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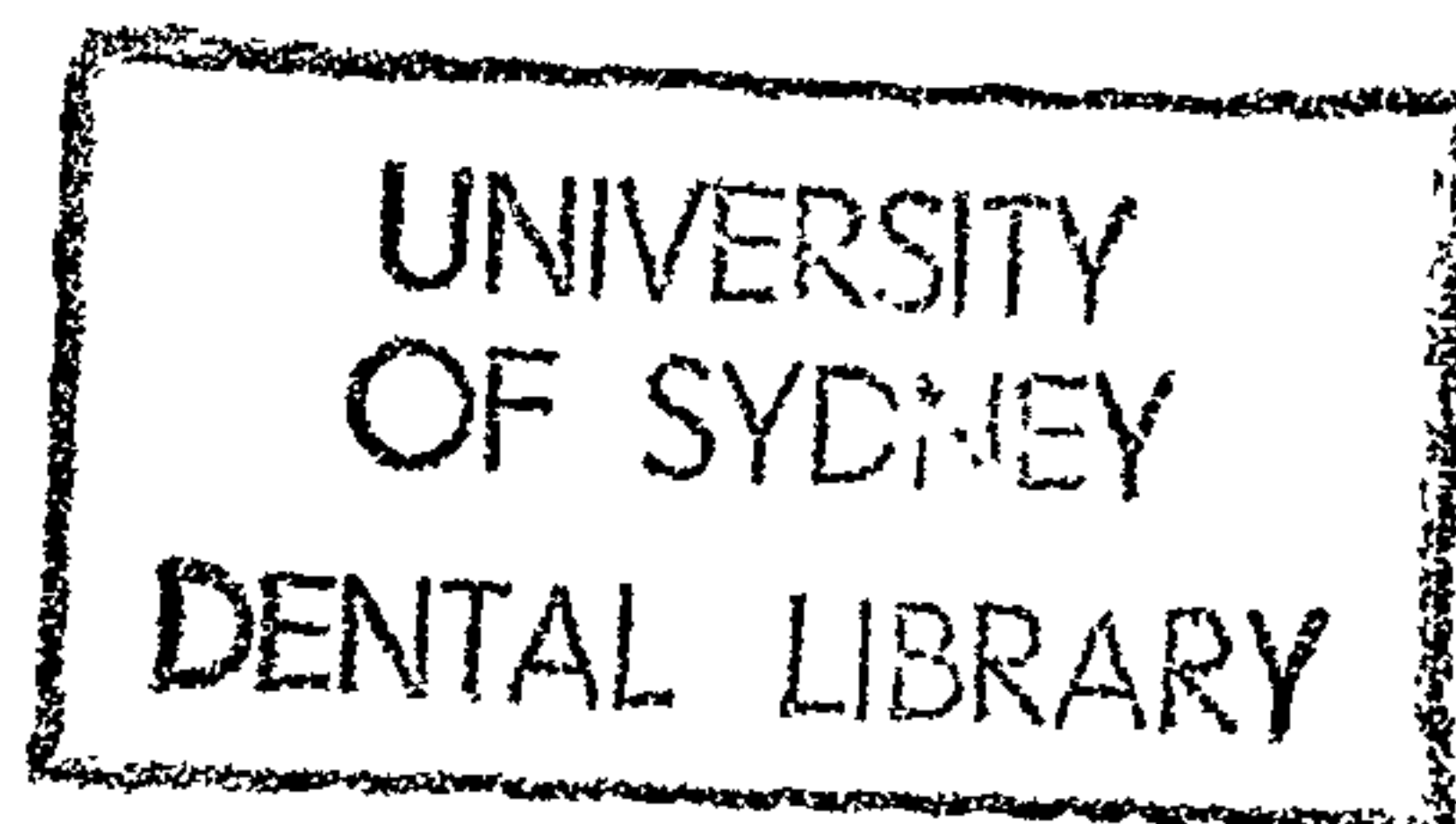
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AN IN-VITRO INVESTIGATION OF THE FIT OF ANTERIOR PORCELAIN
AND PORCELAIN-METAL FULL-VENEER RESTORATIONS.

Thesis submitted to the University of Sydney
as partial requirement for admission to the
degree of Master of Dental Science.

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PREFACE

When C.H. Land introduced the porcelain jacket crown in 1902, it enabled the application of the desirable aesthetic qualities of porcelain to be applied to full veneer dental restorations. Both the early clinical techniques and the initial development of dental porcelains were, however, empirically based and it was not until 1923 that the aesthetic, biological and functional attributes were well understood and applied using a dependable technique.

Some shortcomings associated with the fit and physical strength of the restoration had become apparent. These shortcomings prompted the development of the porcelain fused to metal restoration in the 1950's in an effort to combine the aesthetic qualities of dental porcelain with the strength and accuracy of fit of cast metal. This successful combination of porcelain and metal has subsequently eroded the prestigious position of the porcelain jacket crown even though recent research has resulted in techniques purported to increase both the fit and the strength of such crowns.

The development of the porcelain fused to metal restoration has not been without its problems. For example, there is some dissatisfaction with the overall aesthetics of these restorations when compared with the platinum foil jacket crown and, secondly, distortion of the metal during fusing of the porcelain has been reported to affect the fit of such restorations.

Clinically the fit of a dental restoration is most frequently associated with the discrepancy at the margin of the cemented

(II)

restoration. Distortions arising during fabrication of the crown and an excessive thickness of the cementing or luting agent are the two main factors which are likely to contribute to the degree of marginal discrepancy (or misfit) of a full veneer restoration. The in-vivo assessment of fit is restricted to instrumental probing and visual and radiographic examination. In-vitro techniques have been developed to measure the marginal discrepancy but have either been confined to external linear measurements or have necessitated destruction of the cemented crown.

In 1972 McLean and von Fraunhofer introduced a technique for measuring marginal discrepancy which enabled a cross section of the marginal area to be viewed without destruction of the cemented crown. This technique involved the examination of a rubber replica of the cement space between tooth and restoration. The accuracy of their technique was verified in this present investigation. Only slight modifications were found to be necessary to obtain an accurate replica of the cement space.

This technique was then used to study the contour of the cement space under cemented full veneer porcelain restorations. The affect of fabrication distortions on cement contour especially in the shoulder regions was considered. The marginal discrepancy was assessed and related to the clinical acceptability of the restorations. The fit of the crowns was assessed not only with respect to marginal discrepancy but to overall axial discrepancy in the shoulder region. The clinical significance of such an assessment has been discussed.

C O N T E N T S

P A R T A.

R E V I E W O F L I T E R A T U R E

	Page
1. THE DEVELOPMENT OF THE PORCELAIN JACKET CROWN	1
2. THE STRENGTH OF DENTAL PORCELAIN	9
(a) The brittleness of glass	9
(b) Static fatigue	15
3. INCREASING THE STRENGTH OF DENTAL PORCELAIN	17
4. DISADVANTAGES ASSOCIATED WITH PLATINUM AS A MATRIX MATERIAL	21
5. ELIMINATING THE PLATINUM FOIL	25
6. THE DEVELOPMENT OF THE PORCELAIN FUSED TO METAL RESTORATION	27
7. THE PHYSICAL PROPERTIES OF THE MATERIALS USED IN THE PORCELAIN FUSED TO METAL RESTORATION	33
(1) The porcelain metal bond	33
(2) The difference between the melting point of the metal and the fusing temperature of the porcelain	36
(3) The difference in co-efficients of thermal expansion	36
(4) The metal strength	38
8. ALLOYS AND PORCELAINS	40
9. DISADVANTAGES OF THE PORCELAIN BONDED TO METAL SYSTEM	43
(1) Inherent residual stress	43
(2) Inaccuracy of castings	45
(3) Instability of castings	46
(4) High reflective properties of the core porcelain	49
(5) Greatly increased laboratory time and procedures	50

(IV)

10.	TOOTH PREPARATION COPING DESIGN AND DIE CONSTRUCTION	51
	(a) Tooth preparation - the porcelain jacket crown	51
	(b) Tooth preparation - the porcelain-metal crown	52
	(c) Coping design	54
	(d) Die construction	56
11.	AN ALTERNATIVE TECHNIQUE FOR THE FABRICATION OF PORCELAIN FUSED TO METAL RESTORATIONS	58
12.	THE MARGINAL DISCREPANCY OF ANTERIOR FULL CROWN RESTORATIONS	62
	(i) The effect of cement on marginal discrepancy	63
	(ii) Factors influencing filtration	67
13.	THE MEASUREMENT OF MARGINAL DISCREPANCIES OF VENEER CROWN RESTORATIONS	72
14.	THE FLOW PROPERTIES OF ZINC PHOSPHATE CEMENT	77
	SUMMARY	

P A R T B.

O R I G I N A L I N V E S T I G A T I O N

THE STATEMENT OF THE PROBLEM - THE AIM OF THE INVESTIGATION	84
---	----

T H E M E T H O D

ESTABLISHING THE METHOD	90
(1) The determination of the powder/liquid ratio of a luting consistency mix of Dalton's Zinc Phosphate Cement.	92
(2) The determination of the flow properties of Dalton's Zinc Phosphate Cement.	97

(3)	The determination of a mix of Impregum with flow properties comparable to Dalton's Zinc Phosphate Cement.	104
(4)	An investigation of a rubber replica technique for accurately determining the axial discrepancy of cemented full veneer restorations.	114
B.	APPLICATION OF THE METHOD	126
(a)	The porcelain jacket crown	126
(b)	The porcelain fused to metal crown	129
C.	THE CLINICAL ACCEPTABILITY OF THE FIT OF THE FABRICATED CROWNS	132
R E S U L T S		133
A.	The Porcelain Jacket Crowns	133
B.	The Porcelain Fused To Gold Crowns	151
C.	A Comparison Of The Axial Discrepancies Of Porcelain Jacket And Porcelain Fused To Metal Restorations.	163
D.	The Clinical Acceptability Of The Fabricated Crowns.	165
E.	A Comparison Of The Marginal Discrepancies Of The Porcelain Jacket and Porcelain Fused To Metal Crowns	169
D I S C U S S I O N		179
A.	The Porcelain Jacket Crown	180
(1)	The Platinum Foil Crowns	180
(2)	The Refractory Die Crowns	185
(3)	A Comparison Of Porcelain Jacket Crowns Prepared By The Platinum Foil And Refractory Die Techniques	187
B.	The Porcelain Fused To Metal Crown	188
(1)	Nature Of The Fit Of The Crown	188
(2)	Control Of Film Thickness And Fit	191
(3)	The Fit Of The Crowns At Non-Shoulder Regions	194
C.	A Comparison Of "Flanged" And "Cylindrical" Type Of Preparations	195

(VI)

D.	The Clinical Acceptability Of The Marginal Fit Of The Crowns	197
E.	A Comparison Of The Marginal Discrepancies Of The Porcelain Jacket And Porcelain Fused To Metal Crowns	201
C O N C L U S I O N S		203
A.	Porcelain Jacket Crowns	204
	(a) Platinum Foil Crowns	204
	(b) Refractory Die Crowns	205
B.	Porcelain Fused To Metal Crowns	206
C.	A Comparison Of Flanged And Cylindrical Type Preparations	207
D.	The Clinical Acceptability Of The Marginal Fit Of The Crowns	208
E.	A Comparison Of The Marginal Discrepancies Of Porcelain Jacket And Porcelain Fused To Metal Crowns	208
S U M M A R Y		210

(VII)

L I S T O F T A B L E S

Table No.		Page
1.	The determination of a clinical luting consistency for Dalton's Zinc Phosphate Cement.	94
2.	Consistency test in accordance with AS. 1186 (1972) for Dalton's Zinc Phosphate Cement.	99
3.	Film thickness of mixes of Dalton's Zinc Phosphate Cement of different consistency.	100
4.	The film thickness testing of Impregum.	108
5.	Consistency testing of Impregum.	109
6.	A comparison of the flow properties of Dalton's Zinc Phosphate Cement and Impregum.	110
7.	Axial discrepancy in the shoulder region of "cemented" porcelain crowns using direct sectioning and rubber replica techniques - Refractory die crown.	123
8.	Axial discrepancy in the shoulder region of "cemented" porcelain crowns using direct sectioning and rubber replica techniques - platinum foil crown.	124
9.	Axial discrepancies at the shoulder region of crowns employing the platinum foil technique and cylindrical shoulder preparations.	134
10.	Axial discrepancies at the shoulder region of crowns employing the platinum foil technique and flanged shoulder preparations.	136
11.	Axial discrepancies at the shoulder region of crowns employing a refractory die technique and cylindrical shoulder preparations.	138
12.	Axial discrepancies at the shoulder region of crowns employing the refractory die technique and flanged shoulder preparations.	140
13.	Measurements of the labial and lingual shoulder region of one polished surface for two refractory die crowns with flanged gingival contours.	142

(VIII)

14.	Summary of overall means of axial discrepancies in the shoulder region.	144
15.	Average discrepancies of two crowns at several different regions.	146
16.	Axial discrepancy measurements of the labial shoulder region of crown 1C before porcelain application.	152
17.	Axial discrepancy measurements of the labial shoulder region of crown 1C after porcelain application.	154
18.	Axial discrepancy measurements at the labial shoulder region of crowns with a cylindrical gingival contour.	156
19.	Axial discrepancy at the labial shoulder region of crowns with a flanged gingival contour.	158
20.	An overall comparison of the axial discrepancies at the labial shoulder region of cylindrical and flanged porcelain fused to metal crowns.	160
21.	Comparison of overall means of axial discrepancies at the shoulder region of porcelain jacket and porcelain fused to metal crowns.	164
22.	Clinical assessment of full veneer crowns by six experienced clinicians.	166
23.	Mean marginal discrepancies of crowns considered clinically unacceptable by one or more clinicians.	168
24.	A comparison of the mean "e" values of the crowns corresponding to their marginal discrepancy.	170
25.	Comparison of the overall means of the axial and marginal discrepancies of the crowns in the shoulder region.	172
26.	A comparison of the clinical assessment marginal discrepancy and axial discrepancy in the shoulder region of the platinum foil porcelain jacket crowns.	174
27.	A comparison of the clinical assessment, marginal discrepancy and axial discrepancy in the shoulder region of the refractory die porcelain jacket crowns.	176

28. A comparison of the clinical assessment marginal discrepancy and axial discrepancy in the shoulder region of the porcelain fused to metal crowns. 178

(X)

L I S T O F I L L U S T R A T I O N S

Figure No.		Page
1.	A photomicrograph and adjacent tracing showing points of measurement of the axial discrepancy in the labial shoulder region of a cemented porcelain jacket crown.	88
2.	Photograph showing consistency discs obtained for three powder/liquid ratios of Dalton's Zinc Phosphate Cement.	103
3.	3(a) Photograph showing the consistency of size of Impregum discs obtained during a consistency test according to Australian Standard number 1186 (1972). 3(b) Photograph showing a comparison of slumped discs obtained from a luting mix of Dalton's Zinc Phosphate Cement and an Impregum mix with equal lengths of catalyst base and thinner.	113
4.	Photographs illustrating the steps required to obtain a rubber replica section of the cement space beneath a cemented full veneer restoration.	117(i) 118(ii)
5.	Photograph showing a machine made for sectioning the embedded rubber impressions.	120
6.	Photograph showing a typical polished section ready for microscopic examination.	122
7.	Photograph showing the two types of gingival contour used in the tooth preparations.	127
8.	Photograph showing a porcelain fused to metal casting ready for porcelain application but with the metal reservoir retained.	131
9.	Diagram illustrating the typical contour of the cement space beneath a platinum foil porcelain jacket crown.	147
10.	Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of platinum foil porcelain jacket crowns.	148
11.	Diagram illustrating the typical contour of the cement space beneath a refractory die porcelain jacket crown.	149

(XI)

12. Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of refractory die porcelain jacket crowns. 150
13. Diagram illustrating the typical contour of the cement space beneath a porcelain fused to metal crown. 161
14. Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of porcelain fused to metal crowns. 162

P A R T A

R E V I E W O F L I T E R A T U R E

1. THE DEVELOPMENT OF THE PORCELAIN JACKET CROWN

The making of the first porcelain teeth is credited to Dr. Du Bois de Chement who succeeded in implementing the idea conceived by the French chemist Duchateau in 1774. Lee (1961) stated that Duchateau and de Chement obtained their ideas and knowledge of porcelain manufacture from Sevres and other porcelain manufacturing concerns.

However, the early experimentation with porcelain was confined to the field of dentures. It was not until C.H. Land conceived the principle of using platinum foil sheet and tube as a matrix material, that porcelain became useful for restorative procedures.

There is some doubt as to the year Land developed the technique. In 1889, he reported on five years experience in fusing porcelain for inlays and crowns, which would take his earliest efforts back to 1884. Oppice (1929) referred to 1895 as the year of introduction of the Land crown although the literature does not support this view.

According to Argue (1916), Land developed the platino-porcelain crown in 1886 and the all porcelain jacket crown in 1902.

Land (1903) stated that other makers had antedated him regarding the porcelain jacket crown but did not mention their names. He said "The dawn of the new era, which revealed a field of greater scope and increased value (of porcelain) was first made known to the profession by a publication of an article in the 'Independent Practitioner' of August 1886 entitled, 'A new system of restoring badly decayed teeth'. In addition, an original paper entitled 'Metallic enamel coatings and fillings', appeared in the August 1887 issue of the same journal".

However, it would seem reasonable to assume that Land developed the first practical porcelain jacket crowns and that he evolved two types. The first, which was really a development of a porcelain fused to metal crown will be discussed elsewhere.

The second type was developed by Land about 1902. This technique employed the use of a matrix of platinum or gold foil over which the porcelain was fused. A slip porcelain facing was employed. The whole surface of the matrix was covered with porcelain and the platinum matrix was stripped from the inside of the crown prior to its cementation. A high fusing porcelain was used for the first firing over the matrix. A porcelain of lower fusing point was then used to unite the slip facing with the first bake and to build the crown up to full contour. In this technique the matrix was adapted directly onto the prepared tooth.

Spalding (1904) developed this technique further. He described two ways for building up the crown onto the matrix.

Either a ground slip facing could be used, or the crown could be built up and carved with the porcelain body. The dental porcelains then were not as well developed as they are today and use of the porcelain slip facing provided better colour control. Spalding suggested that full crown buildups with body porcelain be limited to premolars.

Goslee (1903) criticised the advocates of the porcelain jacket crown because of the lack of strength and consequent fractures associated with the technique. He also claimed that they were often too bulky and shapeless and he preferred the use of contemporary post crown methods, such as the Logan or Richmond crowns. However, these methods entailed pulp removal. Such criticism did not appear to slow further development of the porcelain jacket crown. This was probably due to a change in philosophy about this time, concerning deliberate devitalization of teeth, which up until then had been considered quite routine. This change can be seen in a quote from Land's paper in 1902 - "Pulp destruction should always be the last resort". He felt sure that - "this new process is likely to prove the most efficient method of tooth restoration and preservation that has ever been devised".

Fabrication of the porcelain jacket crown was done by the direct method, until 1908. The platinum matrix was adapted onto the patient's tooth. Usually a soldered joint was employed. Successive bakes of porcelain were made and the crown tried back onto the tooth between bakes to check fit and contour.

In 1908 Baldwin advocated constructing the porcelain jacket

crown over a platinum matrix which was adapted onto a copper amalgam or cement die. According to Smythe (1963), this is the first mention in the dental literature of the use of a die. The matrix was checked in the mouth then returned to the die. The porcelain was added and the crown was returned to the tooth to check fit and contour. This could be considered an indirect-direct technique.

Riethmueller (1909) developed a direct-indirect technique. He adapted the platinum matrix to the tooth, soldered the seams, replaced the matrix and took an overall plaster impression. The impression was painted with a separating varnish and a model poured with ceramic inlay investment. This model, incorporating the platinum matrix, was utilized to build up the porcelain crown.

Frank, also in 1909, presented a technique involving a compound impression of the prepared tooth taken inside a copper or silver band, which was correctly festooned for gingival contour. A wax impression of the arch and a wax squash bite were taken. The compound impression was filled with zinc phosphate cement to make a die. It was then seated in the wax impression and a working model poured with plaster. Smythe (1963, p.10) claims this was the first use of a working model with a removable die and therefore the first fully indirect technique.

Schneider (1909) advocated the use of the "Steele's self-locking matrix", or tinner's joint matrix. He also advocated the use of only one firing.

Already some of the disadvantages of the Porcelain Jacket Crown were being realised. Because of the shrinkage upon firing

of the dental porcelain, it was observed that there was a lifting up of the platinum foil from the margin. To allow shrinkage of the porcelain without distorting the platinum matrix in the vital shoulder region, Straussberg (1911) advocated ditching the porcelain down to the platinum matrix, about one millimetre from the shoulder before firing the first bake. Others advocated a readaptation of the foil after the first core firing.

Straussberg also criticised the use of slip facings. He claimed the technique was time consuming, resulted in poor final contour and therefore poor aesthetics. He also claimed that the facing became overfired and was thus weakened by the fusing cycle and that the union between facing and body porcelain was not as strong as a crown fused to a glass in a single mass. In the discussion following the presentation of this paper, Pruden questioned whether a prepared vital tooth was strong enough to withstand forces applied to a crowned tooth. Others including Straussberg questioned the use of the porcelain jacket crown for "close bite cases", because of failure due to fractures.

As late as 1914, Villain was still advising the use of gutta percha for seating crowns but most of the profession was using zinc phosphate cement. In 1915, Custer advocated cementing porcelain jacket crowns with silicate cement.

Coston (1912) advocated the use of silicate cement set under pressure for the formation of dies for porcelain jacket crown construction, claiming that such dies would withstand both burnishing and swaging of the platinum foil matrix.

Argue (1916) spoke in favour of the porcelain jacket crown, claiming the desirability of conservation and maintenance of a healthy pulp. He also stressed the importance of accurate shoulder fit and the dangers of cement solubility and bacterial proliferation in the resultant space.

Lewis (1918) also advocated the maintenance of a vital pulp and introduced the concept of the removable amalgam die set in articulated models.

Several other writers wrote papers claiming the advantages or disadvantages of the porcelain jacket crown. Buell (1920) praised the porcelain jacket crown because of the soft tissues's tolerance to porcelain, the poor thermal conductivity of porcelain and its aesthetic qualities. He also suggested the use of a cast core of silver and gold alloy for non-vital teeth. He and Parfitt (1923) advocated the use of a paper tube wrapped around the die to produce better condensation of porcelain. Parfitt also suggested the use of a glaze porcelain of lower fusing temperature to obtain a glazed finish without distortion of the rest of the crown.

Hovestadt (1919) also wrote in favour of the porcelain jacket crown. He laid stress on several factors including tooth anatomy and histology and their influence on proper tooth preparation. He wrote "The cardinal principle of the porcelain jacket crown is the exact reproduction of the natural tooth in shape and colour. The second principle is the protection of the pulp and peridontal membrane from injury. The third principle is the protection of the soft tissue so that its function will continue normally after

tooth restoration with the crown. The fourth principle is the correct restoration of all anatomical details such as cervical contour, contact points, occlusion and articulation". He also stated that "porcelain outweighs any other material in regard to tissue tolerance". This still holds true according to the work of Alison (1958), Pini (1958) and others. Hovestadt recognised the need for correct diagnosis with radiographic aid, if necessary, before contemplating porcelain jacket crown restorations. He also stressed the need for temporary coverage for pulp protection and employed celluloid crown forms filled with gutta percha for this purpose.

Scherer (1922) emphasised the importance of establishing and maintaining the health of the gingival tissues and supporting structures.

Vehe (1922) stressed the importance of occlusal considerations in case selection for porcelain jacket crowns. He stated that, "balanced articulation be established with the restoration and the immediate area at least ... not only in centric but in eccentric".

By the end of 1923 the porcelain jacket crown had been accepted as a desirable restoration. Its aesthetic, biological and functional attributes were well understood and a dependable technique for producing it has been evolved.

In the author's opinion it is not considered necessary to review in detail the technique for the fabrication of porcelain jacket crowns. This has been done adequately by Smythe (1963)

and Carter (1965). There are, however, some aspects of the technique that have some bearing on the original research conducted as part of this thesis. These are now reviewed.

2.

THE STRENGTH OF DENTAL PORCELAIN

Dental porcelain is recognised as a friable material even under the most ideal circumstances. This results from the glassy nature of porcelain. In meeting the requirements of modern dentistry, dental porcelain has developed into a highly translucent glass-like material with properties greatly influenced by this vitreous or glassy phase (Southan 1970). A better understanding of the nature of dental porcelain and its inherent properties may be gained by a closer consideration of the glassy state.

(a) The Brittleness of Glass

Glasses are non-crystalline amorphous solids without a regularly repeating long-range order of atoms that exist in crystals (Warren 1937). They have a high degree of elasticity, moderate to high tensile strength and a complete lack of plastic flow - properties which render glasses excessively brittle.

According to calculations based on atomic bonding forces, glasses should have very high tensile strength values, of the order of $1-100 \times 10^6$ p.s.i. Actual observed strengths however are only $1-100 \times 10^3$ p.s.i. (Kingery 1963, p604). Griffith in 1920 expounded the "Flaw Theory" of the strength of glass to account for this discrepancy. According to this theory, stress concentrations around small cracks and flaws approach theoretical values and initiate fracture.

The theoretical strength will remain the true fracture stress of the material and can actually be reached in small volumes of the specimen, even though the average fracture stress may be low.

Kingery (1963, p606) stated that it is surface rather than interior flaws that lead to fracture. Furthermore, the degree of stress concentration depended on the degree of sharpness of the crack tip, with increasing sharpness resulting in increasing stress concentration. The position, orientation and shape of such flaws was also important. Thus, on glass specimens, strength tests measure not the bond strength of the glass but the stress concentrating effect of the most serious flaw, in the most highly stressed area. Relating this theory to dental porcelain and in particular porcelain jacket crowns, it becomes evident that any surface flaw can initiate fracture through stress concentration. Particularly vulnerable areas are those at the point of applied stress, such as contact regions and supportive regions for example and in particular the gingival shoulder area.

Gurney (1964) classified the sources of flaws in glasses in the following ways:-

- (i) Submicroscopic voids.
- (ii) Bubbles.
- (iii) Foreign matter on the surface of reheated glass.
- (iv) Mechanical damage.
- (v) Moisture.
- (vi) Effect of intrinsic stresses.

(i) Submicroscopic voids

Gurney described submicroscopic voids as spaces in the molecular structure of the glass formed during cooling, where equilibrium conditions cannot be achieved by molecular movements. These cannot be demonstrated in glass specimens on porcelain jacket crowns but as Gibbs and Cutler (1951) stated such flaws represented an irregularity in the glassy lattice structure.

(ii) Bubbles

Bubbles can act as stress concentrators, especially if they exist near the surface, as the rapid cooling of their thin walls predisposes to cracking and thus stress concentration (Gurney 1964). Large bubbles weaken a specimen by substantially reducing the amount of glass in a particular cross section. The porous nature of dental porcelain is well documented (Vines et al. 1958, Semmelman 1957, Southan 1971, p.265). Even under optimal condensation and vacuum firing procedures, the total pore volume of a typical dental porcelain is 1.3% (Southan 1971, p.267). Further pore elimination is prevented by surface tension factors.

Cracking of walls of pores near the external surface is eliminated by a reorganization of molecules in a viscous state at glazing temperatures. However the internal surface is different. Not only are small pores present due to voids between powder particles before firing but, as Southan (1972) demonstrated, larger internal faults exist over the entire internal surface with a concentration at the shoulder region. This is due to the inability of the porcelain to wet the platinum foil.

Further work by Southan (1973) explained the reason for the occurrence of these faults. When porcelain powder is applied to platinum foil there is a sporadic condensation in the contact region, resulting in poor adaptation to the foil and a spongy appearance. Voids up to three quarters of a square millimetre showing very poor adaptation have been noted. At levels within the porcelain specimen this was not the case. A vaulting effect resulting from the comparatively free, three dimensional movement of all particles occurred. The areas of poor adaptation are due to the characteristics of particle movement. The movement of the larger porcelain particles is restricted at first and subsequently the surface tension of the receding vehicle tends to pull smaller particles towards centres created by the larger stranded particles.

Thus, after condensation, these vaults exist. Upon firing, the tendency for flow of the porcelain over the foil to eliminate these vaults is restricted because the solid-liquid interfacial energy, between platinum and dental porcelain, is high, or more simply, the dental porcelain does not wet the platinum foil. The concentration of defects around the gingival shoulder is explained by gravity localising larger particles around this region during condensation. The size and shape of a vault at the platinum surface would largely determine the type of defect developed in the crown after firing. The vaults become voids, which because of the high interfacial energy between the platinum and dental porcelain are reluctant to leave the platinum. Even if they do leave the foil

surface, they lie close to this surface and the rapid cooling of their thin walls will cause internal stress and predispose to cracking as the foil is removed.

Southan is convinced that it is these internal faults which are the cause of most failures of porcelain jacket crowns.

However not all pores or bubbles are stress concentrators, such defects can even act to increase the strength of a specimen by acting as "crack stoppers". By impeding crack propagation these voids will strengthen the material. Thus a surface checking will tend to occur rather than complete fracture (Kingery 1963,p.621).

(iii) Foreign matter on the surface of reheated glass.

During refiring, impurities may dissolve partially in the surface and form glasses with different physical and chemical properties from the parent glass. Surface roughness, as a result of such contamination, may also occur. Both factors produce weakness by concentrating stress in the porcelain especially where there is more than one firing. Therefore foreign matter not only detracts from the aesthetic value but may also result in a decrease in strength of a porcelain crown.

(iv) Mechanical damage.

It is well known that strong glass is greatly weakened by contact with other glass or hard bodies. This is because such contact causes the surface of the glass to be cracked, scratched, abraded or bruised. A typical scratch on glass is not a crack but results in numerous transverse cracks which result in stress concentration. The porcelain jacket crown is subject to much

abrasion and surface damage both during fabrication and during function. The surface is usually completely ground with abrasive stones during the shaping-up procedures. The final glazing eliminates these transverse cracks with a reorganisation of molecules in a viscous state at glazing temperatures.

(v.) Effect of Moisture

Preston (1942) stated that when exposed to water glass absorbs a moisture film which breaks up some of the silica bondings in the surface layers. This produces a weakened surface structure analagous to a cracked one.

Gurney (1964) explained the process further. Alkali ions in the glass dissolve in the water and are replaced by hydrogen ions. These attract water molecules into the space originally occupied by the alkali. The water molecules however, are too large for the space and so a state of internal stress is set up.

However, moisture can act as a strengthening factor. Mould (1960) showed that unstressed glass with cracks was strengthened by immersion in water. This process called "aging", operated presumably by rounding the crack tips, so reducing their effectiveness as stress concentrators. In service, porcelain jacket crowns are continually in a moist environment and this moisture effect has some bearing on the strength.

(vi) Effect of Intrinsic Stresses

In studies on glasses, Andrade and Toien (1937) found cracks orientated in directions normal to the predominant tensions set up

during shrinkage cooling from the molten state.

b) Static Fatigue

Another important factor in the strength of glass is static fatigue. It has been recognised that glass could be broken by stresses far below ordinary short-time breaking stress, provided the stress is applied for a sufficiently long time and that moisture is present (Baker & Preston, 1946). In metals, the stress need not fluctuate periodically for this fatigue phenomenon to occur (Orowan, 1944). The corrosion of glass by water has been discussed in the previous section. Although static fatigue must be closely related to this corrosion process, the dissolution must be of a particular type that will lead to flaw growth and increase the stress concentration at the crack tip. This must continue until the crack is of such a size that the applied stress produces a stress at the flaw tip equal to the intrinsic strength of the glass.

Static fatigue can occur in a porcelain jacket crown. The crown is subject to both periodic and constant stress and is in a moist environment. Periodic stress is applied during masticatory function and the applied forces can be high. However, constant stress is applied to other areas such as the contact region. The phenomenon of the resultant anterior component of force is often referred to in Orthodontic terms, but this same force, although it may be small, is constantly being applied to the contact areas of a porcelain jacket crown. If a flaw exists in this region,

then, with the presence of moisture, flaw growth over a long period of time can result in static fatigue. Saklad (1958) used a penetrating die to demonstrate the presence of flaws on the external surface of porcelain jacket crowns which appeared flaw free upon inspection by the naked eye. Thus it seems likely that many porcelain jacket crowns are cemented with flaws which could predispose to static fatigue. Even by applying Saklad's test to ensure external flaw free restorations, Southan (1972) has shown the presence of internal flaws which are inherent to the use of the platinum foil matrix.

3.

INCREASING THE STRENGTH OF DENTAL PORCELAIN

Because of the disadvantages of the glassy state of porcelain, many efforts have been made to increase the tensile strength of glass and then relate this to dental porcelain.

Methods which have been used include:-

- a) Etching
 - b) Toughening or tempering
 - c) Dispersion strengthening
 - d) Chemical stressing
- a) Etching.

Etching would be an unacceptable method because aesthetic properties of the porcelain would be affected. Also, any strength increase achieved by etching could not be considered permanent when the crown was placed into function in the mouth.

- b) Thermal tempering.

Thermal tempering cannot be used to significantly strengthen a porcelain jacket crown because the thinness of sections in the crown does not allow the required differences in cooling rates to be obtained.

- c) Dispersion strengthening.

Dispersion strengthening has been used in dental ceramics. This process was claimed to limit the size and growth of Griffith flaws (Hasselman & Fulrath, 1966). In dispersion strengthening, crystalline grains of alumina are introduced into the porcelain

powder. Batchelor and Dinsdale (1960) showed that the strength of the fired body increased progressively with the proportion of added crystalline alumina but only to a maximum of 25-30 percent alumina content. Above this level the strength did not improve. This crystalline phase is the dispersed phase. The flaw size in the fired porcelain is then restricted by the average distance between dispersed particles in the matrix. Cook and Gordon (1964) suggested that, to be successful, a composite of this type should have interfaces, the strengths of adhesion of which are less than the cohesive strengths of the solid phases.

McLean and Hughes (1965) stated that the thermal co-efficient of the dispersed phase should be similar to, but not equal to, that of the glass matrix. If there were no differences in thermal expansions, the composite would behave as a homogeneous solid with the fracture passing through the glass or the crystalline inclusions. If the difference in co-efficient of thermal expansion is too great the composite tends to crack on cooling (Binns, 1962, Frey & McKenzie, 1967). Alumina fulfils this requirement in most ceramic materials.

McLean and Hughes (1965) found that the modulus of rupture of dental porcelain could be approximately doubled by using dispersed alumina as a reinforcing phase in the glass matrix. Highest values were obtained by increasing the fineness of the alumina.

The disadvantage of this mechanism however arises due to the difference in refractive index of alumina and the glass matrix; with the addition of alumina increasing the opacity of the fired

article. Opacity is a feature of all heterogeneous structures and is related to interfaces between different phases. In practice therefore, the addition of alumina is limited to the core porcelain so that the aesthetic properties of the finished crown are minimally influenced. Most manufacturers have modified their core porcelains to include the alumina phase and this contributes significantly to the strength of the porcelain jacket crown.

Alumina profiles can be used to further reinforce the body porcelain. Aesthetic considerations, however, limit the placement of these profiles to the lingual surface only. Sherrill and O'Brien (1974) have shown that such laminates or profiles of alumina fused into the crown with body porcelain, produced crowns which were 40% stronger than crowns constructed with felspathic porcelain for both core and body layers. The author however, finds these profiles are difficult to grind to fit the lingual contour of the crown. They are not widely used in the profession.

d) Chemical stressing

Southan (1968, p310) established that chemical prestressing could be applied effectively to dental porcelain. This was a method that had no effect on the optical properties of the material. This method involves changing the composition of the surface, resulting in surface compression. Any tensile forces must then overcome these surface compressive forces before initiating flaw growth.

The most effective technique employed to achieve chemical prestressing is ionic-diffusion, first described by Kistler in 1961.

He reported a strengthening method whereby small monovalent ions in the surface layers of glass were replaced by larger ions at relatively low temperatures. He induced replacement of alkali ions in the surface of glass by exposing that surface to the molten salt of another alkali. By "stuffing" a larger ion, for example potassium, into a site formerly occupied by a smaller ion, such as sodium, surface compressive forces were set up. A maximum observed stress in the compressed surfaces of glass discs after such treatment was 120,000 p.s.i.

Southan showed that this process could be applied to dental porcelain. Adair (1971) proposed practical treatments involving immersing fired porcelain jacket crowns in molten potassium nitrate for various times and temperatures and related the treatment to different brands of dental porcelain. Adair claimed that all materials tested were strengthened by a factor of at least two and some were trebled.

