AN INVESTIGATION OF

DENTAL LUTING CEMENTS

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ABSTRACT

The retentive power of selected dental luting cements has been investigated in-vitro with regard to the effects of taper, temporary cementation and recementation.

A standard test method has been developed from measurements of clinically observed tapers and cementation pressures achieved, and account has been taken of the dimensions of human teeth. These observations have indicated a mean clinical taper of 17^0 to 30^0 and an initial pressure of 6 kg typically reducing to 3 kg.

The order of retention of the various cements has been found to be composites > glass-ionomers/polycarboxylates > zinc phosphate > EBA cement. Prior use of eugenol-based temporary cements appears to have no adverse effect, except possibly in the case of resin-based composites in conjunction with a volatile cleaning/drying agent.

These studies indicate that the effect of taper may be more complex that the literature suggests. In contrast to the accepted view of a monotonic relationship between retention and taper, the current study indicates that for most cements there may in fact be an optimum taper in the range 7^0 to 15^0. The reason for this is unclear.

Recementation appears to have no adverse effect on retention. A separate clinical survival study ranked the cements in the order glass-ionomer/polycarboxylate > zinc phosphate > EBA, in full agreement with the in-vitro data.

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DECLARATION

This thesis is the original work of the author with the exception of the help and guidance acknowledged in the text.

Simon M. Black.

INTRODUCTION

The current clinical practice of attempting to prepare teeth for crowns with an "ideal" taper of 5-7^0 is based on work by Jorgensen[1] in 1955, which lays claim to be the first analysis of the relationship between taper and retention in the laboratory. However, analysis of the data shows that some of the points on Jorgensen's hyperbolic graph relating retention to taper are in fact extrapolated, and that the shape of the curve relies heavily on a single data point. Furthermore the work was carried out using cements which relied on a micromechanical effect to retain crowns whereas modern cements exhibit a degree of adhesion to dental tissues. In addition Jorgensen model used galalith (a plastic moulding substance made from casein and formaldehyde) instead of dental tissue, and turned brass instead of cast gold crowns. The model also varied from clinical practice in that the crowns had open tops, so that any component of retention derived from the occlusal portion of the preparation was lost.

In view of this, it is surprising that Jorgensen's work has been so readily accepted and so rarely challenged. For example, Kaufman et al[2] in 1961 investigated the

relationship between taper and retention using a model with closed-topped cast crowns, and should have been able to critically appraise Jorgensen's earlier paper. However, the authors chose to present their data in a different form to that of Jorgensen, making comparison difficult. Indeed they did not even compare their results with those of Jorgensen. If the data of Kaufman et al is analysed according to Jorgensen's method however, this does not appear to support Jorgensen's conclusion of a hyperbolic relationship between retention and taper.

In view of the widespread acceptance of Jorgensen's views on taper it was therefore considered important to investigate the effect of taper on retention in detail using human dentine and complete gold crowns with both clinically accepted and more recently developed cements. A study was therefore planned according to the following protocol.

1. Development of a laboratory model using human dentine and currently available dental cements.
2. Measurement of human teeth to find the range of tapers that can be produced in human dentine.
3. Determination of the force required to dislodge gold crowns cemented to human dentine cores of varying taper using a range of cement lutes.
4. Investigation of any relationship between retention and taper, and comparison with the data of Jorgensen and

Kaufman.

5. Determination of the site of separation and its possible relevance to retention.
6. Examination of dentine surfaces before and after separation for any correlation between surface and retention.
7. Investigation of the effect of prior temporary cementation on subsequent permanent retention.
8. Investigation of the effect of recementation on crown retention.

A clinical survival analysis of crowns was also carried out in order to relate clinical data to the various materials used for cementation.

LITERATURE REVIEW

INTRODUCTION

The use of cements to retain inlays in teeth was first seen among the Mayan peoples of South America whose culture dated from 2500 B.C., reaching its height between 300 A.D. to 900 A.D. These Indians inlaid the labial aspects of their front teeth with polished stones for cultic reasons using a cement which consisted mainly of calcium phosphate[3].

Surprisingly, there is no information on the use of dental cements in the Egyptian or Greco-Roman civilisations which showed more interest in extracting teeth than restoring them. Although in 1746 Pierre Fauchard[4] described post crowns and the use of "MASTIC" (a resin gum) to attach prosthetic teeth to posts, he relied on mechanical retention to hold his posts in root canals.

EARLY CEMENTS

Modern dental cements first appeared in the 1880's but some of the early examples contained zinc chloride which was harmful to the pulp and resulted in these cements falling from use[5]. In the early 19th century the forerunners of zinc phosphate cements were evolving with

the Ostermann formula in 1832 and Weston's insoluble cement in 1880[6]. Zinc phosphate and the weaker but less irritant zinc oxide/eugenol were the only acceptable dental luting cements available until the 1950's[7]. In the late 1950's in an attempt to produce a cement stronger than zinc oxide/eugenol, which would be suitable for cementing crowns, but not as acidic as zinc phosphate, Brauer et al[8,9], used zinc oxide and 2-ethoxybenzoic acid to produce ZOE/EBA cements and by 1968 Phillips et al[10] were prepared to endorse the use of ZOE/EBA cements for the permanent cementation of crowns.

ADHESIVE CEMENTS

None of these dental cements had adhesive properties and relied on the cement penetrating the irregularities on the surfaces of the dentine preparations and the fitting surfaces of the crowns to mechanically lock the two together. In 1986 Smith[11] produced a cement that adhered to hard tooth tissues. His cement used polyacrylic acid with zinc and magnesium oxides to make a polycarboxylate cement. This cement adhered to enamel (apatite), dentine (collagen and apatite) and to the oxide on the surface of some base metals, but not noble metals[12].

