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THE IN VIVO FIT OF CASTINGS FROM TWO IMPRESSION SOURCES

A COMPARISON STUDY OF THE IN VIVO FIT CHARACTERISTICS OF CASTINGS PREPARED FROM A POLYSULPHIDE RUBBER TRAY IMPRESSION AND A DIETRICH'S COMPOUND BAND IMPRESSION SOURCE, USING A RECOVERABLE ELASTOMER REPLICA OF THE CEMENTING LUTE SPACE.

BY

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A CLINICAL RESEARCH STUDY SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN PROSTHODONTICS, (RESTORATIVE DENTISTRY).

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THE IN VIVO FIT CHARACTERISTICS OF CASTINGS

FROM TWO IMPRESSION SOURCES.

ABSTRACT.

A study was undertaken to establish whether selected characteristics of fit of castings differed depending on whether either a polysulphide rubber or a thermoplastic impression source was used. Sixteen full crown preparations in seven patients were used to register impressions using the impression materials sequentially, each preparation therefore furnishing a "matched pair" of dies. Two resultant castings were sequentially "cemented" on the same tooth in vivo using a recoverable elastomer material in place of a conventional phosphate cement. The thickness of the recovered elastomer material was measured directly under an optical stereomicroscope as well as indirectly by a photodensity technique. It is assumed in this study that the space between casting and preparation, occupied by the elastomer material, represents the cement thickness and hence the lack of fit had the casting been permanently cemented.

In spite of a very limited sample size, the frequent observation of a thinner lute thickness suggested a better casting fit when polysulphide rubber had been the impression source. This difference of fit reached a statistically significant level around the more occlusal aspects of the preparations.

Other relevant findings hinted that the average lack of fit at the buccal margin of castings exceeded that recorded at the lingual. This was further reflected in a tendency for castings to seat obliquely in the lingual direction. Some tentative hypotheses have been developed to partially explain these observations, and as well, some suggestions for further research have been proposed.

RESUME

Le but de cette étude est de déterminer si certaines caractéristiques d'adaptation des coulées varient selon l'utilisation d'un matériau d'empreinte en caoutchouc de polysulfure ou en thermoplastique. Seize couronnes complètes ont été posés chez sept patients pour enregistrer les empreintes, en se servant successivement des matériaux d'empreinte; chaque préparation fournissait donc "une paire jumelle" de modèle de pierre. Ensuite, les deux coulées ainsi obtenues ont été cimentés successivement sur la même dent en vivo au moyen d'un matériel élastomère récupérable au lieu du ciment conventionnel en phosphate. L'épaisseur du matériel élastomère récupérable a été mesurées directement sous un stéréomicroscope optique et indirectement grâce à une technique de photodensimétrie. Dans cette étude, on suppose que l'espace qui existe entre la coulée et la préparation, occupée par le matériel élastomère, représente l'épaisseur du ciment d'où le manque d'adaptation si la coulée avait été cimentée de façon permanente.

Malgré l'échantillonnage très réduit, l'observation fréquente d'un film moins épais suggère un adaptation plus précis de la coulée lorsque le caoutchouc de polysulfure est la source de l'empreinte. Du point de vue statistique, cette différence d'adaptation prend des proportions importantes lorsqu'il s'agit des aspects occlusifs des préparations.

D'autres découvertes à ce sujet laissent entendre que la déficience moyenne de l'adaptation au pourtour buccal des coulées dépasse celle enregistrée au pourtour lingual. Cette tendance se reflète également dans la propension qu'ont les coulées à se fixer obliquement en direction linguale.

L'auteur présente certaines hypothèses probables qui expliquent partiellement ces observations et avance quelques suggestions sur les recherches futures.

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INTRODUCTION

The inability to precisely predict and quantitatively assess the eventual fit of a cemented cast gold crown in situ before its actual irreversible cementation has left a serious gap in the understanding and prognostication of clinical success.

Clinically, the usual procedure has been to assess the fit of a crown margin prior to cementation, whereas this is not the functioning unit, and it is as yet undetermined how the properties of the fit before cementation relate to the situation after cement has been introduced.

Many studies conducted in-vitro have assessed the individual component accuracies of the materials and techniques per se. However, there have only been a few in-vitro studies on the overall characteristics of fit of castings when cemented: Fusayama et al; 1963; Bassett, 1966; Christensen, 1966; McCune, Phillips, Swartz, and Mumford, 1971; and Jones, Dykema, and Klein, 1971. Fewer still have been performed in-vivo: Yoshida,1959; Murata, 1967; and McLean and Fraunhofer, 1971.

However, without knowing precisely what dimension of fit is being routinely achieved clinically, it becomes difficult to define the ideal requirements of a casting by the available technology. Also, until a method of quantitative assessment is found, capable of application to a longitudinal study, it will be difficult to determine what degree of fit is biologically compatible. Consequently, to date, there has been conflicting information owing to a mechanical rather than biological bias to the study of margins. For example, much has been stated on the gingival placement of margins without any actual correlation to the fit of these margins. Consequently, this has left biological compatibility and an estimation for prognosis open to clinical opinion which Christensen,(1966), demonstrated to be highly subjective.

The current study was designed to investigate and compare quantitatively the characteristics of fit when cemented of unvented type III gold castings for anterior tooth full coverage preparations, obtained from two common impression techniques in-vivo.

A Dietrich's thermoplastic compound impression source,held in an unannealed copper band, was compared to that of a polysulphide rubber impression source (catalytic set), held in a custom tray,as a pair for each of sixteen tooth preparations.

An elastomer of similar flow and film properties was substituted for phosphate cement as the cementing medium for the castings, (table I). This cement lute replica was recoverable without sacrificing the tooth.

The variables in the laboratory phase of casting construction were controlled as a constant for each member of each pair of impression sources by ushering the pair through a split of the same mix of die stone, and waxing, spruing and then investing them as a pair together in the same casting ring.

The comparison and analysis were made by microsectioning and micromeasurement of the embedded cement lute replicas as mutual pairs in the bucco-lingual plane. This was complemented by a prior overall assay of the recovered membranes in three dimensions by photodensity estimations of the lute thicknesses.

Additional concepts were under investigation:

It was questioned whether there would be any significant differences between the impression sources which would persist to the final cemented fit of their castings, despite changes occurring during the laboratory proceedures, and the effects of the particle component and hydrodynamic manipulation of cement flowing within a semi-closed system.

Fusayama et al.(1963) demonstrated that an overall passive innate space is needed for cement in the order of 30µm to allow optimum seating of castings. It was thus postulated for the current study that the expected poorer adaptation of the Dietrich's impression compound might produce a slightly oversized die and hence a more passively fitting casting in certain aspects than would castings from the Rubber impression source. Consequently, this might allow greater cement flow and permit further seating to compensate, cancel out, or even improve upon the anticipated closer innate fit of the castings from the Rubber source prior to cementation.

Routinely, researchers from Hollenback (1928), to Dimashkieh et al.(1974) and others, reported that castings never seat to their theoretical capability during cementation, and were particularly anxious at the reflection of this effect at the marginal seal. This led to many suggestions to compensate for the cementation effect but usually without any substantiating scientific evidence, except for the merits of venting as shown by Jones, Dykema, and Klein,(1971). Other suggestions have included the empirical over-waxing of margins, Bassett, (1966), and Smith and Potter, (1928); the superimposition of long bevels onto shoulder preparations, Stein, (1975); and various concepts of internal relief of castings on which Fusayama et al.(1964) contributed the most information. However, there is little information scientifically defining the differential location of binding zones beneath a casting, except for an in-vitro study of the fit of castings to their dies uncemented, by Teteruck and Mumford, (1966).

A critical look was also aimed at the claimed advantage of recording extra unprepared tooth structure beyond the limits of the prepared chamfer margin in order to more easily produce a defined and superior crown margin. This has classically been suggested as an advantage of a band impression technique.

Dietrich's Elastic Impression Compound is best classified with the A.D.A. Type I model compounds and the impression waxes as a non-elastic thermoplastic compound suitable for rigid band impressions. As such, it must be considered as capable of moderate accuracy reproduction per se. relative to polysulphide rubber which is a truly elastic material of considerable accuracy if properly supported in thin sections. A.D.A. Specification 3 and 19,(1967), and Schnell and Phillips,(1958).

Comparing the coefficients of thermal expansion and conductivity, and the setting contraction, of polysulphide rubber to impression compounds; as by Hollenback (1957), Roydhouse (1962), Combe and Smith (1965), and Phillips and Skinner (1973), and the relatively high permissible flow specification for Type I compounds at mouth and room temperatures allowed by A.D.A. testing, it is evident that a compound impression may not record quite the same detail nor be as stable as polysulphide rubber. Clinically, however, Dietrich's is thought to be suitable for full crown restorations where there is little to no infrabulge beyond the preparation margin. Because the compound requires the support of a band, the impression technique carries a possible advantage of permitting fuller entry and easier recording of this critical area. A band concept may, therefore, directly affect the philosophy of margin placement and design by enabling the preparation to be terminated closer to the epithelial attachment. Of course, great care is needed to avoid tearing the attachment.

The work by Christensen (1966) on the detectability of subgingival margins under the most detailed scrutiny in-vitro, suggested that a cemented fit of 119μm would be accepted as good. However, the available studies on cement lute discrepancies at crown margins indicate that greater deviations than this are occurring routinely. Analysing this observation, it was considered that when a margin is selectively accepted during the more usual clinical assessment procedure prior to cementation, a similar limit for margin discernability probably applies. This innate margin discrepancy would be subsequently compounded once cement has been introduced.

The author of the current study has been concerned that the limitations of normal clinical discernability might be more significant in determining what is clinically acceptable than is the variation in fit resulting from the technology of the currently used methods for indirect restorations. Never-the-less, the available technology might be seriously criticized in tolerating an inherent range of fit to at least the upper limits of margin detectability, rather than adhering closer to the ideal 25μm fit as defined by the A.D.A. Specification 8. for the grain size of Type II phosphate cement.

Differences between available technologies may thus pass clinically undetected, unless extra-ordinary means, such as in the current study, are being applied. These differences may later be shown to have a biological significance, even though the overall effect of cementation is expected to mask or dilute any significant mean differences between any two impression sources under study. However, were this to occur, it would not necessarily negate the significance of any innate difference between the castings, but instead, may be an indication for a new cement technology.

The terms "clinically acceptable", (probable synonym, "clinically detectable prior to cementation"), "clinically achievable", for the current technology, and "biologically acceptable" need to be discussed and better defined for castings.

The current study purports to record differentially what fit is being actually achieved by gold castings for full crown preparations on anterior teeth in-vivo, using and comparing routinely available technology under careful and controlled conditions.

REVIEW OF LITERATURE

Previous Methodologies of Investigation

The basic methodology of this paper was described by McLean in 1971, and stands as the only differential in vivo technique to date. It also holds to standard clinical procedure.

The other clinical studies are by Murata (1967), and Yoshida (1959) who investigated the fit of castings made in vivo on teeth slated for extraction, and of random castings on teeth which, for various reasons, required extraction in a dental school clinic.

However, the bulk of information and understanding has come from laboratory models which allude to the clinical situation, but which by limiting out variables to analyse a particular accuracy, may exclude factors that could overwhelm or modify the component under test in vivo, especially when considering the host of phases of fabrication. As an example, the use of a modified Verticulator by McCune and Phillips (1971), and also by Jones, Dykema and Klein (1971) to guide the vertical seating of a casting inevitably diminished any oblique seating, which this current clinical study and other authors consistently demonstrated.

Studies by Jorgensen (1960), Kaufman, Coelho and Colin (1961), Bassett (1966) and McCune, Phillips, Swartz and Mumford (1971) relate cement lute thicknesses to the vertical displacement of a casting before and after cementation, the overall displacement being calculated as the average film thickness, or by geometry of the die, the occlusal, axial, and gingival lute deduced. However, the information so derived is difficult to fully relate to the true clinical situation. Fusayama, Ide, and Hosoda (1964), showed mathematically how the preparation margin shape and the axial taper can greatly affect the size of the exposed marginal cement lute for any given displacement. (Fig.14). Clinically, therefore, a less perfect or less consistent preparation would incorporate a variety of margin and taper configurations to complicate the picture.

Early work by Jorgensen (1960-68), and Kaufman, Coelho, and Colin (1961), analysed the somewhat artificial effect of cement lute flow between precision machine turned metal and plastic dies and corresponding metal wells. A similar effect was achieved in the venting study by McCune, Phillips, Swartz and Mumford (1971) where castings were cemented onto dies produced from stone pours into the actual casting and then separated. More recently, Dimashkieh, Davies, and Fraunhofer (1974) have observed the properties of cementation and fit beneath full coverage restorations made by copper plating an acrylic die and recementing the plated coping after separation. This was subsequently sectioned. These studies, therefore, assume a 100% fit of a casting, and in fact only deduce the behaviour, flow and set of cements in that special situation. However, in the true clinical situation, McLean (1971) pointed out that this concept of tolerance is as yet unfortunately unattainable except at point contacts between the casting and the preparation. Depending on these locations, which in normal pr cedure remain undefined, important aspects of the casting, such as at the margin seal, may still contain large discrepances despite the clinical impression of an excellent fit.

Fusayama et al.(1963), realising the need for a finite cement lute space, experimented with the effect of an improved thermal expansion casting technique on the fit of cemented castings: a compatible copper alloy was substituted for gold, and gross sectioning was performed once cemented onto its extracted tooth preparation. Micro measurements were then made.

Christensen (1966) lined up MOD inlays cemented and burnished onto extracted tooth preparations. Subjective scores made for the exposed occlusal and hidden subgingival margins were assessed against micro-measurements on gross sectioning at the gingival, proximal and occlusal positions.

Jones, Dykema, and Klein (1971) used a modified Verticulator devised by McCune (1968) to ensure the vertical cementation of gold castings onto silver plated copies of master dies. Telemetric measurements were made of the total vertical displacement and marginal opening prior to and post cementation for vented and unvented crowns. No sectioning was performed to establish further differential readings.

Teteruck and Mumford (1966) provided valuable differential information on the fit characteristics of a variety of cast alloys, investments and preparation shapes before cementation, but in this uncemented state it is difficult to relate this to a biological significance in the in situ situation. Castings were seated onto their dies and were then embedded for sectioning and micro-measurement. Of the conclusions, it was stated that the definition of casting accuracy should take into consideration a degree of fit rather than absolute adaptation which is in agreement with the objectives of Fusayama et al. (1963) as described previously.

ACHIEVABLE FIT OF CASTINGS.

The American Dental Association Specification 8 indicates that the minimum film thickness of phosphate cement should be 40μm for type I, and 25μm for type II cement which is thus an effect of the particle size.

Several workers have recorded mean thicknesses at the margin below this value. Fusayama et al. (1963) using an expanded casting technique reported a 13μm minimum film under very heavy loads. Jorgensen (1960) obtained a lowest reading of 14.5μm for vented machined "castings" which he considered to be approaching the effective grain size minimum for the cement. The average gingival film thickness was 33μm with variations being dependent on the angle of taper, crown length, seating load, cement consistency and grain size.

The study by Christensen (1966) subjectively considered the cemented fit of MOD castings as acceptable on a range of fits which on sectioning proved to be 26μm to 119μm for the hidden subgingival margin, and, by linear regression, 39μm was derived as the least acceptable occlusal margin. It is to be noted that the latter measurements were obtained by the cementation of inlays which would, therefore, have offered less resistance to cement flow than a full veneer casting. Also, the final evaluation was taken after burnishing the gold to the tooth preparation directly, and does not necessarily correspond to the initial fit of the casting. However, although Christensen determined that the marginal lute could be reduced by burnishing the gold, a photomicrographic study by Bjorndal and Sahs (1960), showed that gold can never occlude the cement line, and where burnishing had been attempted, a ragged line of gold was observed.

Many workers, of note, Hollenback (1928), Lange (1958), Jorgensen (1960), Kaufman et al.(1961), Fusayama et al.(1963), Bassett (1966), McCune et al.(1971) and Dimashkieh et al.(1974), recorded an occlusal cementation discrepancy.

However, in the latter two studies respectively, a high reading of 1119μm. (depending on the classification of cement used) and 1214.39μm. (depending on the angle of taper used) was produced for the unvented copings of these investigations. Because of the 100% fit concepts of the methodologies used, namely direct pours into the fit surface of the castings (McCune et al.) and directly copper plated "castings" (Dimashkieh et al.), there was no room for axial escape of cement until the copings were subsequently vented.

The refined television micromeasurement study by Jones, Dykema, and Klein (1971) demonstrated the same displacement effect in vented castings, and there was an average improvement in seating through-venting of 84.6μm. for the premolar preparations, and 36.7μm. for a molar group. A maximum buccal gingival discrepancy of 92.34μm. was observed in the non vented premolar group, but from the view point of comparison, the finish lines used were very apically inclined chamfers and feather edges, probably more compatible to the lingual preparation and lingual crown margin data in the current study.

Teteruck and Mumford (1966) performed differential micro-measurement fit studies on uncemented castings. Different shaped preparations and different alloy and investment combinations were utilized. Incomplete seating and binding was routinely recorded, and all axial walls proved to end shorter than their corresponding lengths on the original die.