4.

DISADVANTAGES ASSOCIATED WITH PLATINUM
AS A MATRIX MATERIAL

Several disadvantages associated with porcelain jacket crowns have become apparent. The two most commonly quoted are a questionable degree of accuracy and inadequate strength. The use of platinum foil as a matrix material has been shown to contribute to both the above disadvantages (Southan 1972).

However, although the platinum matrix is the foundation of the whole restoration and is subjected to great heat and deformation force with each firing, there is surprisingly little comment of it in the dental literature.

Straussburg, as long ago as 1911, realized that upon firing of a porcelain jacket crown, there was a lifting of the platinum matrix away from the margins of the preparation. This was only an empirical observation and no attempt was made to measure the degree of the resultant marginal discrepancy.

In 1927 Macbean suggested filling the matrix with refractory material before firing the crown to help resist this observed deformation. Clark (1935) spoke of the force of cohesion which attracted the porcelain to the underlying platinum matrix. When the porcelain shrank the matrix was deformed. Brecker (1961) and Tylman (1961) also acknowledged that shrinkage of the porcelain caused deformation of the platinum matrix. They advocated a wax ditching of the shoulder region which left the area free of porcelain after the first bake. The matrix in the shoulder area was then

reburnished and porcelain was applied and the crown refired.

Because only a small bulk of porcelain was shrinking, Brecker and Tylman maintained that little deformation resulted.

Johnston (1961) also recognised the problem of distortion of the platinum matrix. However, he advocated a method of laying down a ring of porcelain around the shoulder area only, for the first firing. He reasoned that because porcelain shrank towards its greatest bulk, then once the shoulder portion was fused little further deformation would occur.

Carter (1965, p.106) in his thesis commented that although much work had been done on strengthening of porcelain jacket crowns, little had been done to develop a matrix more trustworthy than that introduced by Land in 1902. Although a degree of inaccuracy existed with the use of platinum foil, the dental profession accepted "that there is little doubt the restoration will fit adequately."

However in 1972, Southan listed several other objections to the use of platinum foil as a matrix material for the construction of porcelain jacket crowns. These are summarised below:-

I) Platinum foil was frequently poorly adapted to the internal line angles and gingival shoulder of the crown. This, together with the observed deformation during firing, meant that the supportive features of the shoulder region cannot be fully exploited.

II) The presence of the tinner's joint was undesirable because a resultant localised gingival margin discrepancy of at least 75µm existed. A soldering technique whereby excess thickness of foil could be stoned down has been developed but Southan suggested that

this was difficult to undertake and rarely performed. The presence of the tinner's joint space however did provide for a venting effect during cementation.

III) Wrinkles in the matrix produce internal surface flaws. This was undesirable in a brittle material such as dental porcelain. The number of wrinkles can be reduced with efficient swaging methods but Southan claimed that they were difficult to eradicate completely.

IV) Tags of foil might be implanted into the incisal region and tinner's joint area of the crown which would also produce surface flaws in the fired body. Smith (1975) showed that 6% of crowns he surveyed had tags of foil at the incisal region.

The nature of these surface flaws and how they affect the strength of porcelain will be discussed in the next chapter.

V) Southan claimed that the edge strength of stone dies was not adequate to withstand thorough burnishing and swaging of the platinum foil. Any resultant chipping or abrasion would produce inaccuracies in the fired crown.

VI) Because platinum is a ductile material and is used in foil form of 25 μm (0.001 inches) it would distort when pulled over small undercut areas in the preparation.

VII) Southan showed that even if the matrix was perfectly smooth, it was impossible to eradicate all voids and defects at the porcelain-platinum interface. He attributed this to two causes. First, there was a tendency for a sporadic condensation of porcelain at the platinum surface particularly at the shoulder region. Secondly, because of the high surface tension between platinum and

porcelain, the energy supplied in normal firing cycles was insufficient to completely eliminate the voids caused by the sporadic condensation, again resulting in surface flaws in the fired crown.

Southan claimed internal voids or defects as the most important disadvantage of the use of platinum foil and attributed the common failure of porcelain jacket crowns to this cause.

Thus, the use of platinum foil as a matrix material has been shown to contribute to the two disadvantages most commonly associated with the porcelain jacket crowns namely;

- (1) a questionable degree of accuracy and
- (2) a lack of strength resulting in a common
and unpredictable mechanical failure.

5. ELIMINATING THE PLATINUM FOIL

Several methods for increasing the strength of the porcelain in porcelain jacket crowns have been discussed. However, the problem of internal defects associated with the platinum foil matrix described by Southan (1972) still exists.

In 1969 Vickery proposed a technique involving the use of a refractory die prepared directly from the mouth impression, therefore eliminating the platinum foil. However, the refractory materials then available were not satisfactory. Another disadvantage was that the master model was destroyed during firing of the porcelain.

Southan and Jorgensen (1972) also proposed a technique involving a refractory matrix. However, they used a double impression technique so that the stone master die was maintained at all times. In this technique a stone model is poured from a rubber based impression of the tooth preparations. The master die is removed and coated with a thin layer of varnish or wax in all areas except the gingival shoulder. Southan claimed that this resulted in a "sloppy" fit in all areas except the gingival margin thus leaving adequate room for cement. A second rubber based impression is taken of the varnished crown preparation and is poured up with a refractory matrix - the one recommended being "Deguvest".* The high fusing aluminous core porcelain is built up directly onto the refractory die and fired. Large cracks which appear after the initial firing

* Degussa, C.B. Dental Division, Frankfurt, West Germany.

are filled in with core porcelain and the core is fired again. If further cracks develop the process is repeated until a dense crack free core exists. The refractory die is then removed by sandblasting and the core is fitted onto the stone master die. The body layers are then built up directly onto the stone die with the core acting as the matrix.

Southan claimed several advantages of this technique;

- (i) the elimination of platinum foil,
- (ii) the elimination of internal surface faults of crowns and
- (iii) a consistently greater precision at the gingival margin.

6.

THE DEVELOPMENT OFTHE PORCELAIN FUSED TO METAL RESTORATION

The glass-like behaviour of all porcelain jacket crowns has resulted in a certain lack of confidence in this type of restoration. The recent developments, discussed in chapter 3 and 5, have not had adequate time to be evaluated clinically and may have come too late to salvage the prestigious position that the porcelain jacket crown once had. This is because of the development of the porcelain fused to metal crown.

History

As stated earlier the concept of combining porcelain to metal for dental purposes was initiated by Land in 1886. He described a technique which consisted of a shell crown soldered together from platinum or iridoplatinum tube and sheet of 30 gauge (B & W). A porcelain slip facing ground from a denture tooth, was joined to the labial surface of this metal crown with dental porcelain of a lower fusing point. The lingual surface of the metal crown was not covered with porcelain and the tooth preparation was minimal, without a shoulder, and with very little lingual reduction. The preparation was simple and facilitated the fabrication of the metal structure.

In 1891 Capon reported on the restoration of six eroded upper anterior teeth utilizing the type of crown just described. The metal coping was formed and shaped on the tooth then soldered and the porcelain was fired in a small gas furnace.

In 1903 Land elaborated on the technique. He discarded the use of pure platinum as a coping because it was too pliable and too expensive to obtain any thicknesses that would result in adequate strength. He advocated the use of an iridioplatinum alloy. Land realized that the bond between the iridioplatinum and porcelain was purely mechanical - "We must realize that a vitreous mass like all our porcelain bodies does not strongly adhere to non-oxidizing metals and will readily peel off." Land obtained retention of the porcelain to the iridioplatinum firstly by the use of pins. However, he modified the technique by forming undercuts or V-shaped pockets in the wall of the cap. Into these undercut regions a high fusing porcelain was condensed and fired. The high fusing facing was ground and then the two high fusing porcelains were united with an interposed porcelain of slightly lower fusing point.

With the development of a removable platinum matrix for fabrication of the all porcelain jacket crown, the porcelain bonded (mechanically) to metal technique fell into disuse.

However, with the experience of porcelain jacket crowns fracturing when placed in areas of high stress, an effort was made to combine the fracture resistance of gold alloys with the aesthetic properties of porcelain. This led to the development of partial veneer crowns with porcelain or acrylic facings cemented to a gold alloy backing. However, failure of this type of restoration, either through separation of the veneer material from the gold or by discolouration of the veneer material itself, became a problem. Discolouration was attributed at least in part to the infiltration

of fluids and debris between the veneer and the cast gold crown. Lamstein and Blechman (1956) showed the penetration of dyes and bacteria between acrylic resin veneers and gold backings and Swartz and Phillips (1957) showed the penetration of Ca 45 between porcelain veneers and their cast gold backings. A more satisfactory method of combining porcelain to gold was required and attempts to fuse porcelain to gold chemically were made.

The art of fusing ceramics to metal was not new, having been used thousands of years ago for providing ornamentation by the civilizations developing in the middle east. Its development for protection and aesthetic coverage of utilitarian articles such as cookware is of more recent origin. In the early 1950's advances in ceramic knowledge allowed the development of gold alloys and ceramics having compatible physical qualities. The aesthetic advantages of this system for dental restorations became evident.

An absolute dental requirement for the fabrication of a porcelain fused to metal restoration was that the metal did not melt when porcelain was applied to it. Platinum was tried because its melting point was higher than the fusing temperature of high fusing porcelains, but platinum alone proved to be too soft. Alloys with large amounts of platinum presented other problems such as brittleness and contamination of the porcelain. In addition, the casting investments available at the time were inadequate. The development of low-fusing porcelains by the process of fritting - as against the addition of borax - meant that gold alloys that were

more accurate and easily cast could be used as the metal copings. The development of pigment opaques to mask the dark colour imparted to the porcelain by the metal also increased the attractiveness of this type of restoration.

As with the development of dental porcelains the research projects associated with the development of the gold alloys and compatible bonding porcelains were closely guarded by the dental manufacturers. Several systems emerged in the 1950's.

In 1956, Johnston, Dykema and Cunningham published a progress report pertaining to the fusing of a porcelain veneer to a gold casting. They reported on properties such as corrosion resistance adhesive bonding, colours of the porcelain and fusing techniques and presented the clinical results of 75 units - 45 having been in the mouth for more than six months and several for more than one year. The authors were very enthusiastic with the technique concluding:- "It is our considered opinion that with this technique, a long stride forward in dental restorations has been taken, and we anticipate that in the future it will have widely diversified application." However some difficulties were noted. Warping occurred with long span bridges unless the porcelain was applied to separate units each with its own centre of shrinkage. They also reported difficulty in achieving satisfactory shading with the available opaque powders.

Many combinations of metals and porcelains soon appeared with enthusiastic claims by their manufacturers. This led to confusion within the profession and prompted a study by Silver, Klein and

Howard (1960) to evaluate and compare the porcelain fused to cast metal systems. Several factors worried them:- "The profession had no information regarding these procedures and all queries (to the manufacturers) were met with vague and obtuse answers. We did not know what the basic materials were and what physical properties they possessed. Even if the physical properties were known there was no means for comparison, since we had no standards for these materials."

As a result of their studies Silver et al developed a shear test for measuring the bond strength at the junction of metal and porcelain. This is known as the falling ball test. The systems tested were divided into low-fusing and high-fusing. They found that the high-fusing systems although requiring more expensive and complicated casting techniques were stronger, more stable and allowed the greatest technical latitude.

Lyon et al also published an evaluation of the technique in 1960. They found that all available systems presented inherent disadvantages. However, they seemed to favour the lower fusing systems.

In 1963, Johnston, Mumford, Dykema and Phillips published a follow up report on the technique. Their conclusions and recommendations resulted from research and clinical efforts supervised at Indiana University and from close contacts with several laboratories and many clinicians fabricating their own restorations. They also opted for the lower fusing systems and

recommended improved "Ceramco"* No. 1 alloy with "Ceramco" porcelain. They set out clearly a proven technique for both surgery and laboratory procedures.

By 1965 the porcelain fused to metal technique was firmly established. Indeed Mylin in 1965 said "A recent survey revealed that 35% of the total volume of crowns and bridges constructed (in the USA) were fabricated of porcelain fused to metal". Mumford (1965) stated that obvious clinical advantages accounted for this tremendous increase in usage. These were the impact strength and rigidity of the metals combined with the aesthetic qualities and abrasion and stain resistance of the porcelains.

Most work on evaluation of the technique was concentrated in the United States. However, in the late 1950's "Vita"** and Degussa released the first bonded system outside the United States. This has been well received in Europe and Australia. In fact this system is almost exclusively used in these countries and the porcelain bonded to gold alloy technique is often erroneously referred to as the V.M.K. (Vita Metallic Ceramic) technique. Little experimental work outside of the manufacturer's laboratories has been carried out regarding this system.

Today the porcelain fused to gold restoration is a widely accepted and used technique both for single crowns and fixed partial dentures.

* Whip Mix Corp., Louisville, Kentucky, U.S.A.

** Vita Zahnfabrik, Sackingen, West Germany.

7. THE PHYSICAL PROPERTIES OF THE MATERIALS USED
IN THE PORCELAIN FUSED TO METAL RESTORATION

The successful fusing of porcelain to metal for dental purposes depends on several physical properties of both metals and porcelains. These were summarised by Hobo and Shillingburg (1973) as:-

1. The porcelain metal bond.
2. The difference between the melting point of the metal and the fusing temperature of the porcelain.
3. The difference in co-efficients of thermal expansion.
4. The metal strength.

1. The Porcelain Metal Bond

One of the major reasons for the widespread acceptance of the porcelain fused to metal restoration is its greater strength and fracture resistance when compared to the porcelain jacket crown. There has been considerable interest in the way the porcelain and metal are bonded together. The determination of the bond strength is difficult to evaluate by accepted methods for measuring the strength of an adhesive because of stress-concentration at the bond. Rupture during direct tensile tests generally occurs as a coherency failure in the ceramic body (Shell and Nielsen, 1962). Johnston (1956) tested the porcelain fused to metal bond by direct

tensile testing of metal specimens with a layer of porcelain fused between them. Custer (1962) and Silver (1960) used a shear type test. In these cases unless contamination was present the break occurred within the body of the porcelain rather than at the interface. This showed that the ultimate strength of the porcelain was less than that of the bond.

Shell (1962) developed a test which appeared to give a better indication of the actual bonding strength. At least he came up with figures which were in excess of the ultimate strength of porcelain itself. He found the strength of the bond between porcelain and polished noble metal alloys was from 3500 - 4000 p.s.i. There was no apparent difference in the bond strength when the surface of the metal casting was roughened. When alloys were modified with small quantities of certain base metals which were capable of oxidation, the bond strength increased to approximately 11,000 - 12,000 p.s.i. and when a non-reducible oxide of the alloy additions were added to the porcelain and even greater increase in strength occurred. However, the addition of the non-reducible oxides caused discolouration of the porcelain. A metal conditioner or ceramic flux for oxides was used as a metal coating, without a significant increase in strength.

Shell theorised that three factors took part in this bonding action:-

- (1) The mechanical effect - which would give at best a bond with only half the tensile strength of the porcelain. He concluded that the mechanical bond did not play an important role in the bond strength proper and roughening did not add to the shear

resistance at the bond.

(2) Van der Waals forces of melting - comprising about one third of the bond resistance.

(3) Chemical bonding - perhaps a mixture of ionic, co-valent and metallic and comprising about two thirds of the bond resistance.

Ryge and O'Brien (1965) showed mathematically from a study of the wetting angles of porcelain droplets fused on metal, that the wetting or Van der Waals forces are more than adequate to give the degree of bonding that has been found. They determined that the theoretical wetting bond may be seven or eight times greater than the values that are reported in the literature from actual tests.

However, factors resulting in stress-concentrations at the interface can result in fracture of the bond. Such factors include differences in co-efficient of thermal expansion, sharp edges or corners at the interface and deformation of the casting under the porcelain.

The type of firing cycle also has an effect on the strength of the bond. Silver et al (1960), Johnston et al (1962), Mumford (1965) and others agree that vacuum firing enhances the bond strength. In vacuum firing, the porcelain that is in contact with the metal understructure, is denser resulting in a larger surface area for contact with the metal. Therefore the resultant adhesion is greater.

2. The Difference Between the Melting Point of
The Metal and the Fusing Temperature of the Porcelain

Hobo and Shillingburg (1973) stated that the minimum difference between the melting temperature of the metal and the fusing temperature of porcelain should be $300^{\circ} - 500^{\circ}\text{F}$. The metal coping must not distort during firing of porcelain or during soldering procedures. As the metal is heated it becomes subject to flow or creep with a resultant distortion of the coping. Thus, the greater the difference in melting and fusing temperature, the less is the likelihood that creep will occur. The critical temperature (at which distortion of the metal may occur) seems to be approximately 1800°F so porcelains must be used that do not require the metal to be heated beyond this point.

3. The Difference In Co-Efficients
of Thermal Expansion

Another difficulty in the fabrication of porcelain fused to metal restorations stems from differences in the co-efficients of thermal expansion of porcelain and metal alloy. Gold has a high co-efficient of thermal expansion of $(14 \times 10^{-6}/^{\circ}\text{C})$ whereas the conventional dental porcelains have a much lower co-efficient of thermal expansion, $(2 - 4 \times 10^{-6}/^{\circ}\text{C})$. Shell and Neilsen (1962) showed that a difference of $1.7 \times 10^{-6}/^{\circ}\text{C}$, would produce a shear

stress of 40,000 p.s.i. at the gold-porcelain interface in a 1750°F change in temperature. Since the shear resistance to failure of the porcelain-metal bond is of the order of 11-12000 p.s.i., it can be seen that such thermal stresses would be sufficient to cause rupture of the bond with no external assistance. According to Shell the stress at the interface can be calculated from the equation;

$$\text{Stress} = \frac{(\alpha_m - \alpha_p) (T_o - T) E}{2}$$

where $(\alpha_m - \alpha_p)$ is the difference in thermal expansion co-efficients of the metal and porcelain respectively; $(T_o - T)$ is the drop in temperature from the solidification range; and E is the average elastic modulus of the two materials. This equation applies only at the interface. For thin porcelain deposits the stress decreases gradually in the fibres parallel to the interface, proportionally to the distance from the interface, reaching near zero stress at the porcelain surface. For thick porcelain deposits a compressive stress in the porcelain at the interface decreases to zero within the porcelain body and then changes to a tensile stress, which increases in magnitude towards the porcelain surface. A slight difference in the expansion co-efficient, such that a compressive stress is imposed at the porcelain-metal interface is not necessarily beneficial even though it might be argued that a higher tensile stress will then be needed to rupture the bond. This is because a possible beneficial compressive stress at the bond interface is negated by an undesirable

tensile stress produced at the porcelain surface. Therefore a perfectly matched expansion co-efficient would seem the safest to use. To ensure equal stress concentration at the surface it is therefore important to have uniform thicknesses of porcelain.

Shell and Neilsen proposed that a difference in expansion co-efficients may be tolerated and even desired, if techniques could be developed to give a resultant compressive stress on the porcelain surface and tensile stress in the interior. This may be able to be achieved by a tempered glass effect, involving a chill cooling of the porcelain surface and slow cooling of the porcelain interior.

4.

The Metal Strength

The metal coping must be strong and rigid to prevent any deformation either during initial seating of the restoration or when subjected to occlusal forces. This is because the glassy-like structure of porcelain renders it very brittle and inflexible. Thus the more rigid the metal understructure, the less likely the porcelain is to fracture. It is therefore desirable for alloys to have high values for the physical properties of proportional limit, tensile strength and resistance to indentation. In practice the metal coping must be designed so as to ensure an optimum bulk for rigidity. However, the greater the bulk of metal, the greater the tooth reduction necessary. Most writers including Hobo and Shillingburg (1973), Johnston (1956) and Mumford (1965) agree that the metal thickness should not be less than 0.3 - 0.5mm at any

point of the metal coping. However, a metal thickness of 0.5mm can create an aesthetic problem around the gingival shoulder region. Vita/Degudent recommend that their Degudent Universal gold alloy can be thinned to thicknesses of 0.2 - 0.25mm for single crowns and 0.35mm for multiple units.

ALLOYS AND PORCELAINS

The exact composition of the alloys and porcelains used for the porcelain fused to metal technique is closely guarded by the several manufacturers of these products.

The precious alloys consist basically of two types - one platinum coloured and one gold coloured. The platinum coloured alloys are composed essentially of palladium, ruthenium and either silver or gold. The gold coloured alloys are predominantly gold with the addition of several or most of the following constituents; palladium, iridium, platinum, tin, silicon, silver, copper, indium and iron. The effect of these additions is to lower the co-efficients of thermal expansion of the alloys to $7 - 8 \times 10^{-6}/^{\circ}\text{C}$ and to increase the strength properties of the metal.

Non-precious alloys which are basically cobalt - chromium and nickel based alloys are also available for bonding with porcelain. These alloys have been developed because of the high cost factor involved with the precious alloys. Semi-precious alloys with a palladium content have also been developed. Moffa et al (1973) claimed that the brands of semi-precious and precious alloys they tested had more desirable physical properties than their control gold alloys.

Thin (1962) also claimed that the cobalt-chromium alloys had the most desirable physical properties. These were followed by the palladium based and then the gold based alloys. However, Thin also found that the harder cobalt-chromium based alloys become softer with repeated firing cycles. Johnston et al (1956) found more checks

and defects associated with non precious alloys. Sced and McLean (1972) claimed that the presence of chromium oxide at the porcelain-metal interface of chromium based alloys would lead to a questionable bond. Moffa et al (1973) disagreed with this.

However, there are some disadvantages associated with the non-precious and semi-precious alloys. They require more sophisticated equipment such as oxy-gas and oxy-acetylene torches for melting, due to their higher melting temperatures. Analysis of the alloys shows relatively high concentrations of both nickel and beryllium which require certain handling precautions, including exhaust ventilation and power suction cleaning. Beryllium in particular is recognised as being potentially toxic under uncontrolled conditions. The probable functions of this element in dental alloys are to reduce the fusion temperature, improve the casting characteristics, refine the grain structure and aid in strengthening the alloys. Because of these toxic disadvantages no widespread acceptance of these alloys has occurred. Non-precious alloys without beryllium have been marketed but as yet have proved unsatisfactory.

The content of the dental procelains used for bonding to metals is even less well-documented. Development, however, necessitated lower fusion ranges and the possible addition of metal oxides to the opaque to enhance bonding with the oxide layer of the metal.

Requirements for heat-resistant materials in the aerospace industry led to improvements in ceramic-casting techniques, which called for a close matching of the co-efficients of expansion. The co-efficient of thermal expansion of porcelain can be increased to as much as $7 - 8 \times 10^{-6}/^{\circ}\text{C}$ by the addition of an alkali such as lithium carbonate (Hobo and Shillingburg, 1973). Development of opaque porcelains with high coverage power to mask the grey colouration of the metal copings was also necessary. These opaque porcelains are low fusing porcelains as against the high fusing opaques used for porcelain jacket crown fabrication. As such it is important that the low fusing opaques have a high degree of sag resistance during repeated fusing cycles.

9. THE DISADVANTAGES OF PORCELAIN BONDED TO METAL SYSTEM

Although the porcelain-fused to metal technique is a relatively new technique in dentistry, with only about twenty years clinical application, some disadvantages have become apparent in this time. More recent research is helping to overcome these.

The desired physical properties of metals and porcelains have been discussed. The importance of factors such as matching the co-efficients of thermal expansion, the strength of the metal, the difference in melting point between metal and porcelain and the porcelain-metal bond have been seen. However, most of the disadvantages of the system result from an inability to obtain these maximum physical properties. The main disadvantages associated with the porcelain bonded to metal systems can be listed as follows:-

1. Inherent residual stress.
2. Inaccuracy of castings.
3. Instability of castings.
4. High reflective properties of the core porcelain.
5. Greatly increased laboratory time and procedures.

(1) Inherent Residual Stress

Mintz et al (1974) reported the occurrence of inherent structural defects in many porcelain bonded to metal crowns obtained from commercial laboratories and dentists. These defects consisted mainly of cracks, porosities and crazes. Many of these defects could be explained as occurring due to stress release resulting from

the buildup of inherent residual stresses. Neilsen and Tuccillo (1972) showed that a residual interfacial stress at the porcelain-metal junction resulted from the inability to match perfectly the co-efficients of thermal expansion. Even if the co-efficients were matched it was only at one temperature (approximately 700 - 800°F) and a mismatch existed at all other temperatures.

Neilsen and Tuccillo (1972) estimated that this critical fracture point for thermal shear stresses was about 13000 p.s.i. They estimated that a mismatch of co-efficients as low as 0.125×10^{-6} inch/inch/°F resulted in a residual stress of 3,000 p.s.i. A mismatch of just 0.6×10^{-6} inch/inch/°F could result in residual stresses above 13,000 p.s.i. and could thus result in bond failure and stress release. If overall stresses were above 13,000 p.s.i. a complete failure of the bond resulted in separation of porcelain from the metal. Because of uniform stress distribution, only certain points along the bond region may reach the critical level and stress release in these areas may be associated with cracks and crazes. There is evidence that upon refiring the interfacial sheer stress builds up to higher values because of a rise in the fictive temperature and change in thermal co-efficient of expansion of the porcelain.

Added to the interfacial stresses are the stresses created by flaws in the porcelain as explained in a previous section. Any voids or defects at the metal-porcelain bond are similar in effect to internal voids that Southan (1972) described with porcelain jacket crowns. However, the presence of the metal effectively prevents

flaw growth from moisture contamination. Stress release can also cause distortion of the metal casting as is seen later.

(2) Inaccuracy of castings

Mumford (1965) stated that the accuracy of the fit of castings has been a controversial facet of this technique. The high melting point and consequently the greater contraction of the metal (although it may have a lowered co-efficient of thermal expansion) eliminates the use of gypsum bonded investments and necessitates the use of silica or magnesium phosphate bonded investments. The palladium based alloys require a silica bonded type while the gold based alloys require a magnesium phosphate bonded type.

The phosphate investments have improved in handling characteristics since they were first marketed for dental use (Mumford 1965). Variation of the powder/liquid ratio, or the ratio of special liquid to water used in the mix allows for variations in casting dimension. Therefore casting may be made for partial veneer retainers which have the same desirable degree of frictional fit which is obtainable with traditional gold alloys. The full crown casting should have a loose or passive fit to allow for cement. If this were not done, Mumford stated that deformation of the casting during seating could occur resulting in fracture of the porcelain veneer. The palladium alloys cast, by necessity, in the silica type investments do not fit as well according to Mumford. He claimed that more research was needed to develop silica based

investments more suited for use with the palladium based alloys.

(3)

The Instability of the Castings

As early as 1956 Johnston observed that for long bridge spans the metal tended to sag or warp when the porcelain was applied. It was suggested that this could occur in single units but to a lesser extent. Shillingburg (1973) stated that metal copings which fit upon try-in did not seem to fit as well after the porcelain was applied. Silver and associates (1960) stated that shrinkage of the porcelain might buckle or contract the metal, especially in thin regions.

Two forces acting to cause this deformation have been described:

1. Interfacial shear stress.
2. Metal creep at high temperatures.

It has already been mentioned that the interfacial shear stresses, which occur between porcelain and metal, may result in inherent structural defects. In that discussion, it was shown that stress release results in deformation of the porcelain, which because of its glassy nature results in cracks and crazes. However, interfacial shear stress release can also cause deformation in the metal, especially in thin areas. Because of the ductility of the metal such deformation can occur without fracture of the metal and if it occurs when the porcelain is still in a viscous state without deformation of the porcelain. It is for this reason that

manufacturers insist on a minimum thickness of metal in all parts of the metal coping. However, because of aesthetic considerations this minimum thickness can be unacceptable in labial margin regions. Because of this many technicians have tended to decrease the thickness below that recommended and in this way have increased the possibility of warping.

Nielson and Tuccillo (1967) found permanent deformation in porcelain metal strips following firing. Shillingburg's (1973) study, which was more clinically related, showed that the degree of margin distortion was related to the preparation design. The labial margin (where the thickness of metal is limited by aesthetics) was the part that seemed to be most often subject to distortion. The bulk of metal on the lingual and proximal surfaces seemed to minimize such changes in those parts. Shillingburg found that distortion occurred with all four types of finishing lines tested. He stated that the amount of opening exhibited by the chamfer ($47.1\mu\text{m}$) and by the heavy chamfer with a bevel ($29.3\mu\text{m}$) was large enough to be of clinical significance when added to the openings which were inherent in most castings, before the copings were subjected to the firing cycle. The shoulder type of preparations studied seemed to resist distortion best, with the shoulder preparation showing an opening of $10.7\mu\text{m}$ and the shoulder with a bevel preparation showing an opening of $5.8\mu\text{m}$.

The importance of creep properties of porcelain-gold alloys in dental restorations was not recognised until recently. Creep

can be defined as the progressive deformation of a metal under load and it usually involves elevated temperatures. When the porcelain veneer is fired, the restorations undergo cyclic temperature treatments to within a 250 degrees of the melting range of the metal. As the amount of creep or sag that occurs is a function of weight and temperature, then, if the casting is not properly supported, creep results and the restoration is distorted. Some manufacturers have recognised this problem and developed sag-resistant alloys. This involves forced microstructural changes in the alloy so that it becomes less ductile or harder (Nielsen & Tuccillo 1967). The hardening mechanism of porcelain-gold alloys is not completely understood but it is generally accepted that these alloys harden by precipitation of a second phase during cooling. Strength and creep resistance would thus depend on the size, shape, distribution and stability of the precipitated phase. If a fine uniform dispersion of a high-temperature precipitated phase can be achieved, creep resistance will be increased. Nielsen and Tuccillo showed that this was the case.

Other factors resulting from poor techniques can also cause a lack of fit of the casting. If a metal master die is used, scrapings of lower fusing metals may remain inside the coping during the firing process. The components of these alloys can incorporate themselves into the alloys of the coping and reduce the fusing range considerably (Silver 1960). This can result in either melting of the contaminated parts during vitrification, or "grain growth" due to the contaminants. Both results will cause distortion.

Both wax and the coping metals have some elasticity which can compensate for small undercuts or unparallelism. However, after the metal is porcelainised, the porcelain, being an absolutely rigid material, will not permit any spring or give in the metal. Thus the restoration will not seat properly. If forced into place the porcelain will fracture if the metal is distorted.

When the porcelain is fired, tiny grains of porcelain may be deposited inside the metal copings. When the porcelain is fused these tiny particles being transparent, are difficult to see. This can also result in incomplete seating of the restoration.

(4) High Reflective Properties of the Core Porcelain

A complaint often levelled at the porcelain fused to metal restoration is that it appears very flat and lifeless and therefore unaesthetic in comparison with the porcelain jacket crown. This occurs due to the high light reflectivity from the opaque porcelain required to mask the metal coping (McLean & Sced 1976). The masking of these metal interfaces with opaque porcelain presents considerable problems to the ceramist manufacturer. In order to keep the thickness of the opaque layer to a minimum, it is necessary to formulate porcelains with minimum light transmission and high covering power. This in turn means that these materials when covered with a translucent veneer porcelain, become highly light reflective. Thus it is difficult to create a sense of translucency and depth and maximum aesthetics. In order to avoid light reflection of the opaque

porcelain, the technician tends to overcontour the labial face of the crown. This may create a cervical stagnation area and increase the risk of gingival inflammation.

(5) Greatly Increased Laboratory Time and Procedures

The fabrication of a porcelain fused to metal restoration involves many more procedures and much more expensive equipment than for the fabrication of a porcelain jacket crown. Thus these restorations are more expensive for the patient. The wax-up, venting, spruing, investing and casting of the metal coping requires very exacting procedures and requires the use of a vacuum investment machine and oxy-gas equipment. The grinding, degassing and oxidising procedures must be exact to obtain a suitable surface upon which the porcelain will effectively bond. By contrast the porcelain application stage for porcelain jacket crowns is reached in about ten minutes by a skilled technician and merely involves the adaptation of the platinum matrix. However, the increase in strength and fracture resistance afforded by the porcelain fused to metal restoration has seen its acceptance and even preference by the majority of the dental profession.

10. TOOTH PREPARATION, COPING DESIGN
 AND DIE CONSTRUCTION

(a) Tooth Preparation - The Porcelain Jacket Crown

The developments in tooth preparation and the actual techniques employed in the construction of porcelain jacket crowns have been adequately covered by Smythe (1963) and Carter (1965) and will not be repeated here. Over the last seventy-five years there has been much debate concerning the nature of the preparation. Factors such as the presence or absence of a shoulder and its width and angulation to the axial plane, the gingival extent of the finishing line, the sharpness of the internal line angle and the amount of tooth reduction have stimulated much discussion.

It is this author's opinion that most present day clinicians favour a shoulder preparation with a width of shoulder of 0.5 - 1.0mm and that this should be prepared at right angles to the long axis of the tooth. Due to the limitations in the fit at the gingival margin and the refractive properties of the porcelain in this region, it appears to be aesthetically desirable to place the shoulder just below the gingival crest.

Recent photoelastic studies by Walton and Leven (1955), Lehman and Hampson (1962) and Derand (1973) have indicated that there should be no sharp angles or corners on any part of a tooth prepared for a porcelain jacket crown because these were likely to induce stress concentration in the overlying porcelain. This could

result in fracture of the crown. Southan (1972) objected to a sharp internal cervical line angle in the jacket tooth preparation because it was difficult to reproduce with the platinum foil matrix. As a result of these studies it is now accepted by most clinicians that the internal cervical line angle should be rounded.

Bastian (1937) suggested the preparation should be as cylindrical as possible but it is now accepted that some resistance be afforded to the preparation to prevent rotation of the restoration. Each tooth is assessed concerning whether the mesio-distal or labio-lingual dimension is to be the greater.

(b) Tooth Preparation - The Porcelain-Metal Crown

Unlike the controversy associated with the development of an ideal tooth preparation for the all porcelain jacket crown, there is little disagreement as to the ideal tooth preparation for the porcelain fused to metal restoration. Because of the great increase in strength obtained by the combination of metal with porcelain these restorations have been applied to posterior as well as anterior teeth with good success.

Johnston et al (1956) first described a tooth preparation involving a combination of the full veneer gold crown and porcelain jacket crown preparations. They claimed the proximal surfaces of the prepared tooth should approach parallelism. For veneering and contouring, a shoulder should be placed on the labial or buccal half of the tooth. To make room for the metal, the shoulder should be

wider than for the jacket preparation; the width recommended by Johnston being 0.75mm - 1.0mm. The lingual half of the tooth should have a chamfered finishing line. Johnston suggested that the shoulder area should end abruptly in a half groove which is parallel to the cervical half of the labial or buccal contour of the prepared tooth. However, this sharp junction between shoulder and chamfer finishing lines can cause problems associated with the investment used for the technique. Sharp pieces of the relatively soft investment can break off during casting procedures and result in a distorted casting. Therefore a modification to this original design involved a gradual blending of chamfer to shoulder finishing lines;

The only other suggested modification involved a labial or buccal bevel to enable the burnishing of the resultant metal collar against the tooth after cementation. However, this is not widely accepted, especially in the anterior region, because the metal collar although it can be burnished and polished, detracts from the aesthetics of the restoration. A burnishing procedure may result in tensions being set up in the porcelain metal interface in the gingival area and could contribute to failure of the porcelain metal bond.

To achieve optimal strength and aesthetics enough tooth structure must be removed to provide adequate room for both metal and porcelain. The recommendations are that there should be a reduction of 0.75 - 1.0mm of tooth where metal will occlude with an opposing tooth and a reduction of not less than 1.5mm where

the occlusal or incisal areas are to be veneered with porcelain. The incisal reduction on an anterior tooth should be 2.0mm, so there can be 0.5mm of metal supporting a minimum of 1.5mm of porcelain. Other considerations such as the placement of the shoulder in reference to the gingival margin apply as for the porcelain jacket crown.

(c) Coping Design

The coping design for the porcelain fused to metal restoration provided a little more controversy. Shillingburg and Hobo (1973) cited three features of importance to be considered when designing the metal coping. These were:

- (i) The extensions of the area to be veneered in porcelain.
- (ii) The placement of occlusal contacts.
- (iii) The bulk of metal underlying and adjoining the porcelain.