Research aimed at finding a better adhesive dental cement continued, and glass-ionomer cements were developed by Wilson and Kent who patented them in 1973[13,14].

CLINICAL USE OF CEMENTS

Glass-ionomer cements are used in numerous clinical techniques[15] and have been readily accepted by the dental profession for the cementation of crowns, as shown by the following data from a survey in 1990 where 9,846 practising dentists were asked which materials they used most[16].

Cement type	% use
glass-ionomer	42
polycarboxylate	33
zinc phosphate	22
resin (composite)	2
ZOE/EBA	1

Comparison with a similar survey in 1985[16] shows a trend towards an increasing use of glass-ionomer cements primarily at the expense of polycarboxylate cements (a drop of 30%) and secondly zinc phosphate cements (a drop of 15%).

There is a large current literature in the field of dental cements, with almost 400 papers listed in the Index to the Dental Literature in 1990 alone. Only one of these papers[17] however dealt directly with the retention of crowns related to dental cements and none of them

investigated the function of taper. Much of the current research concerns the use of cements as permanent restorations or fissure sealants, mechanical properties such as wear resistance, and their orthodontic or endodontic applications. In fact there is little work being carried out on the traditional, still widely used, zinc phosphate cements[18] except as comparators with more recently developed cements. This is perhaps not surprising as the the material has changed very little over a long period of time and the properties are well known[19]. In fact zinc phosphate has proved to be the bench mark against which all modern cements are evaluated. It also provided the basis of the understanding of dental cements[7].

CAUSES OF CEMENT FAILURE

As Stephens[20] showed dislodgment of a crown cemented to preparation involves shearing in the cement film. The shear strength has both a compressive and a tensile component. In mechanically adhesive cement lutes compression is a more significant component than tension while if the joint is specifically adhesive at one or both interfaces then the effect of the tensile component of shear will increase resulting in increased retention.

This is in accord with the results of Jorgensen and Hols[21] who in 1967 demonstrated a correlation between

retention of crowns and compressive strength supporting the findings of Williams, Swartz, and Phillips[22] who had investigated the retention of orthodontic bands. This led to an erroneous belief that the retentive properties of a cement could be predicted from its compressive strength alone. This or course does not hold for modern adhesive cements. Richter et al[23] in fact found no linear relationship between retention and any single mechanical property such as compressive, tensile, or shear strengths when they compared adhesive polycarboxylate cement with zinc phosphate and ZOE/EBA cement, in keeping with Stephens' suggestion that the overall retention depended on a combination of contributions from such factors.

If there is a significant component of retention to be achieved from adhesion then bonding becomes important. This phenomenon has been the subject of much interest in recent years, and the contribution of the dentine smear layer has been of particular interest.

SMEAR LAYER

The smear layer has been reported by Schulein[24] to have a thickness of 1-5 m^{-2} and varies depending on the type of bur, speed, and coolant system used in tooth preparation[25-28]. The layer has been shown by Schulien[24] to consist of inorganic tooth particles, mineralised

collagen matrix, bacteria, blood and saliva. The exact mechanism of its formation is unclear but it is formed as a function of tooth preparation with rotary instruments. Schulein[24], Dahl[29], Powies et al[30], Asmussen et al[31], and Erickson[32] all consider that the smear layer may be important in the retention of dental materials to dentine by acting as a barrier to the adhesion of resin bonding agents, polycarboxylate cements and glass-ionomer cements.

Dahl[29] reported that the failure of adhesion to dentine with the smear layer left intact was in fact either between the material and the smear layer or a cohesive failure within the smear layer. As a result a number of authorities recommend the removal of the smear layer prior to bonding. This stance is however challenged by others because removal of the smear layer opens dentinal tubules and may result in pulpal irritation[33,34] and it would appear that if the smear layer is left intact the resin of at least one bonding system (Scotchbond dual cure, 3M UK) may not only bond with the inorganic portion of the smear layer but also penetrate the underlying dentinal tubules.

There is a large variation in the bond strengths claimed for bonding to dentine which may result from the intrinsic variability of dentine and/or a lack of a standard test for bond strength[35-37]. The role of the smear layer in bonding and the advisability of removing it is as yet unclear.

CLINICAL EVALUATION

Where cements are used as luting agents there is currently a disparity between in vitro and in vivo findings, due again to a lack of a standard test method and the long period of time required for clinical evaluation. One consequence of this is that few clinical studies have been carried out. Rather, the literature is primarily concerned with comparisons between materials, particularly resin cements and glass-ionomers, and evaluation of new clinical techniques. There appears to be a marked variation between brands of polycarboxylate and glass-ionomer cements, making it difficult to formulate general statements about the properties of these materials. They are also operator sensitive and require careful mixing, and as Billington et al[38] have shown there is a lack of correlation between the manufacturers' mixing instructions and mixes achieved clinically. In 1989 Moody et al[39] investigated the retentive power of polycarboxylate and zinc phosphate cements using cast gold crowns and composite cores and showed zinc phosphate to be more retentive, whereas Kanoy et al[40] investigated their use in retention of cast noble-metal and base-metal crowns to dentine and found polycarboxylate to be the more retentive.

In a 3-5 year clinical study Knibbs and Walls[41] showed

that the survival of crowns cemented with zinc phosphate was slightly greater than that for crowns cemented with polycarboxylate, and further that both cements survived significantly longer than glass-ionomer. The main purpose of their paper however was to investigate the erosion of the different cement lutes, and it is interesting that to note that their in vivo and in vitro results for erosion were contradictory.