The Degree of Casting Accuracy of Various Gold Alloys and Investment Combinations (uncemented)

For Kerr Cristobalite and Ney G 3 gold (in μm)

	Gingival Margins		Occlusal	Axial	
	Buccal	Lingual		Buccal	Lingual
Mean	157	171	155	0	130
Standard Deviation	24	6	60	0	16

For Whip-Mix Ceramigold Investment and Ceramco No.1 Alloy (in μm)

	Gingival Margins		Occlusal	Axial	
	Buccal	Lingual		Buccal	Lingual
Mean	19	31	34	18	19
Standard Deviation	16	8	12	6	12

(After Teteruck and Mumford 1966)

Often the resultant discrepancies of cementation are beyond normal clinical detection but may still be biologically evident. Huffman, Regenos and Taylor (1973) observed the magnification of this vertical displacement effect following the cementation of full mouth splinted gnathological cases even after remount procedures had been previously performed.

Huffman et al. (1973) cite observations by Yoshida (1959) and Murata (1967), made during in vivo studies.

Yoshida (1959) experimented with direct and indirect pattern full crown castings which were cemented onto extracted teeth. No real difference was found between the two groups, but Yoshida was disturbed to find 200μm cement lutes at the occlusal. This was then repeated clinically on teeth slated for extraction, but on sectioning, a discrepancy of 150-200μm was recorded. There was of course no opportunity for longitudinal study.

Murata (1967) surveyed extracted teeth containing full crown castings made at dental school, and found that the cement discrepancies at the occlusal ranged from 50-200μm for bicuspids, and 60-230μm for molar teeth. There was an equal discrepancy at the gingiva.

Fusayama et al. (1963) presume that an initial passive space is required to accommodate the cement between a casting and the preparation, and assume that the final cement lute space will be greater than the original space. It was found that a cement thickness may be readily reduced to 40μm, but to go beyond 30μm needed a sudden increase in load to overcome the cement resistance.

To detect the resistance of cement to adaptation one would need to measure this initial passive space, but Fusayama states that there is currently no way of recording this differentially except by a summation of the component accuracies to fabrication. According to Fusayama, the original space for an indirect pattern full crown casting is therefore 10 to 20μm at the axial wall, which explains why 90μm was recorded occlusally and at the cervical shoulders owing to the resistance of the cement which was forced to squeeze through this narrow space.

Fusayama studied the improvement in seating achieved by cementing a slightly expanded casting(produced from impression and die expansion techniques.) It was concluded that the occlusal displacement was minimum where the calculated expansion fit (or inate cement lute space) was more than 30μm. This relates well to the in vivo observation by McLean that the external and internal gingival line angles of porcelain jacket crowns when cemented, compared very closely to the fit of cast metal to ceramic crowns despite or possibly because of the platinum matrix which provided an overall even distribution of cement.

Attempting to suggest an optimum film thickness with respect to retention, Fusayama and Iwamoto (1960) tested optimum film thickness strengths between metal plates related to the pressure. The results were described by a hyperbolic curve, with a thickness of 35-40µm at a load of 10kg producing a curve that reached the point nearest zero.

Similar metal plates were cemented onto enamel, dentin and other metals, with different film thicknesses resulting from different seating loads to test the shearing strengths. Separation generally occured at the metal/cement junction. The lute thicknesses that best tolerated a maximum force for retaining inlays was 38µm for enamel, 31µm for dentin, and 24µm for metal. More than 60µm was required to produce the maximum force on wet dentine. However, although these figures are an indication for the required lute, Jorgensen and Esbensen (1968) find them more an examination of the influence of the cement film thickness upon friction rather than retention. It is of interest to note an optimum of 24µm for metal to metal, since it is this application between cast telescopes where cementation becomes suspect with time. It is probable that such telescopes need an uncommon overall adaptation for truly adequate strength.

Fusayama et al. (1964) examined the effect of artificially incorporating an internally relieved or passive fit casting using an application of manicure liquid or tin foil strip applied bucco-lingually. At 15kg cementation pressure, the result was in favour of some spacing: (a "compatible" copper alloy substitute was used for the gold alloy).

Improvement of The Fit of Castings Following Internal Relief (µm)

	Cervical Shoulder	Occlusal Floor
No relief	110 ± 42	90 ± 22
Manicure Liquid	38 ± 16	120 ± 34
Tin foil	34 ± 5	82 ± 10

(After Fusayama et al., 1964.)

Smith (1971), commenting on cements, states that, although the A.D.A Specifications probably represent the best results possible, the usual inaccuracy of castings results in film thicknesses in the order of 100µm for phosphate cements and similarly for the newer cements.

The in vivo study by McLean and Fraunhofer (1971) suggested that up to a 120µm lute at the gingiva was acceptable clinically and this could possibly be extended to consider 160µm. The differential results obtained were:

	Axial wall	Occlusal floor	Mesio-cervical external line angle	Disto-cervical external line angle
MOD inlay	105.3±71.9	142.0±94.6	60.0±71.8	68.0±89.9
Metal ceramic crown	75.4±38.0	138.6±61.9	66.7±60.8	26.1±26.2
Porcelain jacket crown	92.9±53.1	112.3±66.4	77.7±45.6	48.8±51.1

(For PJC, labio-lingual aspect determined.)

CLINICAL ACUITY AND COMPETENCE.

The present armamentarium is rather too crude and subjective to satisfactorily detect open margins when protected subgingivally.

In the study by Christensen (1966), the margins of ten inlays, constructed and finished onto extracted teeth, were evaluated by ten instructor dentists, and their subjective opinions of fit were equated to microscopic measurement. Gingival margins with openings up to 119µm were accepted, whilst proximal and occlusal margins with as little as a 26µm opening were rejected. Statistical correlation showed that the proximal and occlusal scores assigned by the operators had a significant relation to the actual microscope measurement, but for the gingival, no such relation held. There was more disagreement on the clinical acceptability of gingival margins than any other location. Also explorer examination of visually accessible margins was found to be superior to, and more reliable than, explorer or radiographic examination of visually inaccessible margins.

McLean (1971), by micro comparison of a new explorer tip to an adjacent human hair of 40µm diameter, demonstrated that the hair may be indiscernible to the probe. The same explorer after only three weeks use may be inadequate to detect 80µm. In the same study, detecting the marginal leakage of inlays radiographically by tracing the bitewing and comparing it to the cement lute replica could, at best, only be related to a 60µm to 80µm discrepancy. In addition the orientation of the metal may often shield a large deficiency.

Bjorn (1970) performed a radiographic survey to relate defective gold and porcelain margins to bone loss. He found 83% of gold restorations and 74% of porcelain to have defective margins. A margin defect of 0.22mm was found in 68% of the gold, and in 57% of the porcelain restorations, which was greater than that determined earlier for amalgam fillings by Bjorn in 1969. However, it must be noted that radiographic assessment is not refined enough for a significant evaluation, and if bitewing radiographs are used, any information for the buccal and lingual aspects are excluded for an in vivo situation.

Other methods of visualizing the full seating of a casting include cutting occlusal vent holes or windows for direct examination. However, this would not take into account any innate space between the uncemented restoration and the preparation. Furthermore, Jones, Dykema, and Klein (1971) feel that the limit of visual acuity is only 50μm even under ideal situations of accessibility, which the above situation is not. This limit is confirmed by Igarashi and Woelfel in an unpublished research report cited by Huffman, Regenos and Taylor (1973). Also Phillips R.W. states that the human eye is limited to discerning a cement line of 30 to 50μm wide.

Since a piece of articulating paper of 50 to 70μm and a human hair of 40μm is detectable between occluding natural teeth, it is probable that cementation discrepancies ranking more in the order of 100um would be biologically significant but, unfortunately probably not immediately apparent clinically by the techniques available. However, even if occlusal discrepancies are searched for using plastic shim stock paper of 0.0005 inch or 12.5μm thickness, it is doubtful whether any clinician could work within such accuracies.

PERIODONTAL CONSIDERATIONS AT THE CROWN MARGIN: BIOLOGICAL COMPATIBILITY

That microbial plaque is largely responsible for continuing caries and periodontal disease, as shown by Loe (1965, 1967), is no longer questioned. According to Alexander (1971), it is clinically evident that plaque retention is greatest in regions which are more inaccessible and less self cleansable, namely the facial and lingual cervical areas and interproximally. Yet, it is into these locations that foreign prosthetic material, exhibiting varying surface retention properties, is to be introduced, and by techniques which tax the ability to recreate the original anatomy least of all improve upon it.

Goldman (1951) described the buccal gingival connective tissue fibres as being less coarse and fewer than in other locations, thus correlating form with function in a region that sustains less stress. However, this thinner, less bulky buccal gingiva and alveolus might also be least prepared to receive the unnatural additional stress of a crown margin, and it is, indeed, here that early problems most frequently arise.

The position of the gingiva dictates that it will be in intimate contact with most major restorations. Local irritation elicits an acute inflammatory response which Ivancie (1958) states is a reaction to eliminate or neutralize the irritant, ending in resolution and repair. However, irritation due to a cemented restoration cannot be completely resolved, and a chronic state of gingival inflammation persists. Goldman (1973) observed that apical migration of the epithelial attachment often follows gradually if the deeper gingival barrier fibers are destroyed, resulting in pocket formation and an early, perhaps precipitated, periodontitis.

Irritation From The Crown-Cement-Tooth Margin.

The Effect of the Cement-Lute Line at the Gingiva

Norman, Schwartz, and Phillips (1963) indict the gradual dissolution of the peripheral cement line as causing plaque stagnation and consequent inflammation. All the values for cement solubility in distilled water fall within the A.D.A. specification of 0.2% after 24 hours, but the saliva environment can be quite different. The solubility of phosphate cement in weak organic acids, such as citric acid, may be 10 to 20 times greater. This can be in the order of 1.9% solubility at pH4 as opposed to 0.1% in distilled water. In addition, other oral corroding agents are abundant. Acids, ammonia and sulphides are present depending on the diet and oral flora. The cements do not all react similarly. Thus zinc phosphate cement is readily softened by hydrogen sulphide, and yet the other classes of cements are not affected.

Waerhaug (1960) stated that soft tissues can adjust just as well to rough as to smooth material provided that no movement occurs between the two. This could occur where a margin were dropped into an existing deep pocket and exacerbated if the tooth also exhibited some mobility. However, roughness leads to plaque accumulation which in turn leads to inflammation. Removal of this subgingival margin plaque is usually impossible, hence why real healing against a restoration is rare.

Jones, Dykema and Klein, (1971) observed in vitro that when set cement was cleaned away from the tooth, a portion of the cement pulled out of the margin, leaving an open margin with no cement.

It is reported by Silness and Hegdahl, (1968), that this cement line can in fact have a total surface area of several square millimeters.

Furthermore, if blood tissue or debris inclusions occur during cementation, organic voids may remain in the cement line, priming them for culture and breakdown, which may contribute to the dark gingival line observed over some porcelain jacket crowns, or indeed promote plaque associated disease. (Shelby 1972)

Waerhaug (1953), in a histological study of acrylic crowns placed in two dogs, noticed that where necrotic tissue was trapped in the cement margin seal owing to imperfectly adapted margins, further irritation to the surrounding epithelium and connective tissue ensued.

However, it was shown experimentally by Waerhaug and Stein (1952) that the mere presence of a crown margin, no matter the material, will alter the flora in the gingival sulcus.

Consideration on The Location of The Crown Margin.

The data for this debate can be divided into its animal or human study sources. However, the animal studies can be criticised for their small sample size, the different oral flora from the human subject, and the difficulty in establishing an oral hygiene regime. The human studies have been disadvantaged by a lack of histological information which has limited the analysis to scoring methods. Regrettably the longest longitudinal study has been only three years. (Richter and Ueno 1973).

A small, animal study on the location of margin placement by Karlsen (1970) demonstrated greater inflammatory reaction histologically in conjunction with further subgingival extention of castings and with poorer fits. A band of inflammatory cells could be followed from the gingival margin to beyond the apical part of the pocket.

Interestingly, in instances where no casting or temporary was inserted following tooth preparation, there were no signs of inflammation.

An animal study by Marcum (1967), proposed that there was beneficial response where the margins were located at the gingival crest as opposed to being sub or supra gingiva which was contrary to other investigations.

In a two year longitudinal study of eleven human subjects by Hergman, Hugoson and Olsson (1971), the one year Gingival Index (Silness and Löe 1963) was higher for teeth with artificial crowns than for those without. Yet at two years, the difference was not statistically significant. There was no statistically significant difference for the Plaque Index related to crown margin placement. However, the obtained differences all tended to suggest that subgingival placement was the more injurious to the gingival tissues.

Larato (1969) conducted a survey of service veterans presenting with crown restorations. Subjective scoring indicated that 83% of all crowns with sub-gingival margins were associated with inflammation. In contrast, only 21% of crowns with the gingival margins positioned at a height even with the gingival crest were associated with gingival inflammation, while supra gingival placement reduced the frequency of inflammation to 16%.

Richter and Ueno (1973) attempted to get away from the interpretation inherent in animal studies, and set up a three year longitudinal study with humans. Intra subject comparisons were derived by using crown castings to fit dual margin preparations, that is to say the buccal margin was prepared for a sub and supra gingival section. Applying gingival and plaque indices, there were no statistical differences for the margins. However, when inflammation was observed, it was only in the case of sub-gingival margins, but of the latter only three out of twelve exhibited this response.

Amsterdam (1974), summarizing 25 years in periodontal prosthetics, says "the least desirable place to terminate a margin is just supra-gingivally" since it is the free gingival margin which is the area of greatest plaque formation. Amsterdam advises a restriction to partial coverage if a completely supragingival margin is the treatment required, otherwise margins must be meticulously prepared and placed sub-gingivally.

Yuodelis (1973), feels that "the merit of a good casting must not be underrated", provided that over-contouring is avoided. A casting may set up an environment for dramatically improved healing where previously it was inhibited because of underlying softened carious dentine, erosions, old cervical restorations, and deep furcation involvements. Thus Richter and Ueno too were lead to state that inflammation is not axiomatic following full crown therapy if of excellent marginal fit and contour.

Waerhaug (1953) also feels that it is probable that well fitting crowns may not cause sufficient irritation to cause a deepening of a pocket. He does not qualify a well fitting casting from the concept of cement margin seal, but does state that the crown margin must not come closer than 0.4mm to the epithelial attachment.

Waerhaug observed "in one case where the preparation had passed beyond the bottom of the existing pocket, and where the crown did not completely cover the preparation region, reattachment was attained all the way to the cervical margin of the crown."

Tissue Tolerance To Materials per se.

Many authors, Waerhaug (1956) and Rosen (1964) commend the gingival response to gold foil, which if superbly produced most nearly achieves the optimum properties for the given available technology. This becomes due firstly to the rigid discipline of the technique, then to the very close adaptation to the margin without the presence of an intervening cement line, thirdly to its potential high burnishability and polish which implies low surface porosity, and lastly to the lower free surface energy which lowers its wettability and minimizes plaque retention. (Glantz, 1969) In comparison, Glantz found that dental porcelain, silicates, cobalt-chrome alloy, stainless steel, and corroded silver-tin amalgam, have high surface energies in excess of 100 dynes/cm whereas organic oral liquids and plaque have surface energies around 55 dynes/cm. The higher surface energy of a solid, the more easily wettable it is by lower surface tension liquids. Thus in overall comparison, both enamel and dentine with a critical surface energy of 46 dynes/cm are less likely to be wetted by plaque than any foreign surface clinically useful or available. For example, the mean surface energy between stimulated saliva and polytetrefluoroethylene plates is only 30 dynes/cm, but this is unusable clinically. Also to note, heat cured poly-methyl-methacrylate has a low free surface energy, 41.2 dynes/cm, but because of porosity and liquid absorbability, it is unduely retentive of plaque.

Of interest, tooth structure exposed to topical fluoride has a reduced free surface energy which may facilitate its self cleansability. The contact presence of lactic acid, however, raises the free surface energy of enamel and dentine rendering them hydrophilic until subsequently polished with pumice.

The Gingival Response To Restorative Procedures.

a) Preparation.

Use of any rotary instrument, even a rubber cup, may remove the entire crevicular epithelium. Fortunately, the injury is reversible and heals, according to Waerhaug (1960) and Löe (1968) within fourteen days, and according to App (1961) in up to thirty days.

b) Impressions.

Harrison (1961) showed that mere introduction of a cotton string into the gingival crevice causes cell injury. Impregnated strings showed greater damage. There is though some agreement, that lesions allowed to heal against clean tooth structure leave no permanent damage.

Stein and Glickman (1960) observe that copper band impressions frequently detach gingival tissue from the root face. However, it was felt that this was temporary provided no particles of compound or wax remain in the area.

c) Cementation.

Waerhaug (1953) described the excess residue of cement left uncleared from a gingival sulcus as a "strong irritant".

COMPENSATION TECHNIQUES TO IMPROVE CEMENTED FIT.

Bassett (1966) lists several proposals:

1) Internal surface relief.

2) Perforation of crown; venting.

3) Passive fit of castings.

4) Overextending the gingival margins.

5) Increasing the taper of axial preparation walls.

1) <u>Internal Surface Relief.</u>

In 1928, Hollenback observed that the more precise the fit of an inlay, the more space is required for cement. He etched the fit surface in aqua regia for up to 30 minutes, finding this especially important for full crowns.

Bassett (1966), by measuring the total vertical displacement during the cementation procedure in vitro, compared the effects of stripping and venting versus that of non venting, the load being 45Kg and applied for 10 minutes.

