but showed great variations
between different subjects. Chewing forces for different foods
did not vary to a great extent in the same subjects. Pressures
were found to vary from 6-9 pounds in some subjects, up to 50 pounds
in others. No consistent pattern emerged from this study.

Beke (1967) suggested the term "margin of safety," meaning
the relationship between the biting force needed for chewing and the
maximum force capable of exertion. He felt that the figures given
by Tylman were accurate, who gave 52 pounds as the average for females
and 64 pounds for males. Tylman suggests that Black's "Gnathodynamo-
meter" gave a measure of the tolerance of the periodontal membrane:
rather than an indication of the combined efforts of the muscles of
mastication. Klaffenbach (1936) calculated that if a test instrument
showed a biting force of 50 pounds and the total area of contact is
0.0379 sq. ins. on the restoration, the intensity of the force is
1,319 psi. It would follow that the compressive strength of amalgam
restorations in place is more than adequate for normal use.
In view of the variation in various figures given in the literature, it is difficult to relate the test die results to conditions as found clinically, but it is clear that the forces used to fracture the test specimens in all cases were well above the forces to which the restoration will be subjected in actual service. The evidence from this study, therefore, would indicate that provided all factors in the preparation of the cavity and the manipulation and condensation of the amalgam are carried out in accordance with recognised principles as discussed in the review of the literature, the strength of the base forming material will not affect the strength of the restoration in service. The base forming material must set and be of sufficient strength to remain undistorted by the forces used to condense the amalgam. The durability of the restoration is dependent on many factors other than the compressive strength of the base material; most of these factors are the direct responsibility of the clinician, but caries susceptibility of the individual patient and his oral care will also have some bearing on the life of the restoration. It would appear that a base materials pulpal effect is a far more important consideration in the selection of a base for amalgams than its compressive strength.

B. The Marginal Deterioration of Amalgam Restorations

The great variations in marginal breakdown and deterioration observed in the clinical survey do not appear to follow any real pattern, except
that there was a significantly higher incidence of both gross failures and margins assessed as being poor in the case of amalgams placed over Plastór. This can probably be related to the use of lower condensation forces in efforts to reduce displacement of the base material when condensing the amalgam, and the inherent weakness of large sections of amalgam supported by unset and easily compressible material when subjected to occlusal loadings. Although slight variations are seen in the case of the set base materials, it was not felt that these were of definite clinical significance as there is, of necessity, substantial variations in this type of clinical study.

There was no correlation between the rate of marginal deterioration and the caries rate. Figs. 24 and 25 show two cases, both originally placed on the same day with the same materials and techniques, four years after placement. Patient A, showing considerable deterioration of the margins, presented with three cavities, whereas patient B, with margins almost fault-free, presented with seven cavities, neither having received any treatment within this period. This non-correlating observation has been made in many patients during this survey.

It was frequently observed that there was great variation in the degree of deterioration between patients, but individuals did not show such great variation between restorations. The deduction may well be that the patient's individual salivary constitution may be
related to the marginal deterioration in some way. Other contributing factors may be the morphology of the teeth, as related to the inability of the operator to avoid a slight marginal "flash" and the dietary habits of the patient providing a corrosive environment for marginal failure.

The value of re-finishing restorations after a period of service as suggested by Matsuda and Fusayama (1970) was confirmed by observations made during this study. It was felt that many cases of apparent deterioration were in fact due to the fracture of small particles of excess or flash at the cavo-surface angle, leaving a poor marginal finish. Figs. 26 and 27 show a restoration with poor margins after a period of service of only seven months, and the effect of re-finishing and polishing of the margins. It was observed that this procedure was most effective when carried out at six to eight months after placement of the restoration and that subsequent deterioration was much reduced following this procedure.
Amalgams four years after placement. All were in a similar condition regardless of the cavity base material used (Patient A)

Amalgams four years after placement. All were in a similar condition regardless of the cavity base material used. (Patient B)
Fig. 26

Restoration after ten months' service showing severe marginal deterioration.

Fig. 27

Same restoration after re-finishing and polishing. There was no noticeable change in the condition of the margins over the ensuing six months; little change can be anticipated over a long period.
CHAPTER FIVE

SUMMARY

1. The literature concerning the durability of amalgam restorations has been reviewed.

2. The physical properties of the principal cavity base materials have been reviewed, and attention drawn to the fact that there is some disagreement in the literature concerning the role of the cavity base material in relation to the strength and durability of the restoration in service.

3. Dies of Chromium cobalt alloy were constructed of typical Class I and Class II cavities where excavation has been carried out to the point of near-pulpal exposure. The dies were restored with amalgam over different bases and tested for "restoration strength" in a Hounsfield Tensometer.

4. A clinical survey was carried out over periods of up to 52 months, observing the relationship between the fracture and deterioration of restorations and the cavity base material used.
5. The conclusions reached from this investigation were:

a. The compressive strength of the cavity base material is not of importance with regard to the durability of the restoration; the material must be set and need only be of sufficient strength to resist the forces of condensation of the amalgam.

b. Actual fracture of restorations in service was not a common cause of failure; marginal breakdown, corrosion and recurrent caries account for a large majority of replacement work.

c. The means of providing durable amalgam restorations at the present time are adequate; some marginal deterioration is inevitable, but this will be minimised by repolishing the restoration 6–8 months after insertion.
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