PULPAL CHANGES

Questions about pulpal irritation due to glass-ionomers led Swift[42] to postulate that this may be the reason for a drop in their clinical use as luting agents. Woolford[43] has demonstrated a pH as low as 2 in a thin mix of glass-ionomer, which would be expected to cause pulpal irritation. Plant[44] has investigated this clinically and Hume and Mount[45] have evaluated the response of mouse fibroblasts to glass-ionomers. Both authorities agree that the material is cytotoxic, and Plant has gone as far as to say that the material should not be used where a liner cannot be placed, and as such is contraindicated for the cementation of crowns. The possibility that microleakage is responsible for pulpal irritation under metal crowns can largely discounted as Garver et al[46] have reported negligible amounts of leakage with glass-ionomer cements; in fact the only cement showing a large amount of

leakage in their study was zinc oxide/eugenol. With regard to the treatment of the dentine surface, Christensen[47] recommends cleaning the preparation with pumice slurry and further states that blasting the fitting surface of the crown with aluminium oxide significantly improves retention. Glass-ionomer lutes are becoming more common for cementing orthodontic bands, probably as a result of fluoride leaching and uptake by enamel[48].

However, generalised comments on the properties of glass-ionomers should be treated with caution because the term 'glass-ionomer' encompasses a range of materials used for such diverse purposes as restoratives, luting agents and fissure sealants, in which both powder/liquid ratio and acid molecular weight vary according to application. For example, glass-ionomer luting cements may be formulated with lower molecular weight acids, and could therefore reasonably be expected to promote a different pulpal reaction to glass-ionomer restoratives.

ACRYLIC RESIN

Acrylic resins have been used in dentistry since 1937, but these early unfilled resins were toxic to the dental pulp and were rarely used as cement lutes. Most modern resins are based on Bowen's resin (BIS-GMA) which was introduced in 1962, and use fillers and comonomer solvents to control the viscosity. With the advent of acid-etch

retained prostheses resin cements have been further developed[49] and improvement in wetting and viscosity have made them suitable for conventional crown cementation. These materials rely on micromechanical locking to retain conventional crowns but some have been shown to exhibit a thick lute film[50]. Resin cements which contain monomers with reactive hydrophylic functional groups are now available and work carried out by Aboush and Jenkins[51] and Atta et al[52] have shown them to have an improved tensile bond over the earlier micromechanical bond. Mojon et al[53] compared the tensile bond strength to a flat amalgam surface of (i) a resin cement having a reactive functional group (4-methacryloxyethyl-trimellitic anhydride) (ii) glass-ionomer cement and (iii) zinc phosphate cement, to investigate their relative retentive power to an amalgam core, and found the ranking of the cements to be resin > glass-ionomer > zinc phosphate.

The claim of some manufacturers that the new composite resin cements do not irritate the pulp and are suitable for crown cementation is supported by Malone et al[6], Inokoshi et al[54] and Uchiyama[55]. This, in conjunction with the low solubility, high compressive strength, and adhesion to both hard tooth tissues and some dental materials has resulted in composite resin cements being used to cement all types of crowns and bridges[16]

METHODS OF ASSESMENT

In the investigation of retention in dentistry flat surfaces are usually used to find the shear and tensile bond strengths of adhesive materials, but for the examination of crown retention where either micromechanical or adhesive retention, or a combination of both, are involved a model of the clinical situation is usually employed which is complicated by the large number of variables to be accounted for.

Part of the difficulty in interpreting the literature is that many differing models are used. These can be atypical of dental practice as in the case of Jorgensen[1] who used non-dental materials and techniques (an open topped crown and lathe), or a mixture of dental and non-dental materials as used by Kaufman[2] or as in Felton's work all dental materials and techniques[56]. It may appear preferable to attempt to mimic the clinical conditions as Felton[56] did and use a dental handpiece to prepare the teeth, but it can lead to problems such tooth samples of different sizes which complicates the comparison of the cements used to retain crowns[57]. In addition, some workers have studied inlays[58], rather than crowns, making comparison between workers difficult. A further factor which may influence the retention is the cementation force. This can vary from finger pressure[58] to 50 kg

which Fusayama and Hosoda[59] claim to be the maximum cementing load used clinically.

Tensile testing by its nature is prone to errors with the danger of misalignment of the test piece producing a tear test rather than a tensile measurement, a problem which has been addressed by different workers in various ways. For example, Kaufman[2] prepared his model tooth on a lathe and cast the model crown with an axial extension from the "occlusal" portion of the crown to be used for pulling the crown from the preparation, while other workers like Richter et al[23] have use multiple ring devices to ensure alignment during crown removal.

As a further problem, the majority of work in this field is concerned with a comparison of cement retention without reference to the taper involved, which appears to have been arbitrarily chosen and therefore quite variable. If taper influences retention a comparison of the work of different authors then becomes difficult.

An indication of the confusion in this area is shown by the various rankings of cements as they have appeared in chronological order.

DATE	FIRST AUTHOR	RANKING (> shows a significant difference)
1969	GRIEVE[57]	ZP = PC > ZOE
1976	SAITO[60]	PC > ZP
1976	SILVEY[61]	ZP = ZOE = PC
1970	RICHTER[23]	ZP = PC = EBA
1978	OILO[62]	ZP > PC For a rough surface
		PC > ZP For a smooth surface
1982	MCCOMBE[58]	GI > ZP
1983	FINGER[63]	GI = PC = ZP
1985	BURKL[64]	C > ZP
1986	UCHIYAMA[65]	C > ZP
1986	CHAN[66]	PC > C > ZOE = ZP Taper 30^0
		PC > C > ZP = ZOE Taper 7^0
1986	DHAL[67]	GI = PC = ZP
1987	ALFIED[68]	PC = EBA = ZP
1988	OMAR[69]	GI = PC >ZP
1989	BLACK[17]	C > PC = GI > ZP > ZOE

There appears to be little consensus in these rankings. However the work by Chan[66] in this table suggests that the effect of taper on retention may be cement-dependant and may therefore be influencing cement rankings. It is clear from this that a standard technique to evaluate dental cements is essential to attempt to resolve this problem.