The Total Vertical, Cementation Displacement and its Improvement By Venting. (Bassett,1966):

Crown I		Crown II	
Electrostripping (150 seconds and 50 seconds)	170µm	Aqua Regia Stripping (5 minutes)	150µm
Then Venting	20µm	Then Venting	10µm

Jelenko put out the Electro Dip unit for reverse electroplating advising a 30 second application. However, tests by Igarashi and Woelfel (1970), upon a flat strip of dental gold alloy evidenced only a removal of 6µm after 30 seconds, which would not be clinically significant.

Fusayama et al. (1964) investigated the effect of the application of nail varnish or tin foil to the dies. The lack of seating was improved by 34 to 44µm. There was no significant difference between the two methods except that the varnish was less controllable and could produce undercuts. The results obtained with the tin foil relief procedure were superior to that obtained previously by venting. Very similar improvements of seating were obtained by using foil relief on only the bucco-lingual aspects, and was considered the most easily managed technique. Since the foils used were very thin, it was claimed that nothing detracted from the retention properties of the casting. According to Fusayama, direct internal surface relief using dental burs has the disadvantage of irregular loss of bulk and consequent uncontrolled cement lute thicknesses.

The question has, however, been asked, what occurs to the retention properties of a crown with internal relief, and if seriously detracted should the procedure be dropped in complete favour of venting. A study by Jorgensen and Esbensen (1968) shows this not to be a serious problem from the point of view of overall crown retention.

2) Venting.

Jorgensen (1960) stated that hydrodynamics are the prime consideration in all cementation work, the principal rule to obtaining the thinnest film being to produce the maximum cement flow during the initial stage of the cementation process. When considering the physics of viscosity, Jorgensen finds it more difficult to conceive of cement flowing gingivally uphill through the increasing wedge of the taper, than for it to flow occlusally through a vent, since this could occur rapidly and early. The average film thickness of 33µm at the gingiva for a ten degree taper fell to 17.5µm when the crown was vented, but for a twenty degree taper, the drop was from 24µm non-vented to 20µm vented, a fall of only 16%.

Also in (1960), Jorgensen claimed that defects in the cement film due to the liquid/powder filtration effect can be virtually eliminated by an occlusal vent which allows a liquid flow both occlusally as well as gingivally and thus reduces the filtration excess of phosphoric acid at the periphery. The latter is discussed subsequently.

Fusayama et al. (1964) differ, indicting the technique of venting as inconvenient, and advocate other methods of providing space for cement.

In a venting study by McCune, Phillips et al. (1971) the range fell from 32-76µm at the axial wall, unvented, to 10-46µm vented. At the occlusal, the mean fell from 476µm unvented to 141µm vented. There was some variation depending on the catagory of cement used. It should be noted that the high unvented readings were in part owing to the 100% perfect fit concept of the method used which ruled out an innate space for the cement lute.

An in-vitro telemicromeasurement study on extracted tooth preparations (5-7°taper) by Jones, Dykema, and Klein (1971) showed that all vented crowns seated further with respect to the mean differences pre- and post-cementation. The vented molar group always showed the least mean difference between the vented and non-vented categories. Throughout, it appeared that the molar crowns seated slightly further than the premolar group. The only catagory showing a significant mean difference above 40µm (A.D.A. limit, Specification 8) between vented and non-vented castings was the natural tooth pre-molar group, the largest difference being 92.34µm on the buccal margin. This bears out other observations of the effect of occlusal constricture. The opinion was held that vented crowns, because of the decreased resistance to cementation, could slip past any interferences whereas non-vented crowns would not, but this was not proven.

Courtade (1966) recommends the occlusal venting of crowns to permit full seating and to minimize post-operative sensitivity caused by the pressure of the cement liquid on the many open dentinal tubules.

Experimental evidence from studies on dogs and monkeys by Bender, Seltzer and Kaufman (1959) using cultures of Streptoccus Faecalis shows that pressure from an impression frequently forces micro-organisms through the dentinal tubules and into the pulp. Venting will reduce the required seating pressure for the same fit. Care must therefore be taken to clean any preparation of saliva, blood and plaque before cementation, and some operators advocate the prior use of a varnish, as a preliminary seal.

Kaufman (1961) agrees that venting will allow further seating, and will increase the retentive ability of castings by 19-32% as a consequence of the improved adaptation to the preparation, and to the actual increase of coverage in the marginal area.

3) Passive Fit of Castings.

What might appear to be a very precise fit of a casting may in reality be due to binding at undeterminable locations which in fact may be inhibiting further seating. McLean (1971)

The work by Teteruck and Mumford (1966) on uncemented castings indicated that all veneer castings tend to bind. Furthermore, any snug binding fit regions have no innate space available to accommodate the expected current cement particle thickness, and thus lift poorer regions of fit before cementation into an increased discrepency after cementation. (Kurosu and Ide, 1961; Kaufman et al. 1961)

Attempts have been made by Fusayama et al. (1964) to produce extra expansion techniques to produce a passive fit casting to provide this space. A goal of more than 30μm spacing was established to prevent a significant occlusal displacement of a veneer casting on cementation. However, according to the data by Bassett (1966), other techniques by acid etching and reverse electroplating were not the whole answer to further seating.

Kaufman et al. (1966) found no correlation in vitro between the mechanical grip of an uncemented casting and its retention value after cementation. Uncemented retention values ranged from 0 to 18.3 lbs.. However, not only was there no correlation between the unseating loads before and after cementation, there was a slight negative correlation of -0.11 after 25 trials. This suggested that tighter tug back fits may encourage a thicker overall cement film after cementation to above that for optimum strength, whereas more passive even fits performed better.

4) Over-extending The Gingival Margins.

Unless a compensation is made, the design of a preparation margin has a great influence on the width of the exposed cement lute for a given degree of vertical displacement during cementation of the casting. Fusayama et al. (1964) found that cement exposure was greatest on the shoulder preparations, being as great as the lack of vertical seating (Fig.14) When a chamfer was used, the cement line decreased depending on the inclination of the chamfer. The width of exposed cement of a shoulderless crown remained minimal and more constant regardless of the lack of seating, and was more a pure function of dimensional accuracy than of a reflection of the occlusal cement build-up.

Bassett (1966) cites the advice by Smith and Potter (1928) to overlap the gingival margins of cast crowns in the wax-up to compensate for finishing and cementation. The margins in the current study were generally degrees of chamfers prepared by a 260-8P diamond point, and the wax-ups were taken to just overlap the chamfer margin rather than butt joint to it. Other workers have incorporated a heavy apically inclined bevel gingival to a shoulder preparation (Stein 1975), so that the cement lute will remain minimal for any given vertical displacement of the casting.

The inherent periodontal dangers of permitting an overextended margin to possibly remain post cementation of the casting have already been discussed (Waerhaug 1953) , and will be discussed further in the current study.

PROPERTIES OF CEMENTATION.

These are a function of the relationship of the properties and structure of the cement to the shape of the innate space between a casting and the tooth preparation,in conjunction with the seating load during cementation.

Smith (1971), states that the actual film thickness achieved under ideal conditions is a function not only of the particle size of the powder but also of the viscosity characteristics of the mix, the type of appliance being cemented, and the circumstances of cementation.

Structure of Zinc Phosphate Cement.

The reaction of mixed phosphate cement produces a composite structure which is repeated in other systems. Non-crystalline phosphates of zinc, magnesium and aluminum are formed which surround unreacted cores of larger cement particles. (Savignac, Fairhurst and Ryge, 1965). Better cement properties are achieved from cement mixes containing the minimum amount of reacted matrix.

In 1967, the revision of the American Dental Association, Specification No.8. was brought into line with the Federation Dentaire International, Specification No.6. to classify two types of phosphate cement on the basis of particle size.

Type I has a permissible maximum film thickness of 25µm,and is best used for the cementation of castings.

Type II has a maximum film thickness of 40µm and is preferred for all other purposes.

Jorgensen and Petersen (1963), in work on the grain size distribution in phosphate cement, found that, during initial cementation, the viscosity of the mix becomes the predominant determining factor for seating. Yet under favorable conditions, which depend not only on viscosity, but also on the size and duration of pressure, and on the shape and approximation of the surfaces, the film thickness can be reduced to the size of the largest powder particles. These in turn may be further crushed until the increasing number of smaller particles can withstand the full cementation pressure. Thus a concept of an effective grain size becomes more important information for a cement product than its particle size distribution in the pure powder form. Both Smith, and Jorgensen and Petersen question the relation of current Specification testing to this clinical situation.

Schouboe, Paffenbarger, and Sweeney (1956) showed that for some resin cements a film thickness as low as 10µm can be achieved, but in clinical practice the resins have exhibited poorer prognosis in other properties than have the well tried phosphate cements. The latter have changed very little over the last forty years except for a reduction in grain size and a reduced solubility rating as by the A.D.A. Specifications.

Cement Filtration Effects.

It became apparent to Lange in 1955 that correctly mixed phosphate cements will separate back into powder and liquid phases during the cementation of veneer crowns.

Observation by Jorgensen (1960) of the response of phosphate cement between flat plates seen under a microscope, showed how the larger groups of wettened cement particles, mostly between 20 to 50µm, clump together. When the compression approaches the diameter of these clumps, the higher viscosity of the latter causes it to be squeezed out more slowly than the surrounding medium, but owing to the different pressures in these lumps centrally as compared to at its periphery, there is a continued fluid movement out to each periphery. The liquid phosphoric acid component is filtered out from the clumps of particles such that each periphery may have been washed completely devoid of powder.

In cementation of a veneer casting, the excess cement is forced out through the narrowing space between the conical surfaces of the crown and preparation. When this space is small enough to jam the largest particle clumps, filtration will begin.

Factors Affecting the Degree of Filtration Beneath Castings as Determined by Jorgensen (1960).

1) Increasing the cementation pressure.

This increases filtration since the extra expression of cement also expresses more liquid through the filter.

2) Short duration pressure.

Prolongation of the seating pressure beyond one minute had no additional filtration effect. (Born out in previous observation by Jorgensen in film thickness studies).

3) Increased cement viscosity.

This effectively reduces the filtration because of the reduced total flow of the cement. However, this method would be no use clinically.

4) Taper of the preparation.

Small angles of taper increase the filtration effect markedly because the width of the slit between the axial preparation and the casting decreases the most rapidly during cementation seating. Cement will pass through this diminishing space until either the occlusal excess is cleared, or until the slit becomes so narrow that the cement flow ceases, because there is gold to tooth binding or because the width of the effective grain size has been achieved.

5) Internal surface relief.

If relief is provided over the entire fit surface except for the terminal two millimeters gingivally, the cement lumps will be trapped occlusally to this zone, and once the filtration effect is started, there may be a wash out of the important gingival cement by the liquid component expressed.

6) Occluso-gingival escape grooves.

These can be incorporated to assist the cement flow. However, dilution of the cement film was observed from the inlets of these escape grooves to the narrow slit between crown and preparation.

7) Spot binding of the fit surface before cementation.

This may set up irregular narrow slits between the tooth and casting, thus producing additional filtration zones with surrounding areas devoid of proper cement.

8) Shoulder preparations.

These exhibited no filtration differences from other margin finishes. The expression of cement ceased as soon as the gingival slit became narrow enough to trap the larger powder lumps.

9) Venting.

A one millimeter occlusal vent virtually cut out all significant filtration wash out except across internal discrepancies, and thus became the advocated optimum.

Jorgensen pointed out three probable adverse effects of filtration. Pulp injury may be a consequence of the diffusion of free acid into the cut dentinal tubules. Also, secondary injuries to the tooth structure may follow where a cement margin seal is predominated by the phosphoric acid component which may wash out more rapidly resulting in an open margin. Thirdly, insufficient retention may eventually result.

It should be noted that this data on filtration was obtained using precision machined dies and machined "crowns". The related true clinical picture is more complicated since there are more various and frequent binding areas for filtration effects to occur and, greater regions of poorer fit in which the space does not approach the minimum filtration prerequisite. However, the more retentive the preparation, and the nearer aspects of the casting fit to below 30μm, the greater is the likelihood of the phenomenon.

Seating Force At Cementation.

Since virtually all previous studies have been in vitro, the choice for the seating load has been empirical rather than rational, and then rated according to the optimum cement film thickness arising from the range investigated. Such optimum forces may not be achievable under normal clinical practice, and as such becomes added argument for venting where the cement resistance is reduced and a lesser more manageable force is sufficient for optimum seating, as advocated by Kaufman et al. (1961) Courtade (1966) and Jones et al. (1971).

Clinically the methods used for application of the seating force are mastication pressure via wooden sticks, gauze, cotton, or rubber; automatic and manual mallets; and strong finger pressure.

Fusayama and Iwamoto (1961) described the relationship of the cement film thickness, held between two metal plates, to the compressive load as a hyperbolic curve with the lowest critical point at approximately 30µm. at a loading of 10Kg..

In similar load experiments on cements films between glass plates, Porche (1961) found that an increase above 12Kg. produced no significant decrease in the film thickness.

Fusayama et al. (1963,1964) found that the film thickness beneath unrelieved crowns was readily reduced down to 40µm, but to drop below 30µm, required a sudden increase in force to overcome the cement resistance. He found, however, that 15Kg. was sufficient even for non-relieved castings, and that there was essentially no improvement in seating where this was raised to 50Kg..

Jorgensen (1960) found very little improvement in film thicknesses above a 5Kg. load. This was, however, between precision machined dies and "crowns".

At 0.5Kg. the average film thickness was 47µm.

At 4.0Kg. the average film thickness was 29µm.

At 10Kg. the average film thickness was 22.5µm.

Other laboratory studies may have used excessive loading relative to the true clinical situation. Bassett (1966) used 45Kg. In retention experiments, Kaufman et al. (1961) used a clamp exerting a 40Kg. cementation load. McCune, Phillips et al. (1971) used a static 33Kg. load applied through a modified Verticulator. The latter was also adopted by Jones, Dykema and Klein (1971).

Alternatively, Colman and Kirk (1965) used hand pressure only, and Christensen (1966) used a "simulated masticatory pressure" via the point of an orange wood stick squeezed between tooth pucks by hand.

An objective relation of the clinical situation to the laboratory model was made by Grieve (1969). A bite fork with electric strain gauges recorded an average force of 90 Newtons as the patient closed in the molar region. This force was translated to a seating mass of 9Kg. held for one minute in the in vitro study. 84 to 90µm cement film thicknesses were recorded beneath the full crown gold castings under such loading.

The clinical study by McLean (1971) on cement lute replicas used actual mastication pressure applied via a rubber mat.

Igarashi, during experiments on the effects of venting, found that patients produce about 30Kg. masticatory force in the bicuspid region, but that this dropped off rapidly during the first minute. He therefore, suggests that complete seating requires rapid seating and that this implies venting.

It should be noted that, since masticatory closure operates on the principle of a class 111 lever anterior to the masseter, seating a casting via masticatory pressure would appear to be of a greater advantage the more posteriorly it is acting.

Murata (1967) in seating experiments with unvented bicuspid crowns showed that the optimum available force for cementation clinically was via the full mastication force in direct centric occlusion.

	cement lute (at the occlusal)
Mallet plus finger pressure	200-300µm.
Wood stick	120-180µm.
Centric occlusion	60-150µm.

Influence of Duration of Cementation Pressure.

Most authors applied the chosen pressure for the official setting time of the cement used plus a safety margin. Since a patient may not be able to sustain this force adequately, the findings of Jorgensen (1960) are important. For phosphate cement at 5Kg. there was little improvement after one minute.

At 0.25 minutes the average film thickness was 70μm.

At 1.0 minutes the average film thickness was 37μm.

At 8.0 minutes the average film thickness was 33μm.

Influence of Viscosity.

Jorgensen and Petersen (1963) and Smith (1971) state that the cement film thickness is a function both of the viscosity and the particle size. During initial cementation, the viscosity is the determining factor resisting the seating pressure.

Jorgensen and Petersen felt that the current cement consistency test, A.D.A. Specification 8., 4, 3, 2. is in reality a measure of the viscosity rather than of the effective grain size, unless there were very coarse particles present in the powder. This was concluded because extention of force and time beyond that of Specification 8. will cause further extrusion and compression of the setting cement. Modifications have been suggested, but notwithstanding, the Specification test stands as a useful comparison.

Assuming proper mixing and prompt insertion, the viscosity of phosphate cement is a function of the powder/liquid ratio, the temperature, and rapidly increases with time which renders further expression of the cement correspondingly difficult, (Jorgensen, 1960). This caused

Jorgensen to recommend that a very low film thickness can be obtained by applying cementation pressure (4Kg.) for one minute, using a rather thin, cooled cement mixture (0.7gm.powder/0.25ml. acid, and 12°C.) under an occlusally vented casting.

A comparison of the flow properties of Impregum to Zinc Phosphate cement, which is an important basis for this paper, is found under Materials.

Oblique Seating.

Investigations by Lange (1955) showed that cemented crowns always seat obliquely on their preparations. The cement film was often found to be very thin occlusally on one of the tapering axial surfaces, and at its thickest on the opposite axial surface. His experiments showed that filtration occurred at the narrow slits on either side of the close contact zone.

Jorgensen (1960) found that all castings seated slightly ascew following cementation. He felt that this was an inevitable consequence of the hydrodynamic conditions existing when two conical surfaces separated by a fluid medium are compressed together. The end result is an uneven gingival discrepancy. However, where the resultant average film thickness was thin, the obliquity was at a minimum.

Similar oblique seating was discovered by Bassett (1966) even though a guide groove had been incorporated into the preparations.

Aware of the effect, McCune et al. (1971) developed a modified Verticulator to standardize the vertical seating of their castings in their investigation of vented castings.