Stanought (1967) described three variations for areas of porcelain extension:-

- (1) Full labial and lingual porcelain coverage with a lingual collar. Antagonists of this design claim that while minimal increase in aesthetics is obtained greater lingual tooth reduction is necessary if overcontouring is to be avoided.
- (2) Labial and incisal or occlusal porcelain coverage with a metal cingulum or lingual coverage. This is the most favoured design. Craig et al (1973) following studies on stress distribution

stated that the porcelain-metal junction should be removed from sites of load application for anterior teeth. This coping design allows the porcelain-metal junction to be placed midway between the incisal contact point and any contact area of the cingulum. For posterior teeth also, the porcelain metal junction is removed from sites of load application but antagonists claim that the resultant porcelain occlusal surface will result in excessive wear of occluding natural teeth or metal restorations.

(3) Labial porcelain with a metal protected incisal or occlusal surface. This design overcomes the excessive wear caused by porcelain on occluding surfaces. However, it places the porcelain-metal junction close to areas of occlusal contact, or load bearing areas, which could result in tensile stress concentration at the metal-porcelain interface with resultant fracture. Creep of the thin incisal metal under load could also result in stress concentration at the porcelain-metal interface.

The placement of the proximal metal-porcelain junction is also important. Earlier writers such as Johnston (1962) and Mumford (1965) suggested that the junction should be just lingual to the contact area. This would result in improved aesthetics. However, consideration of Craig's (1973) findings would necessitate placing the junction well clear of the proximal contact area so as to minimize stress concentration.

Johnston (1962), Mumford (1965) and Shillingburg (1973) agreed that the metal coping thickness should be not less than 0.3 - 0.5mm in any area where porcelain is to be bonded. As has been stated

earlier the manufacturers of "Deguvest Universal"* claim it can be thinned to 0.2 - 0.25mm for single units without distortion.

In areas where porcelain is not to be bonded the metal should have a thickness of 0.75 - 1.0mm which would decrease in the chamfer region.

(d)

Die Construction

The development of dies and die materials has been reviewed by Smythe (1963) and Carter (1965) and such discussion will not be repeated here. However, the accuracy of the die does play a significant role in the degree of fit of the cemented restoration.

Traditionally amalgam dies had been used for porcelain jacket crown construction. However, because of their long setting time, difficulty in localising in full arch impressions and the development of high strength stones they have become obsolete.

The minimal dimensional change, convenience of manipulation and accurate arch location of stone dies has resulted in their routine use by many laboratories and clinicians for crown construction. Southan (1972) objected to their use in conjunction with platinum foil matrices for porcelain jacket crown construction. He claimed that their low edge strength prevented thorough burnishing and reburnishing procedures and therefore increased the degree of misfit of such crowns.

* Degussa C.B. Dental Division, Frankfurt West Germany.

Electroplated stone dies have been developed in an endeavour to overcome the problem of low edge strength. Silver is electrolytically deposited against a thiokol or silicone rubber impression and high strength stone is used to form the core and complete the arch cast. There are several disadvantages with this system. Skinner (1960,p468) claimed that distortion of the rubber impression material could occur over the long plating period of eight to ten hours required. The plating baths are expensive and the solutions are highly poisonous. Copper plating is required with compound impressions because the compound contaminates the silver plating solutions.

Dies for the porcelain bonded to metal crowns do not need high edge strengths for metal coping construction. Stone dies are thus commonly used. Subsequent repeated removal of the coping from the die during porcelain application may result in surface abrasion of the stone and prevent future coping or crown remakes necessitated by diagnostic or fabrication errors. Such abrasion may also give a false impression of the degree of marginal fit that the cemented restoration is likely to achieve.

11.

AN ALTERNATIVE TECHNIQUE FOR THE FABRICATION
OF PORCELAIN FUSED TO METAL RESTORATIONS

A technique for crown fabrication incorporating the aesthetic advantages of the porcelain jacket crown and the strength and fracture resistant advantages of the porcelain fused to metal crown was described recently by McLean and Sced (1976).

In developing their technique they were seeking to satisfy several objectives:-

1. Reduction of the thickness of the metal coping usable with clinical safety.
2. Reduction of both the cost of materials and time consumed in making cast copings by the lost wax process.
3. Reduction of the risk of creep of the coping during firing.
4. Avoidance of a dark metal background, thereby avoiding the necessity of using high covering power opaques with high light reflectivity.

McLean decided that the alternative to casting procedures was a swaging technique. However, swaging of a metal coping requires the use of very ductile foils such as platinum. He found that platinum with an expansion co-efficient of $9.7 \times 10^{-6}/^{\circ}\text{C}$ would not permit successful bonding of the feldspar-based porcelains used for cast alloy/porcelain restorations. It is however sufficiently close to that of aluminous porcelain ($\text{Al}_2\text{O}_3 = 6.8 \text{ to } 8.7 \times 10^{-6}/^{\circ}\text{C}$) to permit bonding.

Pure platinum however, does not bond with porcelain.

McLean and Sced found that alloying elements such as indium, tin or copper created oxide films on the surface, which promoted bonding. This resultant bonding gave bond strengths at the porcelain metal interface 85% stronger than a comparative cast gold porcelain system (Degudent/VMK 68 combination). This is a reflection of the existence of a good bond coupled with the greater strength of aluminous porcelain. The unavailability of these platinum based alloys was a disadvantage. To overcome this, the possibility of electrodeposition of metals onto the platinum was investigated. It was found that a good coating material should conform to the following conditions.

1. It must form an oxide.
2. Neither the coating nor its oxides should be significantly volatile nor exhibit any other form of instability at temperatures up to the porcelain firing temperature.
3. The coating should readily alloy with the substrate before it is completely converted to oxide.
4. The oxide should be soluble in the porcelain.
5. The oxide should not discolour the porcelain or react in any way so as to reduce the strength of the porcelain or introduce high internal stresses, e.g. by raising or lowering the thermal expansion of the interfacial porcelain.
6. The coating and its oxide should be non-toxic.

Of the potential coatings investigated by McLean, tin was found to be the most practical and an optimum coating thickness was established as being the range of 0.2 to 2.0 μ m.

The technique developed by McLean is a modification of the original platinum foil technique. A spacing layer of foil (or inner foil) of 0.025mm (0.001 inches) thickness is adapted to the die. An outer foil layer of 0.05mm (0.002 inches) is then adapted on top of the inner foil but is trimmed short of the external cervical margin. This outer foil layer is removed and sandblasted with 27 μ m aluminium oxide to increase surface area for porcelain attachment. It is then degreased and tin-plated in a special "Ceramiplater".* After oxidising in a bunsen flame, the foil layers are again adapted to the die and the aluminous core and body layers of porcelain are built up. When the crown has received its final adjustment and glazing, the inner foil is removed, exposing the outer foil which should be firmly bonded to the aluminous core porcelain.

McLean suggested that these crowns should be cemented with polyacrylic acid based cements - such as zinc polycarboxylate or glass ionomer cement. Both these systems have ion groupings available with an affinity for the Sn^{++} ions of the electroplated foil. Thus according to McLean there is a good chance of some chemical bonding occurring.

* Vita Manufacturing Co., Sackingen, West Germany.

McLean claimed the following advantages for this technique:-

- (1) Reduction of both metal and labour costs in construction.
- (2) Reduction of metal thickness to not more than 0.05mm (0.002 inches).
- (3) Elimination of surface micro-cracks on the fitting surface of the porcelain by the use of the thin platinum foil coating.
- (4) Provision of a porcelain butt fit on the labial or buccal surfaces of the crown with an improvement in gingival aesthetics.
- (5) Reduction of stresses at the metal porcelain interface during cementation procedures.

Only limited clinical trials have been undertaken to date. Of 369 crowns that have been made for both anterior and posterior teeth, only 2 have fractured and McLean claimed these were a result of faulty occlusion. However, as these trials only commenced in June of 1974, insufficient time has passed for a true evaluation of this technique.

12.

THE MARGINAL DISCREPANCY OF ANTERIOR
FULL CROWN RESTORATIONS

Because of the conflicting requirements of aesthetics and gingival health, the placement of the cervical margin of anterior full crown restorations has been a contentious issue (refer chapter 1). It is generally accepted practice, however, to place these margins at or below the gingival crest. While this satisfies aesthetic requirements, the resulting pathology to the gingival tissues is well documented. (Bergman et al 1971, Karlson 1970, Alexander 1968, Waerlang 1960, Marcum 1967).

Newcomb (1974) showed that the degree of inflammation to gingival tissues was associated with the position of the margin within the crevice. He concluded that less inflammation resulted when margins were placed at or near the top of the gingival crevice than at the bottom of the crevice. Most of these writers agreed that it was the marginal discrepancy between tooth and restoration resulting in plaque retention that was the main cause of these pathological changes. Indeed Bjorn et al (1970) observed a direct association between the size of the marginal defects and the degree of periodontal bone resorption.

Another consequence of marginal discrepancies or lack of fit of crown restorations is leaching of cement from under the crown predisposing to secondary caries. The dental luting or cementing agents currently in use all have some degree of solubility

in the oral environment. Jorgensen (1960) claimed that a "filtration" effect that could occur during the cementing of full crowns made cement at the margin even more soluble in saliva and would undoubtedly increase the possibility of secondary caries.

It is therefore important that marginal discrepancies of anterior crowns be kept to an absolute minimum.

These discrepancies apart from impression and die fabrication inaccuracies can be attributed to:

- (1) distortions incurred during fabrication of the crown
and
- (2) the presence of cement beneath the crown.

The factors responsible for distortions associated with the techniques for fabrication of both porcelain jacket and porcelain fused to metal crowns have been discussed elsewhere.

Some of the important factors discussed were that surface tension forces between platinum and porcelain can result in marginal distortions in porcelain jacket crowns and that an imbalance between the co-efficients of thermal expansion of metal and porcelain could result in marginal distortions in porcelain fused to metal restorations. Furthermore, the many technical procedures associated with the fabrication of porcelain fused to metal restorations will increase the likelihood of marginal discrepancies with these restorations.

The Effect of Cement on Marginal Discrepancy

The effect of cement on marginal discrepancies was thoroughly studied by Jorgensen (1960) using precision machined

test crowns. He established that marginal and gingival discrepancy due to the cement was determined by the average film thickness of cement and that the average film thickness was influenced by several factors. These are discussed below.

1. Grain size of the cement powder. The smaller the original grain size the thinner was the eventual film thickness. Because this is a manufacturing variable, the Australian Standards Association has specified that the grain size of the powder for luting agents should be less than 24 μ m.
2. Cementation pressure. An increase in cementation pressure reduced the film thickness a considerable degree. But an increase in the pressure beyond five kilograms was relatively insignificant.
3. Duration of cementation pressure. The cementation pressure had to be applied for one minute for minimal film thickness. Prolongation beyond one minute was without appreciable effect.
4. The powder:liquid ratio. The powder:liquid ratio influenced the viscosity of the cement mixture. An increased viscosity rendered the expression of excess cement more difficult.
5. Temperature of the mix. Increasing the temperature of the mix resulted in a faster setting reaction and a reduced ability of the cement to flow during cementation.
6. Taper of the preparation. An increase in the taper reduced the final film thickness up to a total taper of 20°.
7. Occlusal perforation and venting. If the crown was perforated occlusally the film thickness became only slightly dependent on the taper of the preparation.

As a result of his studies Jorgensen recommended a practical cementing procedure to minimise the film thickness and thereby minimise the marginal discrepancies of restorations. This involved "using a medium cementation pressure maintained for approximately one minute, a rather thin cooled cement mixture and crowns perforated occlusally". However, venting is impractical in porcelain jacket crowns and is limited to the cingulum area in porcelain fused to metal crown restorations. The influence of venting in anterior crown situations is lessened by the limited size of the occlusal platform of the preparation which minimises both the formation of a cement reservoir and the filtration effect occurring during cementation.

Using his cementation procedure and a fine grained cement, Jorgensen was able to achieve very low film thicknesses of the order of $20\mu\text{m}$. However, average marginal discrepancy figures were high, ranging from $115\mu\text{m}$ to $910\mu\text{m}$. Jorgensen attributed this to the hydrodynamic conditions existing when two conical surfaces, with liquid between them, were pressed together.

In a later paper, Jorgensen (1963) explained that these hydrodynamic conditions retarded the flow of cement from the occlusal to the gingival aspect and this resistance to flow was related to the fit of the restoration and taper of the preparation. This explained why venting gave such a marked decrease in gingival discrepancy when the total taper of the preparation was small, that is, below 10° . The large marginal discrepancies exhibited in these test crowns could be attributed to the high degree of precision

of fit of the crowns (of the order of $2\mu\text{m}$) before cementation, thus leaving little room for the cement.

Jorgensen (1960), in another paper in which he studied the structure of a film of zinc phosphate cement, explained the phenomenon of filtration that occurred when the cement was forced to flow in thin films.

He observed that, when carefully mixed, a zinc phosphate cement gave the impression of forming a suspension of evenly distributed powder particles in a liquid. However, microscopic examination of a thin film of freshly mixed cement compressed between two glass plates revealed the presence of numerous minute lumps of the powder, which was otherwise evenly suspended in the liquid. The majority of these lumps were of the order of $20\mu\text{m}$ to $50\mu\text{m}$ with a few obtaining dimensions up to $100\mu\text{m}$. The size and number of the lumps was independent of the brand of cement used and the intensity of spatulation. A further observation was that peripheral to these powder lumps there occurred an area deficient of any powder particles. These areas contained a high concentration of the phosphoric acid solution.

Jorgensen explained that, when the thickness of the cement film had been reduced by compression to the same size as the powder lump, the higher viscosity of the lump caused it to be squeezed out between the plates more slowly than the surrounding less viscous mixture. The lump could be regarded as being caught between the glass plates. Owing to the different pressures

centrally and peripherally the liquid would still be flowing in between the powder particles. The powder lumps would "catch" further powder particles so that only the acid solution was allowed to filter past. The escaping acid would wash away the cement mix peripheral to the lump leaving the areas almost powderless. Thus, the cement lump acted as a filter separating the two phases of the cement mix at the moment the width of the slit through which the cement flowed became smaller than the lump.

In the cementation of a full veneer crown the excess cement was forced out through the narrow passage between the conical surfaces of the crown and preparation.

When the passage became so small that the largest lumps were jammed, filtration would occur. The most susceptible area was where the occlusal and conical surfaces of the tooth joined. When seating the restoration, an increasingly narrow slit developed at this line angle through which excess occlusal cement was required to pass. Powder lumps were caught at the occlusal inlet to the slit and filtration occurred as pressure for flow still existed.

Jorgensen showed that the degree of filtration was influenced by several factors which are listed below.

Factors Influencing Filtration

1. Cementation Pressure

An increase in pressure increased the filtration effect because high pressures resulted in the expression of more cement through the narrow occlusal slit and consequently the expression of more liquid through the "filter". Pressure applied for a short

duration resulted in less filtration than a pressure of long duration although prolongation of pressure beyond one minute did not cause a detectable increase in filtration. However, as discussed earlier a cementation force of ten kilograms produced a minimal film thickness.

To obtain both minimal film thickness and minimal filtration effects a practical technique has evolved whereby the restoration to be cemented has been seated with an intermittent application of pressure for the first 15 - 20 seconds. This allowed for maximum flow of excess cement before the passage of flow became too restrictive and ensured that different pressures existing within the cement mix were kept to a minimum. In this way filtration was kept to a minimum.

2. Viscosity of the cement

An increase in viscosity reduced the filtration because a high degree of viscosity resulted in the expression of less cement. However, an increase in viscosity was associated with increase in film thickness.

3. Taper of the preparation

Small degrees of taper increased the filtration effect because the slit width quickly became so narrow that the expression of excess cement was reduced. However, an increase in taper decreased retention. Jorgensen showed that the optimal total taper for maximum retention and minimal film thickness was of the order of 10^0 .

4. Hollowed crown

If a crown was hollowed out to produce a sloppy fit except in the gingival zone, then the filtration effect did not occur at the occluso-axial line angle but occurred instead at the occlusal aspect of this well fitting gingival zone. Although marginal discrepancy was decreased, Jorgensen argued that filtration in this gingival zone now resulted in washing out of the filtered liquid. The author maintains that if an intermittent pressure is applied then pressure differentials will only be low and therefore minimal filtration will occur. On the occasions when retention is not a problem in full crown restorations it is common clinical practice to obtain a sloppy fit in all areas except the gingival zone for a cast restoration. This can be achieved by stripping of the internal surface. This is not practical for porcelain veneer restorations, however, the same sloppy fit can be achieved by obtaining an oversized die. It was traditionally thought that removal of the foil from porcelain jacket crowns achieved this 'sloppy' fit. However, Southan (1972) maintained that the foil was still a source of gross error because it was pulled away from the vital gingival shoulder region by the shrinking porcelain.

Southan claimed that his refractory die technique although providing a sloppy fit elsewhere, maintained a precise fit at the gingival margin. McLean and Sced (1976) overcame the problem of obtaining an oversized die by using a double foil technique in which the outer foil was not carried over the gingival shoulder region. The inner removable foil was laid down in the normal manner.

5. Escape grooves on the inside of the crown

Such grooves facilitated cement flow and seating of the crown and thereby decreased marginal discrepancy. However, Jorgensen observed that filtration occurred from the inlet of the escape grooves to the narrow slit between crown and preparation.

6. Roughness of the preparation and internal surface of the restoration

This roughness hindered cement flow, acting as a trap for the powder lumps and thereby increased the filtration effect. However, Jorgensen (1968) showed that such roughness significantly increased the retention of the restoration.

7. Preparations with gingival shoulders

Where precision crowns were cemented onto dies filtration occurred as before. However, crowns that were made oversize to the order of 0.1mm, except in the shoulder region showed no filtration. Jorgensen concluded that the expression of cement ceased approximately at the same time as the gingival shoulder slit became narrow enough to retain the powder lumps.

8. Occlusal perforation of the crown

Almost complete elimination of filtration was obtained by making a hole, about one millimetre in diameter, in the occlusal surface of the crown prior to cementation. Under these conditions excess cement at the occlusal would be pressed out through the perforation, thereby eliminating one of the causes of filtration. Very slight areas of filtration occurred on the sides of the preparation where there were irregularities and inspection of

these areas showed that cement flow passed occlusally in the occlusal portion of the preparation and gingivally in the gingival portion of the preparation.

Jorgensen stated several harmful consequences of this filtration effect:

a) Pulp injury

Under normal conditions the phosphoric acid would be bound rather quickly by the powder particles and the pH of the mixture would approach biologic neutrality. After filtration, the acidic liquid might diffuse through the dentine causing injury to the pulp.

b) Secondary injuries to the hard dental tissues

If the filtered liquid extended to the border of the crown it would be washed away by saliva within a relatively short time. The resultant space might lead to recurrent caries.

c) Insufficient retention

Deficiencies in the cement film would decrease the retention between crown and restoration. In some circumstances this might result in the crown working loose.

It could be argued that the inherent distortions associated with porcelain veneer restorations allow adequate room for cement without creating a filtration effect.

13. THE MEASUREMENT OF MARGINAL DISCREPANCIES
 OF VENEER CROWN RESTORATIONS

Many methods have been used to determine marginal discrepancies of full veneer restorations both before and after cementation.

Jorgensen (1960), Greive (1969) and Shillingburg (1973) used a direct measurement of the marginal opening. This involved the microscopic measurement of the distance between the margin of the restoration and a reference point. The reference point was either the margin of the preparation or in the case of Shillingburg's study, a metal plate with crossed lines lightly etched on its surface and embedded in the die base. Shillingburg claimed that this procedure eliminated any errors caused by measuring from a worn or chipped labial finishing line of a die. Marginal discrepancies can only be measured in the vertical plane with this technique. Silness (1970) recognised this disadvantage and formulated mathematical equations to calculate the total area of discrepancy at the gingival margin for different finishing lines of preparations.

However, this technique did have the advantage that successive measurements of the marginal discrepancies could be carried out following different procedures such as firing of the porcelain, removal of the foil and cementation to the die. The influence of each procedure on the marginal discrepancy could therefore be determined.

Dimashkeih et al (1974) reported on a technique for measuring the cement's film thickness beneath precision made full crown restorations. The crown was cemented into position and after setting it was vertically sectioned and the cement film was measured. The effect of film thickness on marginal discrepancy could be determined in this way. However, because the crowns were made by electrodeposition of copper onto cone shaped dies, the influence of the cement on marginal discrepancy was exaggerated because of the exact nature of their fit and the resultant lack of room for the cement. In the clinical situation, the distortions inherent in the fabrication of anterior crowns cause some space to exist between the crown and preparation thereby allowing some room for the cement before any resistance to seating is established. The influence of the cement on the marginal discrepancy in this case would not be as great as it would be for precision fitted crowns.

Investigating the effect of venting on marginal discrepancy of cemented crowns, Jones et al (1971) used an intra-oral television measurement instrumentation which was essentially a petrographic microscope coupled to a closed circuit television system with scan line measurement circuitry. The disadvantages of this system were the cost of the equipment, the associated technical expertise needed and the limitation of measurement only in a vertical plane. It had the advantage of being an 'intra-oral' technique.

Bjorn et al (1970) studied the effect of the marginal fit of restorations on the periodontal bone level and used radiographs to determine the marginal discrepancy of restorations. A times seven magnifier with a scale divided in 0.1mm fractions was used to measure the amount of excess or deficiency of the margins of cemented veneer crowns. However, only discrepancies above 100µm could be determined accurately with this technique and marginal discrepancy determination was limited to the proximal surfaces.

McLean and von Fraunhofer in (1971) presented a technique for estimating the cement film thickness beneath restorations.

The technique employed a polymerisable elastomer (rubber impression material) in place of the cement film. After "cementation" the cured rubber was removed from the restoration and embedded in a resin Scutan* - prior to sectioning and measurement of film thickness and marginal discrepancy. A polyether rubber Impregum** - was found to be the most satisfactory elastomer because it was similar to zinc phosphate cement in working time, setting time and flow as determined by film thickness and consistency comparison tests. While elastomeric materials generally can exhibit stress-relaxation phenomena, McLean maintained that the embedding technique used, whereby the resin and rubber combined chemically,

* ESPE Co., West Germany

** ESPE Co., West Germany

effectively prevented any postsetting dimensional changes. In addition, the shrinkage of the embedding resin was very low and was sufficiently elastic to permit withdrawal of the rubber intact from the tooth or crown surface.

There were several advantages with this technique. It could be used in intra-oral or extra-oral investigations, was simple to master, required no expensive machinery and was accurate. McLean claimed that films as thin as $10\mu\text{m}$ could be reproduced with the technique. In addition sectioning of the resin embedded rubber replica did not involve sectioning of the crown. It could then be "recemented" to tooth or die after an assessment of the marginal discrepancy.

The disadvantage of the technique was that marginal discrepancies could only be determined for "cemented" restorations. The effect of other variables could only be considered in reference to the cemented restoration. Clinically, however, all crowns are cemented so that this technique may be a satisfactory and realistic approach to the evaluation of marginal discrepancies.

McLean (1971) stated that the in-vivo fit of a restoration was determined by means of a sharp explorer or by radiograph but that discrepancies below $80\mu\text{m}$ were difficult to detect by these methods under average clinical conditions. Jones (1971) found that discrepancies above $50\mu\text{m}$ could be determined in areas that permitted visual examination.

It is accepted that no discrepancy should exist at the

gingival margin of dental restorations; that is, there should be a perfect fit. This is not possible clinically. The level of discrepancy that can be considered clinically acceptable, however, is not well discussed in the dental literature.

In McLean's in vivo study, discrepancies ranging from 10-160 μ m were all judged to be clinically acceptable on the basis of standard radiographic and explorer examination. A further five year clinical study of 1000 restorations showed that restorations with marginal discrepancies of the same order of 10 - 160 μ m were clinically successful. McLean maintained that a restoration with a marginal discrepancy below 120 μ m could be considered to be a clinically successful restoration. He further maintained that restorations with cement films greater than 160 μ m at the cervical margins might be clinically successful but that radiographic and exploratory examinations of these restorations would result in their rejection as clinically unsuitable.

It should be remembered that this discussion has been limited to the margins of restorations that are not burnishable either due to their inaccessability or to material limitations.

It would seem that there are two standards of accuracy that apply to dental restorations, technical and clinical. Technical accuracy or perfect precision is the ideal but it cannot be realized. Clinical acceptance on the other hand depends on the knowledge, skill, experience and integrity of the operator as well as his visual acuity and tactile sensitivity; all of which vary from operator to operator.

14. THE FLOW PROPERTIES OF ZINC PHOSPHATE CEMENT

The published literature on cements prior to 1933 was conspicuously lacking in reliable data on the physical and chemical properties of such cements. This prompted Paffenbarger (1933, 1934) to carry out an investigation into dental zinc phosphate cements, so that a specification could be written which would ensure that the dentist had a reliable guide for the purchase of these cements.

The point of Paffenbarger's investigation, with which this investigation is concerned, was the determination of a standard consistency of mixed cement. It was common knowledge among the users of zinc phosphate cements, that to produce mixes of the same consistency, the amount of powder required for a given quantity of liquid would vary with different cements (Paffenbarger 1934). If the relative merits of cements of this type were to be compared satisfactorily, it was necessary that all test specimens be prepared from mixes of the same consistency.

The designing of a satisfactory test for the determination of consistency was most difficult because the following conditions had to be considered:

1. Only a very small specimen should be used as the size of the mixes should be approximately the same as those required in actual dental practice.
2. The test specimen hardens in a few minutes and the addition of any retarding agent which would interfere with the setting would not represent conditions in actual use.

3. The soft unset cement was adhesive or sticky. This made it difficult to measure and to deposit a definite quantity in the test apparatus.

4. The cement corroded many metals and alloys. This had to be considered in the building of the apparatus.

5. The test must be accurate, sensitive and reproducible and must approximate closely clinical conditions.

It was this last point that created a problem. Dental zinc phosphate cement is used as both a base forming and luting material. The consistency of mix for the two uses varies markedly, with the base forming consistency being stiff and putty-like, while the luting consistency is creamy. The manufacturer's mixing directions, which accompanied the individual packages of dental zinc phosphate cement prior to 1934, were indefinite regarding consistency. Almost all of these directions recommended that the cements be mixed to the consistency desired by the individual operator.

Several methods that were currently used in the determination of consistencies of concrete, gypsum and similar materials were tried by Paffenbarger and proved unsatisfactory. Other methods, such as observing the flow of cement down an inclined plane or measuring the length of threads or filaments that the cement reached before rupturing were tried but proved unsatisfactory.

The method finally adopted by Paffenbarger was a modified "slump" test. In this test a definite quantity (0.5 cc) of mixed but unset cement was pressed between two flat plates under a constant load (120 gm) for a definite time (ten minutes). The soft

cement slumped or spread into a disc. The diameter of the disc was used as a measure of the consistency. Different consistencies of mixed cements produced discs of varying sizes.

After much consideration Paffenbarger decided that the only practical approach was to average the luting consistencies used by visitors to his laboratory. The average value of these tests was considered as the preliminary testing consistency. This consistency produced a disc $34^{\pm}$ mm. in diameter. Paffenbarger used mixes of this consistency to obtain data for several properties of seventeen commercially available cements.

However, in June 1934 consistency data were received by Paffenbarger from a group of dentists who were co-operating with the Research Commission of the American Dental Association and the National Bureau of Standards in some experiments with cements. These data were very erratic with the spread between the reported values of individual co-operators as high as 300 per cent. This seemed unreasonably high and could not be readily explained although Paffenbarger showed that the commercial cements were not uniform from batch to batch. Consequently, packages of one of the commercial cements of a single batch number and colour were mailed to twenty-five groups of the co-operating committee for additional consistency tests.

The resulting consistencies produced discs having an average diameter of $30^{\pm}$ mm. Because these groups were located in various sections of the country and under a great variety of climatic

conditions it was considered that this consistency should be adopted and was called the standard consistency. The standard consistency for Dalton's Zinc Phosphate Cement* represents a powder : liquid ratio of 1.35 gm/0.5 ml. In this author's experience such a mix is not suitable for use as either a base forming or luting material. Griffith and Ware (1960) described this consistency "as an average between the thick and thin consistencies which are required in practice". Yet this standard consistency has been used to determine the physical and chemical properties of the zinc phosphate cement.

Bryant (1968) compared the compressive and tensile strength properties of four consistencies for S.S. White Zinc Phosphate Cement,** including a luting consistency; (1.1 gm powder/0.5 ml liquid), standard consistency (1.35 gm powder/0.5 ml liquid) and lining or base consistency (2.3 gm powder/0.5 ml liquid). He found that both the one hour and one week compressive strengths of the four specimen types were significantly different and that the lower the powder to liquid ratio, the weaker the specimen.

The tensile strength values were also significantly different after one hour. After one week, however, while the tensile strength values of the three thicker mixes were almost identical, that of the luting consistency mix was significantly weaker. It was clear then that the consistency of the cement had a significant influence

* England Industries Pty. Ltd. Melbourne Australia.

** S.S. White Dental Mfg. Co. (C.B) Ltd., London England.

on the strength properties at least.

As discussed in the previous chapter Jorgensen (1960) showed that the consistency of the cement also affected the film thickness which in turn affected the marginal discrepancy of cemented restorations. As part of the present investigation involves the establishment of a reliable method for comparing the marginal discrepancies of cemented restorations it would be important then to establish a consistency for clinical use.

SUMMARY

The history and development of the all porcelain and porcelain fused to metal crown have been outlined. It is clear that both techniques have been introduced clinically on an empirical basis. The dental manufacturing companies have provided little information on the composition and physical properties of the materials used in the techniques and little research was carried out initially by the dental profession.

The clinical failure of placed restorations has led to the realization of the inadequacies of both systems. Such realization has prompted much research into the composition of the materials, the effect of their physical properties in relation to dental restorations and the effects of operator variables on these properties. The results of this research has been discussed.

The once prestigious position of the porcelain jacket crown has been eroded as a consequence of its common unpredictable and costly mechanical failure. The likely cause of these failures has been shown to be internal defects associated with the use of platinum foil as a matrix material. Alternative techniques have been developed but the porcelain fused to metal restoration is rapidly assuming the most favoured position for anterior full crown restorations. The development of this technique and the physical properties that enable the satisfactory chemical combination of dental porcelain to alloys of some metals has been discussed.

All techniques for fabrication of permanent anterior full crown restorations involve some distortions. The influence of these distortions on the marginal fit of restorations, with resultant effects on their clinical acceptability has been discussed.

P A R T B

O R I G I N A L I N V E S T I G A T I O NThe Statement of the Problem.The Aim of the Investigation.

The common and unpredictable mechanical failure of the all porcelain jacket crown has resulted in a certain lack of confidence in this type of restoration. A possible explanation for this mechanical failure was given by Southan (1972). He recommended the elimination of the use of platinum foil as a matrix material and presented an alternative technique for fabricating porcelain jacket crowns which employed a phosphate bonded refractory die. Southan claimed that his technique produced a crown with a defect free inner surface and a better fit at the gingival margin. Previous writers, Clark (1935), Tylman (1960), Brecker (1961) and Southan (1972) had observed a lifting of the foil at the gingival margin as the porcelain was fused.

The porcelain fused to metal crown has gained widespread acceptance within the dental profession. This acceptance has arisen because these restorations combine the strength and fracture resistance of some metals with the desirable aesthetic qualities of porcelain.

Johnston (1956), Silver (1960) and Shillingburg (1973) have reported that distortions occurred in the cast metal when the porcelain was fused.

Two forces have been described, which may cause metal distortion. First, because of the ductility of the metal, interfacial sheer stress may deform the metal when the porcelain is still in a viscous state. Secondly, because of the required high porcelain fusing temperatures metal creep occurs.

Shillingburg showed that for single porcelain bonded to metal crowns, the degree of distortion was related to the tooth preparation design and that the shoulder type of preparation resisted distortion more than others.

The clinical significance of the distortions associated with both the porcelain jacket and porcelain fused to metal restorations is that the marginal discrepancy of such restorations is increased.

Attempts to measure such distortions have been limited to external linear microscopic measurements between a point on the margin and some static reference point usually on the die. There are limitations to this system. First, only the behaviour of the external point of the margin of the restoration can be observed. This may not be a true representation of what is occurring over the entire shoulder area. Secondly, no consideration can be given to the effect of the cement on the marginal fit of the cemented restoration. The fabrication distortions maybe clinically

insignificant in comparison to the effect on the marginal discrepancy due to the presence of the luting or cementing agent.

A more comprehensive assessment of fit or misfit of porcelain and porcelain fused to metal restorations and its clinical significance is indicated.

The term "FIT" as applied to a full coverage dental restoration is most often associated with the discrepancy at the margin of the permanently placed restoration. The in-vivo assessment of the fit of such a restoration is restricted to visual examination, instrumental probing and radiographic examination.

Jorgensen (1960) used the term gingival discrepancy and defined it as the mean value of the distance between the gingival borders of crown and preparation. His measurements were restricted to external points of the shoulder region of the crown and preparation and were measurements in one dimension only.

The gingival discrepancy is an important measurement because it gives an indication of the degree of direct exposure of cement to the oral environment. However, a more comprehensive indication of the discrepancy right across the shoulder area would be preferable. It would provide a better understanding of the fabrication errors occurring at the shoulder region, would present more information on the supportive role of the shoulder area of cemented crowns, would better indicate the long term prospects of leeching of the cementing or luting agent and would represent a two dimensional mean measurement.

Thus for the purposes of this present investigation the term Mean Axial Discrepancy has been used. This has been defined as the mean of measurements in the direction of the long axis of the tooth between several points across the shoulder area of the crown and preparation.