JORGENSEN'S[1] HYPOTHESIS

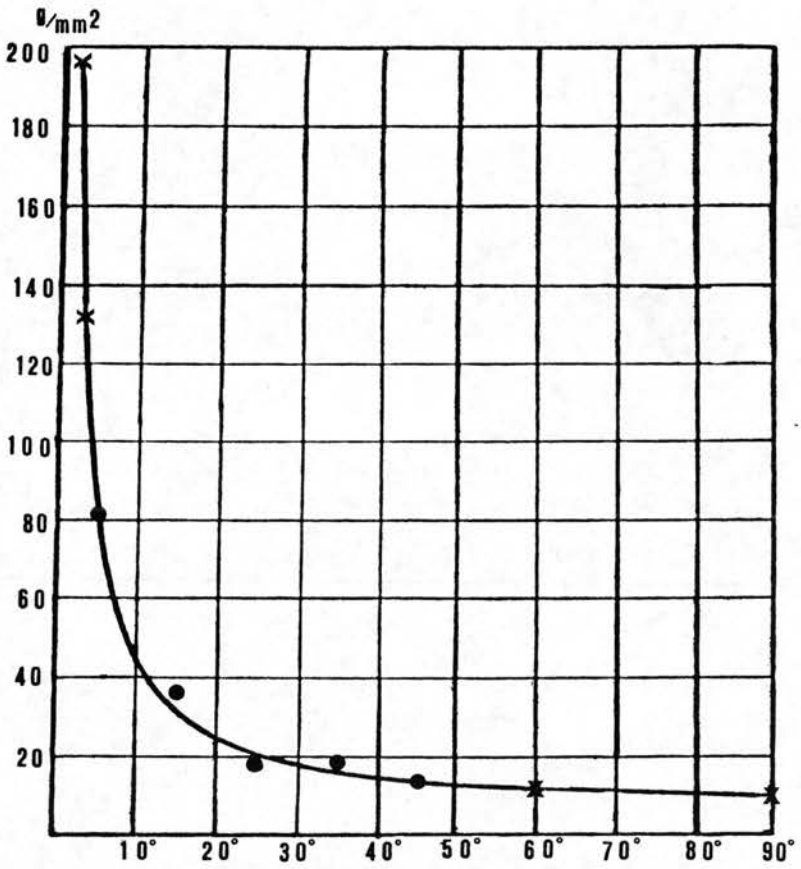
In spite of the above criticisms Jorgensen's conclusion of a hyperbolic relationship between retention and taper has gained almost universal acceptance in dental textbooks. For example Shillingberg et al[70,71], Rosentiel et al[72], Kantorowicz[73], Allan[74], and Roberts[75] quote it directly. Pameijer al[76] refer to Jorgensen indirectly through Shillingberg, while the books of Malone et al[77], Pit Ford[78], and Pickard et al[79] mention the concept of an "ideal" taper with no reference to its origin. Since the study of taper forms the central theme of the current research, it is appropriate therefore to discuss Jorgensen's data in more detail.

Jorgensen's[1] experimental data was expressed in g/mm^2 based on the curved surface of plastic cones and is summarized below.

Taper^0	Retention g/mm^2
5	81.3
10	44.4
15	35.3
20	25.7
25	17.3
35	18.1
45	13.7

The data is also shown graphically in Fig I.1 as it originally appeared.

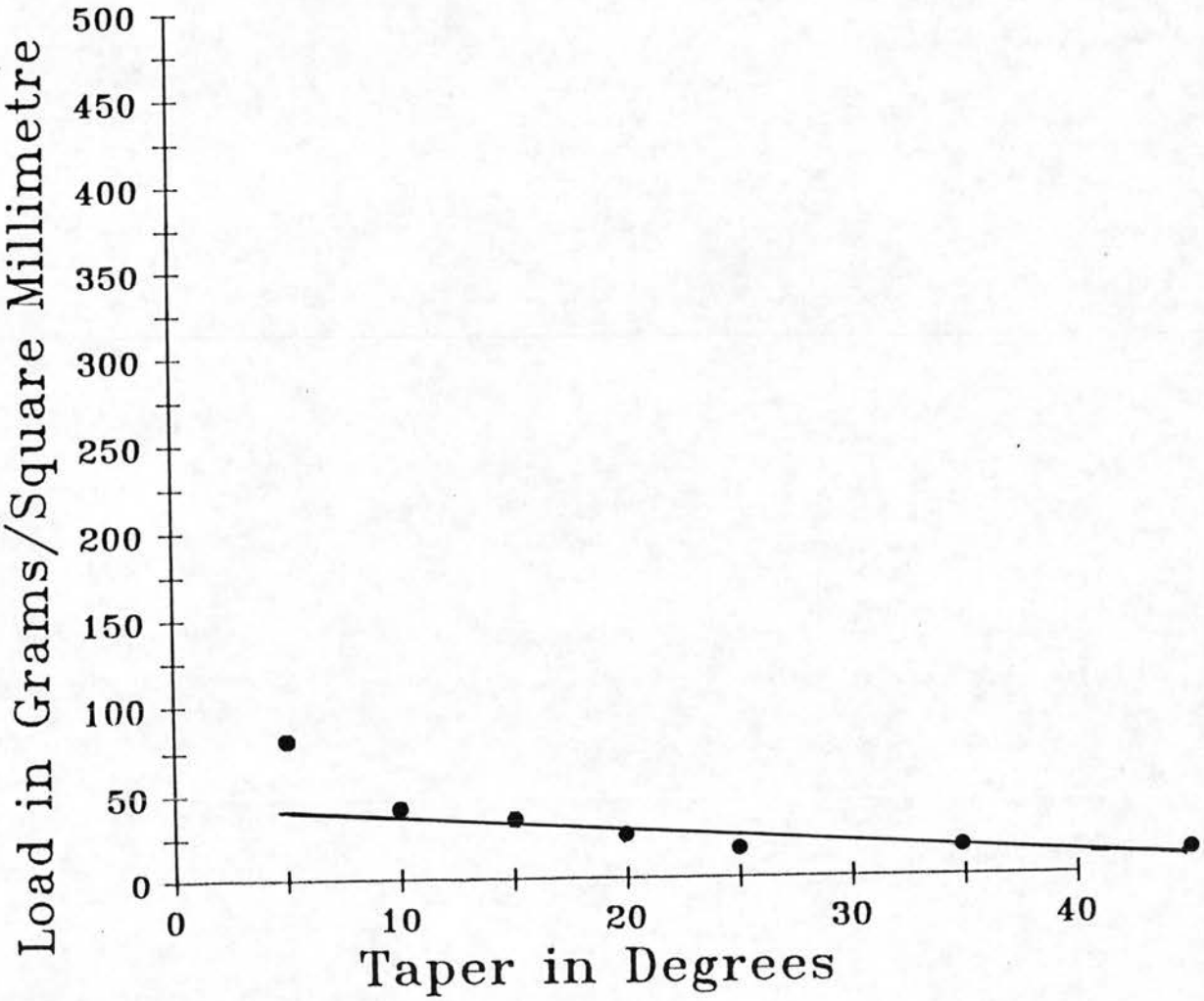
I.1 "The relationship between the retention and convergence angle in cemented veneer crowns" taken from Jorgensen[1] and including original extrapolated points (x).