Jones, Dykema, and Klein (1971) adopted the same equipment, but used precise television micromeasurement to record the gingival margin discrepancies. No statistically significant difference was determined between the buccal and lingual cement lutes at the crown margins, which was contrary to the observations of all previous investigations and to the findings in the current study. However on reflection, this is not so surprising, since oblique seating can only occur in conjunction with some vertical cementation displacement, which if minimized by a successful venting procedure would reduce the expected oblique seating. Nevertheless any guidance factor resulting from the use of the Verticulator must be investigated, before the above conclusion can be drawn.

COMPARISON OF IMPRESSION MATERIALS.

Class 1 Impression Compounds.

Skinner and Phillips (1973) describe the coefficient of thermal expansion as considerable relative to other materials: namely $\alpha = 250 \times 10^{-6}/^{\circ}C$ as compared to $150 \times 10^{-6}/^{\circ}C$ for polysulphide rubber. For compound, this may amount to an average contraction of 0.3 to 0.4% merely across the thermal fall from mouth to room temperature.

Combe and Smith (1965) describe a volume expansion as large as 1.38 to 2.29% over the same temperature rise.

Specification No.3 of the American Dental Association allows a maximum flow of 6% at mouth temperature and 85% at 45°C. To this degree any distortion following removal from the in vivo prepartion may have no recovery, but, clinically, this is presumed negligible.

Roydhouse (1962) describes that compound materials will cool unevenly since they exhibit very low thermal conductivity such that any central portion will lose heat more slowly. Since the material contracts on cooling, the central core cooling the most slowly, will also be the last portion to contract. Meanwhile the outer parts are already hard such that the force of contraction may not be completely compensated by flow which may incorporate in a residual stress in the thicker sections of the material.

In addition, since the flow of the material relates to its temperature, late manipulation may not completely reorientate the molecular structure which will then tend to return to a more stable shape. Phillips (1973), thus suggests rapid pouring since the relaxation of these stresses occurs quickly after removal from the preparation.

Polysulphide Rubber Impression Material.

Jorgensen (1957), using sections of polysulphide rubber floating free on mercury, demonstrated a thermal construction of 0.23% from 37^0C to 22^0C. This was verified by McLean in 1961 showing a 0.2% contraction.

According to Phillips and Skinner (1973), the practical significance of the thermal coefficient of expansion for polysulphide rubber is a 0.26 linear shrinkage during this temperature drop from mouth to room temperature. Phillips suggests that stone for dies is mixed at oral temperature to compensate for this shrinkage.

Asgar (1971) relates that a polymerization change occurs, but its degree depends on the test method used. A free floating specimen thus exhibited larger changes than that of a restricted sample as in an adhesive impression tray.

The Dimensional Changes in Polysulphide Rubber Test Samples with Time:

	Free Floating Sample		Restricted Sample	
	30 minutes,%	3 days,%	30 minutes,%	3 days,%
Polysulphide Rubber A	-0.03	-0.11	+0.02	-0.10
Polysulphide Rubber B	-0.05	-0.13	0.00	-0.13

(After Hollenback 1957)

Jorgensen (1957) determined this linear contraction to vary from 0.13 to 0.39% after 24 hours. McLean (1961) found this to be 0.25% after seven to twelve hours. The American Dental Association Specification No.19 thus allows a permissible 0.4% contraction.

According to Specification 19, an elastomer is required to reproduce a line 0.025mm (0.001 in.) wide. Work by Shippee (1960) on the deviations of the dimension of casts copied by various elastic impression techniques demonstrated an average deviation of 0.0013 inches for thiokol rubber. For double pours this rose to 0.019 inches.

Schnell and Phillips (1958) demonstrated that a more accurate impression is produced when the thickness of the rubber between a master die and the impression tray is reduced to an evenly distributed 2-4mm. The theoretical optimum (Bassett, Vander Heide, and Smith, 1969) may be lower but slight additional space must be provided to reduce the elastic strain during removal of the impression and to equalize the thickness of the material with that in the mesiodistal direction.

Braden (1966) showed that the setting of polysulphide rubber is a continuous process with no clearly definable set point. This agreed with earlier findings by Schnell and Phillips in 1958.

Chong and Docking (1969) showed that particularly for polysulphide material the estimated clinical setting time does not correspond to the time when the material attains its optimum recovery properties and instead suggest a time relating to a permanent deformation test.

Birtles, Podshadley, Dilts and Neiman (1971) investigated the controversy on the accuracy of pouring polysulphide impressions at various intervals after separation and after allowing 15 minutes intra oral set, it was found that the more accurate dies were poured immediately after separation.

Figure 1: Preparation of cuspid.

METHOD AND MATERIALS.

Sample.

Sixteen anterior teeth in seven human subjects were prepared in vivo for full coverage veneer crown restorations. Of each, a polysulphide rubber* and Dietrich's** thermoplastic impression was taken as a pair. Each pair was poured, waxed up and cast together using splits of the same mixes and investing the pair together within the same casting ring to standardize the variables. A polyether elastomer was then substituted as the cementing medium for each casting in turn. The elastomer cement lute replica was then recovered, in the manner later described, photographed, then aligned and sectioned with its pair member in the bucco lingual place for micro comparison.

Preparation.

Standard veneer crown preparations were made using a 260-8P diamond to produce a buccal finish line as a light apically inclined chamfer placed a half to one millimeter subgingivally.

Elsewhere the margin was finished to a less accentuated chamfer subgingivally.

Teeth with major direct restorations or serious fluting were rejected since this was found to interfere with the subsequent withdrawal of the cement lute replica. To assist this withdrawal, the preparation was gently smoothed with a high speed silicone point*** under a water spray, followed by Zircate**** pumice on a brush. (Fig.1)

*Kerr Permlastic (Light Body)	Kerr Canada.
Neo Plex (Heavy Body)	Lactona Co. Philadelphia,Pa. U.S.A.
**Dietrich's Elastic Inlay Impression Material	Hygienic Dental Mfg., Akron,Ohio U.S.A.
***Dedeco Tan Midgets	Dental Development and Mfg.Corp.,Washington, U.S.A.
****Zircate Powder	Caulk Co., Toronto, Canada.

Impressions.

The pairs of impressions were taken by a single operator during a single appointment and according to the manufacturer's instructions.

Polysulphide Rubber

1) Retraction: by 8% racemic epinephrine string, Racord*, for five minutes.
2) Matrix: an acrylic custom tray with rubber adhesive.
3) Set: Chemical. Light body rubber was syringed onto the preparation followed up by heavy body in the tray.
4) Time: ten minutes intra orally.

Dietrich's

1) Retraction: by the extension of copper band matrix towards the epithelial attachment.
2) Matrix: a festooned unannealled copper band with multiple tiny retention punctures from an 8/0 Busch** bur.
3) Set: is thermoplastic and is first conditioned in boiling water, and then tempered during manipulation until finger comfortable. After seating the material, it was chilled with very cold tap water.
4) Time: is three minutes intra orally.

The impressions were poured within thirty minutes of recording using splits of the same mix of Velmix*** stone in the proportions of 5ml. distilled water at room temperature to 20gms. of powder mixed under vacuum for thirty seconds.

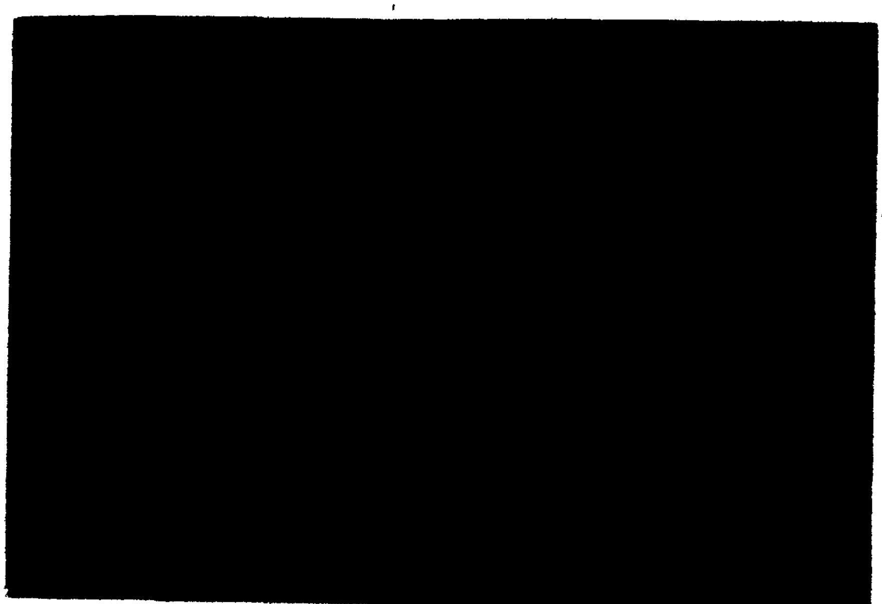
*Racord — Pascal Co., Bellevue,Wa., U.S.A.
**Busch Burs — Pfingst Co. Inc., New York, U.S.A.
***Velmix Stone — Kerr Canada, Don Mills, Ontario, Canada

Figure 2

Laboratory phase completed.

Figure 3

Split mix of Impregum for sequential cementation of matched pairs of castings.



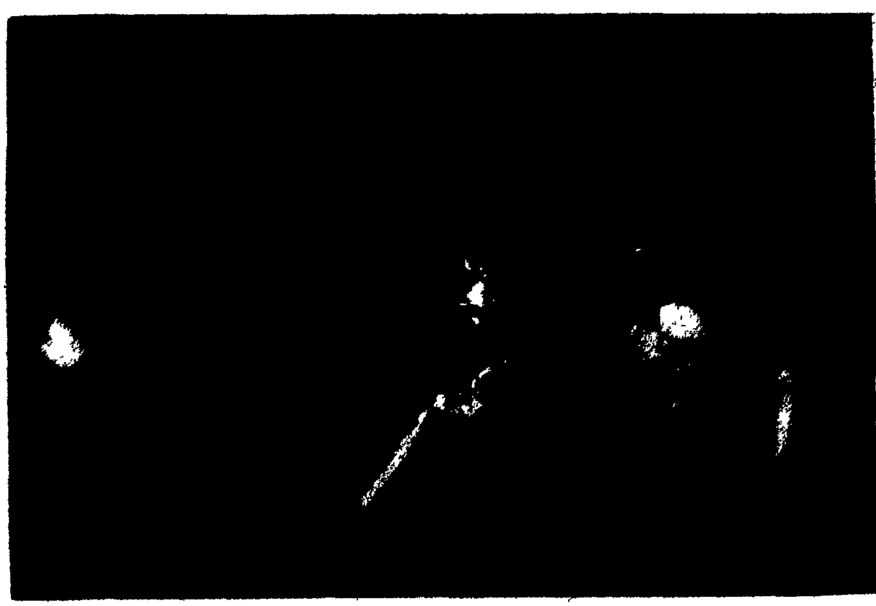


Figure 4

Full seating of casting under heavy finger pressure, followed by maintenance under masticatory load until "cement" is set

Laboratory Phase.

The wax copings were made by dipping and then redefining the margins. The margins were just overwaxed to avoid a future butt joint or a short margin, to the chamfer in gold.

Each member of each pair was sprued identically at an incisal axial line angle, then invested together in the same casting ring such that for each pair the investment properties, gold alloy and temperature was constant. New Class III gold alloy was used.

The fit surface of the castings was left untouched except where there had been a small bubble in the investment. The external margin was taken down with fine sandpaper discs but there was no finishing or burnishing of the gold against the tooth structure. (Fig.2).

Cementation Phase.

Independent evaluations of the uncemented fit of the copings were made using a new explorer in vivo by operative demonstrators teaching in the graduate school of dentistry. Where either member of the coping pair was not accepted as good without criticism on any aspect of the margin, the complete pair was rejected and new impressions were taken to preserve the constant.

Impregum*, a polyether elastomer, was used as a cement lute replica for the normal cementing medium, owing to its similar flow properties to phosphate cement. (Table 1).

*Impregum E.S.P.E. Co., Germany

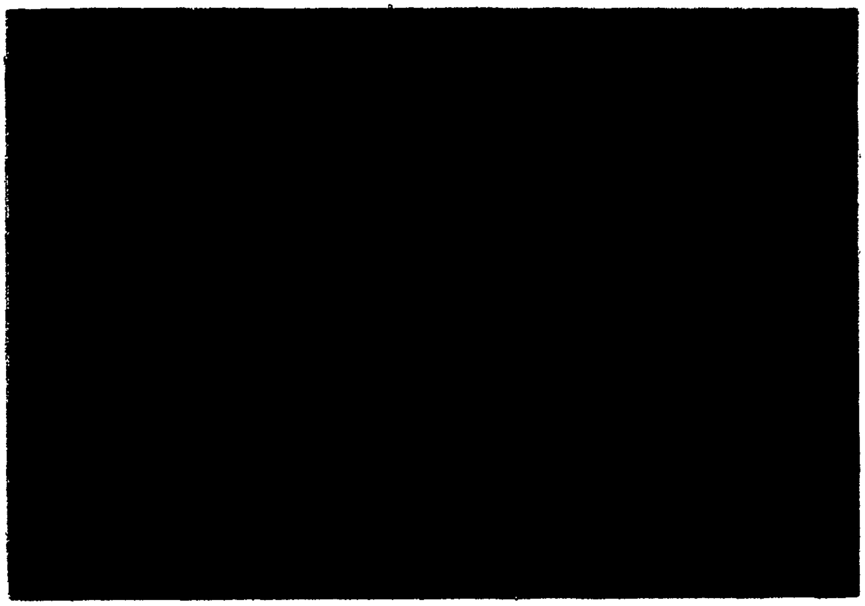


Figure 5

Cement lute replica withdrawn intact from the tooth preparation.

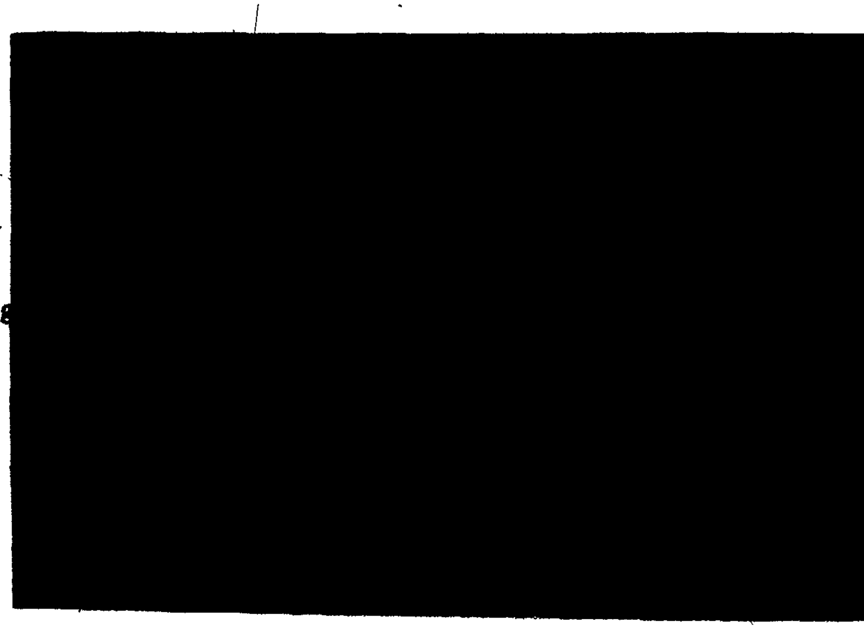


Figure 6

Scutan pour bonds with the recovered lute replica, which is subsequently withdrawn from the fit surface of the casting by warming it to obtain slight expansion.

Figure 7

Matched pair of recovered lute replicas set up for scoring by photodensity estimations of lute thicknesses, which was repeated for each of the axial and marginal surfaces.

The copings were loaded with a split mix of Impregum (Fig.3), and, at random, seated on the preparation firstly under forceful finger pressure through an orange wood stick, and then held under masticatory load (Fig.4) ensuring that the force was being applied as nearly as possible axially. Full set was after five minutes, and the elastomeric properties allow the withdrawal of the crown coping from the tooth. In principle, the cement lute replica stayed intact adhering to the fit surface of the casting. In reality, this was a very delicate operation and often required frustrating repetition. To improve the predictablilty, a separating agent such as a silicone spray* was useful if allowed to dry thoroughly on the tooth first. The preparations needed to be scrupulously cleaned between operations, with a soft gauze and water.

Recovery of The Cement Lute Replica Membrane.

The Impregum lute intact on the fit surface of the copings (Fig.5) was gently washed with a water spray then left at room temperature to dry completely.

A cone of masking tape was wrapped around the coping to accommodate the Scutan** epimine plastic that was syringed to the fit side of the cement lute replica via a shortened 18½ gauge needle.