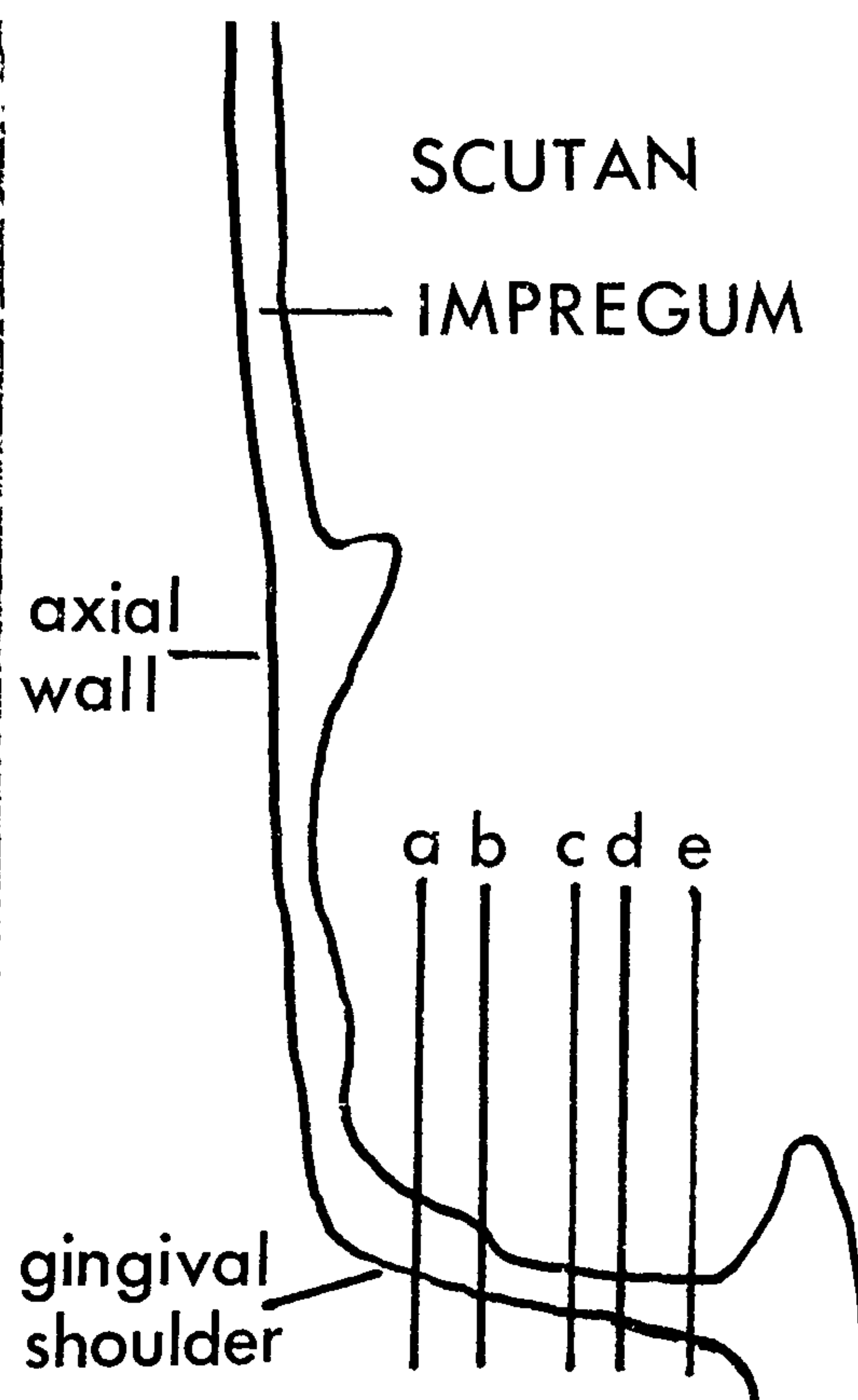
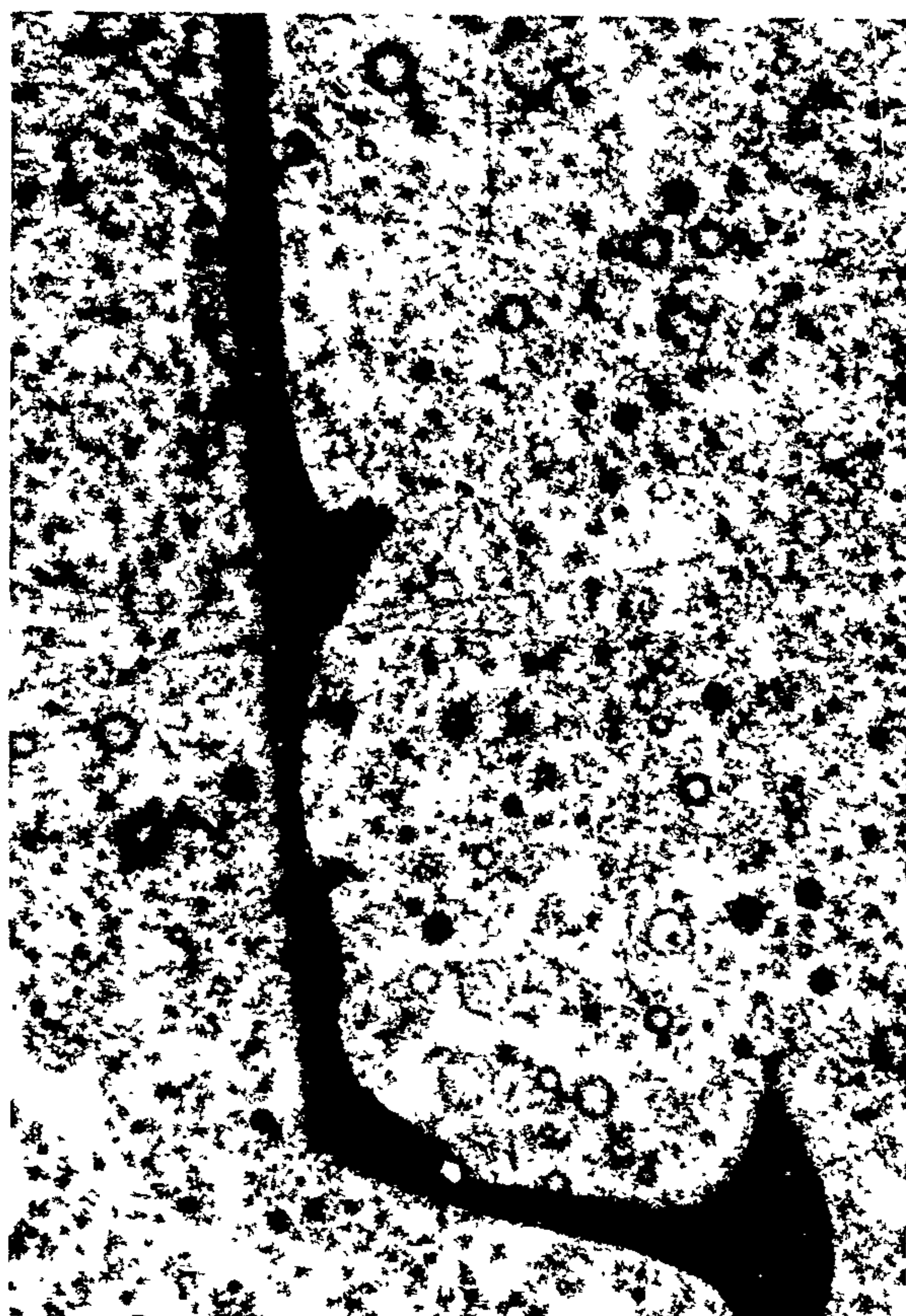
This has been diagrammatically presented in Figure 1 where the length of line "e" represents the gingival or marginal discrepancy and the average lengths of lines a,b,c,d,e represents the Mean Axial Discrepancy of the restoration in that region.

The degree of axial discrepancy of full veneer restorations is determined by the accuracy of the fabrication technique and the thickness of the luting agent. The thickness of the luting agent will be determined by the physical properties of the agent, its manipulation and the ability of the excess material to flow from under the placed restoration. The preparation also plays a role here, with factors such as degree of taper, axial height, smoothness and roundness of the line angles affecting the flow of the excess luting material. It is therefore important that the preparation is well designed and that the fabrication techniques are accurate and that provision is made for the flow of excess cementing or luting agent.

Any axial discrepancy arising from the fabrication techniques will usually result in the luting agent being exposed to the oral environment. Since all acceptable luting agents are to some degree soluble, the extent of the gingival discrepancy will influence the leeching of the cement, which in turn, will influence the retention of plaque. The retention of plaque and debris will increase the

Figure 1 - A photomicrograph and adjacent tracing showing points of measurement for obtaining the axial discrepancy in the shoulder region of a cemented porcelain jacket crown. Measurement point "e" corresponds closely to the gingival or marginal discrepancy.

FIGURE 1



likelihood of early breakdown of the tooth and periodontal structures. If insufficient space is available for the luting agent the crown may not be able to be seated completely. This will not only lead to exposure of the cement to the oral environment but may also cause traumatic occlusion. Breakdown of tooth and periodontal structures or fracture of the crown may result.

It is therefore of real clinical importance to ascertain the accuracy of techniques of fabrication for dental restorations involving the use of porcelain.

The AIM of this investigation was threefold.

1. To establish a suitable technique for measuring the axial discrepancy of cemented full veneer restorations.
2. To determine the axial discrepancies in the shoulder regions of full veneer porcelain and porcelain fused to metal restorations.
3. To relate the axial discrepancy results obtained to the clinical acceptability of such restorations.

ESTABLISHING THE METHOD

One of the aims of this investigation was to establish a method for measuring the axial discrepancy of full veneer restorations.

This involved a sequence of minor investigations.

- 1) The determination of the powder/liquid ratio of Dalton's Zinc Phosphate Cement which provided a clinically acceptable consistency for the purposes of luting (cementation).
- 2) A determination of the flow properties of a mix of this cement with this powder/liquid ratio.
- 3) The preparation of a mix of Impregum possessing flow properties comparable with this zinc phosphate cement.
- 4) An investigation of a rubber replica technique for accurately determining the axial discrepancy of cemented full veneer restorations.

As a result of these investigations it was possible to establish a technique for examining axial discrepancy.

These studies will now be detailed.

When required, statistical analysis was carried out and the number of values used to establish each mean has been indicated in the findings.

The standard deviation was calculated by means of the formula:-

$$S.D. = \sqrt{\frac{\sum (x - \bar{x})^2}{n-1}}$$

where x was the value for a single reading or specimen.

$\bar{x}$ was the mean value for n specimens and

n was the number of specimens

Where an indication of the statistical significance of the difference between two results was required a Student's "t" test (Spiegel 1961) was applied using the formula,

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2} \times \frac{n_1 + n_2}{n_1 n_2}}}$$

where s was the standard deviation and the numbers 1 and 2 represented the two values being compared.

For the purposes of this research, the difference between two values has been termed "statistically significant" when the "t" test indicated that a difference occurred at the 97.5% confidence level.

(1) The Determination of the Powder/Liquid Ratio
of a Luting Consistency Mix of Dalton's Zinc Phosphate Cement

As mentioned earlier, Jorgensen (1960) established that the axial discrepancy of cemented crowns was influenced by the viscosity or consistency of the cement mix. The thicker the mix, the greater was the axial discrepancy.

It was therefore considered necessary to establish a luting consistency suitable for clinical use which could be used for crown cementation if axial discrepancies of different fabrication techniques were to be compared. It was decided that Paffenbarger's (1933) method of averaging out several mixes of experienced clinicians was a satisfactory approach.

Dalton's Zinc Phosphate Cement was used because it,

- (a) passes Australian Standard No. 1186 for zinc phosphate cements.
- (b) was found by Griffith and Ware (1960) and Bryant (1968) to be comparable to other luting agents, and
- (c) is in regular usage.

To establish a clinically acceptable luting consistency mix of this cement the assistance of six experienced clinicians was employed.

Each clinician was provided with a cool, clean, dry glass slab onto which was placed $1.5 \text{ gm} \pm 0.02 \text{ gm}$ powder and $0.5 \text{ ml} \pm 0.02 \text{ ml}$ liquid. Ambient conditions of $21 \pm 1^\circ\text{C}$ temperature and $55 \pm 5\%$

relative humidity prevailed. The clinicians were asked to mix the cement to a consistency they thought appropriate for the cementation of a single full veneer crown. After mixing, the unused powder was reweighed and the appropriate powder/liquid ratio determined. The glass slabs and spatulas were carefully cleaned and washed before any further mixing was carried out. Each clinician prepared five mixes thereby yielding a total of 30 mixes.

Results

The mean powder/liquid ratio was then calculated for each clinician and has been presented in Table I. The overall mean for the five clinicians was 1.15gm powder/0.5ml. liquid. The means for the clinicians ranged from 0.93 to 1.29gm/0.5ml. liquid.

Table 1

The Determination of a Clinical Luting Consistency
for Dalton's Zinc Phosphate Cement.

Clinician	Powder: Liquid Ratio (gm/0.5ml) for each mix					Mean
	1	2	3	4	5	
1	1.17	1.19	1.29	1.36	1.26	1.25 (0.08)*
2	1.27	1.24	1.30	1.26	1.40	1.29 (0.06)
* * 3	0.93	0.93	0.88	0.96	0.93	0.93 (0.03)
* * 4	1.09	1.03	1.05	1.07	1.15	1.08 (0.05)
5	1.12	1.12	1.02	1.14	1.06	1.09 (0.05)
6	1.44	1.27	1.20	1.30	1.17	1.28 (0.09)

* Standard deviation in brackets.

Overall Mean = 1.15gm powder/0.5ml liquid
Overall Standard Deviation = 0.148

** Denotes female clinician

Discussion

The powder/liquid ratio mix found in this present study (1.15gm/0.5ml.) compared favourably with Bryant's (1968) ratio of 1.10gm. powder/0.5ml. liquid for a luting mix. His ratio was, however, based on personal preference alone. In contrast an attempt was made here to average that preferred by six clinicians.

Another observation was that female clinicians tended to use a thinner mix for cementing crowns than did male clinicians. However, due to the small number of operators in this study, this could only be considered as an empirical observation and further work would be required to determine if this trend was significant.

Griffith and Ware (1960) determined that the powder/liquid ratio for a standard testing mix of this cement required 1.35gm. powder/0.5ml. liquid.

Conclusion

A clinically acceptable luting consistency for the cement was determined. This used a powder/liquid ratio of 1.15gm./0.5ml.

This study also emphasized that the powder/liquid ratio of Dalton's Zinc Phosphate Cement used for luting full veneer restorations

was significantly different from the powder/liquid ratio used for standard testing required for Australian Standard Specification number 1186 (1972).

(2) The Determination of the Flow Properties
of Dalton's Zinc Phosphate Cement.

As mentioned previously the axial discrepancy of full veneer restorations is partially determined by the thickness of the luting agent. This thickness will be influenced by the physical properties of the cement, its manipulation and the ability of the excess cement to flow from under the restoration. McLean and von Fraunhofer (1972) used mixes of standard testing consistency and film thickness tests to assess the flow properties of zinc phosphate cement. Jorgensen (1966) had previously determined that the axial discrepancy was influenced by the powder/liquid ratio of the cement.

It has been established in this study that the powder/liquid ratio of cement used for luting full veneer restorations was different from the powder/liquid ratio used to obtain standard testing consistency. It was therefore considered necessary to establish the film thickness and consistency of cement suitable for luting purposes.

Consistency and film thickness tests in accordance with Australian Standard Specification Number 1186 (1972) were carried out to determine the average disc diameter of Dalton's Zinc Phosphate Cement mixed to three different powder/liquid ratios:-

- (a) Clinical luting consistency (see Table 1),
(1.15gm. powder/0.5ml. liquid).

- (b) Standard testing consistency (1.35gm. powder/0.5ml. liquid).
- (c) Base forming consistency as determined by Bryant (1968), (2.80gm. powder/0.5ml. liquid).

Results

The average disc diameters obtained from the consistency test have been presented in Table 2. The average disc diameters for the luting, standard testing and base forming mixes were 34 μ m, 30 μ m and 12 μ m respectively. The results of the film thickness test have been presented in Table 3. The mean film thickness (to the nearest 5 μ m) for the luting, standard testing and base forming mixes were 15 μ m, 25 μ m and 150 μ m respectively.

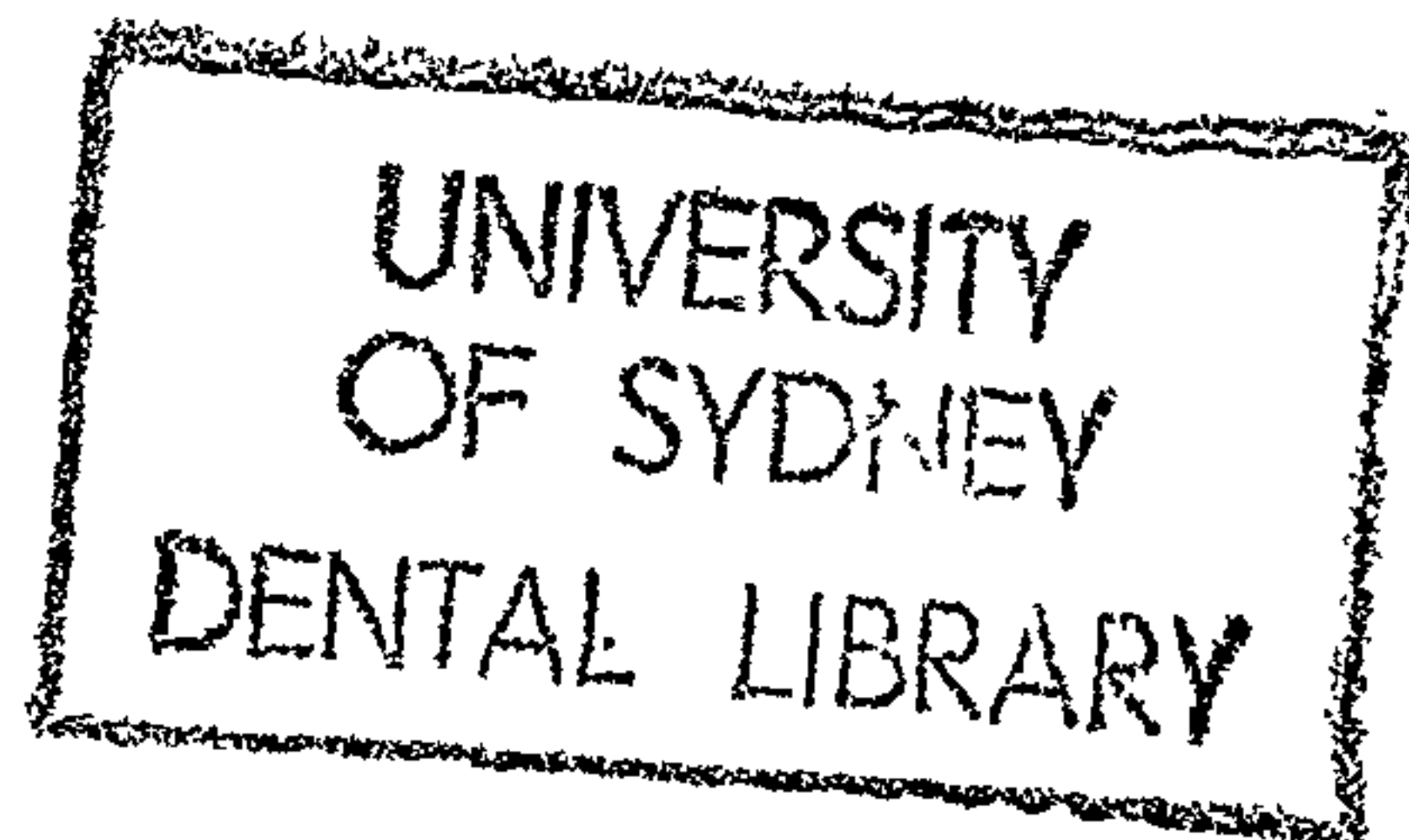


Table 2

Consistency Test in Accordance with AS 1186 (1972)
for Dalton's Zinc Phosphate Cement.

Mix	Disc diameter (mm)		Average disc diameter (mm)
	Short axis	Long axis	
Luting	33	34.5	34^{+1}
	32.5	34	
	34	35	
Standard Testing	30.5	31	30^{+1}
	29	30	
	29.5	30.5	
Base Forming	12	12.5	12 1
	10.5	12.5	
	11	12	

Table 3
 Film Thickness of Mixes of Dalton's
 Zinc Phosphate Cement of Different Consistency

Mix	Film thickness (μm)	Mean film thickness (nearest $5\mu\text{m}$)
Luting	17	15
	14	
	16	
Standard Testing	26	25
	25	
	26	
Base Forming	150	150
	166	
	145	

Discussion

It was interesting to note that the consistency measured by the average disc diameter for a luting mix obtained in this research (34^{+1} mm.) was identical with that obtained by Paffenbarger. It was also apparent that the powder/liquid ratio greatly effected the ability of mixed cement to flow and this is emphasised in a pictorial form in Figure 2.

The film thickness of a luting consistency mix was significantly lower than that of a mix of standard consistency. Three tests were carried out at each consistency and the mean values were $15\mu\text{m}$ and $25\mu\text{m}$ respectively (reported to the nearest $5\mu\text{m}$ according to Australian Standard Specification Number 1186 1972).

The $15\mu\text{m}$ film thickness of a mix of luting consistency indicated it is unlikely that the film thickness would be a factor which would significantly limit the positive seating of full veneer restorations during cementation, for two reasons:

- i. Fabricating techniques may result in average distortions greater than $15\mu\text{m}$.
- ii. Restorations that can be easily removed from a preparation may have average discrepancies greater than $15\mu\text{m}$.

Another possible explanation for the axial discrepancies obtained during cementation has been suggested by Jorgensen (1960).

It would appear that the inability of the excess cement to flow from under the restoration was likely to be a more limiting factor than film thickness. Jorgensen's filtration theory recognised that any factor which limited such a flow would tend to increase the axial discrepancy. The very large axial discrepancies obtained by Jorgensen could possibly be explained as follows. First, he used machined ground precision restorations which allowed very little room for cement. Secondly, he used a mix of standard testing consistency cement to seat the restorations.

This present study has shown that the flow of such a mix was significantly less than that of a mix suitable for luting purposes.

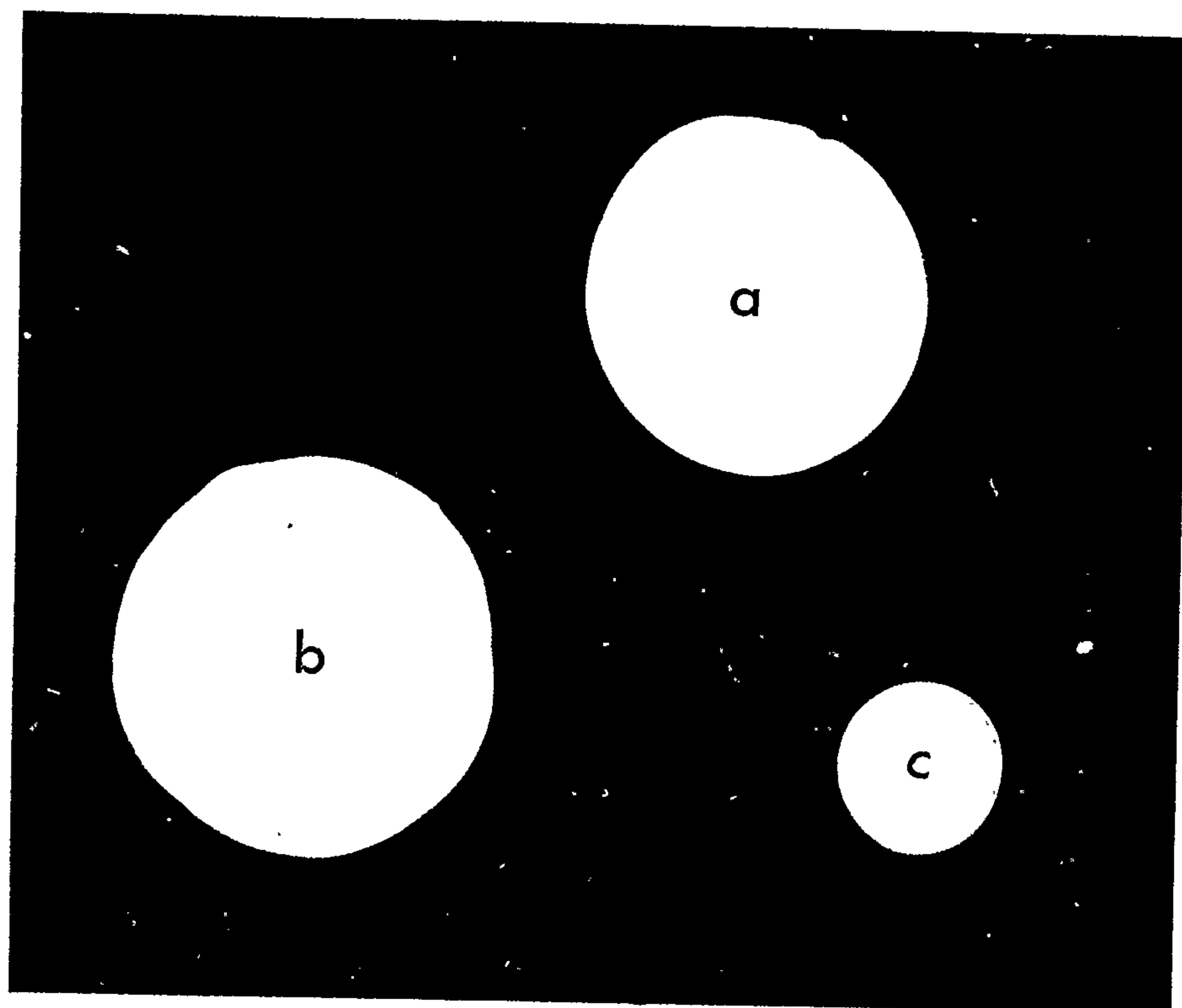
Conclusion

This study showed that the film thickness and consistency of Dalton's Zinc Phosphate Cement were significantly different when mixed at consistencies suitable for luting, standard testing or base forming purposes. The luting mix was found to have a film thickness of $15 \pm 5 \mu\text{m}$ and a consistency measured by average disc diameters of $34 \pm 1 \text{mm}$.

Figure 2 - Photograph showing consistency discs obtained for three powder/liquid ratios of Dalton's Zinc Phosphate Cement.

- (a) Standard mix with a powder/liquid ratio of 1.35gms./0.5ml. liquid.
- (b) Luting mix with a powder/liquid ratio of 1.15gms./0.5ml.
- (c) Base forming mix with a powder/liquid ratio of 2.8gms./0.5ml.

FIGURE 2



(3) The Determination of a Mix of Impregum with Flow Properties Comparable with Dalton's Zinc Phosphate Cement.

In 1971 McLean and von Fraunhofer presented a technique for estimating the film thickness of cement beneath cemented dental restorations (chapter 13). In their technique they employed a polyether impression material, Impregum, which they claimed had similar flow properties to De Trey's Zinc Phosphate Cement. They stated that film thickness determinations in accordance with BS 3364 produced a film of 22 μ m with Impregum and 20 μ m with De Trey's cement. Consistency tests in accordance with ISO RI566 (1970) gave an average disc diameter of 30mm for the cement and 35mm for the rubber. They concluded that the results of these two tests indicated that the flow properties of the two materials were comparable.

However, the mix of cement used by McLean and von Fraunhofer was of standard testing consistency. It has been established previously in this present research programme that standard testing and luting mixes of Dalton's Zinc Phosphate Cement have statistically different flow properties. If the cement film thickness beneath full crown restorations was to be investigated using the rubber replica technique described by McLean and von Fraunhofer, then, it was essential that the flow properties of the rubber should be comparable to those of the cement mix of luting consistency.

Because Impregum has a catalyst/base system, the ratio of catalyst to base cannot be altered without significantly affecting other properties such as setting time, working time, consistency and flow. However, the ESPE company provides a thinner which can be used to alter the flow properties of Impregum without significantly affecting other properties.

The AIM of this aspect of the study was to prepare a mix of Impregum with a ratio of catalyst, base and thinner such that the flow properties were comparable to a luting mix of Dalton's Zinc Phosphate Cement.

Method

Film thickness and consistency tests for Impregum were carried out employing procedures similar to those of the Australian Standards Specification Number 1186 for dental zinc phosphate cements. Some modifications to the specification were made because of the different nature of the two materials.

The specification required a testing period at 180 seconds after commencement of mixing the zinc phosphate cement. However, according to the manufacturer's instructions for Impregum, a mixing time of 45 seconds, working time of 120 seconds and a holding time of 5 minutes was required. Thus a testing period for Impregum at

180 seconds after the commencement of mixing would result in flow tests being applied during the holding time. As the holding time represented the setting time this was undesirable. Therefore, a time of 90 seconds after the commencement of mixing was selected for the Impregum tests. This represented twice the mixing time, the same as specified for the zinc phosphate cements.

Two standard packs of Impregum, containing catalyst, base and mixing pad, were used. The manufacturer's mixing instructions were followed closely. The delivery of catalyst and base from their respective tubes has been determined by the manufacturer such that equal lengths of catalyst and base expressed onto a mixing pad provided the correct ratio. Therefore equal lengths of catalyst and base were extruded onto the mixing pad. These were thoroughly spatulated for forty-five seconds. A portion of the mix was placed between two flat plates of known uniform thickness.

At 90 ± 5 seconds after the commencement of mixing a load of 150N (15kgf) was applied. Ten minutes after the commencement of mixing the load was removed and the thickness of the two plates with the rubber in between them was determined. The difference in the thickness of the two plates before and after the test was taken as the film thickness.

A modified plastic syringe calibrated to deliver 0.50 ± 0.02 ml. of mixed but unset Impregum was used for the consistency test. The Impregum was transferred to a flat glass plate. 90 ± 10 seconds after the commencement of mixing, a mass of 120 gm. (consisting of a

glass top plate of 20gm and a 100gm weight) was placed carefully and centrally on top of the rubber mass. Ten minutes after the commencement of mixing the weight was removed and the lengths of the major and minor axes of the slumped disc of rubber were recorded.

Results

Film thickness and consistency determinations were made for equal lengths of catalyst and base from the two packs and also for a mix with equal lengths of catalyst, base and thinner. The results of these determinations have been presented in Table 4 and Table 5 respectively.

Mean film thickness values for mixes with equal lengths of catalyst and base were; pack 1 - 25 μ m and pack 2 - 25 μ m. A mix with equal lengths of catalyst, base and thinner had a mean film thickness value of 15 μ m.

Average disc diameters for mixes with equal lengths of catalyst and base were; pack 1 - 26mm and pack 2 - 25mm. A mix with equal lengths of catalyst, base and thinner had an average disc diameter of 32mm.

A comparison of these results and those obtained for the zinc phosphate cement (see Tables, 1 and 2) has been presented in Table 6.

Table 4

The film thickness testing of Impregum

Mix	Film thickness μm	Mean film thickness to nearest $5\mu\text{m}$
<u>Pack 1</u> Equal lengths of catalyst and base	22 30 26	25
<u>Pack 2</u> Equal lengths of catalyst and base	25 25 30	25
Equal lengths of catalyst base and thinner	15 15 20	15

Table 5
Consistency testing of Impregum

Mix	Disc diameter (mm)		Average disc diameter (mm)
	Short axis	Long axis	
Pack 1 Equal lengths of catalyst and base	27 24 25.5	27 26 26	26
Pack 2 Equal lengths of catalyst and base	24 24 24.5	26.5 24 26	25
Equal lengths of catalyst base and thinner	31 32 31	32 32.5 32	32

Table 6

A comparison of the flow properties of Dalton's
Zinc Phosphate Cement and Impregum

Material	Mean film thickness to nearest 5 μ m	Average disc diameter (mm $\pm$ 1)
Daltons Zinc Phosphate Cement (luting consistency)	15	34 (0.61)*
Impregum (equal lengths of catalyst, base and thinner)	15	32 (0.93)

* Standard deviation in brackets

Discussion

Two different packs of Impregum were used. In each case, the results of film thickness and consistency tests obtained for a mix of Impregum with equally proportioned catalyst and base gave values of 25 μ m (thickness) and 22mm (disc diameter) respectively.

Although film thickness values obtained in this study were similar to those obtained by McLean, consistency test values differed markedly. McLean obtained an average disc diameter of 35mm compared to the 25mm obtained in this study. The standard upon which McLean based his work, ISO R1566 (1970) was identical to the Australian standard, Number 1186 (1972), used in this study although McLean's paper did not indicate the testing time used, no explanation can be offered for this difference.

The results indicated that the addition of thinner significantly altered the flow properties of the Impregum. Film thickness and consistency tests obtained for a mix of Impregum with equally proportioned lengths of catalyst, base and thinner gave values of 15 μ m (thickness) and 32mm (disc diameter) respectively. A comparison of these results with those obtained for the zinc phosphate cement has been presented in Table 6.

The Australian Standard Specification states that film thickness figures should be averaged to the nearest 5 μ m. Both materials attained a film thickness of 15 μ m.

The results for the consistency test gave average disc diameters of 34mm for the cement and 32mm for the rubber. Application of the "t" test applied to these two values indicated that there was no statistically significant difference at the 97.5% confidence level.

An interesting feature of the consistency test was the regular size of the disc obtained (see Figure 3a). Figure 3b compares slumped discs obtained from a luting mix of Dalton's Zinc Phosphate Cement and an Impregum mix of equal lengths of catalyst, base and thinner.

Throughout the remainder of this research programme a mix of Impregum containing equally dispensed lengths of catalyst, base and thinner will be referred to as a luting mix.

Conclusion

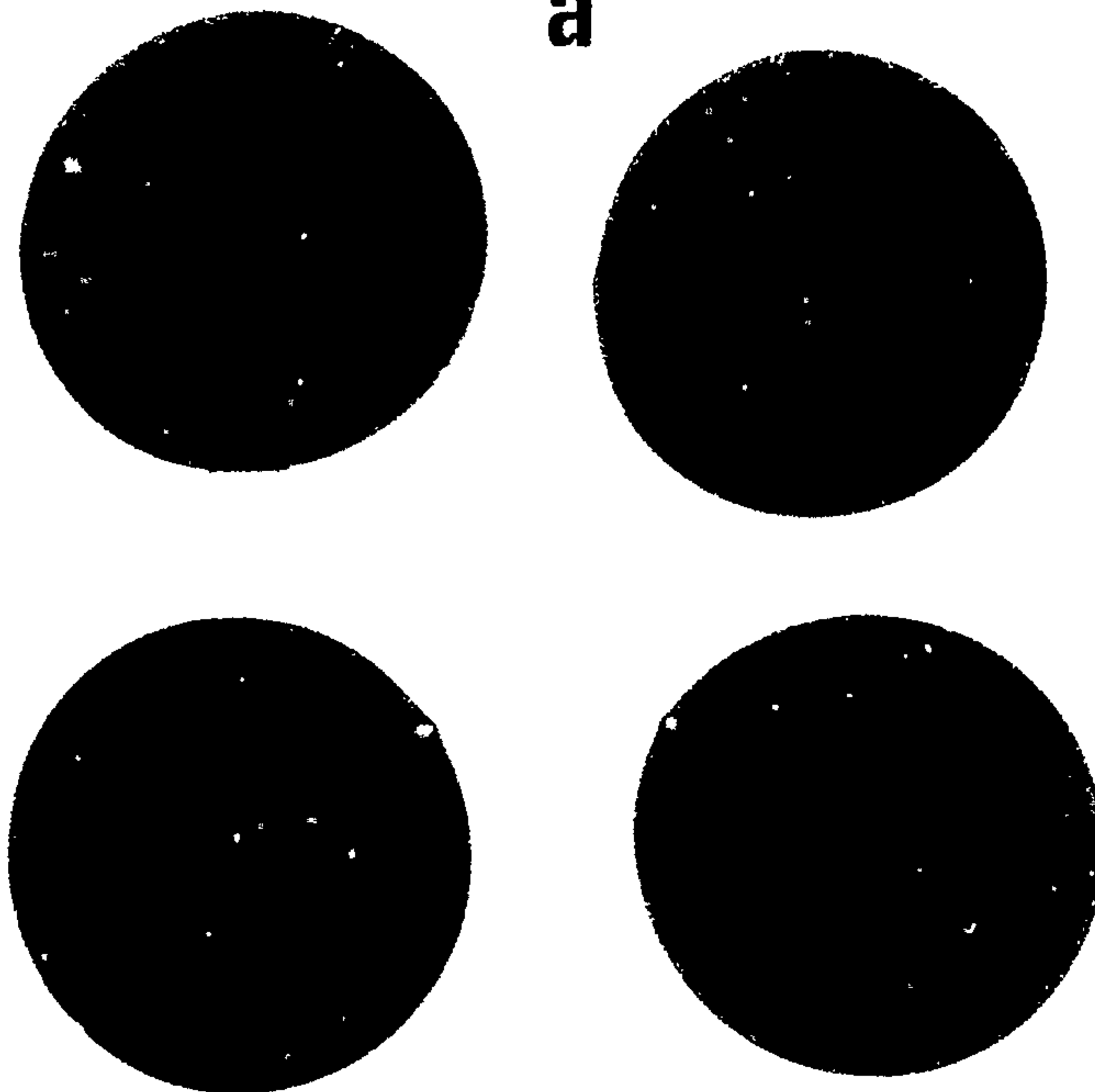
This aspect of the investigation showed that a mix of Impregum could be prepared that had identical flow properties to a luting mix of Dalton's Zinc Phosphate Cement.

Figure 3 (a) - Photograph showing the consistency of size of Impregum discs obtained during a consistency test according to Australian Standard number 1186 (1972).