It can be seen that Fig I.1 contains both experimental and extrapolated (ie calculated) data points which Jorgensen based on an assumed hyperbolic relationship $(Y-5.5)X=380$ between taper and retention. This relationship can of course only be supported by the

experimental data points, which are therefore critical in determining the shape of the curve. In Fig I.2 the experimental points alone are shown on a compressed vertical scale, and it is arguable that with the exception of the 5^0 data point the relationship could equally well have been considered linear.

I.2 Mean retentive power of zinc phosphate cement using Jorgensen's experimental data[1] on compressed axes with alternative linear interpretation of data ignoring 5^0 data point.



It would appear therefore that the significance of Jorgensen's work and the reality of his suggested relationship is critically dependent on a single 5^0 data point. In addition, such a hyperbolic relationship implies that a parallel sided crown would have infinite retention. This is not borne out in clinical practice where parallel sided posts can be removed, albeit with difficulty. Further, the clinical relevance of any relationship based on Jorgensen's experimental model can be questioned since no dental tissues were used, none of the specimens were produced by clinical techniques and the crowns used were open topped.

CURRENT WORK

In view of the significance attached to Jorgensen's results by the dental profession, there is therefore a clear need to further investigate the role of taper in retention, including not only a re-examination of Jorgensen's conclusions but also the establishment of a suitable standard model for the testing of dental cement lutes.

CHAPTER 1.

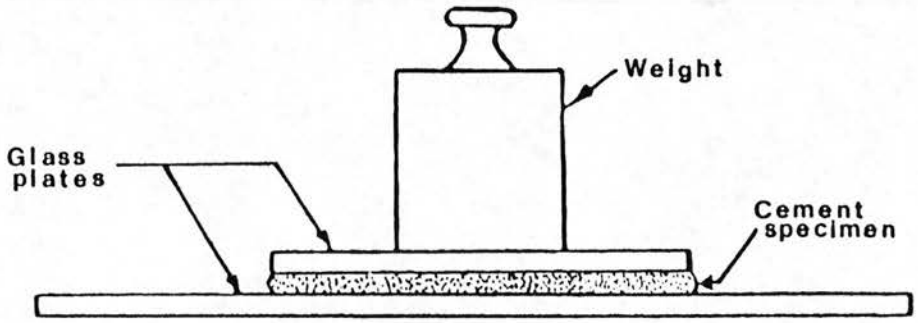
PRELIMINARY EXPERIMENTS IN THE LABORATORY MODELLING OF CLINICAL CEMENTATION

Before cementing crowns on dentine cones (truncated) the load applied to the crowns during clinical cementation had to be determined. Jorgensen[80] advised that hand spatulated phosphate cement in a metal crown required a cementation pressure of not more than 5 kg. He found that pressures between 4 kg and 6 kg gave a cement thickness which varied from 25 to 29 m^{-6}, and he cemented his test pieces using a 2 kg load applied 90 s after the start of mixing, and maintained for at least 10 minutes. Fusayama, Ide, Hosoda[81] considered that the ideal film thickness for phosphate dental cement was 38 m^{-6}. They recommended cementing dental crowns under a static load of 15 kg to 50 kg until set, as they deemed this to be "an average and maximum cementing load used in clinical dentistry"[59]. However they also stated that 15 kg was sufficient for crown cementation and that there was no significant difference between the thickness of cement at the cervical shoulders when using 15 kg or 50 kg. The ability of a clinician to sustain a force of 15 kg on a crown in a patient's mouth is doubtful. A 50 kg load was

considered to be clinically unrealistic.

The British Standard for dental zinc phosphate cement[82], states that the cement will have a film thickness of not more than 40 m^{-6}, under the stipulated conditions. The test consists of squeezing a standard mix of cement between two flat plates, the upper plate being approximately 2 cm^2 (Fig 1.1), and 3 minutes after the commencement of mixing, a load of 15 kg is applied vertically on the top plate. The cement must completely fill the space between the plates, and 10 minutes after the commencement of mixing, the thickness of the cement film between the plates is measured. The film thickness is the average of 3 tests measured to the nearest 5 m^{-6}.