After one hour, the set complex was immersed in hot tap water for ten minutes. The metal coping was then warmed in a flame to effect a slight expansion. A careful tug then parted the gold coping from the lute replica since there is a stronger, though mild, chemical bond of the

*All Purpose Silicone Spray — Dentsply International

**Scutan — E.S.P.E. Co., Germany

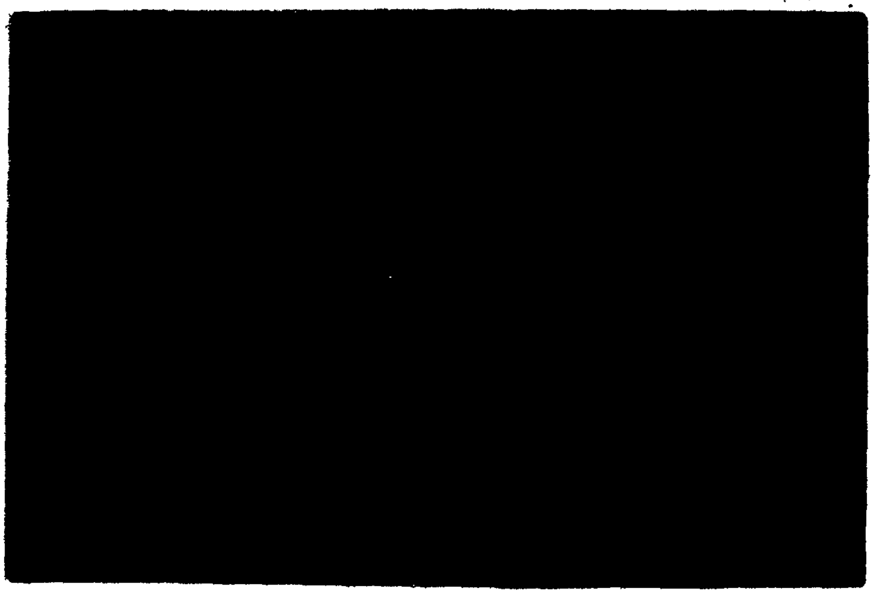


Figure 8

Placement of acrylic spheres and axial alignment in bucco lingual plane.

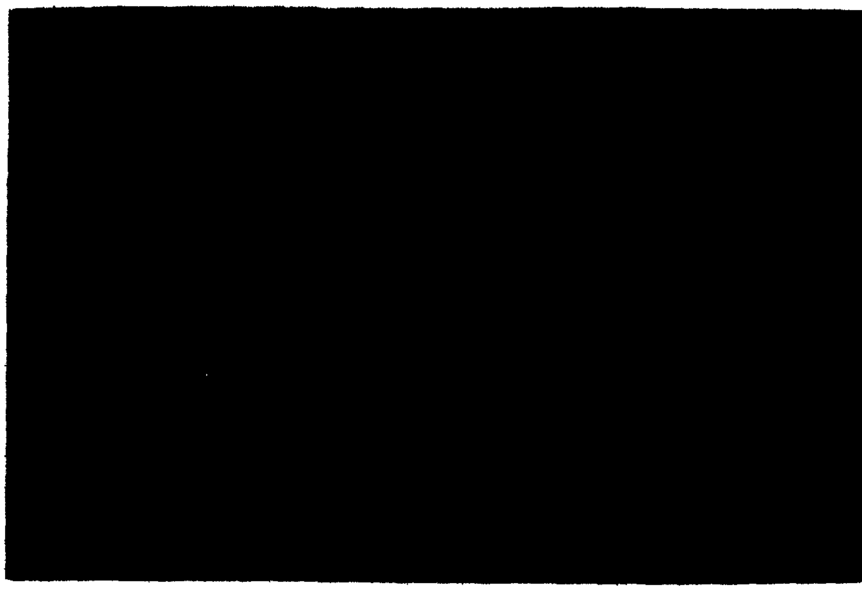


Figure 9a

Parallel alignment in mesial distal plane.

Figure 9b

Impregum to the epimine resin. (Fig.6)

Photographic Assessment.

A photodensity estimation was made from Kodachrome II slides taken of mesial buccal distal and lingual aspects of the recovered membranes in pairs at a constant subject distance of 32 cm. (Fig.7)

An initial subjective scoring of the membrane thickness was made at the actual fit margin (trying to avoid the obvious photodense aspect due to the obliqueness of the material across the chamfer), at the mid-axial and at the axio-occlusal. A heavy thick lute was scored 3, a moderate even density 2, and a thin or compression zone 1.

The scores were later statistically related to the micro-measurements obtained in the sectioning of the paired lute replicas in the bucco-lingual plane. (Table 9). This enabled the photodensity estimations to be applied with confidence to the mesial and distal aspects for collation of the distribution of scores of the fits in three dimensions. (Table 10)

Alignment and Embedding.

Sectioning was required in the bucco-lingual plane. This demanded a mutual alignment of each Rubber Dietrich's lute pair to allow an immediate read off for each section.(Figs. 8, 9).

This was accomplished by first dropping the shortest occluso-gingival axial line angle interproximally and measuring an identical distance down this line with a caliper for each member. At this mark, an acrylic sphere was attached by a spot of Copalite* varnish. This allowed a sighting to be made bucco-lingually to align the two members

*Copalite Cooley & Cooley, Houston, Texas, U.S.A.

Figure 10

Embedding and orientation of previously aligned matched pairs of recovered lute replicas, now mounted for bucco-lingual sectioning.

Figure 11

Bucco-lingual microsectioning.

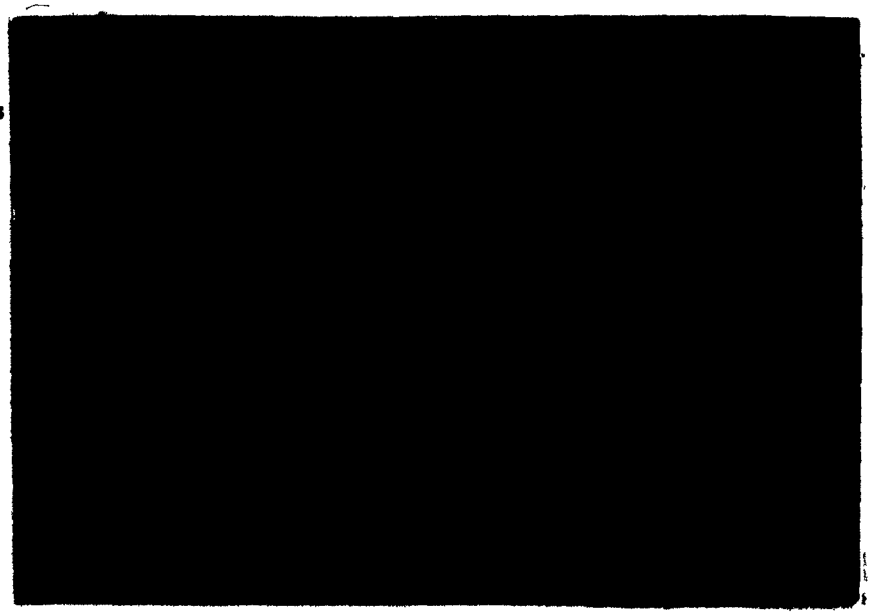


Figure 12

Sequential planes of sectioning of one block.

of each pair, the buccal aspects always facing one direction. The drawn axial lines completed the alignment in the remaining plane. (Figs.8,9) The aligned pair was then framed by two L angle brackets to form an enclosed rectangle, and an embedding pour of Scutan was syringed in. The "buccal" end of the block was stained with a red organic dye*, which also conveniently designated the lute replica originating from the Rubber impression source which was always that placed nearest to the "buccal" edge of the block. For contrast the lingual end was stained green.

Sectioning

The Scutan blocks were cemented onto plastic mounting plates for the Bronwill sectioning machine** using methylene chloride. (Fig.10) The sectioning was along the aligned bucco-lingual plane using a 320 grit diamond wheel of 200μm. width. (Fig.11). A series of sections were taken of 150 dimension, thus furnishing from five to six middle sections depending on the size of the specimen. (Fig.12). The chemical adhesion of the embedding pour of Scutan limited any dragging of the delicate elastomer membrane.

*Transparent Dye. American Handicrafts, Fort Worth, Texas, U.S.A.

**Bronwill Sectioning Machine. Hamco Machine & Electronics, Model 503 Rochester, New York, U.S.A.

Recovered cement lute replica measurements.

Sectioned in the bucco lingual plane.

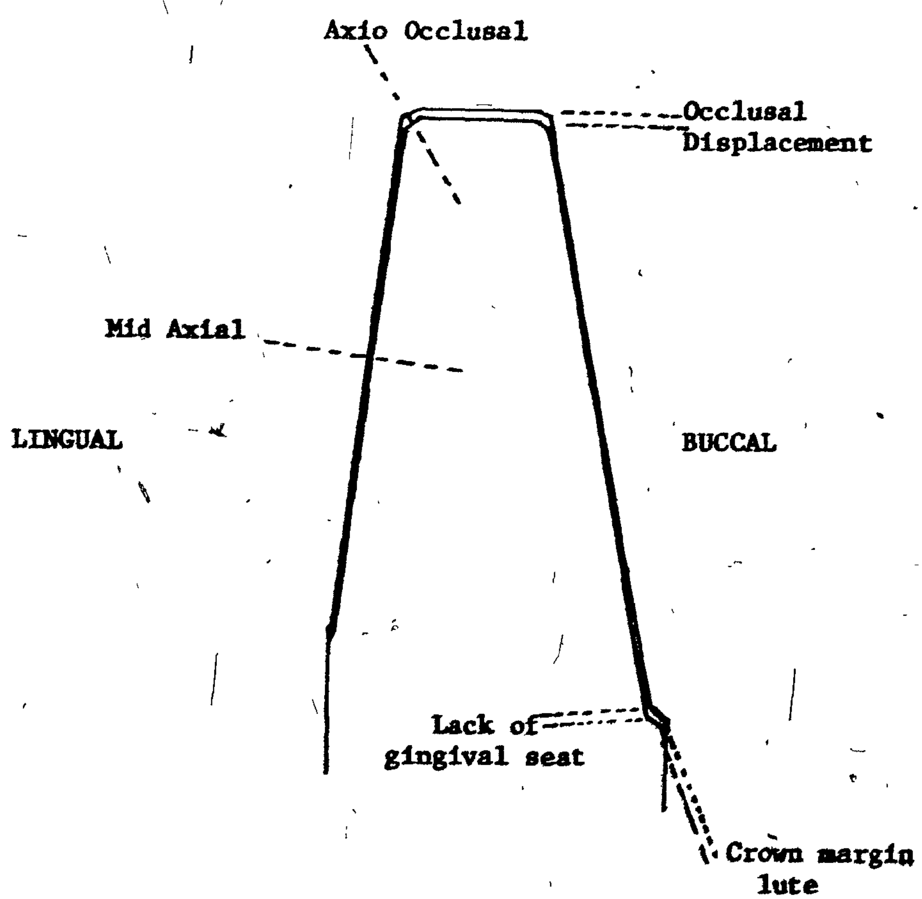


Figure 13

Data Collection.

Measurements of the cement lute replica thicknesses were recorded using a binocular microscope with an eyepiece micrometer grid* graduated to 10µm divisions which permitted 5µm readings to be taken with confidence.

The stereo arrangement made easy the choosing of the mid-section plane since owing to the translucense of the Scutan embedding plastic a divergent cut through the dark Impregum replica on a curve rather that truly at the mid-section could be quickly rejected.

Recordings were taken at the crown margin seal, the lack of gingival seat measured axially, the mid axial, the axio occlusal and the occlusal lute positions on both the buccal and lingual aspects. (Fig.13).

*Bausch and Lomb Co. Scarborough, Ontario, Canada.

Materials

Impregum.

Impregum was chosen as the cement lute replica because in addition to the required elastomeric properties, its flow properties are quite close to properly mixed zinc phosphate cement. It also bonds chemically with Scutan plastic.

Table I

Properties	Impregum	Zinc Phosphate (De Trey)
Film thickness B.S. 3364	22µm.	20µm.
Disk diameter F.D.I. consistency tests (Specification No.6)	35mm	30mm
Setting time	5 min.	3 min.

After McLean and Fraunhofer (1971)

Polyether Impression Material.

This is a polyether base polymer which is cured by the reaction between aziridine rings which occupy the ends of branched polyether molecules.

Skinner and Phillips (1973) state that "The main chain is probably a copolymer of ethylene oxide and tetrahydrafuran." Cross linking and setting is by an aromatic sulphonate ester. The reaction does not produce any by-products, so there is little dimensional change after setting. (Greener, Harcourt and Lautenschlager 1972; and British Patent 1,044,753.).

Work by Pfannestiel in 1972 compared twenty-two thiokol, polyether, and silicone impression materials, and demonstrated that polyether (Impregum) was the most dimensionally stable.

A similar result was obtained by Chong and Docking (1969) showing that Impregum and some silicones have a better elastic recovery than does polysulphide rubber after deformation.

Scutan.

Scutan is a plastic recently developed as a temporary crown and bridge resin. It is related to the epoxy resins in which the oxide of the epoxy is replaced by an imino group: hence epimine plastic. (Marheime and Staehle, 1971). Scutan will bond chemically to Impregum, and hence its usefulness to this study in the recovery and embedding of the elastomer lute replica.

RESULTS

The recovered cement lute replicas were aligned in the bucco-lingual plane and embedded as matched pairs. This permitted comparison readings to be made directly from Dietrich's to Rubber from each middle micro section taken. (Fig. 12).

Table 2

CROWN MARGIN LUTE - COMPARISON OF FIT FOLLOWING CEMENTATION OF CASTINGS OBTAINED AFTER RUBBER AND DIETRICH'S IMPRESSIONS.

Preparation	Buccal			Lingual		
	Dietrich's	Rubber	diff.#	Dietrich's	Rubber	diff.
	µm	µm	µm	µm	µm	µm
A	180	180	0	175	80	+95
B	130	160	-30	215	145	+70
C	110	60	+50	80	70	+10
E	65	60	+5	170	65	+105
F	180	30	+150	70	30	+40
G	25	160	-135	80	70	+10
H	130	115	+15	35	32	+3
I	180	75	+105	25	25	0
J	100	50	+50	210	140	+70
K	30	90	-60	30	45	-15
L	340	75	+265	75	60	+15
M	50	45	+5	10	70	-60
N	20	20	0	20	105	-85
O	150	90	+60	30	40	-10
P	25	105	-80	30		
Q	8	60	-52	10	18	-8
n	16	16	16	16	15	15
Mean	107.68	85.94	+21.75	79.06	66.33	+16.0
S.D.	87.55	46.42	95.52	72.25	38.79	52.95
Paired t-test			$t=0.91^{NS}$ df=15			$t=1.17^{NS}$ df=14

#. Positive differences indicate a closer fit of castings obtained following rubber base impression.

NS. Indicates a statistically non significant difference.

The data in Table 2 indicates no statistically significant difference in the cement lute discrepancy at the crown margin between the castings derived from the Dietrich's and Rubber impression sources. However, a pattern of fit favouring Rubber exists at both the buccal and lingual margin locations of smaller means and standard deviations than for Dietrich's. This was seen to be subsequently repeated at the other preparation sites to a varying degree of significance.

Table 3

GINGIVAL SEAT DISCREPANCY - COMPARISON OF FIT FOLLOWING CEMENTATION OF CASTINGS OBTAINED AFTER RUBBER AND DIETRICH'S IMPRESSIONS.

Preparation	Buccal			Lingual		
	Dietrich's	Rubber	diff.	Dietrich's	Rubber	diff.
	μm	μm	μm	μm	μm	μm
A	250	340	-90	290	200	+90
B	290	480	-190	230	130	+100
C	205	120	+85	190	270	-80
E	120	90	+30	210	130	+80
F	75	210	-135	280	240	+40
G	190	50	+140	165	120	+45
H	240	250	-10	130	150	-20
I	240	280	-40	275	25	+250
J	210	190	+20	270	260	+10
K	450	200	+250	230	180	+50
L	430	160	+270	90	60	+30
M	280	190	+90	170	255	-85
N	70	80	-10	340	75	+265
O	180	65	+115	170	260	-90
P	290	210	+80	160		
Q	45	90	-45	65	25	+40
n	16	16	16	16	15	15
Mean	222.81	186.56	+35	204.06	158.66	+48.33
S.D.	120.18	112.58	125.93	75.81	87.28	104.55
Paired t-test			t=1.11^NS^ df=15			t=1.79^NS^ df=14

Table 3 indicated no statistically significant differences in the mean gingival seat discrepancy of fit between the Dietrich's and Rubber sources of castings, at either the buccal or lingual site of measurement. A closer mean fit is shown for Rubber at both the buccal and lingual locations.

Table 4

MID-AXIAL DISCREPANCY - COMPARISON OF FIT FOLLOWING CEMENTATION OF CASTINGS OBTAINED AFTER RUBBER AND DIETRICH'S IMPRESSIONS.

Preparation	Buccal			Lingual		
	Dietrich's	Rubber	diff.	Dietrich's	Rubber	diff.
	µm	µm	µm	µm	µm	µm
A	65	80	-15	70	40	+30
B	30	80	-50	70	40	+10
C	75	60	+15	85	45	+40
E	110	30	+80	110	30	+80
F	110	130	-20	45	40	+5
G	35	35	0	105	80	+25
H	140	125	+15	65	65	0
I	175	130	+45	210	55	+155
J	70	70	0	85	50	+35
K	90	65	+25	220	160	+60
L	85	85	0	220	70	+150
M	110	100	+10	140	100	+40
N	85	60	+15	60	85	-25
O	80	105	-25	60	120	-60
P	55	50	+5	85	65	+20
Q	20	30	-10	25	20	+5
n	16	16	16	16	16	16
Mean	83.43	77.18	+5.62	103.43	67.81	+35.62
S.D.	40.32	33.66	29.65	62.17	35.63	51.99
Paired t-test		t=0.75[NS.] df=15			t=2.74* df=15	

* Indicates a statistically significant difference ($p \leq 0.05$)

** " " " " " ($p \leq 0.01$)

The paired t-test in Table 4 indicates a statistically significant difference in the mean lingual mid-axial discrepancy between castings derived from the Dietrich's and Rubber impression sources, which was not evident at the buccal. A closer mean fit is shown for Rubber at both the buccal and lingual locations.