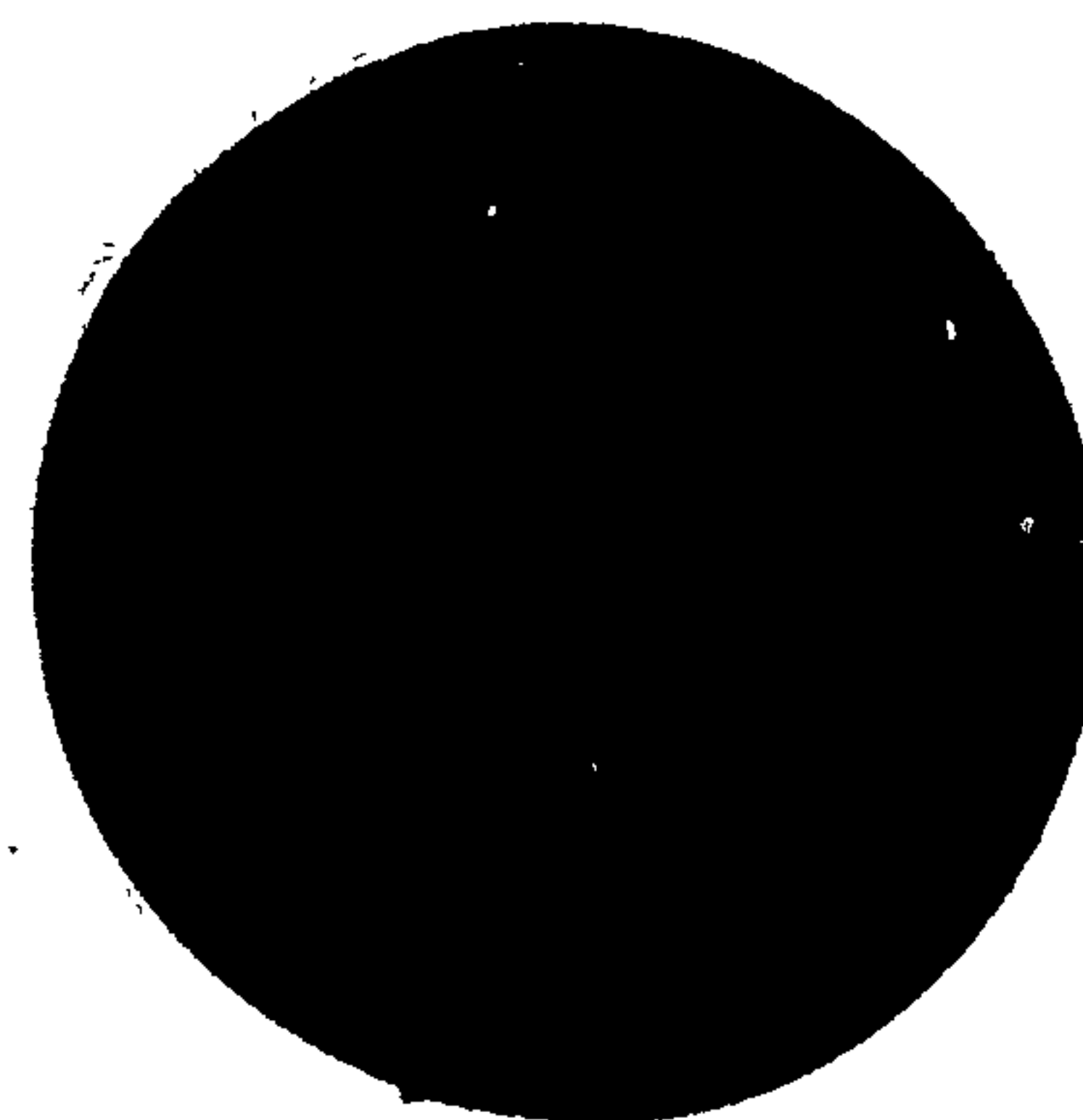
Figure 3 (b) - Photograph comparing the discs obtained with a luting consistency mix of Dalton's Zinc Phosphate Cement and Impregum with equal lengths of catalyst, base and thinner.

FIGURE 3

a



b



(4) Investigation of a Rubber Replica Technique for
Accurately Determining the Axial Discrepancy of Cemented
Full Veneer Restorations

Techniques for measuring the axial discrepancy of full veneer restorations were discussed in the literature review (refer chapter 13). Comment was made concerning the desirability of measuring the axial discrepancy of the cemented restoration as this would most resemble its functional situation. Accepting this approach, then, Dimaskeih's (1974) technique of vertically sectioning the cemented restoration would seem the most appropriate. The disadvantage of this technique was that the restoration was destroyed and therefore the effect on axial discrepancy of different stages of crown fabrication could not be studied.

The technique of McLean and von Fraunhofer overcame this disadvantage. Only a rubber replica of the cement space and its embedding resin were destroyed during sectioning.

This present research programme included measuring the axial discrepancies in the shoulder regions of porcelain fused to metal restorations both before and after the application of porcelain. It therefore seemed preferable to use McLean's technique. However, for clinical significance the results of this technique should be comparable to those obtained by directly sectioning the cemented restorations (as described by Dimaskeih).

The AIM of this aspect of the investigation was to compare the results obtained for the axial discrepancies of cemented crowns by the methods of;

- 1) direct sectioning and
- 2) sectioning of rubber replicas of the cement space.

Method

a) Preparation of specimens

An ideal porcelain jacket crown preparation was cut on a plastic replica of an upper central incisor. Two compound impressions were obtained and amalgam dies fabricated. Each die was trimmed and polished and its base was contoured so that it could be held effectively in a vice. A porcelain jacket crown was fabricated to fit each amalgam die. One crown was fabricated using the platinum foil technique, while Southan's refractory die technique was used for the other. Vitadur* porcelain was used for these crowns and all other porcelain jacket crowns used for this research programme.

The crowns were then cemented onto the dies with a luting mix of Impregum. The dies and crowns were separated and the intact rubber impression was not contaminated. Scutan was mixed according

* Vita Manufacturing Co., Sackingen, West Germany.

to the manufacturer's instructions, applied to the rubber film and carried just over the cervical margins. The chemical combination of Impregum to Scutan ensured minimal distortion of the impression (McLean and von Fraunhofer 1972). After four minutes a further mix of Scutan was used to bond Ney dowel pins* to the set Scutan to enable the specimens to be held in a vice. The specimens were orientated so that the flat edge of the pin corresponded to the mid labial face of the preparation.

After a further thirty minutes, the pins were held in a vice and the dies removed. A further mix of Scutan was used to pour the counterhalf of the rubber impression.

Figure 4 illustrates these steps. 4a shows a crown cemented onto its die with Impregum. 4b shows crown and die removed. The die is covered by a thin film of Impregum. 4c shows the first pour of Scutan. 4d shows the bonded and correctly orientated dowel pins. 4e shows the specimen and die separated. 4f shows the completed specimen with the counterhalf of the impression poured.

The porcelain jacket crowns were then recemented onto their respective amalgam dies using a luting mix of Dalton's Zinc Phosphate Cement.

All cementing procedures carried out during this research programme employed maximum manual pressure that could be applied by the operator.

* J.M. Ney Co. Hartford Connecticut, U.S.A.

Figure 4 - Photographs illustrating the steps required to obtain a rubber replica impression of the cement space beneath a cemented full veneer restoration.

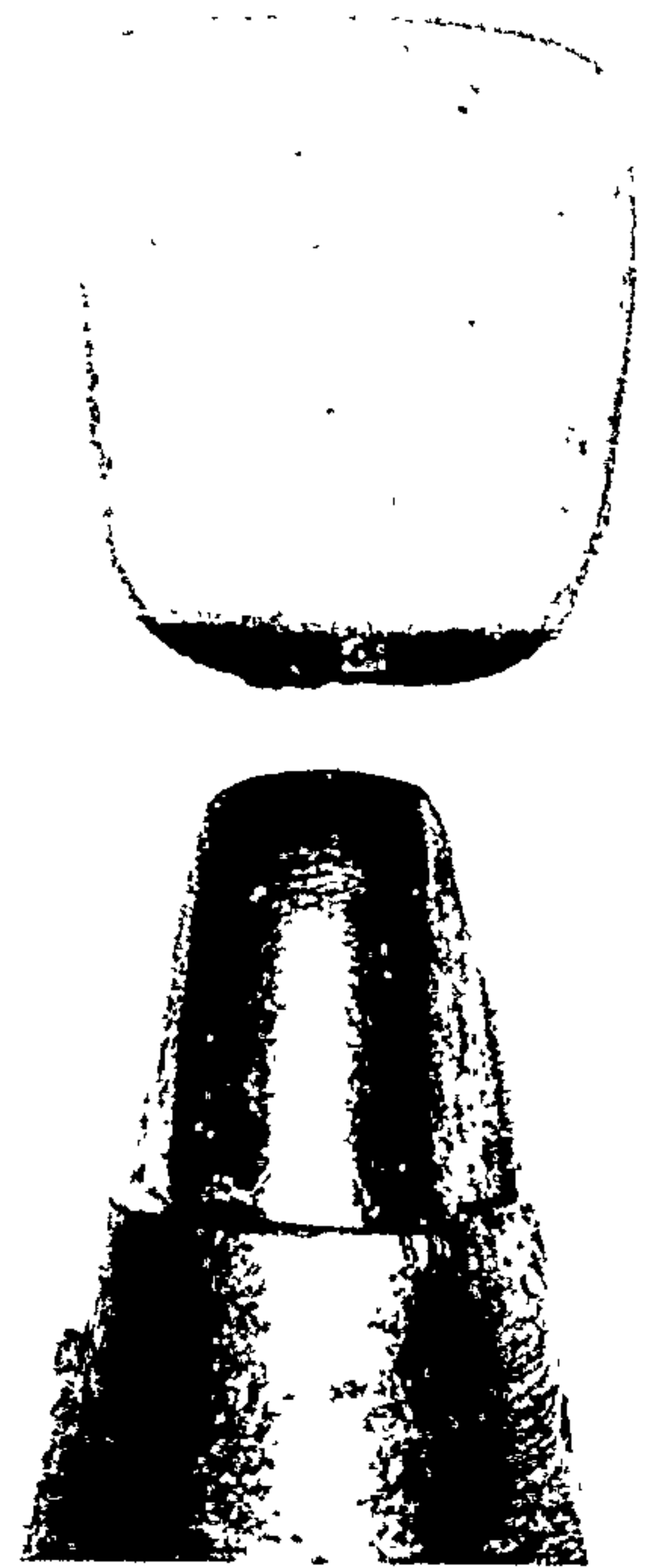
- (a) Crown cemented onto its amalgam master die with Impregum.
- (b) Crown and die separated. The Impregum impression has remained bound to the crown.
- (c) The first pour of Scutan fills the crown and extends over the shoulder region.
- (d) The brass dowel pin is bonded to the first pour with Scutan.

FIGURE 4(I)

a



b



c



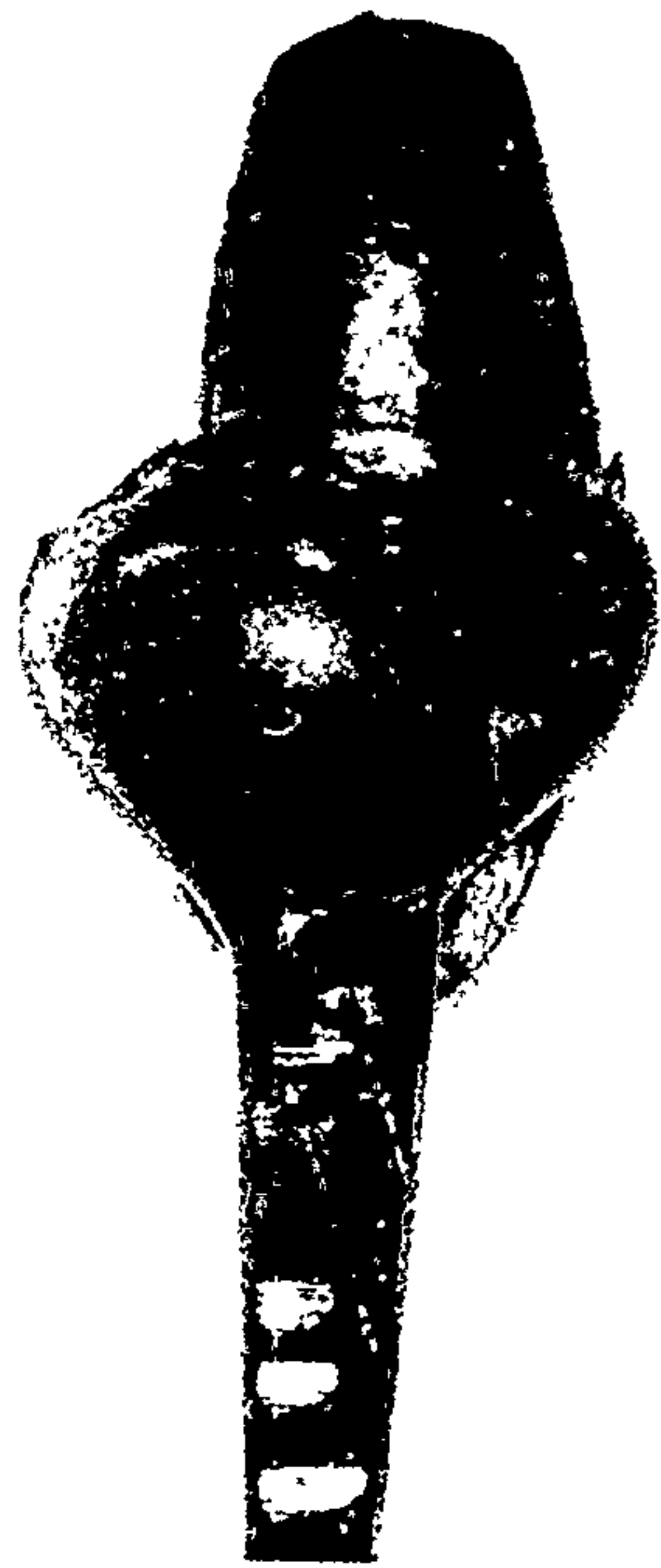
d



Figure 4 - Continued.

- (e) The crown is removed leaving the Impregum film chemically bonded to the Scutan.
- (f) Scutan is applied over the Impregum to give a completely embedded rubber impression of the cement space.

FIGURE 4(II)



e



f

b) Sectioning apparatus

A machine (Figure 5) was made for the sectioning of the specimens. It incorporated a travelling mounting with a one millimetre thread separation onto which was mounted a Kaltenbach* laboratory handpiece. A vice was designed to hold the specimens. Standard, double sided diamond discs proved unsatisfactory in obtaining a clean, non-burned section. However, if the discs were modified to provide large cutting teeth, suitable sections could be obtained. The most satisfactory instrument proved to be Dedeco NM "Slim"** discs. These are inflexible and thin, little heat is generated and a clean section is obtained. They proved satisfactory for sectioning all the materials used in the specimens including porcelain, gold alloy, zinc phosphate cement, Impregum and Scutan.

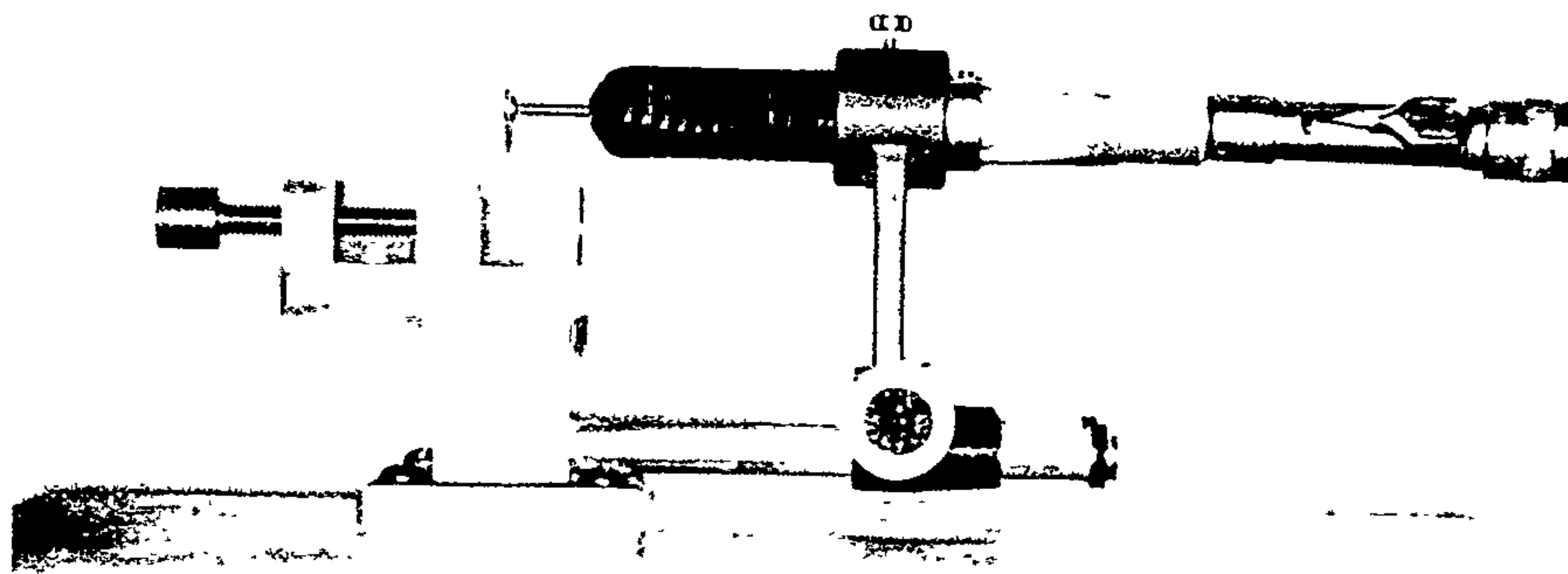
The four specimens - two embedded rubber replicas and two cemented crowns - were then orientated in the sectioning machine vice so that the sectioning disc entered the specimen perpendicular to its labial face and along its long axis. Two cuts were made approximately 0.5mm from the midline. Each cut resulted in the loss of about 1mm thickness of specimen. In this way, four cut surfaces, approximately one millimetre apart, were obtained from each specimen.

* Kaltenbach and Voigt, Biberach Co, West Germany.

** Dental Development and Mfg. Corp., Brooklyn, N.Y. U.S.A.

Figure 5 - Photograph showing a machine made for
 sectioning the embedded rubber impressions.

FIGURE 5



Each cut surface was prepared for microscopic examination by grinding on 220 grit and 600 grit (17 μ m) silicone carbide papers*.

Figure 6 shows one of the polished surfaces of a rubber replica section.

Results

The labial and lingual shoulder regions of two of the polished surfaces were measured in five different places, marked a,b,c,d,e, on Figure 1, with e being closest to the margin. Thus a total of twenty measurements were taken for each specimen. These were averaged to give a mean axial discrepancy of fit for each crown. (see Table 7 and Table 8).

Although a wide variation of measurements occurred within each specimen the mean values obtained were similar with both techniques.

For the refractory die crown a mean of 31 μ m was obtained by the direct sectioning technique. A mean of 35 μ m was obtained by the rubber replica technique.

For the platinum foil crown a mean of 92 μ m was obtained by the direct sectioning technique and 96 μ m was obtained by the rubber replica technique.

* 3M Manufacturing Co. Sydney, Australia.

Figure 6 - Photograph showing a typical polished
section ready for microscopic examination
(x 10)

FIGURE 6

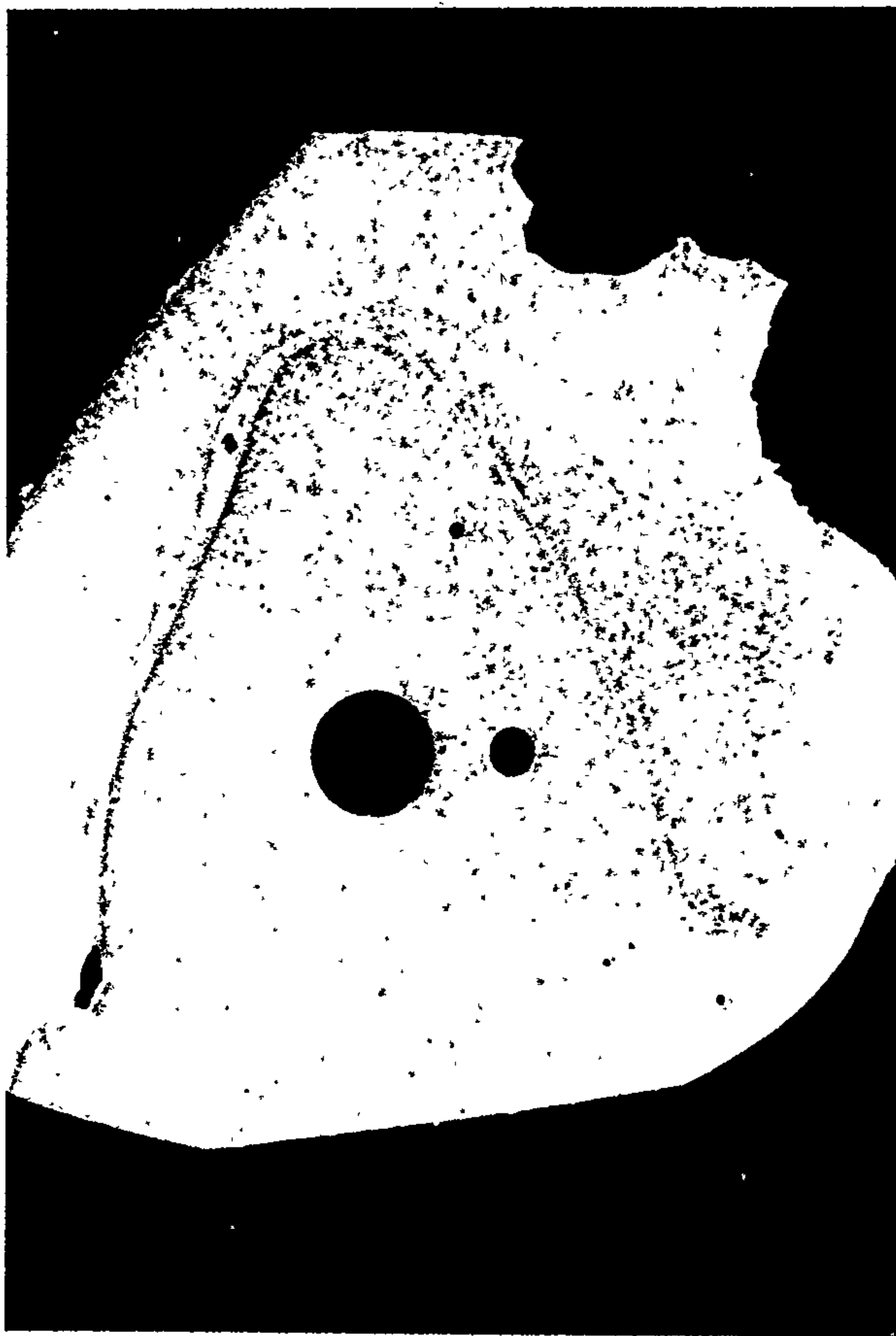


Table 7

Axial discrepancy in the shoulder region of "cemented"
 porcelain crowns using direct sectioning and
 rubber replica techniques.

Refractory Die Crown

Measurement Point	Direct Sectioning Technique				Rubber Replica Technique			
a	42	22	12	34	10	24	10	42
b	38	26	14	36	10	30	34	38
c	46	24	16	40	10	56	38	58
d	42	28	18	40	10	64	40	48
e	46	30	20	50	10	60	72	40
	Mean = 31 μ m S.D. = 11.8 μ m				Mean = 35 μ m S.D. = 21.3 μ m			

Table 8

Axial discrepancy in the shoulder region of "cemented"
 porcelain crowns using direct sectioning and
 rubber replica techniques.

Platinum foil crown

Measurement Point	Crown and Amalgam die sectioned (μm)				Impregum replica sectioned (μm)			
a	78	86	96	88	90	70	100	78
b	84	100	88	90	85	72	130	70
c	86	84	90	96	92	66	126	80
d	102	90	96	94	92	60	142	77
e	98	88	100	104	84	76	94	60
	Mean = 92 μm SD = 6.9 μm				Mean = 96 μm SD = 24.4 μm			

A "t" test applied to each set of figures indicated that there was no statistically significant difference between the direct sectioning and rubber replica techniques.

Discussion and Conclusion

A technique for accurately determining the axial discrepancy in the shoulder region of full veneer restorations at different stages of crown fabrication has been developed. The particular advantage of this technique over a direct sectioning technique is that the restorations are not destroyed during the process.

The findings of this section of the investigation indicated that there was no significant difference in axial discrepancy between the rubber replica technique and the more clinically orientated direct sectioning technique. The rubber replica technique could therefore be used in further investigating the "fit" in shoulder regions of cemented restorations.

Application Of The Method

An accurate technique for measuring the axial discrepancy in the shoulder region of cemented restorations has been established (see previous sections). This technique was then applied to examine and compare the axial discrepancies of cemented porcelain fused to metal restorations and porcelain jacket crowns fabricated by both the refractory die and platinum foil techniques.

a) The Porcelain Jacket Crown

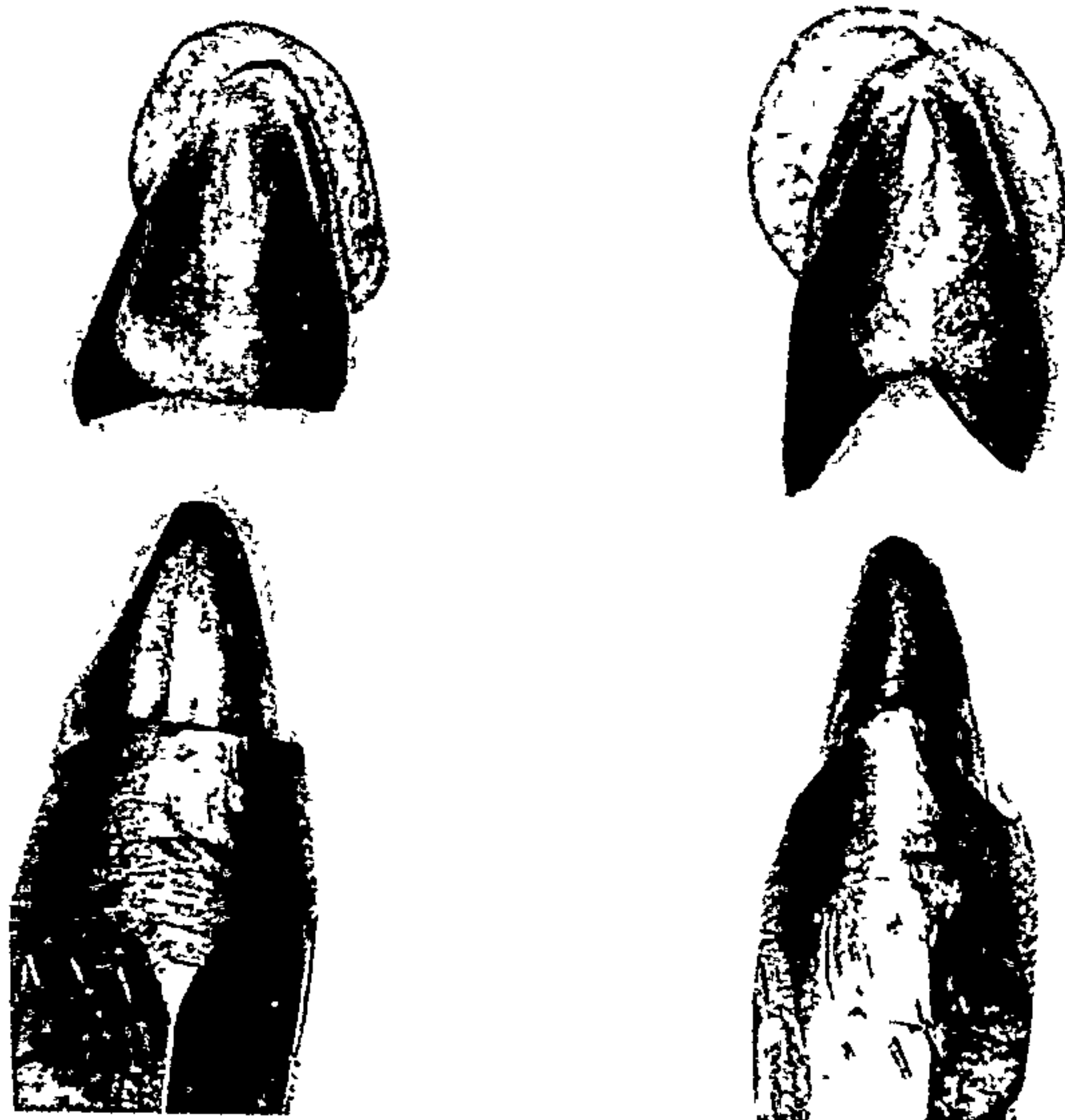
Two types of tooth preparation were employed. The first had a regular circular gingival contour resembling the open end of a cylinder. The gingival contour of the second was irregular with an extension or flange on the labial and lingual aspect of the preparation. Both preparations had a shoulder width of 1.0 - 1.5mm. In future discussion these preparations will be referred to as a cylindrical shoulder preparation and flanged shoulder preparation respectively. Thus a crown constructed on a cylindrical shoulder preparation would have a cylindrical gingival contour. A crown constructed on a flanged shoulder preparation would have a flanged gingival contour. It was considered that these preparations represented the two clinical extremes of gingival contour for anterior crowns. The preparations were cut in plastic replicas of upper central incisor teeth. Compound impressions were taken and ten amalgam master dies were made for each preparation.

Figure 7 - Photograph showing the two types of
gingival contour used in the tooth preparations.

The crown on the left has been fabricated
to fit a preparation with a "cylindrical"
gingival contour.

The crown on the right has been fabricated
to fit a preparation with a "flanged" gingival
contour.

FIGURE 7



During this portion of the investigation the behaviour of the refractory material was in accordance with the manufacturers specifications. No apparent aberrant or inconsistent behaviour occurred.

Traditional platinum foil porcelain jacket crowns were fabricated to fit five amalgam dies for each of the two types of tooth preparation. Crowns employing Southan's refractory die technique were fabricated to fit the ten remaining amalgam dies. In this way a total of twenty crowns were fabricated so that each crown fitted its own amalgam die.

The traditional platinum foil technique used was that currently being taught at the University of Sydney, involving a swaging of foil onto the die and a readaptation of the foil in the shoulder region after the first core firing. The tinner's joint was placed in the proximal region. The refractory die technique closely followed Southan's (1972) recommendations.

The crowns were then "cemented" onto their respective amalgam dies with Impregum. Polished vertical sections of embedded Impregum replicas of the "cemented" axial discrepancy were obtained for each crown by the technique described in a previous section.

Twenty measurements of the axial discrepancy in the labial and lingual shoulder regions were taken for each crown in the manner previously described.

It should be noted that the tinner's joint region of platinum foil crowns was not included in these sections. It was considered that although techniques are available for minimising the effect of the increased thickness of foil at the joint, as described in the literature review, they are difficult to perform and rarely performed (Southan, 1972). However some sections of discrepancy in the tinner's joint region were measured for discussion purposes.

Inconsistent behaviour of the investment was first observed in clinical crowns and appeared to relate to the time of a change in packaging of the material. Widespread observation of this behaviour was reported by many clinicians and technicians.

Metal thicknesses of the copings exceeded the manufacturers minimum specifications in all areas. Complete standardisation of thicknesses was not possible.

b) The Porcelain Fused To Metal Crown

Two tooth preparations again showing the extremes of gingival contour were employed. Both preparations involved a labial shoulder which narrowed interproximally to become a bevel at the lingual gingival finishing line.

The porcelain fused to metal system used was the Vita/Degudent V.M.K. system which has gained widespread acceptance in this country. The techniques used closely followed those recommended by the manufacturer with one major modification. Variable and uncontrollable expansion rates were encountered with the Deguvest* investment. As a result, Ceramigold** investment was used. This gave more satisfactory and consistent results and eliminated grinding of the internal surface of the metal copings.

Ten metal copings were waxed up, cast and prepared for porcelain application, except that the metal reservoir was retained (see Figure, 8) because it facilitated removal of the "cemented" coping from its die without distortion. The castings were visually examined for their marginal fit. All but one were considered by the author to be satisfactory castings on first attempt. The unsatisfactory casting was discarded and replaced.

The copings were then "cemented" onto their respective amalgam master dies with Impregum. Polished vertical sections of

* Degussa, C.B. Dental Division, Frankfurt, West Germany.

** Whip Mix Corp. Louisville, Kentucky. USA.

embedded Impregum replicas of the "cemented" axial discrepancy were obtained for each coping by the technique described in the previous section.

The metal reservoirs were then removed and the copings were oxidised and degassed and the porcelain was applied in three bakes, namely the opaque layer, the body layer and finally small discrepancies were rebuilt. The crowns were then contoured and glazed.

Each glazed crown was again "cemented" onto its respective amalgam die and embedded rubber impressions were obtained and sectioned.

In the case of porcelain fused to metal restorations concern about fit is related to possible distortion of the metal at the labial shoulder region as a result of fusion of the porcelain.

Therefore the labial region of the shoulder of the four polished surfaces for each crown were measured in the five different places as described in the previous section, again giving a total of twenty measurements for each "cemented" crown.

By taking such measurements before and after the application of porcelain the degree of distortion resulting from the fusing of the porcelain was able to be determined independent of other potential causes of distortion.

Figure 8 - Photograph showing a porcelain fused to metal casting ready for porcelain application but with the metal reservoir retained. This enables easy separation of the "cemented" casting and die.

FIGURE 8



C. The Clinical Acceptability Of The Fit Of The Fabricated Crowns

The twenty porcelain jackets and ten porcelain fused to metal restorations were assessed by six experienced clinicians for their clinical acceptability with regards to fit.

Each clinician was provided with a new dental probe and good light. They were asked to assess the crowns with regard to "fit" only. Factors such as overcontouring, poor form and uneven colour patterns were to be ignored.

The fit of each crown was assessed on a Yes/No basis for clinical acceptability and was also allocated one of four gradings - poor, fair, good or excellent. The porcelain jacket crowns were randomly arranged during assessment to prevent clinician bias between fabrication techniques.

RESULTS

Twenty measurements of the axial discrepancy in the shoulder region were taken for each crown. Sets of twenty measurements for two porcelain jacket crowns were presented as examples in a previous section (see Table, 7). The display of further results has been limited to a mean discrepancy and an indication of the range of discrepancy associated with that mean (see for example, Table 9).

A. The Porcelain Jacket Crowns

Table 9 shows the axial discrepancies at the shoulder region of crowns fabricated using the platinum foil technique on cylindrical shoulder preparations. A wide variation of both means and ranges was observed. The overall mean discrepancy for the 100 measurements was 63.5 μ m. The wide variation in discrepancies was reflected in Table 9 and indicated a minimum discrepancy of 10 μ m and a maximum of 174 μ m. There was a tendency for decreasing Impregum thicknesses as measurements were taken further away from the internal cervical line angle, although a second increase in thickness was often observed near the external cervical margin (see Figure 10).

Table 9

Axial discrepancies at the shoulder region of crowns employing the platinum foil technique and cylindrical shoulder preparations.

Crown	Mean	Range
	μm	
1F	41	18-59
2F	87	60-142
3F	24	14-50
4F	111	74-174
5F	54	10-130
	Overall mean = 63.5 μm	

Table 10 shows the results obtained for the axial discrepancies in the shoulder region of crowns fabricated using the platinum foil technique on flanged shoulder preparations. Again there was a wide variation in means and ranges. The overall mean discrepancy for the five crowns was $48\mu\text{m}$. The range of discrepancies for the 100 measurements was between 14 and $120\mu\text{m}$.

Table 10

Axial discrepancies at the shoulder region of crowns employing the platinum foil technique and flanged shoulder preparations.

Crown	Mean (μm)	Range
6F	49	26-98
7F	45	28-68
8F	67	30-120
9F	33	14-58
10F	50	36-64
	Overall mean = $48\mu\text{m}$	

Table 11 shows the axial discrepancies at the shoulder region of crowns fabricated using the refractory die technique on cylindrical shoulder preparations. Again there is a wide variation of both means and ranges. The overall mean discrepancy for the five crowns was 55.5 μ m. The range of discrepancies in the 100 measurements was between 30 and 120 μ m.

Table 11

Axial discrepancies at the shoulder region of crowns employing a refractory die technique and cylindrical shoulder preparations.

Crown	Mean μm	Range
1R	40	32-54
2R	36	22-46
3R	80	62-96
4R	66	40-86
5R	56	30-120
	Overall mean = 55.5	

Table 12 shows the axial discrepancies at the shoulder region of crowns fabricated using the refractory die technique and flanged shoulder preparations. The overall mean discrepancy for the five crowns was 46 μ m. The range of discrepancies in the 100 measurements was between 10 and 110 μ m.

There was a more consistent reading of Impregum thicknesses across a given shoulder region with these refractory die crowns than with the platinum foil crowns irrespective of the gingival contour. A marked increase in thickness at either the internal or external cervical margin was rarely observed. Occasionally what appeared to represent a bubble in the porcelain was detected in the shoulder region. (see Figure 12)

It was observed that for the refractory die crowns with flanged gingival contours there was often a wide difference in measurements of the labial and lingual shoulder region within the one crown.

Table 12

Axial discrepancies at the shoulder region of crowns employing the refractory die technique and flanged shoulder preparations.

Crown	Mean μm	Range
6R	46	30-78
7R	35	10-72
8R	36	10-84
9R	52	24-110
10R	61	44-88
	Overall mean = 46	

Table 13 shows the measurements of the labial and lingual shoulder region of one polished surface for two such crowns. Crown A showed a mean of $25\mu\text{m}$ on the labial shoulder region of the polished surface and $74\mu\text{m}$ on the lingual shoulder region. Crown B showed a mean of $100\mu\text{m}$ on the labial shoulder region and $38\mu\text{m}$ on the lingual shoulder region.