1.1 Apparatus for film thickness test.



The use of a load as high as 15 kg in the British Standard is necessary because of the 3 minute delay before starting the test and does not reflect clinical practice

where a crown is cemented as quickly as possible. As a first experiment therefore a preliminary study investigated the effect on cement film thickness of a reduced testing time more representative of that used clinically.

Experiment 1.1

A preliminary investigation into the effect of a reduced testing time on cement film thickness.

In order to simulate the clinical situation as closely as possible, the British Standard test method was used but the load was applied 55 s after mixing.

METHOD

Two encapsulated cements were used in order to reduce the variability in cement consistency due to hand mixing; zinc phosphate cement PHOSPHACAP*[1], and a polycarboxylate cement BONDALCAP*[2]. Cement film thickness was measured by a variant of the B.S. 3364:1961 for dental zinc phosphate cement[82] as described above, using loads in the range 0.5-2.5 kg applied 55 s after commencement of mixing. All experiments were carried out at ambient temperature and cement film thicknesses were measured using a micrometer gauge 10 minutes after the commencement of mixing. The film thicknesses listed in tables 1.1 and

1.2 show the mean values of 5 tests in each case.

RESULTS

Table 1.1.

FILM THICKNESS IN m^{-6} OF ZINC PHOSPHATE CEMENT (PHOSPHACAP).

Standard Deviation = SD; Standard Error = SE

Film thickness (mean of 5 tests) = F.T.

LOAD, kg	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5
F.T. m^{-6}	32	31	28	33	36	32	29	22	29
SD	(16)	(7)	(6)	(5)	(10)	(13)	(7)	(4)	(6)
SE	(7)	(3)	(3)	(2)	(4)	(6)	(3)	(2)	(3)

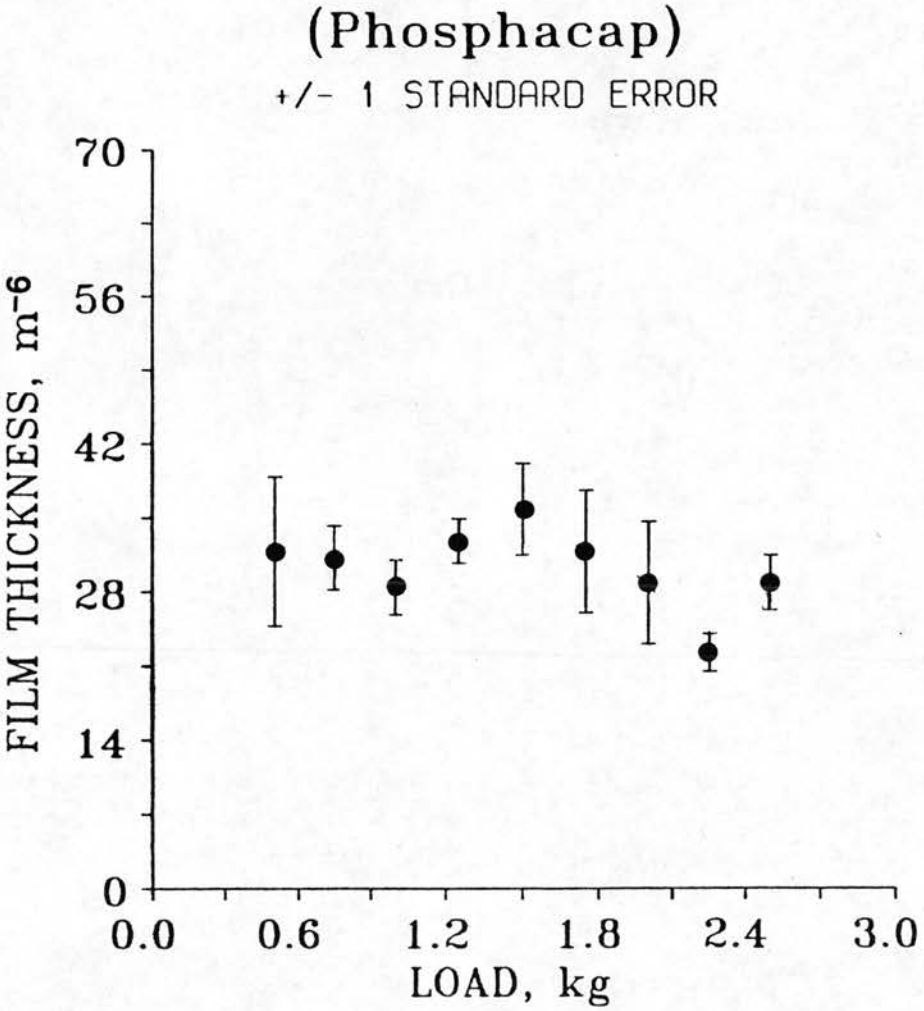
Table 1.2.

FILM THICKNESS IN m^{-6} OF POLYCARBOXYLATE CEMENT (BONDALCAP).