Table 5

AXIO-OCCLUSAL DISCREPANCY - COMPARISON OF FIT FOLLOWING CEMENTATION OF CASTINGS OBTAINED AFTER RUBBER AND DIETRICH'S IMPRESSIONS.

Preparation	Buccal			Lingual		
	Dietrich's	Rubber	diff.	Dietrich's	Rubber	diff.
	µm	µm	µm	µm	µm	µm
A	130	120	+10	90	120	-30
B	40	40	0	180	180	0
C	110	80	+30	40	25	+15
E	130	45	+85	90	10	+80
F	340	90	+250	35	70	-35
G	45	45	0	125	30	+95
H	25	30	-5	180	120	+60
I	170	90	+80	220	140	+80
J	60	90	-30	160	85	+75
K	210	100	+110	360	240	+120
L	65	30	+35	510	245	+265
M	90	170	-80	410	180	+230
N	160	75	+85	40	55	-15
O	290	210	+80	155	245	-90
P	105	45	+60	120	55	+65
Q	60	50	+10	50	30	+20
n	16	16	16	16	16	16
Mean	126.87	81.87	+45	172.81	114.37	+58.43
S.D.	155.33	50.63	74.25	222.69	82.56	92.82
Paired t-test			t=2.42* df=15			t=2.51* df=15

At the axio-occlusal position, Table 5, there are statistically significant differences in the cement lute discrepancies at both the buccal and lingual locations, between castings derived from Rubber and Dietrich's impression sources. A closer fit is described for Rubber at both aspects.

Table 6

OCCLUSAL DISCREPANCY - COMPARISON OF FIT FOLLOWING CEMENTATION OF CASTINGS OBTAINED AFTER RUBBER AND DIETRICH'S IMPRESSIONS.

Preparation	Dietrich's	Rubber	diff.
	μm	μm	μm
A	180	240	-60
B	200	230	-30
C	150	110	+40
E	180	90	+90
F	270	240	+30
G	130	70	+60
H	150	125	+25
I	245	140	+105
J	130	110	+20
K	440	220	+220
L	310	115	+195
M	320	220	+100
N	105	60	+45
O	310	327	-17
P	310	170	+140
Q	95	50	+45
n	16	16	16
Mean	220.31	157.31	+63
S.D.	98.07	80.21	76.42
Paired t-test		$t=3.29^{**}$ df=15	

Observing Table 6, a statistically strong significant difference exists between the mean occlusal cement lute discrepancies of the Rubber and Dietrich's impression sources of castings. A closer fit is shown for Rubber.

Referring in sequence to Tables 2 to 6, it is apparent that the mean difference in the fit of castings drawn from Rubber and Dietrich's impression sources was minor and statistically non significant as measured at the actual crown margin. However, this difference progressively increased axial-occlusally to the extent that the result at the occlusal location could be termed statistically highly significant. Also, smaller means and standard deviations favouring Rubber were apparent throughout, and without any statistical reversals.

Buccal to Lingual Marginal Relationships.

The current data appeared to indicate that there might be a pattern to bucco-lingual differences in the mean cement lute discrepancies for each site of measurement. Of note, at the crown margin and gingival seat locations, the mean cement lute thickness and standard deviation at the buccal site were consistently greater than that at the lingual position for both impression sources of castings. For example, at the crown margin for Rubber, the mean lute thickness was 85.93μm at the buccal location, to 66.33μm at the lingual. This pattern was repeated at the gingival seat position; for Rubber, 186.56μm at the buccal to 158.66μm at the lingual aspect.

Not unexpectedly, this apparent tendency for larger buccal discrepancies showed some reversals in the aspects away from the crown margin. This occurred particularly in the case of Dietrich's at the mid-axial position, where namely the lingual aspect showed the largest lute thickness at 103.43μm, to 83.43μm at the buccal. Similarly, at the axio-occlusal position, the mean lute thickness at the lingual was larger than at the buccal location for castings from both impression sources.

However, for the sample studied, the application of t-tests revealed no statistically significant difference between any of the bucco-lingual mean values at any site of measurement. Nevertheless, a substantiating observation for bucco-lingual differences will be seen to reoccur later as part of the apparent result of the tendency for castings to seat obliquely during cementation.

Bucco lingual differences will be also discussed in the context of the influence of margin design on the cement lute discrepancy at the crown margin (Fig.14) for any given occlusal displacement.

Occlusal Marginal Relationships

In previous reports, the occlusal displacement of castings resulting from their cementation was taken as indicative of the average cement lute thickness at the gingival margin. A direct relation was assumed, and the degree of crown-cement-margin discrepancy was calculated from the precise geometry of the standard dies used (Fig.14). However, arising from observations from the current study (Tables 2, 3, 6), this relationship as a pure function was questioned. Correlation analyses were made between the occlusal and gingival seat discrepancies, and between the occlusal and crown margin discrepancies. (Tables 7 and 8)

Influence of the geometry of a preparation on the margin discrepancy for a given occlusal displacement following cementation of a full crown casting. (After Fusayama et al. 1964).

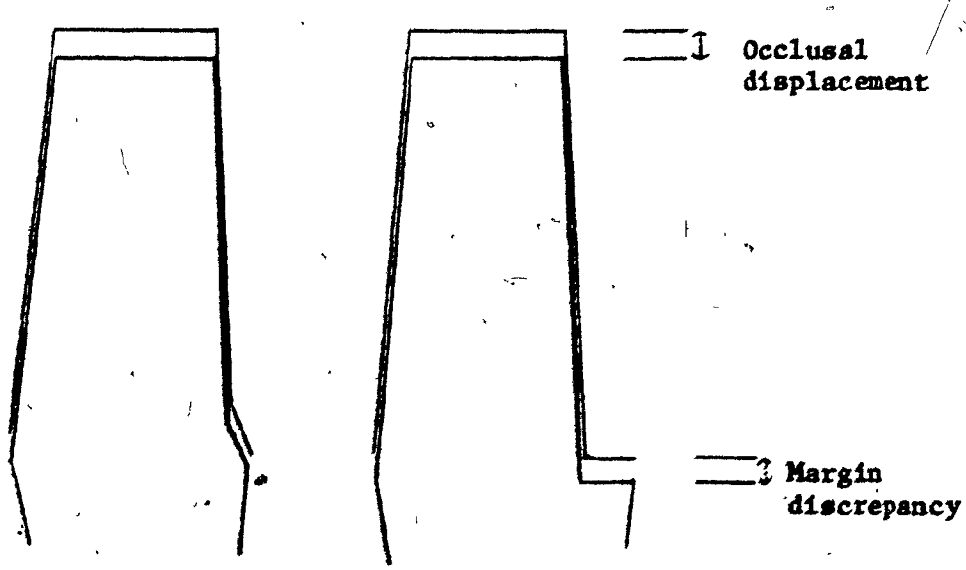
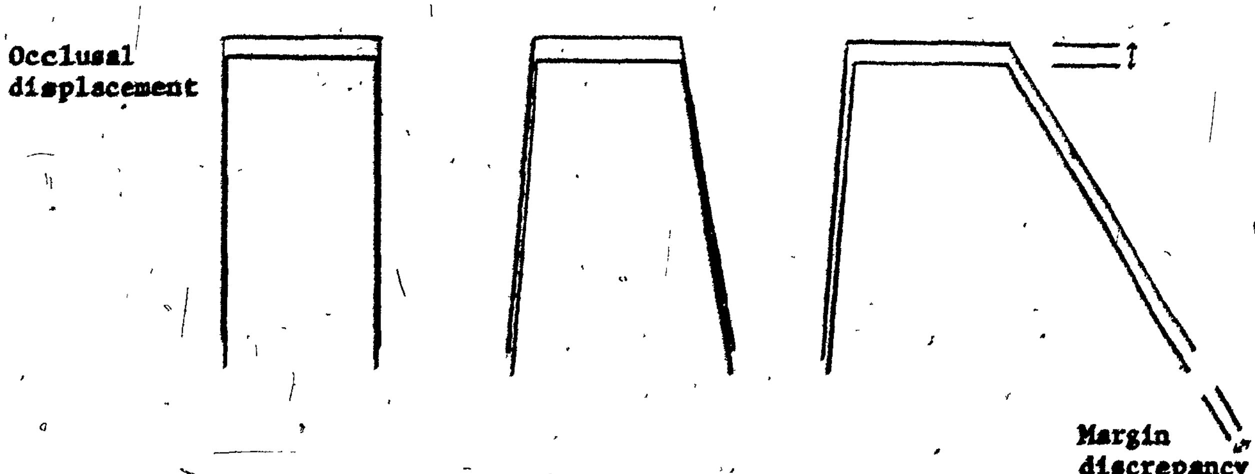


Figure 14. Influence of feather edge, bevel, and shoulder preparation margin.



Influence of angle of taper, parallel, slight and divergent.

Table 7

OCCLUSAL DISCREPANCY RELATED TO THE GINGIVAL SEAT DISCREPANCY.

Impression source of casting	n	Occlusal-Buccal Correlation coeff.	Occlusal-Lingual Correlation coeff.
Rubber	15	0.42	0.56*
Dietrich's	16	0.68*	-0.072

It is evident that the relationship shown in table 7 is not as uniformly strong as had been previously supposed.

Table 8

OCCLUSAL DISCREPANCY RELATED TO THE CROWN MARGIN DISCREPANCY.

Impression source of casting	n	Occlusal-Buccal Correlation coeff.	Occlusal-Lingual Correlation coeff.
Rubber	16	0.25	-0.046 (n=15)
Dietrich's	16	0.21	-0.302

Table 8 indicated that there was no statistically significant relationship of the occlusal cement lute space to the actual crown margin lute fit for the given sample size. This may have been partly due to the sleave joint effect of an apically inclined chamfer or bevel margin design which would tend to minimize the effect of occlusal displacement on the crown margin seal. (Fig.14)

Photographic Assessment of Cement Lute Replica Thicknesses.

The recovered cement lute replicas were set up as Rubber/Dietrich's pairs and photographed on the mesial, distal, buccal, and lingual aspects before embedding. (fig 7) From the Kodachrome slides obtained, estimations of the cement lute thicknesses were made at the crown margin, mid axial, and axio occlusal positions. Close fit or compression zones were scored 1, moderate even density was scored 2, and heavy thick zones were scored 3.

The validity of the above scoring was tested by analysing the parametric measurement obtained from the bucco-lingual microsections at the corresponding sites to the individual scores assessed photographically. The readings for Dietrich's and Rubber were combined since it was only the validity of the scoring estimation that was being tested.

Table 9

A COMPARISON OF THE CEMENT LUTE THICKNESSES ESTIMATED AND SCORED PHOTOGRAPHICALLY, TO THE CORRESPONDING PARAMETRIC MEASUREMENT OBTAINED FROM MICROSECTIONS IN THE BUCCO-LINGUAL PLANE FOR 28 RECOVERED LUTE REPLICAS.

	Photographic score catagories		
	1 (Compression or close fit zones)	2 (Moderate even density)	3 (Heavy thick zones)
Number of zones falling into catagory	50	56	62
Mean thickness of lute obtained from corresponding parametric readings. (μm)	47.78 (I)	76.96 (II)	172.18 (III)
S.D. of lute thickness	21.13	30.22	82.49
Range of lute thickness (μm)	10-100	30-170	65-510

Test of significance between means

t (I-II) = -5·67, df= 104

t (II-III) = -8·69, df= 116

The significance of the differences among the three lute thickness means representing photodensity score categories 1,2,and 3, respectively, was determined with the t-test. As Table 9 clearly indicates, the mean measured thickness of the lute in areas on the preparations labelled as being "close fit zones" by the photodensity estimations differed significantly ($p \leq \cdot 01$) and in the right direction from the mean associated with "moderate even density" fit zones. A similarly significant result was obtained in comparing the mean lute thickness from category 2 with category 3.

Thus, the photodensity method of scoring relating to the parametric measurements was shown to have statistical validity. Consequently, the readings could be extended to describe the fuller picture to include the lute thicknesses at the mesial and distal aspects which had been previously excluded owing to the plane of sectioning. Comparisons to the results in Tables 2 to 5 were then available.

Table 10

COMPARISON OF THE DISTRIBUTION OF PHOTODENSITY SCORES OF CEMENT LUTE THICKNESSES AT THE CROWN MARGIN, MID-AXIAL, AND AXIO-OCCLUSAL POSITIONS BETWEEN RUBBER AND DIETRICH'S IMPRESSION SOURCES.

Location of scoring estimation	Impression source material	Number of zones falling into each photodensity score category 1	2	3	Chi-square test
Crown margin	Rubber	17	29	10	$X^2 = 5.47^{NS}$ df = 2
	Dietrich's	14	21	21	
Mid-axial	R	28	22	6	$X^2 = 2.51^{NS}$ df = 2
	D	23	21	12	
Axio-occlusal	R	25	16	15	$X^2 = 6.40^{*}$ df = 2
	D	13	18	25	
All locations pooled	R	70	67	31	
	D	50	60	58	

It should be noted that the mesial, distal, buccal and lingual data have been combined for each photodensity catagory owing to the smallness of the sample sizes in the individual sub catagories.

In Table 10, one sees that in the axio-occlusal regions of preparations, a closer casting fit (cemented) is associated with Rubber impression sources. There was no significant association of closer fit with either impression source at the mid-axial positions for which the readings were fairly evenly distributed except that there were twice as many poor fit zones (category 3) associated with Dietrich's. A similar distribution to the mid-axial position was shown at the crown margins where twice as many poor fit zones (category 3) were associated with Dietrich's.

By pooling all the locations of scoring estimations (Table 10), Rubber exhibited 40% more close fits (1) than Dietrich's although this was mostly attributed to the superiority of fit by Rubber at the axio-occlusal position. However, the data mildly suggested a similar result at both the crown margin and mid-axial locations.

Of greater note, Dietrich's produced 87% more thick heavy lutes (3) than Rubber and this difference was equally distributed in all locations of scoring. Namely, this was a distribution of 21 to 10 poor fits at the crown margin, 12 to 6 at the mid axial, and 25 to 15 at the axio-occlusal locations.

The significance levels demonstrated in Table 10 concurred with those achieved from the parametric measurements (Tables 2 to 5) in that a non significant difference between the castings of the two impression sources existed at the crown margin which increased to strong significance at the occlusal aspects. Also a similar pattern of closer fits favouring Rubber continued throughout.

The current photodensity scoring was analysed for any confirmation of the findings by Teteruck and Mumford (1966) who had observed a greater tendency for uncemented castings to bind selectively on the mesio-distal aspects of their dies, for anterior tooth preparations.

Table 11

A COMPARISON OF PHOTODENSITY SCORES OF CEMENT LUTE THICKNESSES OF THE BUCCO-LINGUAL TO THE MESIO-DISTAL ASPECTS OF CEMENTED CASTINGS FOR A RUBBER IMPRESSION SOURCE.

Photodensity Score Catagories	Location of scoring estimations	
	Buccal + Lingual	Mesial + Distal
1	29	41
2	32	35
3	23	8
Chi-square test	$x^2 = 9.44^{**}$ df=2	

Table 12

A COMPARISON OF PHOTODENSITY SCORES OF CEMENT LUTE THICKNESSES OF THE BUCCO-LINGUAL TO THE MESIO-DISTAL ASPECTS OF CEMENTED CASTINGS FOR A DIETRICH'S IMPRESSION SOURCE.

Photodensity Score catagories	Location of scoring estimations	
	Buccal + Lingual	Mesial + Distal
1	21	29
2	24	36
3	36	19
Chi-square test	$x^2 = 10.57^{**}$ df=2	

Tables 11 and 12 contained the same sample size. Both tables demonstrate the tendency of mesio-distal aspects of the castings to be associated with an increased frequency of "close fit zones", (1). For Rubber, 41 close fit or compression zones were located on the mesio-distal aspect to 29 on the bucco-lingual. For Dietrich's, the respective frequencies were 29 and 21. The frequency of category (2), or "zones of average fit", for Dietrich's demonstrated a similar distribution of 36 zones on the mesio-distal aspect to 24 bucco-lingually, whilst for Rubber the distribution was more equal.

For the distribution of the "heavy thick lutes", category (3), the same pattern continued but the frequency was reversed. Namely, there is a tendency of the bucco-lingual aspects of the casting to be associated with more heavy thick zones of cement lute material. For Rubber, 23 zones of heavy or excessive cement lute were demonstrated at the bucco-lingual aspect to 8 at the mesio-distal. The respective frequences for Dietrich's were 36 to 19.

Oblique Seating of Castings.

Several earlier workers had described the phenomenon of oblique seating of castings during cementation.

During the current study, a macroscopic visual impression of oblique seating was noted from the bucco-lingual micro sections. This was subsequently investigated.