Table 13

Measurements of the labial and lingual shoulder
region of one polished surface for two refractory
die crowns with flanged gingival contours.
(all measurements are in microns)

Crown A		Crown B	
labial	lingual	labial	lingual
24	70	96	42
26	84	100	44
22	72	98	36
30	78	110	26
24	68	86	40
mean=25	mean=74	mean=100	mean=38

Table 14 summarises the overall means of the axial discrepancies of the four groups presented earlier. The cylindrical shoulder preparations had a mean measurement of $63\mu\text{m}$ for the platinum foil technique and $55\mu\text{m}$ for the refractory die technique. The flanged shoulder preparations had a mean measurement of $49\mu\text{m}$ for the platinum foil technique and $46\mu\text{m}$ for the refractory die technique. Because of the wide range of results obtained these relatively small differences of means were considered statistically insignificant.

Table 14

Summary of overall means of axial discrepancies
in the shoulder region.

PREPARATION	TECHNIQUE	
	Platinum foil	Refractory Die
a) Cylindrical Shoulder Preparations	63 μ m	55 μ m
b) Flanged Shoulder Preparations	49 μ m	46 μ m

Table 15 compares average discrepancies at several different areas for two cemented crowns with cylindrical shoulder regions. The labial and lingual axial wall areas had relatively small discrepancies or cement thicknesses for the platinum foil crown. On the other hand the same crown exhibited relatively large discrepancies in other areas. The tinner's joint at the shoulder showed a discrepancy of $141\mu\text{m}$, an increase of $83\mu\text{m}$ on the average discrepancy of the surrounding shoulder area, while the discrepancy of $104\mu\text{m}$ along the mesial wall at joint location compared to discrepancies of $21\mu\text{m}$ and $26\mu\text{m}$ along the labial and lingual walls respectively. The refractory die crown exhibited a more even discrepancy in the different regions measured. The mean shoulder discrepancy was $54\mu\text{m}$ and the labial and lingual walls had discrepancies of $69\mu\text{m}$ and $77\mu\text{m}$ respectively.

A diagram of a typical Impregum replica of the cement space beneath a porcelain jacket crown fabricated by the platinum foil technique can be seen in Figure 9. Several photomicrographs of the shoulder regions of these crowns can be seen in Figure 10.

A diagram of a typical Impregum replica of the cement space beneath a porcelain jacket crown fabricated by the refractory die technique can be seen in Figure 11. Several photomicrographs of the shoulder regions of these crowns can be seen in Figure 12.

Table 15

Average discrepancies of two crowns
at several different regions.

Region measured	Technique	
	Platinum foil	Refractory die
Shoulder	58	54
Tinner's joint		
a) at the shoulder	141	-
b) along the axial wall	104	-
c) at the incisal edge	200	-
Labial wall	21	69
Lingual wall	26	77

Figure 9 - Diagram illustrating the typical contour of the cement space beneath a platinum foil crown.

 Note the relatively large discrepancies at the incisal area and the internal line angle of the shoulder area compared to the small discrepancies along the axial walls.

FIGURE 9

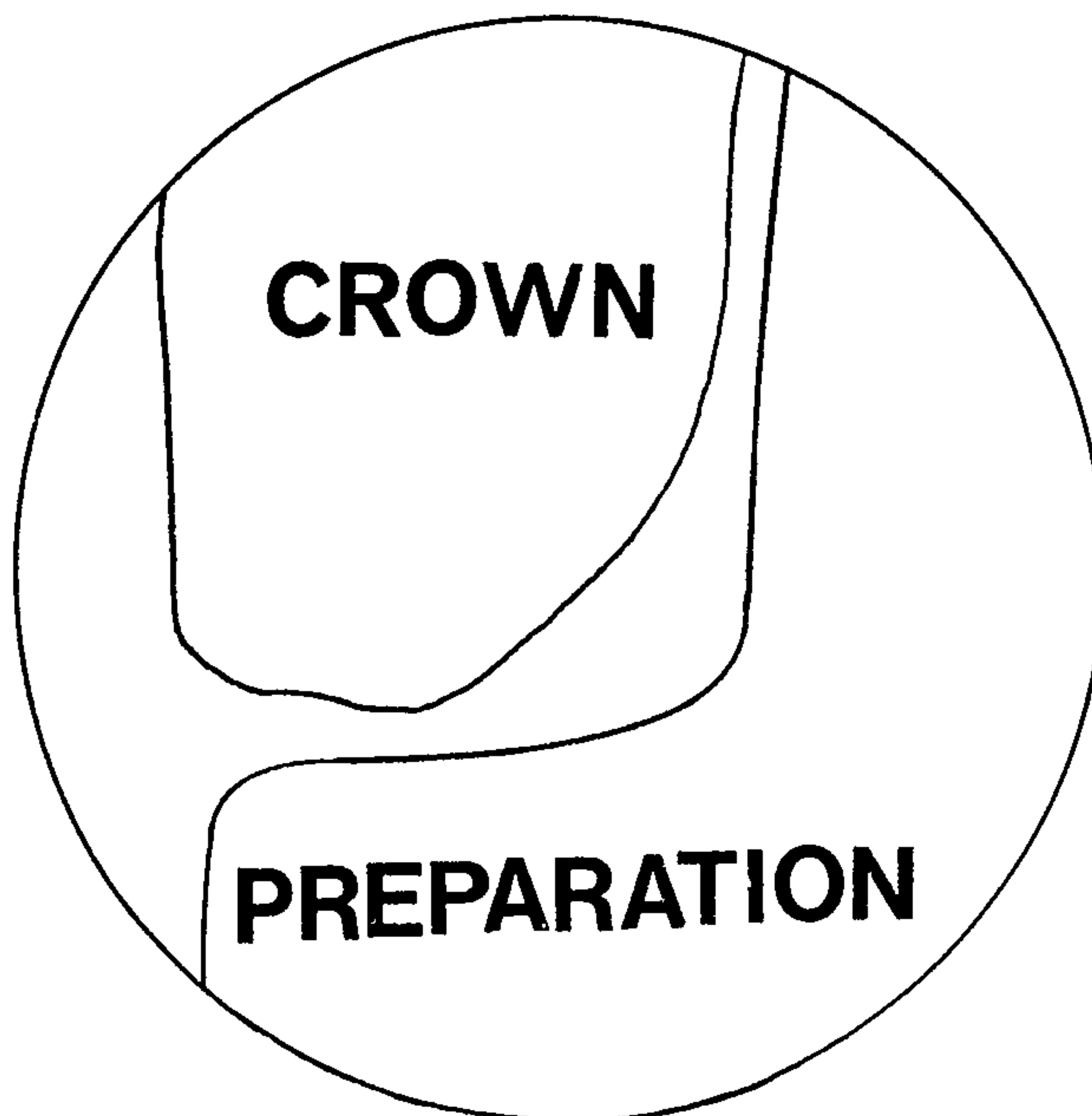
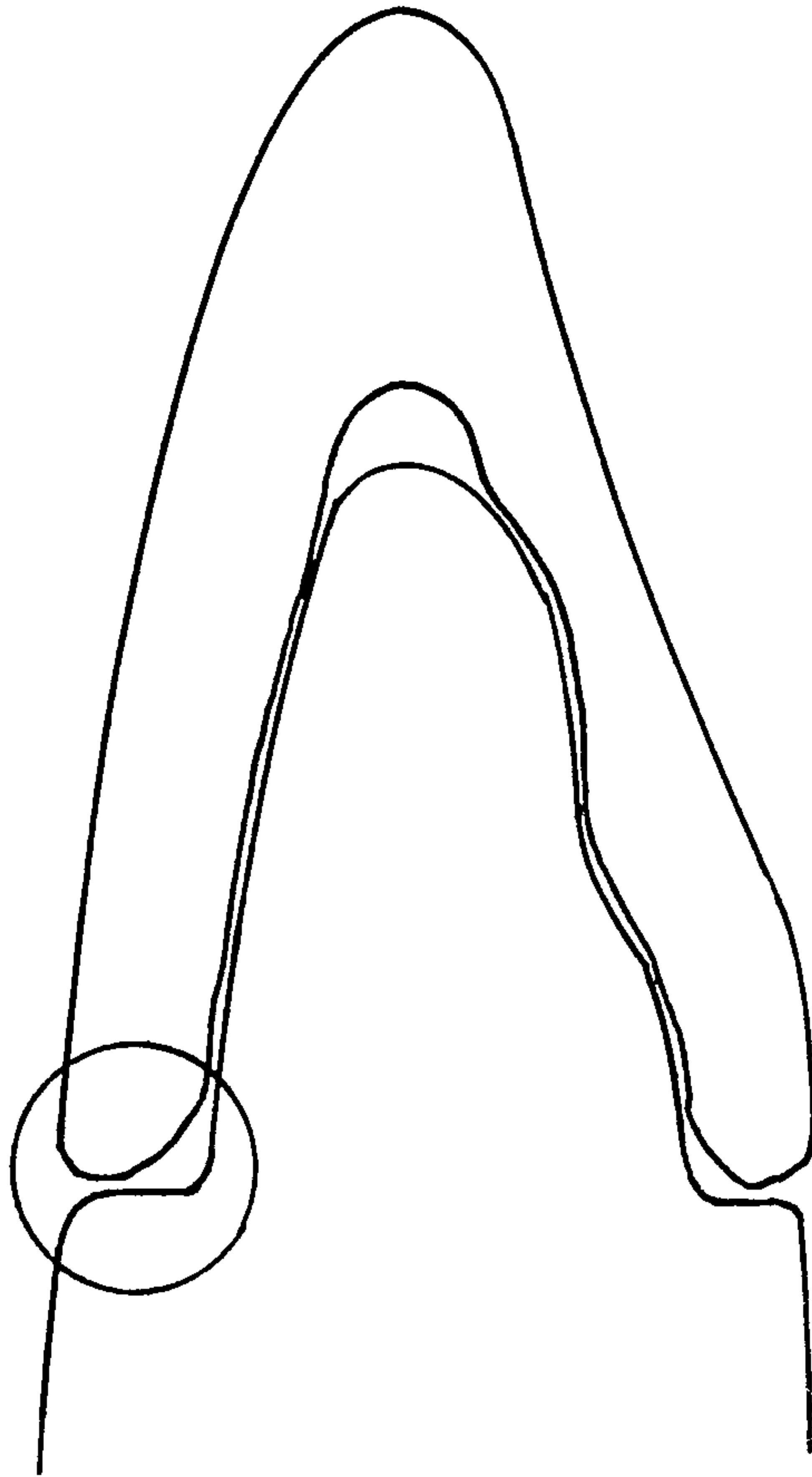


Figure 10 - Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of platinum foil porcelain jacket crowns.

Photomicrographs a,b,d show typical rounded internal line angles indicative of the foil being pulled away from this region. The marginal discrepancies however show little distortion and indicate a successful readaptation of the foil to the shoulder of the preparation in that region after the first core firing.

Photomicrograph c shows a region that was not reburnished after the first core firing. The marginal discrepancy is relatively large.

FIGURE 10

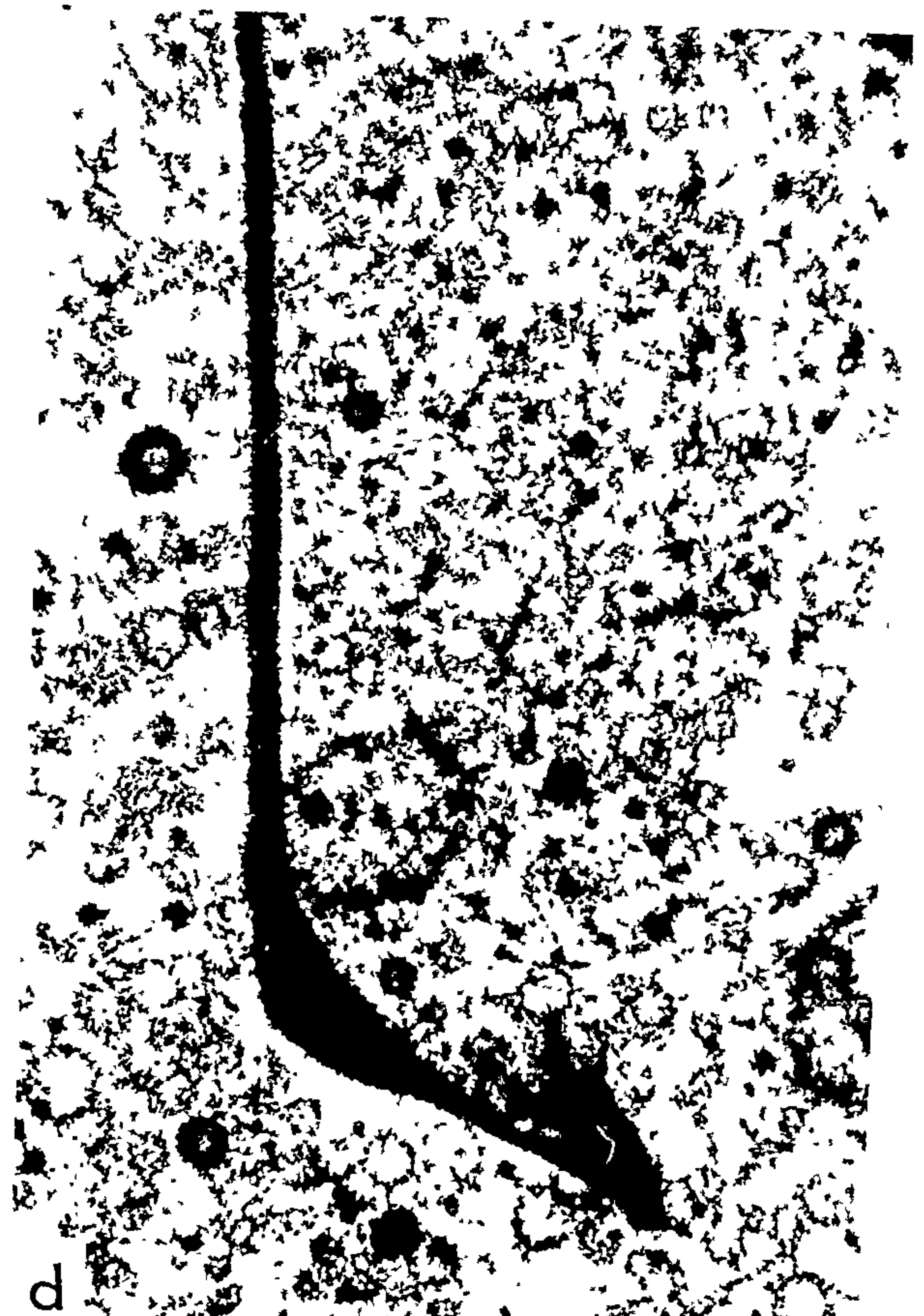
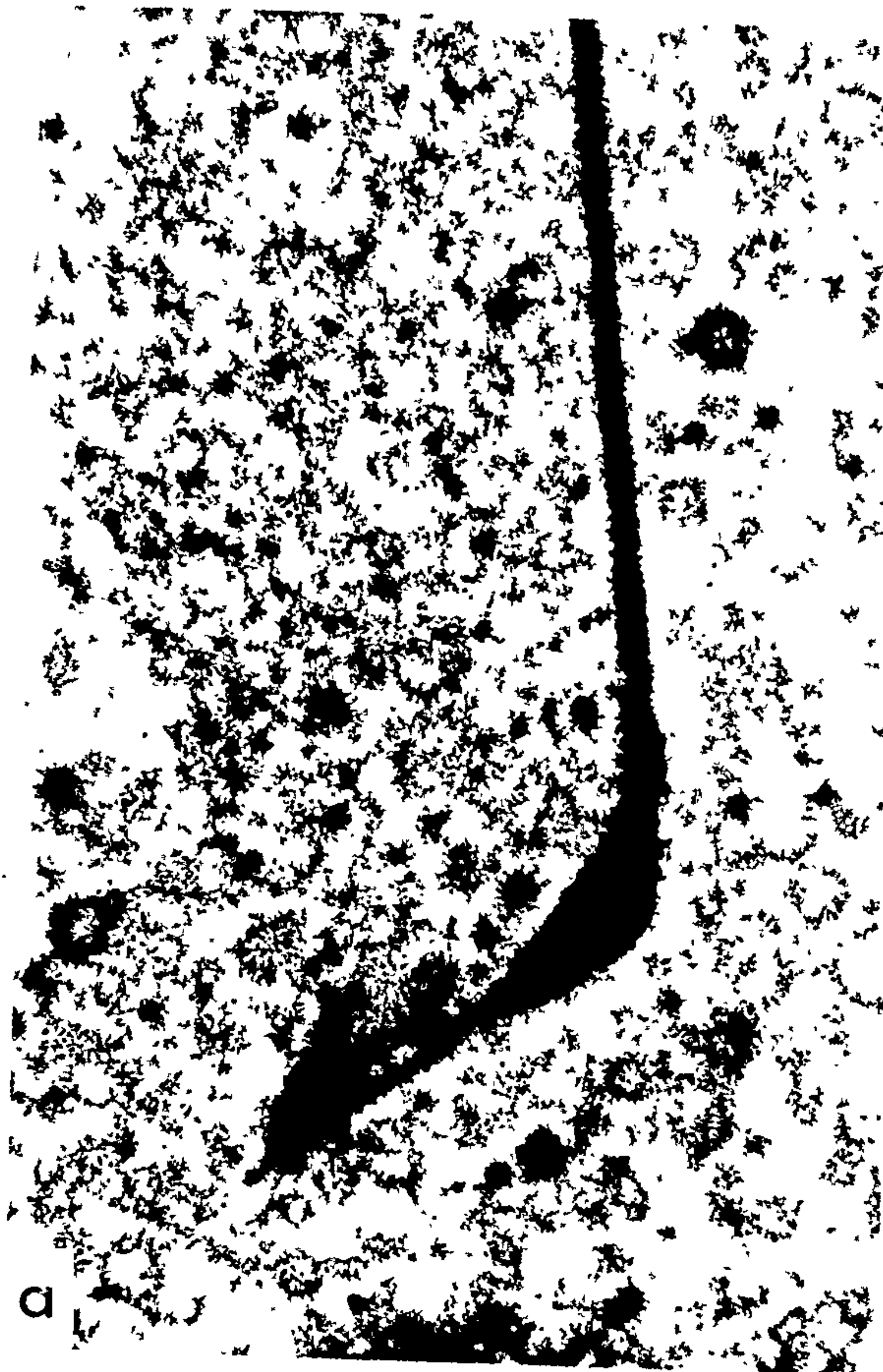


Figure 11 - Diagram illustrating the typical contour of the cement space beneath a refractory die porcelain jacket crown.

The overall cement space is more uniform relative to that observed for the platinum foil crowns although there are some small irregularities especially in the shoulder region indicative of a rough internal surface of the crowns.

FIGURE 11

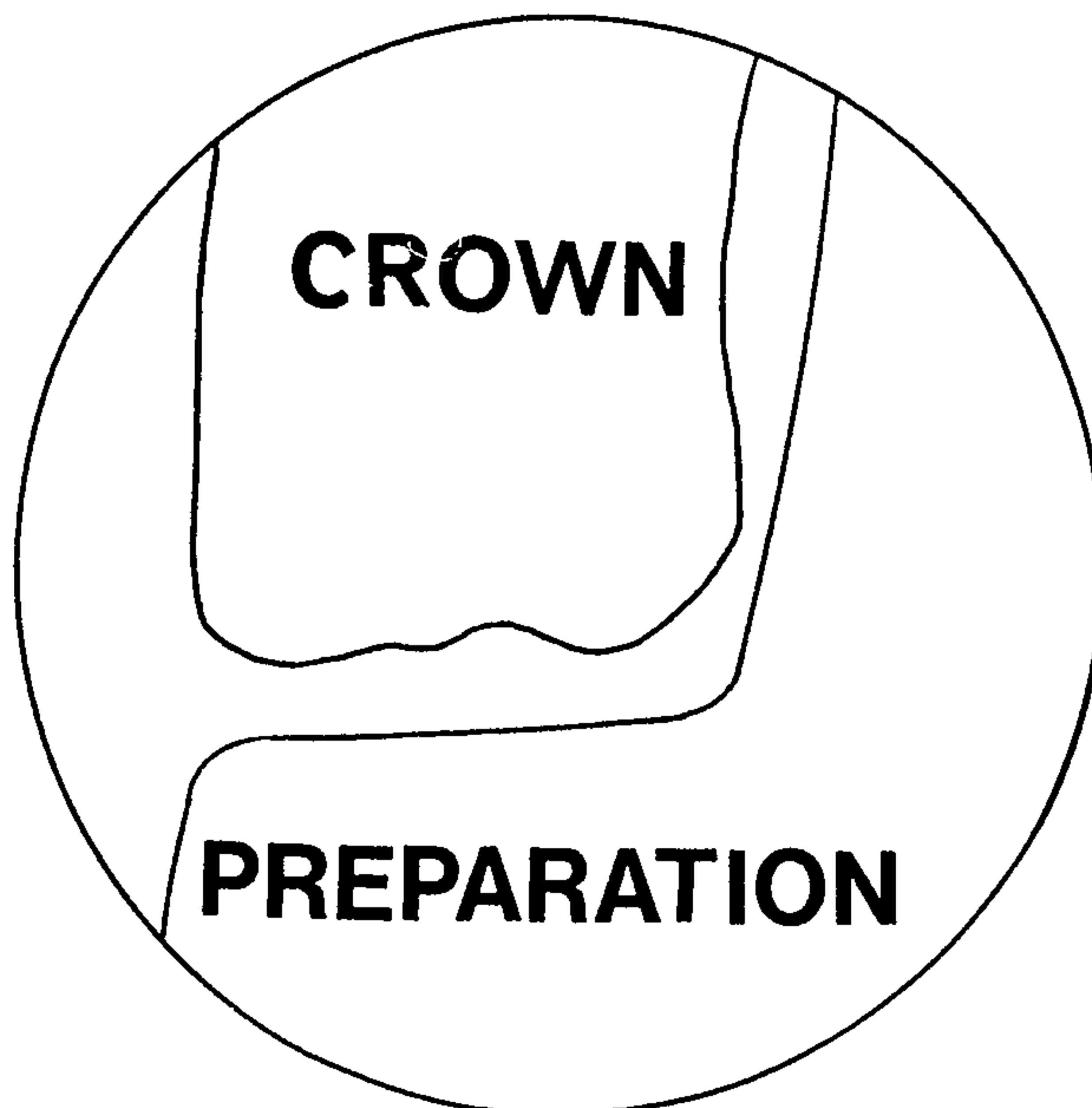
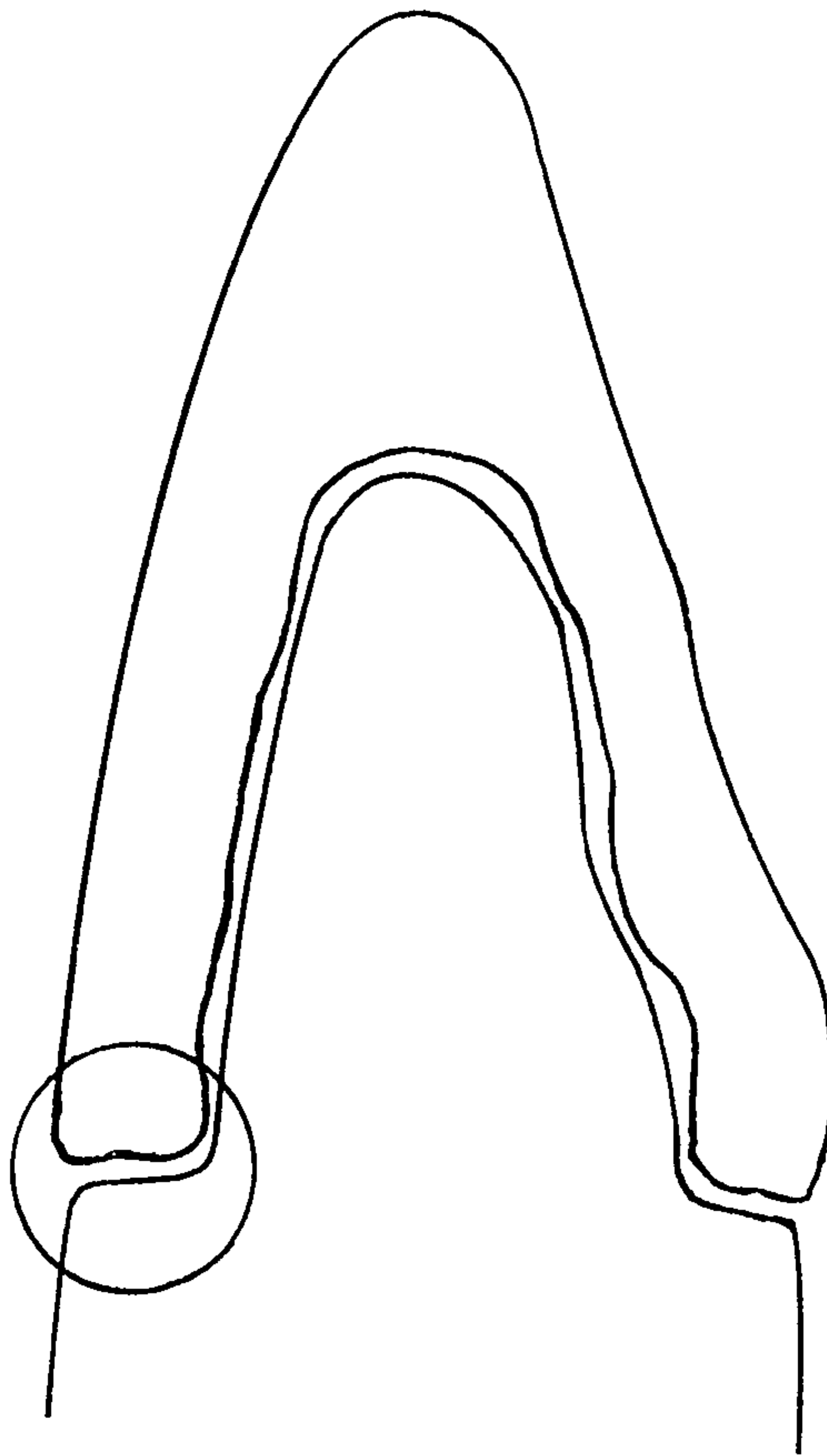
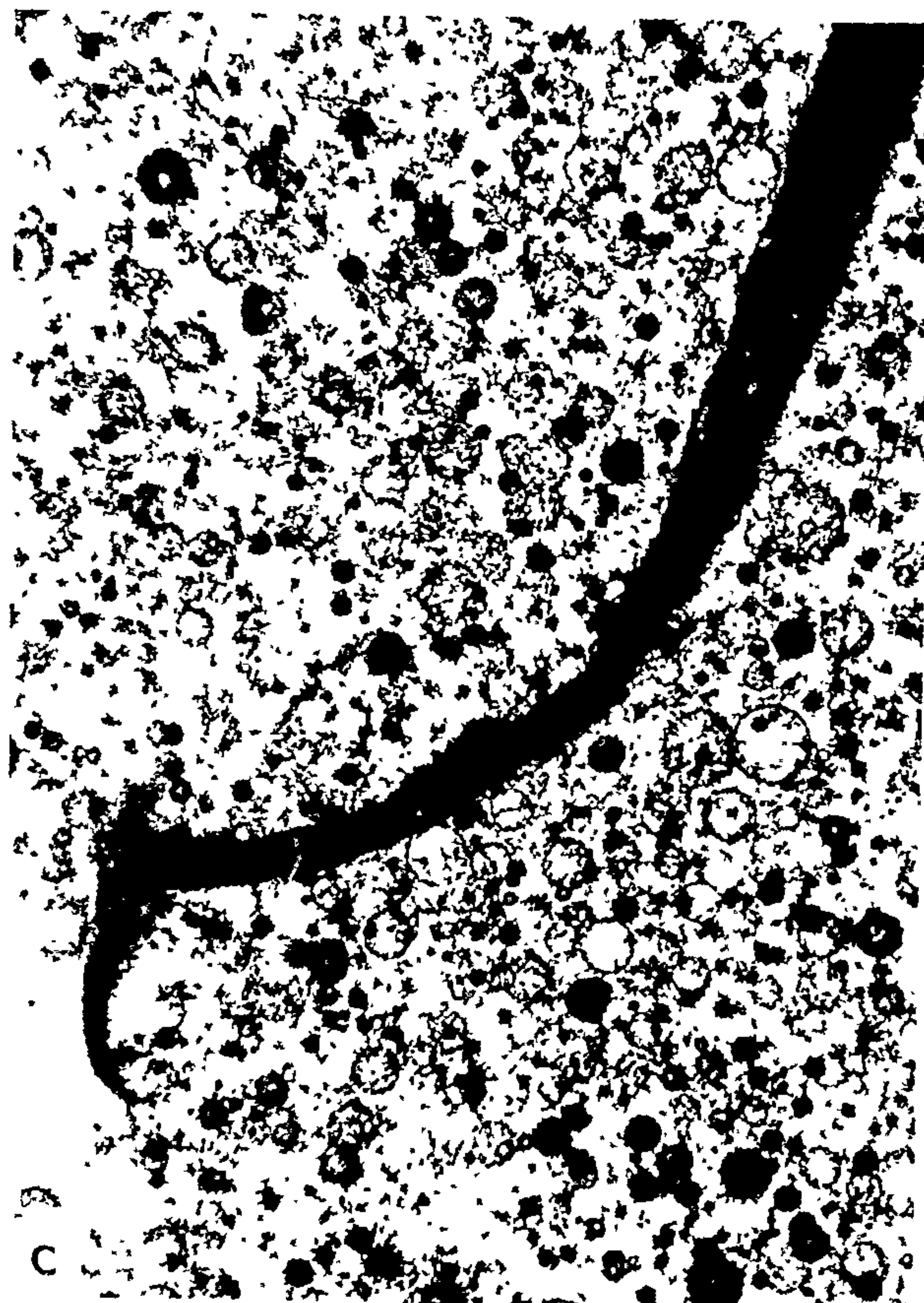


Figure 12 - Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of refractory die porcelain jacket crowns.

Note the more uniform width of the cement space compared to the platinum foil sections and the small irregularities corresponding to the rough internal surface of the crowns especially in the shoulder region.

Photomicrographs a and b show small bubbles opening onto the internal surface of the crowns.

FIGURE 12



B. The Porcelain Fused To Gold Crowns

Sets of twenty measurements were obtained for each crown before and after the firing of the porcelain. Strictly speaking the metal coping to which the porcelain is fused is not a crown but for the purposes of this discussion it is referred to as a crown before porcelain application.

Table 16 shows the twenty measurements for the axial discrepancy of the labial shoulder region for a cylindrically contoured preparation (1C) before fusing the porcelain. It was observed that there was a limited range (12-32 μ m) and low mean value (21.0 μ m) indicative of a well fitting, smooth and even casting.

Table 16

Axial discrepancy measurements of the labial shoulder
region of crown 1C before porcelain application
(μm)

Section	a	30	Section III	a	12
	b	20		b	16
	c	26		c	16
	d	26		d	14
	e	32		e	20
Section II	a	16	Section IV	a	24
	b	20		b	24
	c	20		c	28
	d	24		d	16
	e	14		e	22
Mean value = 21.0μm					
Range = 12-32μm					

Table 17 shows the twenty measurements of the labial axial discrepancy of the crown after fusing the porcelain. Again, the range was small (38-46 μ m) but the mean value (41.7 μ m) was greater by an amount that was statistically significant at the 97% confidence level.

Table 17

Axial discrepancy measurements of the labial shoulder
region of crown 1C after porcelain application.

(μm)

Section I	a	42	Section III	a	40
	b	44		b	40
	c	44		c	38
	d	46		d	42
	e	40		e	42
Section II	a	38		a	46
	b	44		b	44
	c	46		c	40
	d	38		d	40
	e	42		e	38
Mean value = 41.7					
Range = 38-46					

Table 18 shows the overall mean values of the axial discrepancies at the labial shoulder region of specimens with cylindrical shoulder regions or gingival contours before and after fusing the porcelain. Before porcelain application the mean discrepancy of fifty measurements was $36\mu\text{m}$. After fusing the porcelain, the mean discrepancy was $57\mu\text{m}$. There was, therefore an average opening, due to fusing of the porcelain, of $21\mu\text{m}$, or in other words, a 71% increase in axial discrepancy related to fusing of the porcelain.

Table 18

Axial discrepancies at the labial shoulder region
of crowns with a cylindrical gingival contour

(μm)

Crown	Before Porcelain Application	After Porcelain Application	Opening	% Increase
1C	21	42	21	100
2C	53	70	17	32
3C	42	53	11	26
4C	24	57	33	137.5
5C	41	65	24	58.5
OVERALL	36 μm	57 μm	21 μm	71%

Table 19 shows the overall mean values of the axial discrepancies at the labial shoulder region of specimens with flanged shoulder regions or gingival contours both before and after the porcelain was fused. Before fusing the porcelain the mean axial discrepancy was $32\mu\text{m}$ for the fifty measurements. After fusing the porcelain the mean axial discrepancy was $43\mu\text{m}$ for the fifty measurements. The average increase in discrepancy was $11\mu\text{m}$ or 69%.

As seen in Table 19 the influence of fusing the porcelain on the axial discrepancy was irregular. In one case a negative opening of 18% was observed. In another case no opening was observed and yet another case showed an opening of 225%.

Table 19

Axial discrepancy at the labial shoulder region of crowns with a flanged gingival contour.

(μm)

Crown	Before Porcelain Application	After Porcelain Application	Opening	% Increase
6F	46	46	0	0%
7F	19	31	12	63%
8F	23	40	17	74%
9F	55	45	-10	-18%
10F	16	52	36	225%
Overall Mean	32	43	11	69%

Table 20 shows an overall comparison of the axial discrepancies at the labial shoulder region of cylindrical and flanged gingivally contoured porcelain fused to metal crowns. Even though the flanged crowns exhibited an irregular opening pattern, the overall percentage increase in axial discrepancy before and after fusing the porcelain of 69% was similar to the 71% exhibited by the cylindrical crowns.

The distortions observed for both crown types were consistent across the shoulder and extended up the internal labial surface of the restoration.

A diagram of a typical Impregum replica of the cement space beneath a porcelain fused to metal crown is seen in Figure 13. Several photographs of the shoulder regions of these crowns can be seen in Figure 14.

Table 20

An overall comparison of the axial discrepancies at the labial shoulder region of cylindrical and flanged porcelain fused to metal crowns.

(μm)

Crown Contour	Before Porcelain Application	After Porcelain Application	Opening	% Increase
cylindrical	36	57	21	70%
flanged	32	43	11	69%

Figure 13 - Diagram illustrating the typical contour
of the cement space beneath a porcelain fused
to metal crown.

The overall cement space is uniform.

There is some distortion of the metal in the
shoulder region when the porcelain is fused.