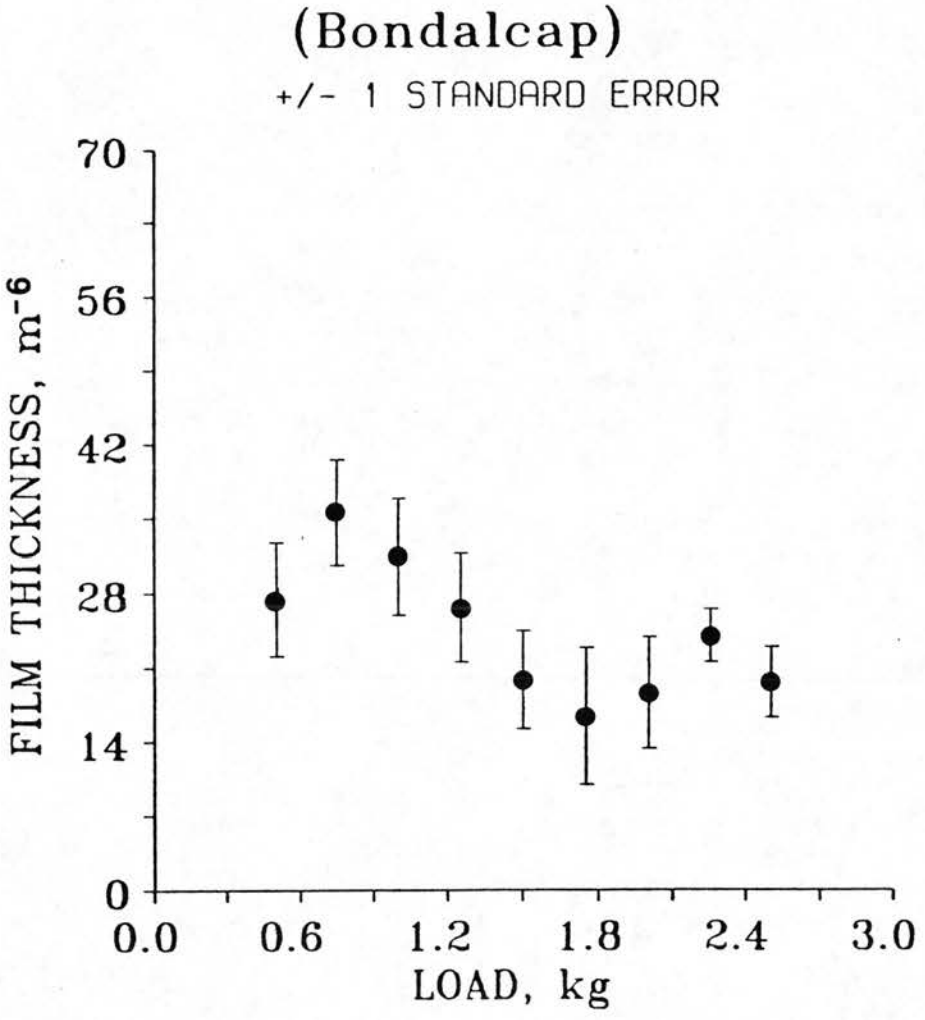
LOAD, kg	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5
F.T. m^{-6}	27	36	31	27	20	16	19	24	20
SD	(12)	(11)	(12)	(11)	(11)	(14)	(12)	(6)	(7)
SE	(5)	(5)	(5)	(5)	(5)	(6)	(5)	(3)	(3)

The results are also shown graphically in Figs 1.2 and 1.3.

1.2 Graph of the film thickness of Zinc phosphate cement.



1.3 Graph of the film thickness of Polycarboxylate cement.



DISCUSSION

The British Standard test method for dental cements requires a film thickness of 40 m^{-6} or less. It is clear from this preliminary experiment that for the range of loads studied all gave a cement film thickness within the British Standard. If cement film thickness were to be used as a guide to a suitable cementation pressure in a laboratory model, the choice of cementation pressure on a clinical time scale would not appear to be critical. A laboratory model simulating clinical conditions should however at least mimic the pressure applied by an average dental practitioner, and it was decided therefore that cement film thickness was too insensitive a guide to the laboratory modelling of clinical cementation pressures.

CONCLUSION

Cement film thickness is not suitable as a guide to the laboratory modelling of clinical cementation pressure. It was decided therefore to investigate directly the range of cementation pressures exerted by dental practitioners.

Experiment 1.2

To evaluate the forces exerted by dental surgeons on the crown of a tooth when cementing crowns.

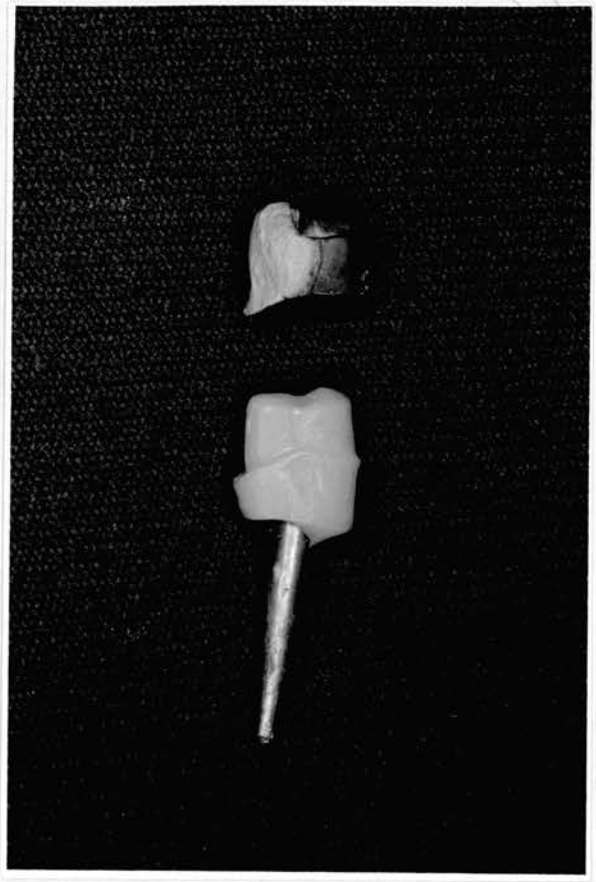
In the light of Experiment 1.1, the forces used by experienced dental surgeons for crown cementation were then investigated.

METHOD

Since experiment 1.1 showed little or no difference in behaviour between phosphate cement and polycarboxylate cement, phosphate cement was selected for this experiment as being a typical dental cement, at least with regard to film thickness.