Using the individual bucco-lingual sections, the lack of fit as represented by the lute thickness at the gingival seat and axio-occlusal positions were studied in order to determine oblique seating. Visualizing the gingival seat section (Fig.15), a positive difference when subtracting the thickness of the buccal lute from that of the lingual indicates oblique

Oblique Seating

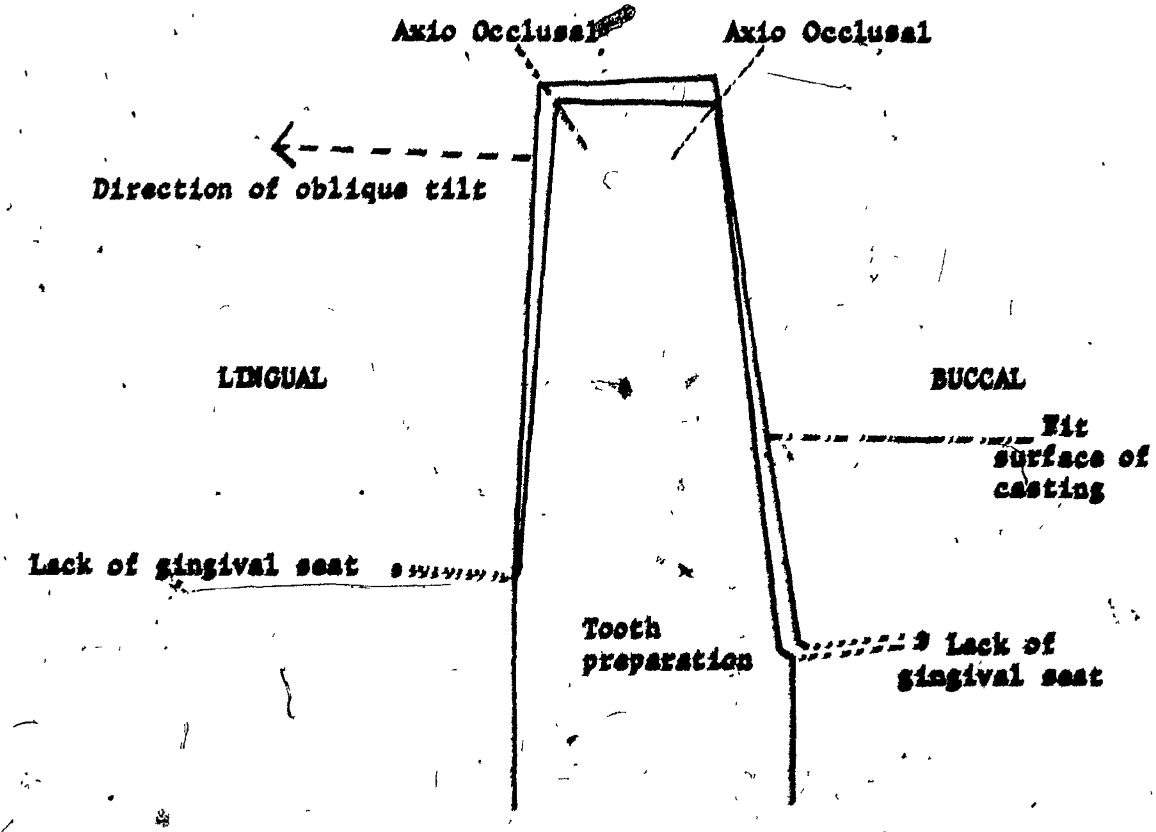


Figure 15

seating occlusally towards the buccal direction. At the axio-occlusal location of such a section, a positive difference when subtracting the lingual lute thickness from that of the buccal would indicate oblique seating occlusally towards the buccal. (Tables 13 and 14).

Table 13

OBLIQUE SEATING FOLLOWING IN VIVO CEMENTATION OF FULL CROWN CASTINGS OBTAINED FROM A DIETRICH'S IMPRESSION SOURCE.

Preparation	Monitor of oblique seating	
	Gingival seat discrepancy: (lingual minus buccal)	Axio-occlusal discrepancy: (buccal minus lingual)
	µm	µm
A	+40	+40
B	-60	-140
C	-15	+70
E	+90	+40
F	+205	+305
G	-25	-80
H	-110	-155
I	+35	-50
J	+60	-100
K	-220	-150
L	-340	-445
M	-110	-320
N	+270	+120
O	-10	+135
P	-130	-15
Q	+20	+10
Mean	-18.75	-45.93
S.D.	45.52	179.95

+ve. values indicate crown occlusally oblique towards buccal
-ve. values indicate crown occlusally oblique towards lingual.

Table 14

OBLIQUE SEATING FOLLOWING IN VIVO CEMENTATION OF FULL CROWN CASTINGS OBTAINED FROM A RUBBER IMPRESSION SOURCE.

Preparation	Monitor of oblique seating: Gingival seat discrepancy: (lingual minus buccal)	Axio-occlusal discrepancy: (buccal minus lingual)
	μm	μm
A	-140	0
B	-350	-140
C	+150	+55
E	+40	+35
F	+30	+20
G	+70	+15
H	-100	-90
I	-255	-50
J	+70	+5
K	-20	-140
L	-100	-215
M	+65	-10
N	-5	+20
O	+195	-35
P		-10
Q	-65	+20
Mean	-27.66	-32.5
S.D.	145.73	75.38

Tables 13 and 14 showed that for both Rubber and Dietrich's castings, 10 out of 15 directional monitors of oblique seating measured at the gingival seat position were related to the same direction registered at the axio-occlusal position recorded contralaterally, though these were not necessarily associated with the same preparations for each impression source. The repeating pattern of negative mean values suggests an apparent trend for oblique seating to favour the lingual direction.

Table 15

CORRELATION OF ACTUAL GINGIVAL SEAT DISCREPANCY TO ACTUAL AXIO-OCCLUSAL MEASUREMENT CONTRALATERALLY IN THE BUCCO LINGUAL PLANE.

Location of Measurement	Coefficient of correlation	
	Rubber	Dietrich's
Buccal Gingival Seat discrepancy to Lingual Axio Occlusal	0.33	0.81**
Buccal Axio Occlusal to Lingual Gingival Seat discrepancy	0.60*	0.42
	(n=15)	(n=16)

Tables 13 to 15 have suggested that oblique seating has occurred during cementation. However, despite some statistical validity, further investigation is necessary to ascertain the influence of the passive innate space between a casting and the preparation prior to its cementation.

Direction of Oblique Seating

The occurrence of +ve and -ve sign monitors for obliqueness of seating gave no immediately apparent directional trend, (Tables 13 and 14), though possible hinting by the consistent negative mean values of tilt that oblique seating towards the lingual may predominate.

Further data, not presented in this thesis, hinted that the shape of a preparation may influence or guide the hydrodynamics of cement flow and hence the resultant direction of oblique seating of castings particularly where the length of one axial wall predominates over the other three aspects.

DISCUSSION

The purpose of the current study was to investigate and compare the characteristics of fit of pairs of unvented full crown castings (type III gold) for anterior tooth preparations, obtained from a polysulphide rubber, tray impression, and a Dietrich's thermoplastic band impression source for each of 16 teeth, following cementation of the castings in vivo.

It was apparent that there have been relatively few previous studies on the overall fit of castings. The problems in obtaining true in-vivo material, and the difficulty in fine sectioning of a hard complex such as a gold casting cemented onto a tooth preparation led to the adoption of several indirect in-vitro methods with inherently limited applications to the more complex clinical situation; namely by Jorgensen (1960), Kaufman, Coelho and Colin (1961), Bassett (1966), McCune, Phillips, Swartz and Mumford (1971), and Dimashkieh, Davies and Fraunhofer (1974). The studies by Fusayama (1963) on expanded castings, and Jones, Dykema and Klein (1971) on the effectiveness of venting gave improved differential information on the overall fit of castings but were again in-vitro.

The clinical studies performed to date have been by Yoshida (1959) and Murata (1967), both relying on the use of teeth slated for extraction, or previously crowned teeth requiring extraction for various reasons. Occlusal cement lutes of 50 to 230 microns were demonstrated. There was an equivalent discrepancy shown at the crown margins.

The concept of recovering a cement lute replica, devised by McLean and Fraunhofer (1971), and extended in the current study, is to date the only truly in-vivo method which does not require the sacrifice of the prepared tooth to measure the space between a casting and its preparation occupied by cement, and thus could eventually be extended into a longitudinal study. A polyether elastomer was substituted for phosphate cement to allow complete recovery of the lute. Impregum was shown by McLean and Fraunhofer (1971) to have equitable properties of flow and disc diameter to phosphate cement (Table 1). The film thicknesses obtained from the current study were in the same order as were obtained in previous studies using actual phosphate cement. A range of fit of 8 to 340 microns was demonstrated at the crown margin in this study, which for the Rubber impression source showed a mean buccal fit of 85.94 microns, and 66.33 microns at the lingual. The mean buccal fit was larger than that obtained by McLean and Fraunhofer for mesial and distal margins of 66.7 $\pm$ 60.8 microns and 26.1 $\pm$ 26.2 microns respectively. However, the latter being taken from the mesio-distal sections of castings on premolar teeth were more compatible to the recordings of fit obtained for the lingual crown margins and the lingual preparation design in the current study.

Fusayama et al. (1963) demonstrated that a cement lute required an overall passive innate space of more than 30 microns for maximal vertical seating. This ranked within the 40 micron and 25 micron particle size requirements for phosphate cement by the A.D.A. specification standards. However, the mean fits of cemented castings achieved in all previous studies have been considerably larger than this minimum grain size except at points of binding or compression contact between a casting and its tooth preparation (McLean and Fraunhofer, 1971). This is due to the large number of variables inherent in an indirect procedure from the shape of the preparation, the impression and laboratory phases, through to the final cementation. Indeed, Teteruck and Mumford (1966) suggested that the definition of casting accuracy should take into consideration a degree of fit rather than absolute adaptation.

If biological acceptability for a subgingival crown-cement-tooth margin were shown to require a fit approaching the effective grain size of phosphate cement powder, it is doubtful whether the limits of clinical acuity for detection of margin fits using current instrumentation by explorers and radiographs are adequate, (McLean and Fraunhofer, 1971). Nevertheless, McLean and Fraunhofer suggested that a margin fit of 120 microns may still be acceptable clinically, but the confirmation of this opinion by longitudinal studies on the basis of the biological implications is still lacking. Such a range of fit is already four times the theoretical objectives of fit for the current cement technology. However, the current study demonstrated that this is indeed the size of fit at crown margins being frequently experienced clinically.

The Current Investigation

Rubber Dietrich's Comparisons

Comparison measurements were obtained from two sources. Parametric measurements of the cement lute thicknesses were obtained from bucco-lingual micro sections of mutual pairs of embedded recovered lute replicas. Secondly, photodensity estimations of lute thicknesses were scored from Kodachrome slides of the recovered lute replicas on the buccal, lingual, mesial and distal aspects before embedding. Of the latter, the bucco-lingual estimations were cross referred to the parametric reading at the same site for statistical validation of the photodensity categories, which were consequently shown to be significant individual groups, (Table 9).

It must be noted that a cement lute is a measure of the impression accuracy, the innate space between a casting and its die, and the effects of cementation.

The control chosen to standardize the aspect of laboratory error was the mutual procedure adopted for each member of each pair of impression sources. Thus, each member of the pair was poured from the same mix of die stone, the pair of copings were waxed, sprued and cast together in the same casting ring, and if the fit of one of the castings was criticized clinically, the whole pair of impressions was repeated.

Postulations had been made in the Introduction that a swamping effect, owing to the multiple phases involved, and the effects of cementation might have nullified any differences between the two impression sources. However, a consistent repeating pattern persisted of closer fits favouring Rubber at all sites of measurement. The mean scores and standard deviations were in all categories greater for the fit of castings from the Dietrich's source than for Rubber, and with no statistical reversals.

Crown Margin Discrepancies

The mean paired difference in the cement lute discrepancy or cemented fit at the crown margin of castings obtained from the two impression sources was not statistically significant despite the closer mean fits for Rubber. The mean buccal fit was 85.94μm, S.D. 46.42 for Rubber, and 107.68μm, S.D. 87.55 for Dietrich's. Similarly, at the lingual, the mean fit was 66.33μm, S.D. 38.79 for Rubber, and 79.06μm, S.D. 72.25 for Dietrich's (Table 2).

The photodensity assays of the lute thicknesses contributed supportive information on the distribution of fit at the crown margin (Table 10). Twice as many poor fit zones (category 3) were associated with Dietrich's than Rubber by 21 to 10. A pattern of more close fits (1) and more average fits (2) were shown for Rubber but were without statistical significance for the sample.

Mid Axial Discrepancies

Not unexpectedly, the individual and mean lute thicknesses at the mid-axial position exhibited the closest fit of castings from both impression sources. This is partly because a long sleeve joint effect is acting between the axial walls of a crown preparation and its casting for any given occlusal displacement, provided that the taper of the preparation is not excessive, (Fig.14). Furthermore, the observation of castings to seat obliquely in the bucco-lingual plane during cementation, necessitates the existance of a fulcrum zone against compressed cement particles in the mid axial region which would thus maintain the latter lute thickness at a minimum despite the rotation.

Again the mean values and standard deviations were smaller for Rubber, but a statistically significant mean difference was demonstrated at the lingual aspect ($p \leq .05$), from the fit of castings from the Dietrich's source, but this was not evident at the buccal location.

The mean buccal fit recorded for Rubber was 77.18μm, S.D. 33.66 and for Dietrich's 83.43μm, S.D. 40.32. The mean lingual fit was 67.81μm, S.D. 35.63, for Rubber and 103.43μm, S.D. 62.17 for Dietrich's.

The photodensity assays revealed no statistically significant differences. However, the pattern of more close fit zones (1) and less excessive lute thicknesses (3) continued to be associated with the castings from the Rubber impression source (Table 10).

Axio-Occlusal Discrepancies

The pattern of closer fits following cementation continued for castings derived from the Rubber impression source, (Table 5), but extended to a statistically significant difference from the Dietrich's source at both the buccal and lingual locations ($p \leq .05$). Similarly, from the photodensity assays there was a stronger degree of association of closer fits to Rubber, ($p \leq .05$).

The mean buccal fit was shown to be 81.87μm, S.D. 50.63 for Rubber, to 126.87μm, S.D. 155.33 for Dietrich's, and similarly at the lingual, 114.37μm, S.D. 82.56, and 172.81μm, S.D. 222.69 respectively. The range of axio occlusal lute thicknesses was in the same order as that obtained for the occlusal location. However, there were larger deviations about the mean values owing to a superimposed tendency for bucco-lingual oblique seating (Tables 13,14,15), which is subsequently discussed.

Occlusal Discrepancies

Not surprisingly, the castings from both impression sources revealed their largest mean cement lute thicknesses at the occlusal position. This was due to the trapping of cement occlusally whilst the narrow mid axial lute was being more rapidly closed during seating. However, the largest mean paired difference between the two impression sources also occurred at the occlusal position, namely of 63μm, S.D. 76.42 to the closer fit of Rubber. This was statistically highly significant ($p < .01$), and thus emphasized the persistent penetration of the different impression characteristics of the two impression materials despite the cementation effect on their castings, and the intermediary variables of the laboratory phase.

The mean cemented fit for Rubber was 157.31μm. S.D. 80.21, and 220.31μm, S.D. 98.07 for Dietrich's (Table 6).

Summary: Rubber Dietrich's Comparisons.

It is apparent that, although no strongly significant difference was shown between the mean fit of cemented castings from the polysulphide rubber and the Dietrich's thermoplastic compound impression sources at the actual crown margin, the significance progressively increased to a highly significant difference from the mid-axial, axio-occlusal, to a maximum at the occlusal position. Since all other conditions were mutual to the castings of each impression pair, the original fit characteristics of the two impression sources are considered to be distinctly different.

Although the Dietrich's compound technique is potentially as capable of achieving as close a fit a casting after cementation as the polysulphide rubber source (as is evident in preparation K, N and P, Table 2), the material and technique is considered to be more liable to poorer impression adaptation to the tooth preparation, or to greater permanent distortion. This was confirmed by the consistently larger means and standard deviations shown for the fit of castings from the Dietrich's source following cementation. Similarly, the photodensity scoring over all four axial and marginal surfaces (Table 10) showed that, although Rubber demonstrated 40% more close fit zones (1) by total, than Dietrich's, the difference was more significant for the occurrence of poor fit zones (3) of which Dietrich's produced 87% more than Rubber, and they were equally distributed over all the locations of scoring.

The significance levels of the mean paired differences of the cement lute thicknesses occurring at a maximum at the occlusal location, and dropping to a minimum at the margin, also related to the thickness of the compound material within the impression band matrix, which would be maximal at the occlusal aspect. This concurred with the description by Roydhouse (1962) of uneven cooling of thermoplastic compounds, especially when in thicker sections, which may incorporate residual stress owing to the low thermal conductivity of the material. On removal of the impression from the mouth the properties of compounds relative to polysulphide rubber may allow some greater release of this stress owing to the high coefficient of expansion, and its high flow at mouth temperature of 6% (Skinner and Phillips, 1973, and A.D.A. Specification No.3) potentially resulting in a permanent deformation on cooling to room temperature.

However, it was apparent that, despite a tendency for inherently greater internal spacing being present in the more occlusal aspects of the Dietrich's castings, this did not permit significantly further seating of the casting, nor minimize the vertical cementation displacement by improving cement flow, to assist the closure of the margin. Obviously, distortions or lack of adaptation are irregular, and binding zones beneath castings exist concurrently to prevent compensating seating.

A concept of passive fit is therefore, subtly different, and should imply an equal, overall passive, innate space between the preparation and its casting greater than the effective grain size of the cement used. This would be particularly important to achieve at the narrow axial fit locations, and especially on the mesio-distal aspects, according to the current study (Tables 11 and 12). Indeed, McLean and Fraunhofer (1971) observed a better than anticipated fit of porcelain jacket crowns relative to castings once cemented, probably owing to the uniform space of the platinum matrix. However, Jorgensen (1960,63) cautioned against reaming out all but the marginal few millimeters of the fit surface of a casting to achieve an overall innate space free of binding interferences. He specified the risk of setting up a cement filtration effect in the effective grain size range of 20 to 50µm which, if occurring at the crown margin, could weaken and wash out the marginal cement lute seal and invite subsequent failure. Given the current accuracy of castings, the recommendation by Jorgensen was to reduce the filtration effect and improve cement flow by venting castings occlusally.