FIGURE 13

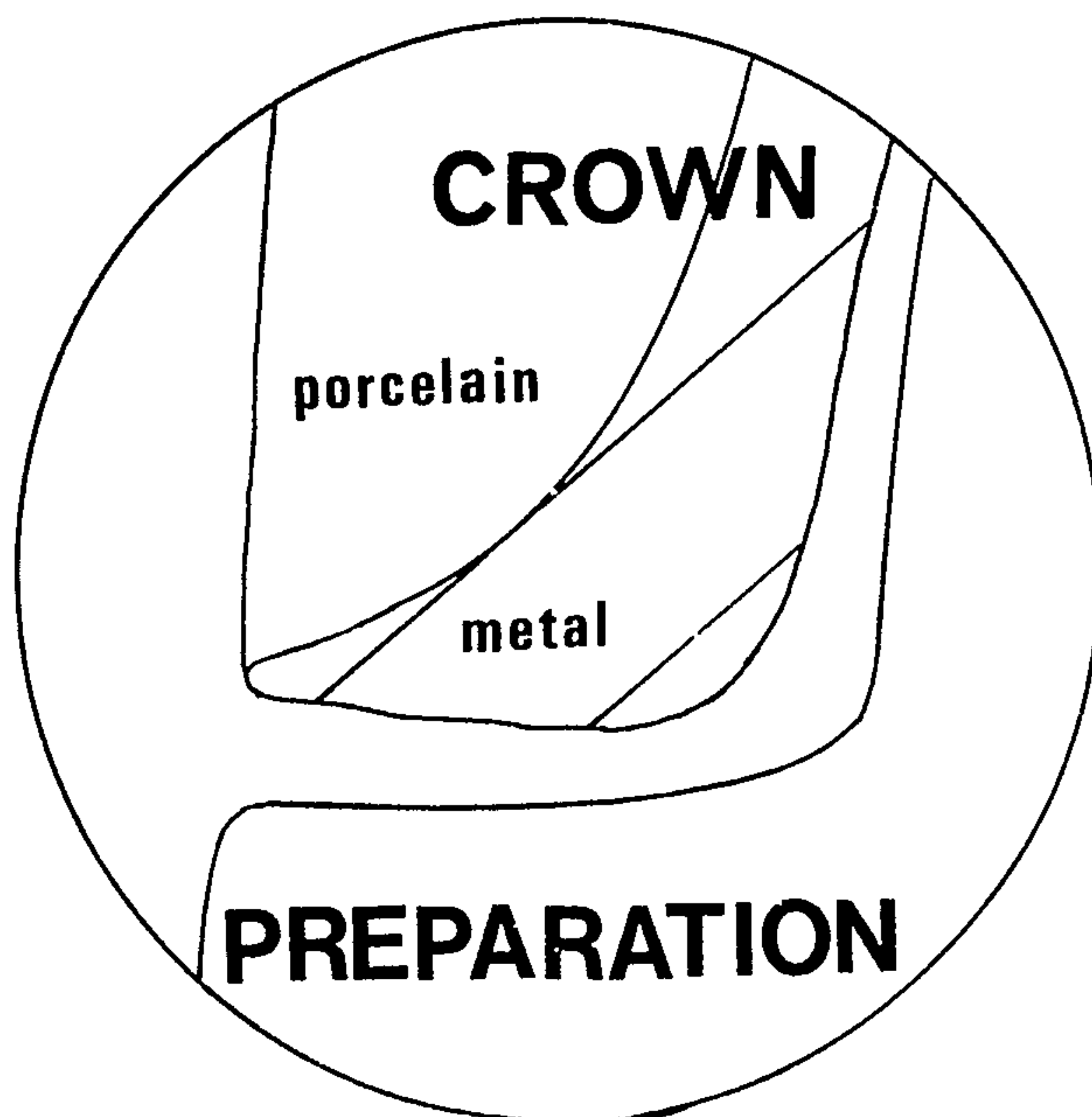
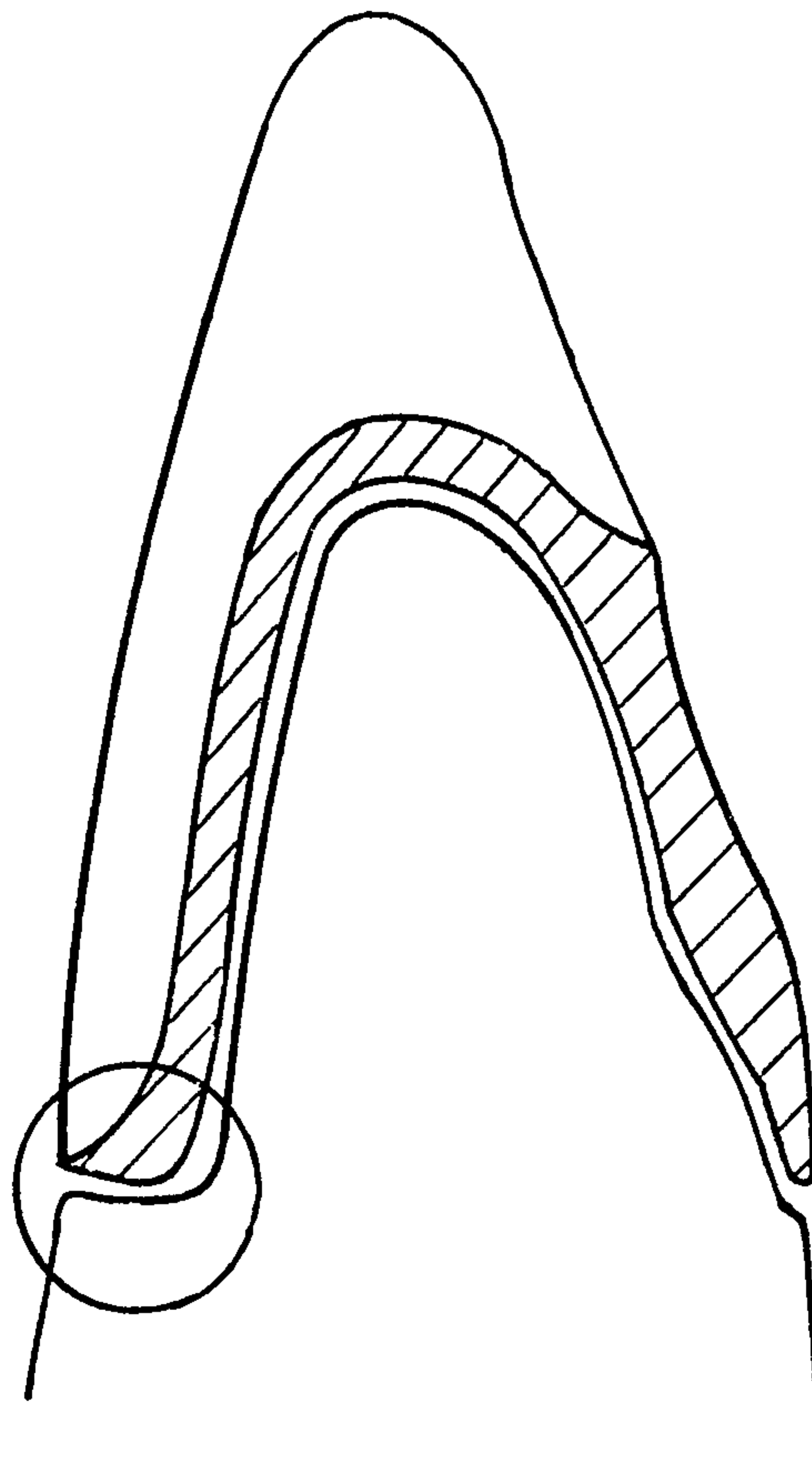


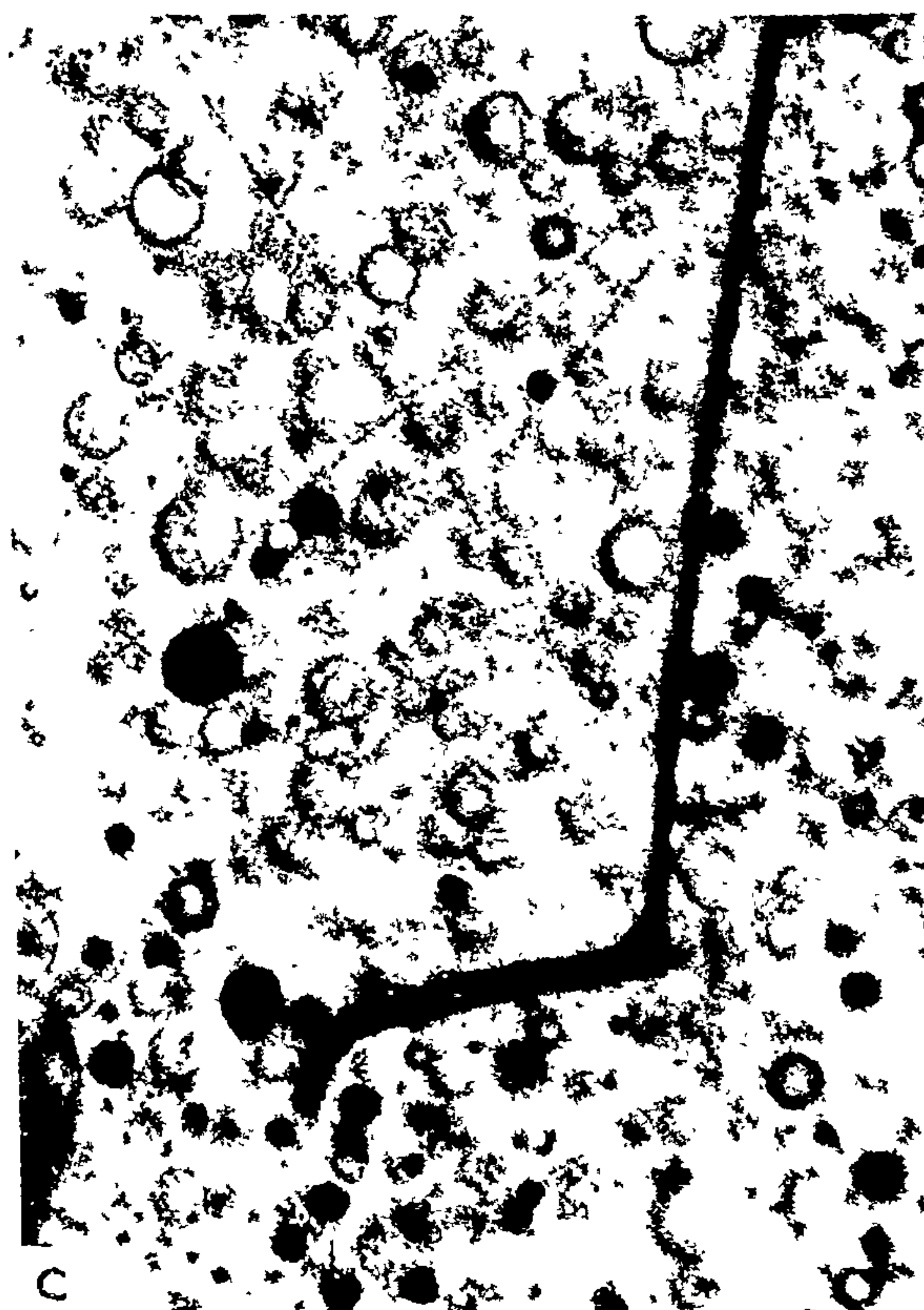
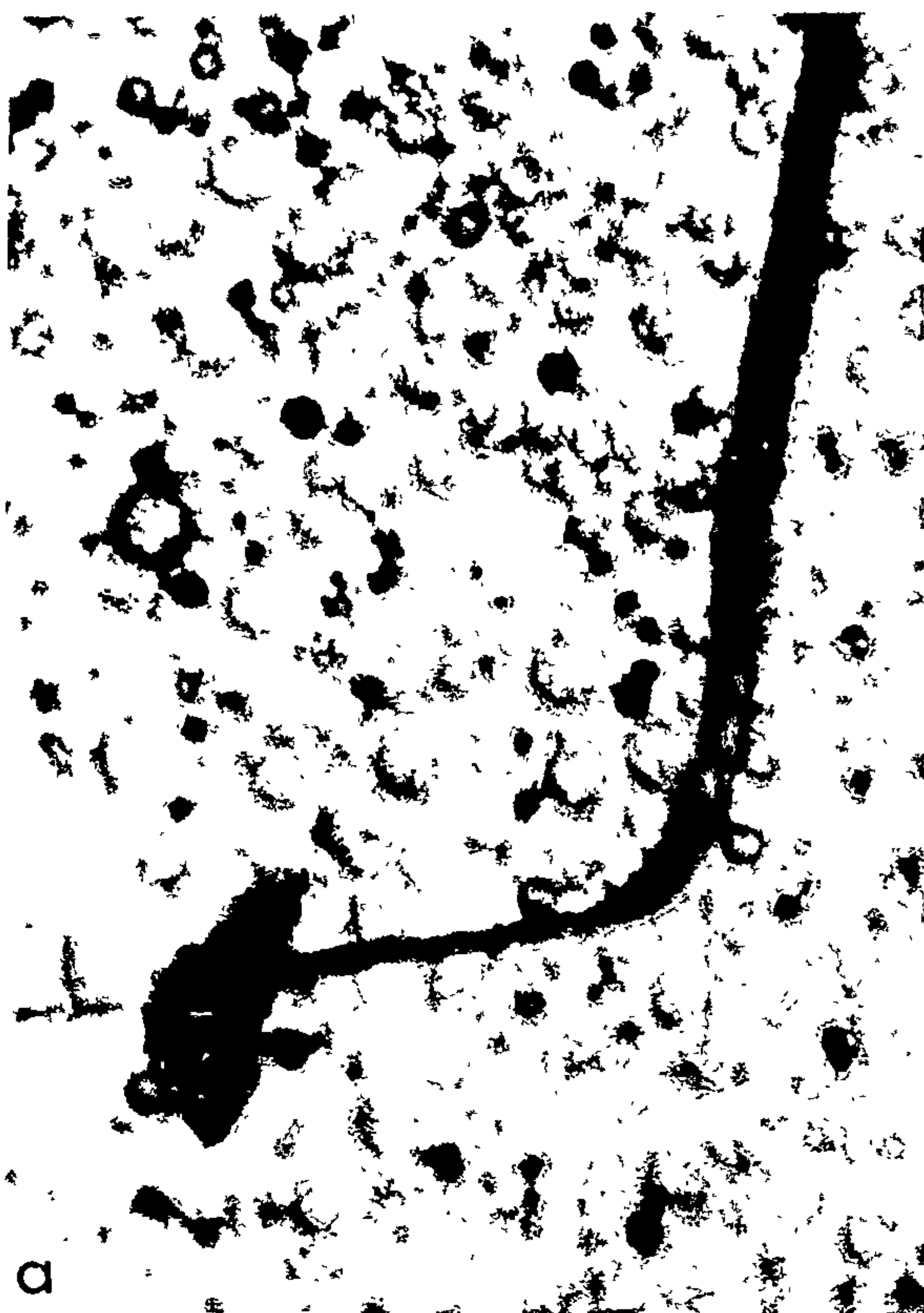
Figure 14 - Several photomicrographs of the rubber impressions of the cement space at the shoulder regions of porcelain fused to metal crowns.

Note the smooth surfaces of the Impregum corresponding to the smooth internal surfaces of the metal and the relatively sharp internal line angles of the shoulder regions.

Photographs a and d are of sections of two different crowns after porcelain application.

Photographs b and c are of sections of the same crown; b before porcelain application and c after porcelain application.

FIGURE 14



C. A Comparison Of The Axial Discrepancies Of Porcelain
Jacket And Porcelain Fused To Metal Restorations.

Table 21 compares the results obtained for the porcelain jacket crowns and porcelain fused to metal crowns. Although the ranges were wide the overall mean values obtained for the cylindrical and flanged crowns were similar for the three techniques. There was, however, a noticeable trend in each case for the discrepancy to be between 11 and 14 μ m less for flanged contoured crowns than for cylindrically contoured crowns. The platinum foil crowns exhibited the most variance while the porcelain-metal crowns exhibited the least variance.

Table 21

Comparison of overall means of axial discrepancies at the shoulder region of porcelain jacket and porcelain fused to metal crowns.
(μm)

Technique	Gingival Contour		Overall	Range
	Cylindrical	Flanged		
P.J.C. (Platinum foil)	63 μm	49 μm	56	33-111
P.J.C. (Refractory die)	55 μm	46 μm	51	35-80
V.M.K.	57 μm	43 μm	50	42-70

D. The Clinical Acceptability Of The Fabricated Crowns.

Table 22 has summarized the clinical assessment of the fabricated full veneer crowns. Each clinician's vote was accorded equal value. Scores of three or more votes were taken as median scores or gradings.

The porcelain fused to metal crowns received consistently more favourable gradings than the porcelain jacket crowns. Eight porcelain fused to metal crowns received excellent gradings while only two refractory die and three platinum foil crowns received excellent gradings. The other two porcelain fused to metal crowns received good gradings. Five refractory die and four platinum foil crowns received good gradings. Three refractory die and platinum foil crowns received fair gradings.

No porcelain fused to metal crown was considered to be clinically unacceptable by three or more clinicians. Two platinum foil and one refractory die crowns were considered clinically unacceptable. In only one assessment, that for a refractory die crown, did the grade given by any one clinician differ by more than one grade from the median. In three cases a split 3-3 vote was recorded. In these cases the median vote was considered the most favourable grading.

Table 22

Clinical assessment of full veneer crowns
by six experienced clinicians.

Technique	Median Grading				Not Clinically Acceptable
	Poor	Fair	Good	Excellent	
Platinum Foil	-	3	4	3	2
Refractory Die	-	3	5	2	1
V.M.K.	-	-	2	8	-

Table 23 shows the mean axial discrepancies in the shoulder region of crowns that were considered clinically unacceptable by three or more clinicians. Only crowns exhibiting mean axial discrepancies above 80 μ m in the shoulder region were considered unacceptable.

Table 23

Mean marginal discrepancies of crowns considered
clinically unacceptable by one or more clinicians

Crown	Votes	Mean (μm)
2F	3	87
4F	1	111
3R	4	80

E. A COMPARISON OF THE MARGINAL DISCREPANCIES
OF THE PORCELAIN JACKET AND PORCELAIN FUSED
TO METAL CROWNS

In this investigation the marginal or gingival discrepancy corresponds closely to the e values measured (see Figure, 1).

Table 24 shows the mean of four e values for the thirty crowns measured. The overall average marginal discrepancy for the platinum foil porcelain jacket crowns was $43\mu\text{m}$ (range $14\text{--}94\mu\text{m}$). The overall value for the refractory die porcelain jacket crowns was $51\mu\text{m}$ (range $10\text{--}86\mu\text{m}$). The overall value for the porcelain fused to metal crowns was $47\mu\text{m}$ (range $10\text{--}92\mu\text{m}$). There was a wide range in each of the three techniques studied. A trend for the overall mean of the platinum foil porcelain jacket crowns to have a lower mean of e values than the other two techniques was observed. Because of the wide range of values this was not significant.

Table 24

A comparison of the mean "e" values of the crowns corresponding
to their marginal discrepancy

(μm)

Crown	Technique		
	Platinum foil	Refractory die	Porcelain fused to metal
1	38	38	75
2	79	39	56
3	20	78	54
4	79	62	64
5	21	51	42
6	33	50	21
7	38	37	24
8	50	36	40
9	25	52	41
10	45	65	52
	Overall mean=43	Overall mean=51	Overall mean=47
	Range=14-94	Range=10-86	Range=10-92

Table 25 compares the overall means of the axial and marginal discrepancies at the shoulder region for the three fabrication techniques. The refractory die crowns exhibited values of $51\mu\text{m}$ for both the axial and marginal discrepancies. The porcelain fused to metal crowns exhibited values of $50\mu\text{m}$ and $47\mu\text{m}$ respectively. The platinum foil crowns exhibited values of $56\mu\text{m}$ and $43\mu\text{m}$ respectively, indicating a significant difference between the two values.

Table 25

Comparison of the overall means of the axial
and marginal discrepancies of the crowns
in the shoulder region.

(μm)

Technique	Axial Discrepancy	Marginal Discrepancy
P.J.C. (Platinum foil)	56	43
P.J.C. (Refractory die)	51	51
Porcelain fused to metal	50	47

Table 26 shows the clinical assessment, average marginal discrepancy and average axial discrepancy in the shoulder region for the ten platinum foil crowns. There was a good correlation between the clinical assessment and average marginal discrepancy values with the largest discrepancies receiving the worst gradings. In all cases the average marginal discrepancy was less than the average axial discrepancy by an amount that ranged between 3 and 33 μ m.

Table 26

A comparison of the clinical assessment, marginal discrepancy and axial discrepancy in the shoulder region of the platinum foil porcelain jacket crowns.

μm

Crown	Assessment	Marginal Disc.	Axial Disc.*	Difference
1	excellent	38	41	3
2	fair	79	** 87	8
3	excellent	20	24	4
4	fair	79	**111	32
5	excellent	21	54	33
6	good	33	49	16
7	good	38	45	7
8	fair	50	67	17
9	good	25	33	8
10	good	45	50	5

* in the shoulder region

** considered clinically unacceptable

Table 27 shows the clinical assessment, average marginal discrepancy and average axial discrepancy in the shoulder region for the ten refractory die porcelain jacket crowns. With the exception of crown two, again there was a good correlation between clinical assessment and average marginal discrepancy. In contrast to the platinum foil crowns these refractory die crowns showed a very little difference between the average marginal discrepancy and average axial discrepancy in the shoulder region. In two cases they were equal and in the other eight cases they were split evenly for the lower value. The range of differences was also much smaller being between 0 and 5 μ m.

Table 27

A comparison of the clinical assessment, marginal discrepancy and axial discrepancy in the shoulder region of the refractory die porcelain jacket crowns.

Crown	Assessment	Marginal Disc.	Axial Disc.*	Difference
1	excellent	38	40	+2
2	fair	39	36	-3
3	fair	78	80	+2
4	good	62	66	+4
5	good	51	56	+5
6	good	50	46	-4
7	excellent	37	35	-2
8	good	36	36	0
9	good	52	52	0
10	fair	65	61	-4

μm

* in the shoulder region

Table 28 shows the clinical assessment, average marginal discrepancy and average axial discrepancy in the shoulder region for the ten porcelain fused to metal crowns. There seemed to be no correlation between clinical assessment and marginal discrepancy. The two crowns (6 and 7) with the lowest marginal discrepancies received good gradings while the other eight scored excellent gradings. Except for crowns 5 and 6 there was little difference (range 0-7 μ m) between the mean marginal discrepancies and mean axial discrepancies in the shoulder region.

Table 28

A comparison of the clinical assessment, marginal discrepancy and axial discrepancy in the shoulder region of the porcelain fused to metal crowns.

μm

Crown	Assessment	Marginal Disc.	Axial Disc.	Difference
1	excellent	75	70	-5
2	excellent	56	53	-3
3	excellent	54	57	+3
4	excellent	64	42	-2
5	excellent	42	65	+23
6	good	21	46	+25
7	good	24	31	+7
8	excellent	40	40	0
9	excellent	41	45	+3
10	excellent	52	52	0

Note - Clinical assessment is of uncemented crowns. Apparent fit is not related to film thickness characteristics of the luting agent.

DISCUSSION

The method for measuring the cement space between preparation and restoration established in this investigation proved satisfactory for comparing the axial discrepancy in the shoulder region of anterior full veneer restorations. This technique also enabled observations of the more general shape of the space between crown and prepared tooth (that is the degree of relief), the effect of fabrication procedures on the thickness of this space and the effect of the space on clinical acceptability of the restoration.

A.

THE PORCELAIN JACKET CROWN1. The Platinum Foil Crowns

The most striking finding relating to the platinum foil crowns was the wide variation of measurements obtained for the discrepancy in the shoulder region both within the one crown (that is as measurements were taken further away from the internal cervical line angle) and between different crowns.

An explanation for this cannot be solely attributed to a raising of the crown due to the presence of the cement because in many areas the crowns were within 10 μ m of the preparation along the axial walls. The contour of the cement space at the shoulder region appeared to indicate a definite pulling away of platinum foil from the internal line angles when the porcelain was fused. This was to be expected because upon firing porcelain shrinks towards its greatest bulk and in the case of a full veneer crown, this is away from the shoulder area. Because the surface tension forces existing between porcelain and platinum foil are high and because of the foil's high ductility the foil is readily pulled with the shrinking porcelain away from both the shoulder and the internal line angle at the shoulder. Reburnishing procedures carried out after the first core firing seemed only to be effective in reducing this distortion of the foil towards the external margin of the shoulder. Foil at the internal line angles was certainly not successfully readapted. This would explain the rounded appearance of the internal line angles seen in Figure, 10.

The clinical significance of these observations and the reason for the relatively close approximation of the restoration to the preparation along the axial walls is not clear. Any difference in compressibility or elastic modulus between the luting (or cementing) agent and the preparation would result in irregular areas of close approximation potentially capable of concentrating stress during load application.

It is possible that the difference in compressibility factors of enamel and dentine could be a cause of fracture of platinum foil crowns in the gingival region where the preparation does not include the cemento-enamel junction. It may be that a resultant tensile stress would occur between areas of the crown overlying enamel and dentine when the crown was loaded. The luting agent which has a compressibility factor approaching that of dentine would not be capable of dissipating such stress. In consideration of the contour of the cement space in the shoulder region observed in this investigation then the elaboration of tensile stresses maybe exacerbated because the load bearing area of the shoulder region is concentrated near the external line angle of the crown and corresponding enamel margin of the preparation (if it exists). As previously discussed Southan (1972) showed that internal voids were concentrated at the shoulder region of platinum foil crowns reducing their capacity to withstand stresses.

Further consideration of the contour of the "cement" space beneath the platinum foil crowns would indicate the undesirability of preparations consisting of partial dentine and partial cast cores.

As seen in Table 15 the cement space along the axial walls (except in the tinner's joint area) of platinum foil crown is relatively narrow. Upon loading, tensile stresses could be set up in the crown corresponding to the junctional area of the metal and dentine because of differences in compressibility factors.

The wide cement spaces observed in the tinner's joint area would further reduce the load bearing capacity of these crowns.

It would seem that the platinum foil technique inherently results in a marked reduction in the available load bearing areas of these crowns. This would limit the overall load that could be applied before stress concentration in these areas induced fracture of the crown.

These observations emphasize the importance of using thorough burnishing and reburnishing procedures if the platinum foil technique is to be used to fabricate porcelain jacket crowns. Without this capacity, gross distortions will occur at the shoulder region which will greatly increase the axial discrepancy of the cemented restoration. Ironically, in an effort to achieve a better fit at the margin the apparent overall strength of the crown maybe decreased. Dental stones currently available cannot withstand such procedures. The disadvantages associated with amalgam dies are such that the swing away from their use is likely to continue. A more widespread acceptance of electroplating procedures is indicated in conjunction with the use of platinum foil. Other newly developed die materials such as glass filled resins may prove satisfactory after adequate clinical evaluation.

If the operator insists on the use of unplated stone dies because of their convenience, accuracy, ease of manipulation and low cost, then either porcelain jacket crowns should be constructed by the refractory die technique or an alternative type of restoration should be employed.

The increase in Impregum thickness in the region of the tinner's joint both at the shoulder and along the axial wall was consistent with all crowns and averaged approximately 75 μ m. This degree of discrepancy was expected because this region contained an additional three layers of foil each 25 μ m thick. Although the foils thickness was increased its ability to withstand the distorting forces was not increased and this region behaved in the same manner as the foil in other regions of the shoulder.

Although methods have been described for reducing the thickness of foil at the tinner's joint, they are seldom carried out in a clinical case. Therefore the tinner's joint is a region occupying 2 - 3mm of the total margin which has a greatly increased axial discrepancy in the shoulder region. In this country the usual location of the joint is interproximally and the shoulder region is often placed subgingivally. Although it may not detract aesthetically from the restoration it may increase irritation to the supporting soft tissues and increases the potential for leeching of the cement and possible subsequent clinical failure.

The relatively large discrepancy between crown and preparation in the incisal region compared with the discrepancy along the axial walls could be expected to give a "reservoir" effect during cementation

(as described by Jorgensen 1960). This would result in a raising of the crown away from the preparation and greatly increase the axial discrepancy in the shoulder region. This was not observed, however, during this study and could probably be explained by the tinner's joint region acting as a vent from the incisal to the external shoulder region.

The diagram of a typical Impregum replica of a platinum foil porcelain jacket crown seen in Figure 10 is at variance with McLean's (1971) example. He shows relatively even thicknesses of Impregum in all areas.

2. Refractory Die Crowns.

The refractory die crowns also showed a wide variation of both means and range values between different crowns. However, there was a more consistent pattern across the shoulder region within the one crown. This could be anticipated because the refractory matrix is not subjected to the same distorting forces as the platinum foil.

Because of the use of an oversized die in all regions except at the shoulder, a much more uniform cement thickness occurred between the crown and the preparation in all areas including the incisal area. It could be expected that the use of an oversized die would result in the smallest discrepancy occurring in the shoulder region because it would be the first to prevent further seating of the crown. However, axial discrepancies in the shoulder region were not significantly less than some discrepancies in other regions.

Possible explanations for this could be:

1. The inability to fabricate the crown directly onto the master die. Thus distortions associated with impression taking and preparation of the refractory die are compounded onto fabrication distortions.

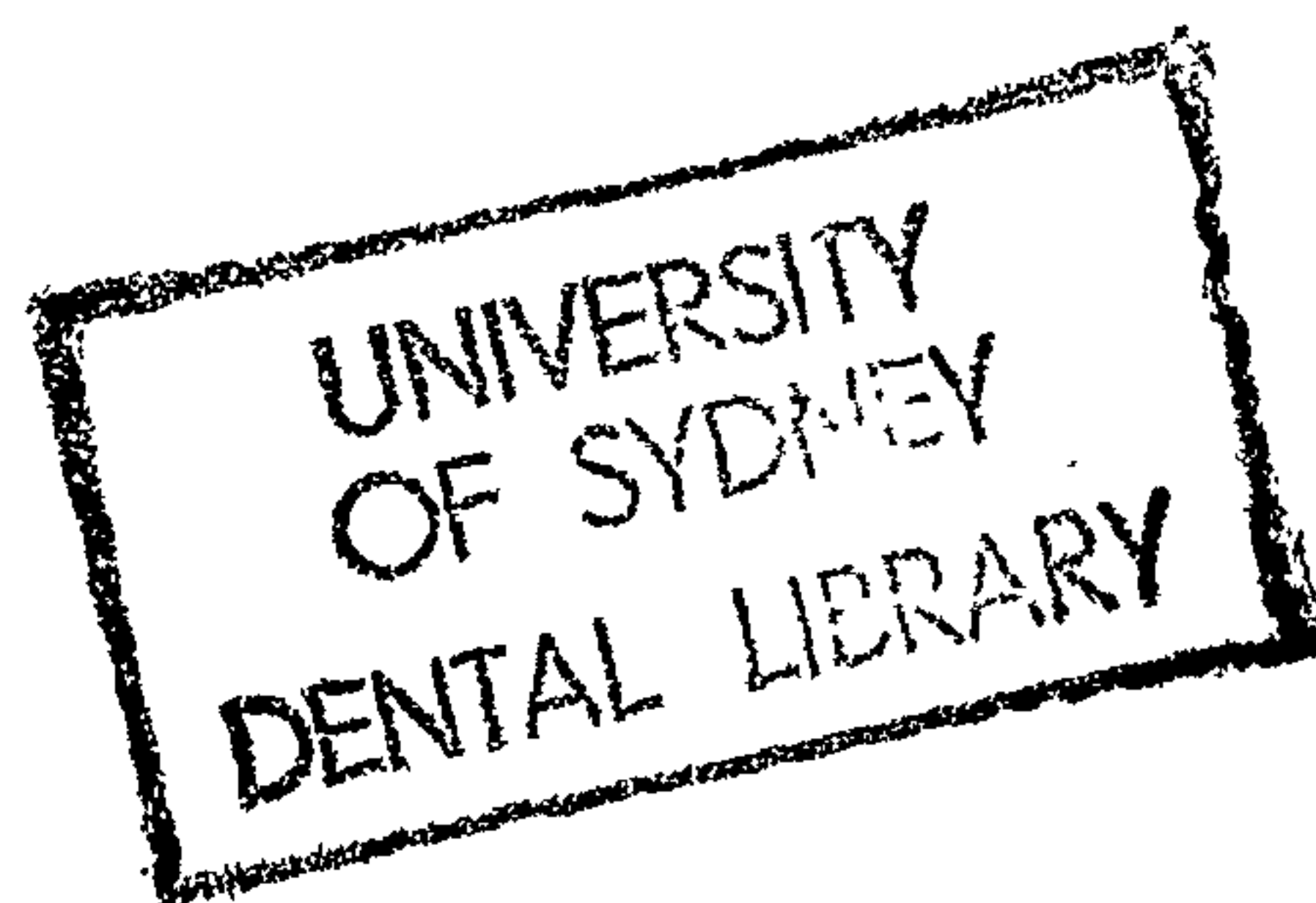
2. Impeded flow of excess cement from under the restorations may occur during luting procedures because of internal surface roughness and lack of venting pathways.

3. The difficulty of achieving a well condensed crack free core layer of porcelain which was evidenced by the occasional bubble being detected in the shoulder region. (see Figure, 13)

4. Fretting of the shoulder area of porcelain during sandblasting procedures.

5. Insufficient expansion of the refractory material used.

6. Operator inexperience with the technique.



3. A Comparison Of Porcelain Jacket Crowns Prepared
By The Platinum Foil And Refractory Die Techniques

No statistically significant difference was observed in the overall axial discrepancy in the shoulder region between the refractory die and platinum foil crowns when the tinner's joint is disregarded. It must be remembered that the claim for a more accurate fit in the shoulder region was only the minor of Southan's claims in favour of the use of the refractory die technique. The major claim, that of obtaining crowns with a defect free inner surface (and by inference, a much stronger crown) was not studied in this investigation.

Invariably it was found that when "cemented" crowns and dies were separated, the Impregum would adhere to the crown for the refractory die technique but to the die for the platinum foil technique. This probably reflected the smoothness of the internal surface of the crowns. The platinum foil crowns appeared smoother and more glassy. The openings of internal sub-surface voids described by Southan (1972) were not evident microscopically and were not penetrated by the rubber, indicating that such openings must be significantly smaller than the film thickness of the rubber, that is 15 μ m. The internal surfaces of the refractory die crowns were not smooth or glassy, but granular, probably reflecting the granular surface of the refractory material used and also accentuated by the sand blasting procedures.

B.

THE PORCELAIN FUSED TO METAL CROWN1. Nature Of The Fit Of The Crown

The most striking finding with these crowns was the regular and consistent Impregum films obtained within each crown. These indicated that the castings were smooth, even and well fitting.

Although there was an average increase of 70% in the rubber thickness following fusing of the porcelain, the final axial discrepancy in the shoulder region of these crowns was not significantly different from that of the porcelain jacket crowns, (see Table 21).

The increase in film thickness that did occur was consistent across the shoulder and also extended up the axial walls. This was in contrast to the distortions associated with crowns prepared by the platinum foil technique which were confined to the shoulder area. This observation tends to suggest that the metal is pulled away from the preparation not only in the shoulder region but also from the axial walls. The diagram in Figure 13 illustrates this point.

The results of this study agreed with Shillingburg's (1973) study. He examined several different coping designs and found that the shoulder design, without a bevel, showed an increase in marginal discrepancy of $10.7\mu\text{m}$ when the porcelain was fused. In this present study, because of the consistency of readings of rubber thickness occurring across the shoulder, the axial discrepancy in the shoulder region could be considered to represent the marginal discrepancy. The increase found was $16\mu\text{m}$. The difference between these two sets of results was not statistically significant.

The bulk and stiffness of the metal especially around the cervical line angle may influence this distribution of stress releasing deformation rather than confining it to the shoulder region as occurs with the platinum foil porcelain jacket crowns. Tuccillo and Nielsen (1967) found such permanent deformation the result of interfacial shear stress following firing.

Table 18 shows that one crown, number 9F - with a flanged gingival contour - showed a decrease in mean axial discrepancy of 10µm after the porcelain was fused. This was inconsistent with other results and may be explained by several factors:-

1. Insufficient application of pressure during cementation could have resulted in incomplete seating of the metal coping.

2. Hobo and Shillingburg (1973) showed that the degree of distortion may be decreased after repeated firings.

3. Tuccillo and Nielsen (1967) demonstrated creep and sag properties in alloys used for porcelain fused to metal restorations when subjected to the required temperature cycles. Distortions such as these could have occurred in the shoulder region.

4. Solid impurities that may have been incorporated into the rubber "cement" could have caused an effective increase in film thickness.

5. Distortions resulting from porcelain fusing may have provided more adequate space for the cement.

6. A slight rotation of coping on the die may have occurred resulting in an increased gap at the shoulder. Although the

preparations were classed as cylindrical this was not strictly the case as small undulations of contour were incorporated into the preparation to minimize any rotational effect.

2. Control Of Film Thickness And Fit.

As discussed earlier the tinner's joint region provides an efficient venting channel for the platinum foil jacket crowns. These crowns possessed very close approximation of the restoration to the axial walls. Although the refractory die technique does not incorporate a venting channel, the production of an oversized die (except in the shoulder region) helps to provide adequate room for the cement (Southan, 1972). No such mechanisms are inherent in the porcelain fused to metal technique. The manufacturers claim that the water-powder ratio of the investments used can be adjusted to produce a slightly oversized coping which does allow adequate room for cement.

Jones (1962) claimed that for full veneered gold crowns a resultant discrepancy of 20-50 μ m should be achieved to allow adequate cement space. The expansion properties of the investments can vary from brand to brand and even within different batches of the same brand. This was evident in this investigation and necessitated a change to the use of Ceramigold investment. If adequate expansion has occurred it can be judged by the ease with which the casting can be tried on the die. Any frictional hinderance suggests an undercompensated casting. Other techniques for obtaining more room for the cement have been described. These include electrolytic stripping or grinding of the internal surface and varnishing of dies before the coping design is waxed up.