Clinically, for both impression sources, the cemented mean fits at the crown margins obtained in the current study lay well within the upper limits of margin acuity suggested by Christensen (1966). However, the standard deviations were high, particularly for Dietrich's. This was partly due to the wide variation in accuracy inherent in all currently used technology for indirect restorative procedures, despite the ideal goal of the 25µm effective grain size of phosphate cement. The discrepancy is further complicated by the displacement and hydrodynamic effect during subsequent cementation. In the Christensen study, if 119μm was being passed as good for the fit of subgingival margins of castings which had been cemented, the same range must apply to the problem of acceptance or rejection of a casting during the normal clinical evaluation procedure prior to cementation. The introduction of cement may subsequently compound this discrepancy substantially, unless it were capable of zero film thickness.

Although statistically significant differences were shown between the two sets of castings, this was absent at the actual crown margin, despite a continuing closer fit for Rubber. The buccal paired mean difference was only 21.75μm, S.D. 95.52, and 16.0μm, S.D. 52.95 at the lingual margin. If the currently achieved range of fit is acceptable clinically, then this paired mean difference cannot be used to indict the Dietrich's compound technique. However, if the biological objective were shown to be a fit in the order of the 25 micron or 40 micron grain size of the cement used, such differences may become significant. However, this degree of fit may imply the need for a new concept in fluid cement (non particle) technology. To date, under the conditions of the current accuracy of castings, such cements as resin systems have had many failings but can, according to Schouboe et al (1956) achieve a film thickness as low as 10μm.

Meanwhile, currently, the mean margin fit following the cementation of castings from either Impression Source did not approach these low values. Some technical suggestions are offered later in this paper to minimize the discrepancy.

The Characteristics of Fit of Cemented Castings Mutual to Both Rubber and Dietrich's Impression Sources.

Buccal to Lingual Marginal Relationships.

Consistently, larger mean fits and standard deviations were seen at the buccal aspect of crown margins and gingival seat position than at the lingual, for both impression sources. For example, for Rubber, the mean fit at the buccal margin was 85.93μm, S.D. 46.42, to 66.33μm, S.D. 38.79 at the lingual.

Since each tooth preparation was constant for each pair of castings, this pattern was considered to be an in-vivo demonstration of the geometric function of the shape of a buccal chamfer relative to the more tapered lingual finish line for any given occlusal cementation displacement described by Fusayama et al (1964) in vitro, (Fig.14). However, for the sample studied, no significant t-values were determined.

It is later described that a margin discrepancy may be compounded by a significant tendency for castings to seat obliquely during cementation, (Tables 13,14,15). Furthermore, for the anterior crown preparation shape, a trend was suggested which opened the buccal margin the wider, as the crowns under study tended to tilt occlusally towards the lingual.

It was, of course, discouraging to indicate that the buccal margin was routinely the poorer fitting since it is there that according to Amsterdam (1974) the earliest signs of periodontal breakdown are often observed, in a periodontal tissue that Goldman (1951) described as weaker than that in all other normal locations, to withstand abnormal stress.

The author later describes design modifications at the margin to minimize the margin discrepancies for a given cementation displacement, but also describes the dangers of over compensating.

Occlusal Marginal Relationships

The correlation of the occlusal cement lute discrepancy, or total vertical displacement, to the gingival seat and crown margin discrepancy was not as uniformly strong statistically (Tables 7 and 8) as had been assumed in average fit studies conducted by Jorgensen (1960), Kaufman et al (1961), and Bassett (1966). This was attributed to the variable effects of any apically inclined margin design, to the degree of innate occlusal and marginal adaptation, to thin margin distortion during casting, and the superimposed effect of oblique seating.

Occlusal - Gingival Seat Discrepancy

For Dietrich's, the relationship followed what had been expected from studies on the geometric influence of margin design on the cement lute discrepancy (Fig.14). Occluso-buccally a strong relationship ($p < .05$) existed corresponding to the larger margin angle of the chamfer preparation. There was no significant occlusal-lingual correlation, which followed the more tapered lingual preparation margin and sleave joint effect expected.

A significant correlation was demonstrated for Rubber at the occlusal-lingual relation, ($p < .05$), but was not strongly evident occlusal-buccally.

Occlusal - Crown Margin Discrepancy.

No significant correlations were shown for either impression source at the actual crown margins. This was again attributed to the sleave effect at the lingual margin, to the large number of variables acting at the buccal crown margin, and particularly to the effect of an apically inclined chamfer or slight bevel if present.

Bucco-Lingual to Mesio-Distal Comparisons.

For the castings of both impression sources there was a significantly greater association of more close fits or compression zones (1) to the mesio-distal aspects, and of heavier thick zones of cement (3) to the bucco-lingual aspects ($p < 0.01$) scored from the photodensity estimations, (Tables 11 and 12).

This concurred with the similar observation by Teteruck and Mumford (1966) on the precementation fit of castings for anterior crown preparations. A greater tendency for mesio-distal binding against the die had been recorded, probably owing to a physical contraction pattern inherent for the geometric shape of anterior crowns during the casting procedure.

It is thus suggested that the mesial and distal fit surfaces of castings for anterior crown preparations, are the most likely sites for selective internal relief when warranted.

Oblique Seating of Castings During Cementation

Jorgensen (1960) described the phenomenon of oblique seating as the inevitable consequence of the hydrodynamic manipulation of a semi fluid cement acting in a semi closed system. Bassett (1966) was unable to reduce this affect using axial guide grooves in crown preparations. However, Jorgensen felt that the greater cement flow obtained through a vented casting would reduce the oblique seating effect by reducing the hydrostatic pressure, and by allowing further seating of the casting. Jones, Dykema, and Klein (1971) did not record any significant oblique seating in their venting studies but a degree of vertical seating guidance was used in their methodology.

In the current study, a macroscopic visual impression indicated a subjective oblique seating which was then born out parametrically.

Significant correlations ($p \leq .01$) were recorded across the contralateral diagonal between the gingival seat and axio-occlusal locations (Table 15) for cemented castings from both impression sources. However, for each impression source the correlation was incomplete across one of the diagonals for the sample.

Bucco-lingual differences at the gingival seat and axio-occlusal positions were also used to monitor the direction of oblique seating (Tables 13 and 14). The direction of oblique seating judged by the gingival seat monitor was the same as that judged by the axio occlusal monitor for 10 out of 15 castings for both the Rubber and Dietrich's impression sources, although, the valid castings, for which this relationship of oblique seating held, were not always those for the same preparations.

The tendency for significant obliqueness of seating can be explained by a rotational displacement superimposed onto a vertical occlusal displacement under the influence of the seating pressure, and the resultant hydrodynamic force of cementation. However, a more specifically designed method of investigation cognizant of the distribution and dimensions of the passive innate space between a casting and the preparation as a possible influence are needed depending on the film thickness potential of the cement to be used.

There did not appear to be any immediately apparent trend for the castings of either impression source to a greater occurrence of obliqueness of seating to either buccal or lingual direction (Tables 13 and 14). Nevertheless, the means of the bucco-lingual differences at the gingival seat and axio occlusal positions chosen to monitor oblique seating were all negative values. This implied a trend for the castings for full crown preparations on the anterior teeth used, to seat occlusally oblique towards the lingual, which would consequently tend to close the lingual margin, but also, would unfortunately tend to rotate the buccal margin open. However more specific testing is required.

Explanations have been offered. Firstly it has been suggested that the directional trend resulted from a lateral bias in occlusal seating pressure produced from the mastication pressure applied through an orange wood stick to the castings. This had been used to maintain full seating following the initial cementation loading which was applied by heavy finger pressure. However, since most of the preparations were upon upper anterior teeth, it would have seemed to be more probable that a resultant force from the mandibular teeth would have been transposed to an oblique tilting of the castings occlusally to the buccal, which was the reverse of the trend described.

Secondly, data not presented in this thesis, hinted that the shape of a preparation may have an influence on the hydrodynamics of cement flow.

It is theorized that during the cementation of a casting, there would be a significantly greater amount of cement to be expressed from between any significantly longer axial wall and the casting, such that a greater resistance to seating might be registered at that location. The crown preparation for an anterior tooth often observes a significantly longer buccal axial wall owing to the position of the labial gingiva. The above theory would, therefore, suggest that, on cementation, the casting would seat less completely on its longer buccal aspect for any given vertical seating pressure. The crown would thus tend to tilt occlusally obliquely to the lingual, which is the observed trend suggested. A clinical impression of another probable example of the effects of fluid flow may offer some substantiation of this theory. Namely, it has been observed that during the recording by a compound band impression of a crown preparation with long occluso-gingival dimensions of which the labial axial wall is significantly the longest, the band may be seen to lift from the buccal gingival aspect such that extra lateral finger pressure is needed to ensure vertical seating of the band.

Compensation for Cementation Displacement

Several authors have suggested measures to compensate for the cementation discrepancy, by decreasing the resistance to cement flow, and by building a tolerance of fit into the crown margin design.

Such methods have included internal relief by burs, aqua regia, reverse electro plating, and foil or varnish spacers. However these measures are empirical and difficult to control. The current study suggests that internal relief would be best applied to the mid axial locations and particularly at the mesio distal aspects for anterior tooth crown castings, selectively when warranted.

Axial guide grooves have been suggested, but are without significant results. Occlusal venting has been shown to improve early cement flow to significantly improve seating but this has remained very unpopular clinically.

Overwaxing or overextending crown margins was suggested as early as 1928 by Smith and Potter to compensate for finishing and displacement. This is abhorred by some clinicians, but of those, many are adherring to this advice inadvertantly.

It should be noted how easy it is to misread the length of a bevel or sleeve beyond a chamfer finish line when relating a casting.

Certainly, if a full finish line is apparent on the fit surface of a casting, this already implies a minor over extention. Something rather than nothing may imply a 50 - 120µm range to the limit of discernability depending on how the fit is assessed. (Christensen 1966, McLean and Fraunhofer 1971, Jones et al.1971, and Phillips 1973).

Where there is an intentional philosophy of establishing a sleeve joint or superimposed bevel, a 120 - 500µm extension may be easily produced. However, owing to the tendency for oblique seating of castings, and also to casting distortion of thin metal margins, a long sleeve joint or a long bevel may worsen the margin seal picture rather than improve it.

The excessive use of metal beyond the preparation margin has been criticized periodontally by Waerhaug (1953,60) in maintaining an uncleansable subgingival plaque. Such an extension is also thought to be liable to distortion during routine subgingival scaling. However other workers have maintained considerable clinical success with a very accentuated long bevel superimposed onto a deep chamfer or shoulder margin as suggested by Stein 1975.

Suggestions arising from the current study.

The expected occlusal cementation displacement of an unvented anterior crown casting was shown to be 157µm. It is thus suggested that a similar length apically incline bevel is superimposed onto every chamfered and shoulder margin to compensate and further close the crown margin.

Conversely, a butt joint margin may demonstrate a 1:1 relationship to the occlusal lute and thus exhibit 157µm of cement at the crown margin which according to Norman-Schwartz and Phillips (1963) may encourage cement dissolution and plaque accumulation. However longitudinal studies are still needed on the biological implications of the degree of margin fit.

Alternatively venting might be recommended, since further seating implies less margin cementation discrepancy and minimizes oblique seating. However, a need for venting implies that the hydrodynamic effect of the currently used particle cements is too great, and suggests the need for new types of zero film thickness cements which in turn will also demand a new technology for indirect restorations of much more consistent and greater accuracy than current castings.

CONCLUSIONS.

The following conclusions were drawn from this study:

It was assumed in this study, that the space between casting and preparation, occupied by the elastomer material, represents the cement thickness, and hence the lack of fit had the casting been permanently cemented. The recovered cement lute was therefore a measure of the accuracy of the impression origin, the laboratory variables and the effects of cementation. The latter two variables were controlled as mutual for each matched pair of impressions which had been recorded sequentially for each crown preparation in vivo. Thus, any statistically significant mean difference in the fit of the matched pair of castings following cementation was attributed to a difference in the characteristics of the impression materials and technique used.

Rubber Dietrich's Comparisons.

1) At all sites of measurement of cement lute thicknesses, smaller means and standard deviations were associated with castings derived from the polysulphide rubber impression source than from the Dietrich's thermoplastic compound, without any statistical reversals.

2) From measurements of the cement lute thickness recorded from the middle bucco-lingual micro sections, no statistical significance was attributed to the mean difference between the matched pairs of cement lute thicknesses for readings taken at the crown margin location, despite a closer mean fit being associated with the Rubber source. However, the mean difference became statistically significant at the mid-axial and axio-occlusal positions, rising to a very high level of significance at the occlusal location, favouring the closer fit of Rubber.

3) An indirect photodensity technique for scoring the cement lute thicknesses supported the distribution described by the parametric

measurements. The photodensity technique for estimating film thicknesses of the recovered cement lutes by scoring into distinct catagories of fit was shown to have statistical validity when related to the associated mean lute thicknesses recorded at the same locations of measurement made parametrically.

4) Castings from the Dietrich's impression source were shown to be capable of achieving as close a fit following cementation as castings from the Rubber source. However, the larger mean values and the greater occurrence of larger fit discrepancies shown by the Dietrich's castings indicate that the Dietrich's impression material and technique is subject to greater permanent distortion or to poorer adaptation than the polysulphide rubber.

By total, castings from the Dietrich's impression source presented 87% more poor fit zones (photodensity category 3) than Rubber, whereas castings from the Rubber impression source produced only 40% more close fit zones (category 1) than Dietrich's.

5) Previous investigators have shown that dental thermoplastic compound materials when in thicker sections are more liable to building up and releasing residual stress during cooling. This may relate to the current study where the greatest mean differences from the polysulphide rubber source (catalytic set) were determined at the occlusal aspects around which the compound impression material would have been at maximum thickness in the copper band matrix.

6) The greater lute thicknesses occlusally and axially determined for castings from the Dietrich's impression source indicated that a greater innate space did not allow for greater compensating seating to assist the closure of the margins by encouraging cement flow. It was concluded

that sufficient binding zones coexisted with regions of greater innate space to control the ultimate seating of the casting.

7) Differences in accuracy between the impression sources persisted and penetrated to the final cemented fit of the castings despite the cementation displacement effect and any uncontrolled variables acting on the casting.

Characteristics of the Fit of Castings Following Cementation, Mutual to Both Impression Sources.

1) No castings seated fully on cementation.

2) The closest mean fits and smallest standard deviations were found at the mid-axial locations.

3) Significantly more close fit or compression zones were shown at the mesio-distal aspects of the anterior crown castings studied, and conversely more excessive lute thicknesses were demonstrated bucco-lingually.

4) A significant tendency was demonstrated for castings to seat obliquely during cementation.

5) Larger mean lute thicknesses were demonstrated at the buccal crown margins (prepared to a chamfer margin finish) than for the more tapered lingual margins, although no significant difference was shown between the means of the samples studied. This was further reflected in a tendency for castings to seat obliquely in the lingual direction, which would have tended to close the lingual margin and rotate the buccal margin open. However, the influence of the geometry and design of a preparation margin on the fit of a crown margin for a given occlusal cementation displacement was thought to the most dominant factor.

6) The mean fit at the crown margins following cementation was within the previously established limits of tactile assessment and acceptance for a subgingival margin. However, the wide deviations about the means suggested that, although these margins had been accepted within these limits prior to cementation, the uncontrolled effects of cementation, using currently available cements, multiply the margin discrepancy of the final functioning unit.

7) Optimum fit at the crown margin using current clinical methodology may require:

a) Passive fit.

This as an objective ought to imply an overall even distribution of fit particularly along the axial walls. A passive fit may still be a close fit rather than an excessively or irregularly spaced fit, provided that no aspect encroaches on the minimum effective grain size of the cement used.

b) Internal relief of the fit surface of castings.

It is suggested that this is selectively applied at the mesio-distal axial walls if binding were suspected in a full crown casting for an anterior tooth preparation.

c) A compensating apically inclined bevel should be superimposed onto shoulder and chamfer margins compatible to the expected average occlusal cementation displacement, which was shown to be in the order of 150μm. If a longer bevel or a sleave joint over-extension were used, oblique seating may be shown to open the margin rather than close it, and so add to the periodontal hazard. For a vented casting, the necessary length of bevel would be reduced, since previous studies suggested that greater seating would be expected.

8) The smallest mean cemented fit at the crown margin was 66µm, recorded for castings from the Rubber impression source, in comparison to the expected 25µm goal defined by the grain size of phosphate cement. The range of fit occurring at the margin was actually shown to be 8-340µm despite careful clinical approval of the margins prior to cementation. Also, for any individual casting, regions of excellent fit were shown to co-exist with regions of poor fit owing to inaccuracies in the casting and the effects of cementation. This occurrence of uncontrolled margin discrepancies partly explains why it is so difficult to estimate the prognosis of any current prosthetic restoration without, sometimes unfairly, throwing the complete onus onto the patient for extraordinary daily maintenance therapy.

9) Longitudinal studies are now needed to determine what dimension of cement lute at the crown margin is biologically compatible when placed subgingivally.

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