Jorgensen (1955) and McCune showed that precision castings (to within 2 μ m) resulted in very large marginal discrepancies (1333 μ m and 476 μ m respectively) because of the inability of the

cement to flow from under the restoration.

No techniques were used in this investigation to provide extra space for cement. The criteria of a non-frictional fit of the casting and the absence of marginal discrepancies detectable by eye or dental probe were considered adequate. Therefore the degree of axial discrepancy in the shoulder region of the metal copings before porcelain application that can be attributed to casting distortion as opposed to the effective presence of the cement cannot be stated. It is conceivable that distortions associated with porcelain fusing might provide an increase in cement space thereby allowing a more positive seating. In this case the finding of a seventy percent increase in average axial discrepancy upon porcelain fusing would have been falsely low due to the simultaneous partial or complete elimination of the effect of the cement.

Several studies (Jorgensen, 1955, Bassett, 1966, McCune, 1968, Jones, 1971) have shown that venting of the occlusal surface of full veneer restorations can in some circumstances decrease the marginal discrepancy of such restorations. Such venting is not possible with an all porcelain restoration and is of limited application for a porcelain fused to metal restoration especially in anterior regions. Here the only possible place for perforation is below the porcelain-metal junction. A consideration of aesthetics, occlusion and operator preference will determine the placement of the porcelain-metal junction. This can vary from 2mm below the incisal edge (either labially or lingually) to the lingual gingival margin.

Clearly venting may not always be possible.

However, in the case of anterior full veneer crowns there are several factors which could assist in minimizing axial discrepancies in the shoulder region and thereby compensate for the lack of venting.

- a. The decreased occlusal table minimizes the "reservoir" effect.
- b. The shape of anterior preparations often incorporates a large taper angle in the incisal two thirds of the labial and lingual surfaces.
- c. A non-frictional fit of the metal coping indicates that some space for cement occurs through normal fabricating techniques.

In addition, the possibility exists of causing interfacial shear stress at the porcelain-metal interface during venting procedures if such procedures involve grinding of the metal after porcelain fusing.

It is for these reasons that venting of anterior porcelain fused to metal restorations is seldom advocated or performed clinically. Further research is needed to study the accuracy of the alternative procedures and the efficiency of venting.

3. The Fit Of The Crowns At Non-shoulder Regions

The lingual axial discrepancies at the bevel region were not studied in this investigation. Distortion in this region is not significant. The metal is not subject to the forces exerted by the shrinking porcelain, relatively small casting inaccuracies may be minimized by burnishing procedures without stressing the porcelain-metal junction and the bulk of the metal seems to minimize distortion (Shillingburg 1973).

C. A COMPARISON OF FLANGED AND CYLINDRICAL TYPE OF PREPARATIONS

It was observed that for crowns made to fit flanged preparations there was often a marked difference between the measurements for the labial and lingual shoulder regions within the one crown. This was especially evident when there was a relatively large discrepancy between crown and preparation along the axial walls.

Thus for the refractory die type porcelain jacket crowns where an oversized intermediate die was used, four of the five flanged crowns fabricated exhibited differential degrees of axial discrepancy between the labial and lingual shoulder regions. Although the axial discrepancy at the lingual marginal region was not measured for the porcelain fused to metal crowns, an observation of the discrepancies along the axial walls again demonstrated a marked difference.

These observations could be attributed to a slight rocking effect caused by the misfit of the crowns, with the junction of the flanges acting as a fulcrum. A slightly greater cementation pressure on one side of the crown, incisal to the fulcrum, would thereby result in a closer adaptation to the shoulder region on the opposite side.

These observations would indicate that, although, in overall comparison, flanged preparations resulted in crowns with comparable axial discrepancies in the shoulder region to the cylindrical type, the junction of the flanges acting as a fulcrum point could represent an area of high stress concentration during loading.

Furthermore, although the mean axial discrepancy for the flanged preparations was similar to the mean discrepancy for the cylindrical preparations, because of the rocking of the crown about the fulcrum during cementation, it was inevitable that the discrepancy on one side of the flanged preparations would be much greater than the mean discrepancy for the cylindrical type. Because this applies to the shoulder region on one side as well as the axial wall, this greater discrepancy is potentially of considerable clinical importance.

Although an oversized intermediate die was not used for the porcelain fused to metal crowns, other factors, including stress release in the wax patterns and expansion of the refractory investment material, could result in the relatively large discrepancies or relief along the axial walls needed for discernable rotation to take place. Because of the relatively small discrepancies along the axial walls of the platinum foil porcelain jacket crowns this rotation effect was not measurable. Thus the more that allowance is made for the presence of cement, the more it is likely that rotation on seating will occur.

Clinically, therefore, the flanged type of preparation would seem undesirable. A dilemma exists for the clinician, however, because in an effort to cause minimal irritation to the supporting soft tissues and to provide maximum aesthetics, this type of preparation is often indicated by the gingival contour about the tooth.

D. THE CLINICAL ACCEPTABILITY OF THE MARGINAL FIT OF THE CROWNS

The crowns were assessed for their fit at the margins while seated on their individual master dies by six experienced clinicians using direct vision and sharp dental explorers. Such an assessment was confined to the predefined marginal discrepancy, except where a large gap existed and the axial discrepancy was apparent.

It could be argued that this did not represent the true clinical picture and that such an assessment was more critical than an intra-oral assessment for several factors:-

1. The assessor has good access to all the gingival margin, interproximally, labially and lingually and discrepancies that might not be apparent intra-orally are well exposed to examination by this method. (This would especially apply to the tinner's joint area of the platinum foil crowns.)
2. Intra-orally small point discrepancies which may not occur elsewhere may provoke a critical assessment unrepresentative of the average marginal discrepancy.
3. Undercontouring and overcontouring of the gingival aspect of the restoration may be confused in an intra-oral assessment with a marginal discrepancy.

Discrepancies inherent in impression taking and die pouring procedures (Jones 1962) did not influence the assessment used in this study. A more complete assessment of fit would include these

variables - which are, however, identical for the different crown techniques.

As discussed previously the marginal discrepancy has limitations in its ability to predict the clinical longevity of restorations. It would, however, seem to be the only available practical guide assuming there are no faults or defects associated with the fabrication techniques.

Table 20 summarised the results obtained for the "clinical" assessment. There was no statistically significant difference in gradings between the two types of porcelain jacket crowns. However, the porcelain fused to metal crowns were consistently awarded a better grading. This was consistent with results measuring the rubber films where the range of values both within the one crown and between different crowns was more consistent than with the all porcelain crowns even though there was no significant difference in average axial discrepancy in the shoulder regions.

Results in Table 21, indicated that only crowns with an average measured axial discrepancy above 80 μ m were considered to be clinically unacceptable by one or more of the six experienced clinicians. This agreed with McLean's (1971) claim that discrepancies less than 80 μ m could be difficult to detect either by use of radiographs or sharp dental probes.

McLean distinguished between clinical acceptability and clinical success. He based his study on the premise that a restoration that withstood five years' service without obvious signs

of leakage and recurrent caries was clinically successful. He claimed that gingival or marginal discrepancies below 120 μ m should be achieved to obtain a clinically acceptable and successful restoration but that restorations with discrepancies up to 160 μ m could be successful but would tend to be rejected by a conscientious operator before cementation.

Bjorn (1970) in a study on the relationship of marginal fit to periodontal bone level used radiographs to assess the interproximal gingival discrepancy. She found that seventy-four percent of porcelain crowns surveyed had gingival discrepancies greater than 200 μ m and that such defects were usually associated with pathologically reduced periodontal bone levels. It could be concluded that either many operators are cementing crowns that should be considered clinically unacceptable or that measures for assessing the fit of restorations are inadequate, especially in interproximal regions.

It would seem apparent from this discussion that the distortions associated with the careful and proper fabrication of porcelain and porcelain fused to metal full veneer crowns do not affect their clinical acceptability because techniques available for the clinical assessment of these crowns are not sufficiently critical to detect such distortions. This is emphasized by the fact that restorations with axial discrepancies far in excess of those attributable to such distortions are successful clinically.

This does not imply, however, that the operator should not strive for the ideal, a perfect fit, at the margins. Any measures

and techniques that can enable crowns to more closely approach this ideal deserve consideration even though the discrepancy was already beyond clinical detection. Such measures should be aimed at reducing distortions during fabrication procedures but at the same time allowing adequate room for the cementing or luting medium.

E. A COMPARISON OF THE MARGINAL DISCREPANCIES
 OF THE PORCELAIN JACKET AND PORCELAIN
 FUSED TO METAL CROWNS.

The fit of a restoration is assessed clinically with reference to the discrepancy at the margin or the external line angle.

Jorgensen (1960) used the term gingival discrepancy in relation to full crowns. For the purposes of this discussion the terms marginal and gingival discrepancy are synonymous but differ from the average axial discrepancy in the shoulder region which has previously been defined.

A comparison of the three fabrication techniques failed to show any significant difference in marginal discrepancy values. There was a good correlation between these marginal discrepancy values and the axial discrepancy values (in the shoulder region) for the refractory die and porcelain fused to metal crowns. However, a significant difference occurred between the overall marginal discrepancy (43 μ m) and axial discrepancy (56 μ m) values for the platinum foil crowns. This was expected as it has already been observed that the majority of Impregum thicknesses associated with these crowns decreased as measurements were taken further away from the internal cervical line angle. Table 26 which in part compares average marginal discrepancy results with average axial discrepancy results emphasizes this point because in all cases the average axial discrepancy values are lower by an amount that ranged between 3 and 33 μ m.

These results do seem to indicate that a clinician does base his assessment of the fit of a crown on the apparent marginal discrepancy. This is reliable for porcelain fused to metal and refractory die porcelain jacket crowns where it can be assumed that a similar fit occurs over the entire shoulder region because of the good correlation of marginal discrepancy and axial discrepancy values within the one crown. However, such an assessment can be misleading with regard to platinum foil porcelain jacket crowns which showed a significant difference between the marginal and axial discrepancy values within the one crown.

The clinical significance of these results is that the platinum foil crown which fits well at the margin and thus provides a good barrier against leaching of the cement maybe weakened because other areas of the shoulder with wider spaces may result in a decrease in the load bearing potential of the crown.

Although there was a tendency for the platinum foil crowns to have lower marginal discrepancy values than the other two techniques they scored significantly worse gradings than the porcelain fused to metal crowns in the clinical assessment of fit. An explanation for this could be due to two factors:

- 1) The tinner's joint area which was not assessed for marginal or axial discrepancy values, may have swayed the clinicians to opt for a worse grading.
- 2) The smooth even character of the entire shoulder region of the porcelain fused to metal crowns may have resulted in them receiving significantly better gradings.

CONCLUSIONS

There follows a summary of the individual findings and trends that have been discussed in the preceding pages. Many of the findings in this investigation were not statistically significant. The available techniques for fabrication of the anterior full veneer crowns investigated here resulted in a wide variation in the axial discrepancies in the shoulder region. Both the statistically significant findings and the observed trends have been presented in this summary.

A.

Porcelain Jacket Crownsa) Platinum Foil Crowns

1) There was a wide variation of means and ranges for the axial discrepancies in the shoulder region of these crowns both within the one crown and between different crowns.

2) There was a tendency for Impregum thicknesses to decrease as measurements were taken further away from the internal cervical line angle.

3) The platinum foil was pulled away from the shoulder region upon firing the porcelain.

4) Reburnishing procedures after the first core firing can minimize this distortion of the foil especially in the region of the external line angle.

5) The uneven relief of the shoulder region was attributed to:-

i) Reburnishing procedures giving only partial readaptation to the shoulder region.

ii) Further distortion occurring in subsequent firing procedures.

6) The uneven relief of the cement space maybe a cause for clinical failure by limiting the area capable of withstanding applied stress.

7) Stone dies are not adequate for the fabrication of platinum foil porcelain jacket crowns with well fitting margins because of their inability to withstand thorough reburnishing procedures.

8) There was a wide variation of relief between preparation and restoration at different regions of the crowns.

The tinner's joint region showed relatively large discrepancies while the labial and lingual axial walls showed relatively small discrepancies when compared to the shoulder regions.

9) The platinum foil technique results in a marked reduction of load bearing areas for porcelain jacket crowns.

10) Distortions of the platinum foil occurring in the tinner's joint area of the shoulder were consistent with distortions observed in other regions of the shoulder.

11) The tinner's joint region is capable of acting as a vent during luting procedures preventing any apparent "reservoir" effect occurring at the incisal edge where the axial discrepancies were wider than any other region.

b) Refractory Die Crowns

1) The crowns showed consistency of measurements of the axial discrepancy across the shoulder region within the one crown.

A marked increase at either the internal or external cervical margin was rarely observed.

2) There was again a wide variation of means between different crowns.

3) The relief in all regions under the cylindrical crowns was much more consistent than with the platinum foil crowns.

4) This author questions whether "Deguvest" investment provides adequate expansion of the intermediate die.

5) There was no statistically significant difference in axial discrepancies at the shoulder region between the refractory die and platinum foil crowns.

B. Porcelain Fused To Metal Crowns

1) Deguvest investment proved unsatisfactory for providing adequate and consistent expansion of the metal copings.

2) The relatively small Impregum thicknesses showed that the metal copings were smooth, even and well fitting before porcelain application.

3) A significant increase in axial discrepancy in the shoulder region of crowns after the porcelain was fused of approximately 70% occurred for both types of preparation. The cylindrical crowns, however, were more consistent in the degree of increase.

4) The irregular degree of increase observed for the flanged preparations could be attributed to;

- i) the affect of porcelain application and
- ii) a rocking effect occurring about a fulcrum at the junction of the labial and lingual flanges.

5) The distortions of the metal copings that occurred were consistent across the shoulder and up the internal labial surface suggesting the metal is pulled away during porcelain firing from not only the shoulder region but also along the axial walls.

6) The influence of the presence of the cement could not be dissociated from the distortions due to casting the metal or fusing the porcelain with the method used in this investigation for measuring the axial discrepancies in the shoulder region.

7) The results obtained in this investigation were similar to those of Shillingburg's (1973) study.

8) There was no statistically significant difference of axial discrepancies in the shoulder region between porcelain jacket and porcelain fused to metal crowns.

C. A Comparison Of Flanged And Cylindrical Type Preparations

1) There was no overall significant difference in axial discrepancies at the shoulder region between cylindrical and flanged preparations for any of the crown types.

2) Depending on the degree of relief under the flanges, this type of preparation can result in a rocking of the crown about a fulcrum at the junction of the flanges, causing unequal degrees of axial discrepancies in the shoulder regions.

3) There was a tendency for flanged crowns to have overall less discrepancy in the shoulder region than cylindrical crowns.

D. The Clinical Acceptability Of The Marginal

Fit Of The Crowns

1. There was no statistically significant difference in gradings between the two types of porcelain jacket crowns assessed.
2. The porcelain fused to metal crowns were consistently awarded better gradings for fit than the porcelain jacket crowns.
3. Only crowns with an average measured axial discrepancy above 80µm were considered to be clinically unacceptable by one or more of the six experienced clinicians.
4. The distortions associated with the careful and proper fabrication of porcelain and porcelain fused to metal full veneer crowns do not affect their clinical acceptability because techniques available for the clinical assessment of these crowns are not sufficiently critical to detect such distortions.

E. A Comparison Of The Marginal Discrepancies

Of Porcelain Jacket And Porcelain Fused

To Metal Crowns

1. There was no significant difference in overall marginal discrepancy values between the three fabrication techniques studied.
2. There was a good correlation between marginal and axial discrepancy values for the porcelain fused to metal crowns and the

refractory die porcelain jacket crowns.

3. There was significant difference between the overall marginal and axial discrepancy values for the platinum foil porcelain jacket crowns.

4. There was a good correlation between clinical assessment gradings and marginal discrepancy values for the porcelain jacket crowns but no apparent correlation for the porcelain fused to metal crowns.

5. A clinical assessment of fit of the entire shoulder region based on marginal discrepancy is reliable for porcelain fused to metal and refractory die porcelain jacket crowns but not for platinum foil porcelain jacket crowns.

SUMMARY

A technique first described by McLean and von Fraunhofer (1971) for estimating the cement film thickness beneath placed restorations has been verified.

This technique involved the taking of a rubber replica of the gap between the tooth preparation and the restoration and then determining the thickness of the rubber. The technique was adapted for an in-vitro investigation and some modifications were necessary to ensure an accurate correlation between the rubber thickness and the cement film thickness that would be obtained clinically.

This modified technique was then used to measure axial discrepancies of cemented anterior full veneer restorations in the shoulder area. Because the crowns were directly fabricated onto individual master dies the resultant discrepancies could be attributed to two factors;

- 1) distortions associated with the particular fabrication technique and
- 2) the presence of the luting or cementing agent.

The axial discrepancies in the shoulder region were found to be within the range considered to be clinically acceptable. A study of the contour of the cement film in both the shoulder region and elsewhere allowed some discussion as to the likely effects on the crowns of load application, namely, stress concentration and flow of excess cement.

Three types of anterior crowns were compared; porcelain

jackets fabricated by a platinum foil technique, porcelain jackets fabricated by a refractory die technique and porcelain fused to metal crowns. There was no statistically significant difference in average axial discrepancies between the three techniques.

The crowns were assessed for their clinical acceptability by several experienced clinicians. Only crowns with average axial discrepancies exceeding 80 μ m were considered to be unacceptable for clinical use.

A comparison of average axial discrepancies and average marginal discrepancies showed a good correlation with the porcelain jacket crowns fabricated on refractory dies and the porcelain fused to metal crowns. However, the porcelain jacket crowns fabricated on platinum foil matrices showed consistently lower marginal discrepancy values.

The selection of a material and method of fabrication for restoring a full veneer situation is dependent on many factors. One of these, of particular interest to the clinician, is the ability of the technique to provide an accurately fitting crown for the prepared tooth.

This investigation of three types of crowns found no statistically significant difference in their ability to fit in the shoulder region. Each technique is, however, open to abuse and presents particular manipulative problems.

Crowns are frequently returned to the clinician from the laboratory with less than acceptable fit. The ability of the clinician to adequately assess the fit of the crown before cementation and his integrity and judgement in selecting and rejecting prepared crowns before cementation are then of paramount importance.

BIBLIOGRAPHY

Adair, P.H. - The chemical strengthening of dental porcelain.M.D.S.
Thesis, University of Sydney, p.114, 1971.

Adair, P.H. - The chemical strengthening of dental porcelain M.D.S.
Thesis, University of Sydney, p.31, 1971.

Alexander, A.G. - Periodontal aspects of conservative dentistry
Brit. Dent. J. 125:3, p.111-114 (Aug.), 1968.

Allison, J.R. and Bhatia, H.L. - Tissue changes under acrylic and
porcelain pontics Abstract. J. Dent. Res., 37:1, p.66-67
(Feb.), 1958.

Andrade, E.N. and Tsien, L.C. - On surface cracks in glasses.
Proc. Roy. Soc., 159 (A): p.346-354, 1937.

Argue, J.E. - Adaptation of the porcelain jacket crown.
Dent. Cos. LVIII, p.1362-1366, 1916.

Baker, T.C. and Preston, F.W. - The effect of water on the strength
of glass. J. Appl. Phy. 17:3, p.179-188 (Mar.), 1946.

Baldwin, D.H. - Porcelain shell crowns. Dent. Cos. L, p.408, 1908.

Bastian, C.C. - Porcelain jacket crowns. Proceedings of ninth
Aust. Dental Congress. Sydney, p.429-431, 1937.

Batchelor, R.W. and Dinsdale, A. - Some physical properties of
porcelain bodies containing corundum. VIIth Int.
Ceram. Cong. Trans. Lond., p.31-38, 1960.

Bergman, B., Hugoson, A. and Olsson, C. - Periodontal and prosthetic
conditions in patients treated with removable partial
dentures and artificial crowns. Acta. Odontol. Scand.,
29:6, p.621 (Dec.), 1971.

Binns, D.B. - Science of ceramics. Vol. 1. London. Academic Press,
p.315, 1962.

Bjorn, A., Bjorn, H. and Grkovic, B. - Marginal fit of restorations
and its relation to periodontal bone levels. Odontol. Revy.
21, p.337-346, 1970.

Brecker, S.C. - Crowns. W.B. Saunders Co., Philadelphia and London,
p.372, 1961.

Bryant, R.W. - Base forming materials for amalgam restorations.
M.D.S. Thesis, University of Sydney, p.121, 1968.

Buell, C.K. - Technique for the construction of a hand carved
porcelain shell crown. Dent. Cos. LXII, p.437-441
(disc. 537-539), 1920.

Capon, W.A. - Porcelain dental art. Dent. Cos. XXXIII, p.268-270,
1891.

Carter, R. - The anterior porcelain jacket crown. M.D.S. Thesis,
University of Sydney, 1965.

Clark, E.B. - Manipulation of dental porcelain. J. Amer. Dent. Assoc.
22:1, p.33-40 (Jan.), 1935.

Cook, J. and Gordon, J.E. - A mechanism for the control of crack
propagation in all brittle systems. Proc. Roy. Soc.,
282-(A): p.508-520, 1964.

Coston, W.A. - Porcelain jacket crowns. Dent. Cos. LIV, p.452
(clinic), 1912.

Craig, R.G., El-Ebrashi, M.K. and Farah, J.W. - Stress distribution
in photoelastic models of transverse sections of porcelain
-to-gold crowns and preparations. J.Dent. Res. 52:5,
p.1060-1064 (Sept.), 1973.

- Custer, F. - Effect of certain variables in the bond strength of porcelain fused to gold. International Association for Dental Research. 40:94 (Abstract), 1962.
- Custer, L.E. - A system of making porcelain jacket crowns without fusing. Dent. Cos. LVII, p.1356-1360, 1915.
- Derand, T. - Studies of porcelain jacket crowns by means of two-dimensional photoelastic experiments. Odont. Revy 24, p.373-388, 1973.
- Dimashkieh, M.R., Davies, E.H. and von Fraunhofer, J.A. - Measurement of the cement film thickness beneath full crown restorations. Brit. Dent. J. 137:10, p.281-284 (Oct.), 1974.
- Frank, H.J. - The porcelain jacket crown. Dental Review XXIII, p.420-424, 1909.
- Frey, W.J. and McKenzie, J.D. - Mechanical properties of selected glass-crystal composites. J. Mater. Sci. 2:2, p.124-130 (Mar.), 1967.
- Gibbs, P. and Cutler, I.B. - On the fracture of glass which is subjected to slowly increasing stress. J. Amer. Ceram. Soc., 34: 7, p.200-206 (July), 1951.
- Goslee, H.J. - Porcelain crowns. Dental items of interest. XXV, p. 161-172, 1903.
- Grieve, A.R. - Finishing cavity margins. Brit. Dent. J. 125:1, p.12-17 (July), 1968.
- Griffith, A.A. - Phenomena of rupture and flow in solids. Translation: Roy. Soc. London. 221A 4: p.163-198 (Oct.), 1920.

Griffith, J.R. and Ware, A.L. - An evaluation of dental cements.

Aust. Dent. J. 5:5, p.285-289 (Oct.), 1960.

Gurney, C. - Sources of weakness in glass. Proc. Roy. Soc.,

282(A): p.24-33, 1964.

Hasselman, D.P.H. and Fulrath, R.M. - Proposed fracture theory of
a dispersion-strengthened glass matrix. J. Amer. Ceram.

Soc. 49:2, p.68-72 (Feb.), 1966.

Hobo, S. and Shillingburg, H.T. - Porcelain Fused to metal: Tooth
preparation and coping design. J. Pros. Dent.

30:1, p.28-36 (July), 1973.

Hovestadt, J.F. - Principles and art technique of porcelain.

Dental items of interest. XLI, p.599-618, 1919.

Johnston, F.J., Dykema, R.W. and Cunningham, D.M. - The use and

construction of gold crowns with a fused porcelain veneer -

a progress report. J. Pros. Dent. 6:6, p.811-821 (Nov.),

1956.

Johnston, J.F., Phillips, R.W. and Dykema, R.W. - Modern practice

in crown and bridge prosthodontics. W.B. Saunders Co.,

Philadelphia and London, p.333, 1961.

Johnston, J.F., Mumford, G., Dykema, R.W. and Phillips, R.W.

- Construction and assembly of porcelain veneer gold

crowns and pontics. J. Pros. Dent., 12:6, p.1125-1137

(Nov.), 1962.

Jones, E.H. - Some aspects of gold inlay fabrication. M.D.S. Thesis,

University of Sydney, p.202.

- Jorgensen, K.D. - The relationship between retention and convergence angle in cemented veneer crowns. *Acta Odont. Scand.*, 13:1, p.35-40, 1955.
- Jorgensen, K.D. - Factors affecting the film thickness of zinc phosphate cements. *Acta Odont. Scand.*, 18:4, p.479-489, 1960.
- Jorgensen, K.D. - Structure of the film of zinc phosphate cement. *Acta Odont. Scand.*, 18:4, p.491-501, 1960.
- Jorgensen, K.D. and Petersen, G.F. - The grain size of zinc phosphate cements. *Acta Odont. Scand.*, 21:3, p.255-270, 1963.
- Jorgensen, K.D. and Esbensen, A.L. - The relationship between the film thickness of zinc phosphate cement and the retention of veneer crowns. *Acta Odont. Scand.*, 26:3, p.169-175, 1968.
- Karlsen, K. - Gingival reactions to restorations. *Acta Odont. Scand.*, 28:6, p.895, 1970.
- Kingery, W.D. - Introduction to ceramics. New York, John Wiley and Sons, Inc., 1963.
- Kistler, S.S. - Stresses introduced into glass by replacing alkali ions near the surface by other alkali ions from a melt. *Full. Amer. Dent. Assoc.*, 26:11, p.1786-1797 (Nov.), 1939.
- Lamstein, A. and Blechman, H. - Marginal seepage around acrylic resin veneers in gold crowns. *J. Pros. Dent.*, 6:5, p.706-709. (Sept.), 1956.
- Land, C.H. - Porcelain restorations. *Dent. Cos.*, XXXI, p.191-192, 1889.
- Land, C.H. - Porcelain dental art. *Dent. Cos.* XLV, p.437-443, 1903.

Lee, P.W. - Ceramics. Reinhold Publishing Corp, New York.

Chapman and Wall Ltd., London, Introduction, chapter 1,
1961.

Lehman, M.L. and Hampson, E.L. - A study of strain patterns in
jacket crowns on anterior teeth resulting from different
tooth preparations. Brit. Dent. J., 13:11, p.337-345 (Nov.),
1962.

Lewis, D.N. - The porcelain jacket crown. Dent. Cos. LX, p.260-261
abstract, 1918.

Lyon, D.M., Cowger, G.T., Woycheshin, F.F. and Miller, C.B.
- Porcelain fused to gold - evaluation and aesthetics.
J. Pros. Dent., 10:2, p.319-328 (March), 1960.

Marcum, J.S. - The effect of crown marginal depth upon gingival
tissue. J. Pros. Dent., 17:5, p.479-487 (May), 1967.

McBean, C.O. - Porcelain as applied to dentistry. J. Amer. Dent.
Assoc., 14:1, p.138-153 (Jan.), 1927.

McLean, J.W. and Hughes, T.H. - The reinforcement of dental porcelain
with ceramic oxides. Brit. Dent. J., 119:6, p.251-267 (Sept.),
1965.

McLean, J.W. and von Fraunhofer, J.A. - The estimation of cement film
thickness by an in-vivo technique. Brit. Dent. J., 131:8,
p.107-111 (Aug.), 1971.

McLean, J.W. and Sced, L.R. - The bonded alumina crown. I. The bonding
of platinum to aluminous dental porcelain using tin oxide
coatings. Aust. Dent. J., 21:2, p.119-127 (April), 1976.

McLean, J.W., Kedge, M.I. and Hubbard, J.R. - The bonded alumina crown.

2. Construction using the twin foil technique. Aust. Dent. J., 21:3, p.262-268 (June), 1976.

Mintz, V.W., Caputo, A.A. and Belting, C.M. - Inherent structural defects of porcelain-fused-to-gold restorations: A preliminary report. J. Pros. Dent., 32:5, p.544-550 (Nov.), 1974.

Moffa, J.P., Guckes, A.D., Okawa, M.T. and Lilly, G.E. - An evaluation of non-precious alloys for use with porcelain veneers. Part 1. Physical properties. J. Pros. Dent., 30:4, p.424-431 (Oct.), 1973.

Moffa, J.P., Guckes, A.D., Okawa, M.T. and Lilly, G.E. - An evaluation of non-precious alloys for use with porcelain veneers. Part 2. Industrial safety and biocompatibility. J. Pros. Dent., 30:4, p.432-441 (Oct.), 1973.

Mould, R.E. - Strength and static fatigue of abraded glass under controlled ambient conditions: III, aging of fresh abrasions. J. Amer. Ceram. Soc. 43:3, p.160-167 (Mar.), 1944.

Mumford, G. - The porcelain fused to metal restoration. Dent. Clinics. Nth. Amer., p.241-249 (March) 1965.

Mylin, W.K. - Present status of porcelain fused to metal restorations. J. Kentucky. Dent. Assoc., 14:3, p.152-155 (June), 1962.

Neilsen, J.P. and Tuccillo, J.J. - Calculation of interfacial stress in dental porcelain bonded to gold alloy substrate.

J. Dent. Res., 51:4, p.1043-1047 (Aug.), 1972.

Newcomb, G.M. - The relationship between the location of subgingival crown margins and gingival inflammation. J. of Periodontology, 45:3, p.151-154 (March), 1974.

Oppice, H.W. - Porcelain jacket crowns. J. Amer. Dent. Assoc., XVI, p.27-34 (disc. 35-37), 1929.

Orowan, E. - The fatigue of glass under stress. Nature, London, 154:3906, p.341-343 (Sept.), 1944.

Paffenbarger, G.C., Sweeney, W.T. and Isaacs, A. - A preliminary report on the zinc phosphate cements. J. Amer. Dent. Assoc., 20:11, p.1960-1982 (Nov.), 1933.

Paffenbarger, G.C., Sweeney, W.T. and Isaacs, A. - Zinc phosphate cements: Physical properties and a specification.

J. Amer. Dent. Assoc., 21:11, p.1907-1924 (Nov.), 1934.

Parfitt, J.B. - Construction of the all-porcelain jacket crown. Brit. Dent. J., 44:11, p.1203-1204 (Nov.), 1923.

Pini, C.E. - Co-report-Hygienic considerations in crown and bridge prosthesis. Int. Dent. J., 8:2, p.357, 1958.

Preston, F.W. - The mechanical properties of glass. J. Appl. Phy., 13:10, p.623-634 (Oct.), 1942.

Riethmueller, R.H. and Hough, H. - The all-porcelain jacket crown. Dent. Cos. Ll, p.1258-1265, 1909.

- Rosenstiel, E. - The taper of inlay and crown preparations. Brit. Dent. J., 139:12, p.436-438 (Dec.), 1975.
- Ryge, G. and O'Brien, W.J. - Contact angles of drops of enamels on metals. J. Pros. Dent., 15:6, p.1094-1100 (Nov.), 1965.
- Saklad, M.J. - The disclosure of cleavage and fracture lines in porcelain restorations. J. Pros. Dent., 18:1, p.115-119 (Jan.), 1958.
- Scherer, J.W. - A plea for better gingival restoration in crown and bridgework. Dent. Cos., LXIV, p.610-615, 1922.
- Schneider, A.E. - The porcelain jacket crown. Dental Review XXIII, p.1165-1166 (clinic), 1909.
- Semmelman, J.O. - A method of measuring porosity of porcelain teeth. J. Dent. Res., 36:6, p.945-949 (Dec.), 1957.
- Sced, I.R. and McLean, J.W. - The strength of metallic/ceramic bonds with base metals containing chromium. A preliminary report. B. Dent. J. 132:3, p.232-234 (March) 1972.
- Shell, J.S. and Nielsen, J.P. - Study of the bond between gold alloys and porcelain. J. Dent. Res., 41:6, p.1424-1437 (Nov.), 1962.
- Sherrill, C.A. and O'Brien, W.J. - Transverse strength of aluminous and feldspathic porcelain: J. Dent. Res., 53:3, p.683-690 (June), 1974.
- Shillingburg, H.T., Hobo, S. and Fisher, D.W. - Preparation design and margin distortion in porcelain-fused-to-metal restorations. J. Pros. Dent., 29:3, p.276-284 (March), 1973.

Skinner, E.W. and Phillips, R.W. - The science of dental materials.
5th Edition. W.B. Saunders Co., Philadelphia and
London, 1960.

Silness, J. and Hegdahl, T. - Area of exposed zinc phosphate cement
surfaces in fixed restorations. Scand. J. Dent. Res.
78, p.163-175, 1970.

Silver, M., Klein, G. and Howard, M.C. - An evaluation and comparison
of procelains fused to cast metals. J. Pros. Dent., 10:6,
p.1055-1064 (Nov.), 1960.

Smith, G.A. - Laboratory errors in porcelain crowns. Brit. Dent. J.,
139:3, p.98-101 (March), 1975.

Smythe, J.D. - Porcelain jacket crowns. M.D.S. Thesis, University
of Sydney, 1963.

Southan, D.E. - The physical properties of modern dental porcelain.
Ph. D. Thesis, University of Sydney, 1968.

Southan, D.E. - The development and characteristics of dental
porcelain. Aust. Dent. J., 15:2, p.103-107 (April), 1970.

Southan, D.E. and Jorgensen, K.D. - Faulty porcelain jacket crowns.
Aust. Dent. J., 17:6, p.436-440 (Dec.), 1972.

Southan, D.E. and Jorgensen, K.D. - Precise porcelain jacket crowns.
Aust. Dent. J., 17:4, p.269-273 (Aug.), 1972.

Southan, D.E. and Jorgensen, K.D. - An explanation for the occurrence
of internal faults in porcelain jacket crowns. Aust. Dent.
J., 18:3, p.152-156 (June), 1973.

Spiegel, M.R. "Statistics" The Schaum Publishing Co. New York,
p.188-189, 1961.

Spalding, E.B. - Replacing the entire natural enamel with porcelain.

Dent. Cos., XLVI, p.467, 1904.

Standards Association of Australia - Dental zinc phosphate cement.

Aust. Stand. No. 1186, 1972.

Stanought, D. - A study of the bonded porcelain technique.

Dental Technician, 20:3, p.22-28 (March), 1967.

Straussberg, M. - Technique of the all porcelain jacket crown.

Dent. items of interest, XXXIII, p.909-915, 1911.

Swartz, M.L. and Phillips, R.W. - A study of adaptation of veneers

to cast gold crowns. J. Pros. Dent., 7:6, p.817-821

(Nov.), 1957.

Thin, Vu-thi - A study of the Brinell hardness of metals used in

conjunction with the porcelain fused to metal technique.

M.S.D. Thesis, University of Indiana, 1962.

Tuccillo, J.J. and Nielsen, J.P. - Creep and sag properties of

a porcelain-gold alloy. J. Dent. Res. 43:3, p.579-583

(June), 1967.

Tylman, S.D. and Tylman, S.G. - Theory and practice in crown and

bridge prosthodontics. W.B. Saunders Co., Philadelphia

and London, p.644, 1961.

Vehe, W.D. - A rational method of application of porcelain in the

restoration of individual teeth. J. Amer. Dent. Assoc.

10:5, p.583-588 (May), 1923.

Vickery, R.C., Badinelli, M.S. and Waltke, C.D.T. - The direct

fabrication of restorations without foil on a

refractory die. J. Pros. Dent., 21:2, p.227-234

(Feb.), 1969.

Villain, H. - The fixing of bridges and crowns by means of gutta percha. Transcript of Sixth Int. Dent. Congress, p.746, 1914.

Vines, R.F., Semmelman, J.O., Leo, P.W. and Fonvielle, F.P.Jr.

- Mechanisms involved in securing dense, vitrified ceramics from preshaped partly crystalline bodies.

J. Amer. Ceram. Soc., 41:8, p.304-309 (Aug.), 1958.

Waerhaug, J. - Histological considerations which govern where the margins of restorations should be located in relation to the gingiva. Dent. Clinics. Nth. Amer., 4:1, p.161-176, (March), 1960.

Walton, C.B. and Leven, M.M. - A preliminary report of photoelastic tests of strain patterns within jacket crowns. J. Amer. Dent. Assoc. 50:1, p.44-48, 1955.

Warren, B.E. - Xray determination of the structure of glass.

J. Appl. Phy., 8:10, p.645-654 (Oct.), 1937.