A preparation for a porcelain-bonded-to- nickel-chrome crown was constructed in self-curing acrylic resin DURA LAY*[3]. This was mounted on a Ney pin and a model cast in Velmix so that the acrylic preparations was easily removed from the model (Fig 1.4). The crown form was waxed on a separate die using normal dental laboratory techniques and cast in Forte nickel-chrome alloy*[4].

The acrylic crown preparation was placed on a Sensotec load cell*[5], model 41/571, range 0 to 227 kg, at 10 v (Fig 1.5). The signal was processed through an RDP L252 load amplifier*[6]. The output was fed to a UNILAB 532.001 analogue to digital computer interface*[7]. The variable from the interface was stored on a floppy disc. The graphics facility of a BBC Micro*[8] were used to plot load against time. ASCII Files were also stored on disc for subsequent transfer to a mainframe computer for



1.4 Nickel-chrome crown and acrylic crown preparation.

1.5 Sensotronic load cell with preparation and crown.

statistical analysis.

Ten practising dental surgeons were asked to cement the crown on to the acrylic crown preparation as if it were for a patient, using their normal clinical techniques. They were allowed to rehearse without cement to make sure that they were conversant with the apparatus.

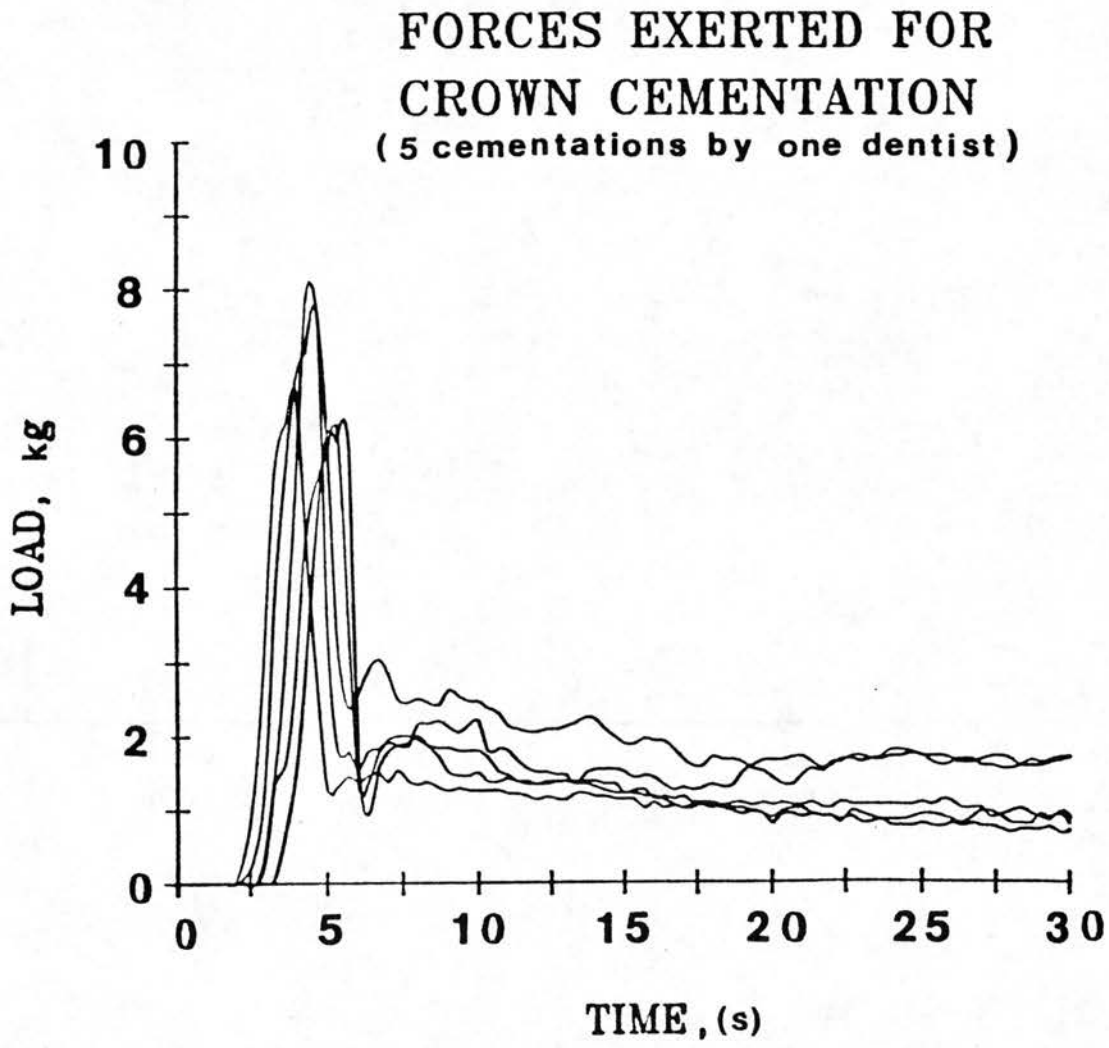
The load exerted by the operator was monitored for 30 s. Initially, monitoring was for only 15 s, but some operators took longer than this therefore the time was increased to measure the maintenance force applied by each operator. After the 30 s monitoring, the crown and the acrylic crown preparation were separated by placing them in a saturated solution of sodium bicarbonate which neutralized the phosphoric acid and allowed the luting cement to be completely removed without damaging the die or the nickel-chrome crown. Each operator cemented the crown 5 times.

RESULTS

Analysis of the data showed that individual operators were able to produced consistent forces on 5 occasions (Fig 1.6).

The maximum loads used by different operators varied from 10.6 kg to 1.3 kg (a range of 9.3 kg). The mean was 5.5 kg, with a standard deviation of 2.6 and standard error of 0.37 kg. This gave a 95% probability of the

1.6 Force exerted in 5 cementations of a nickel-chromium crown by one operator.



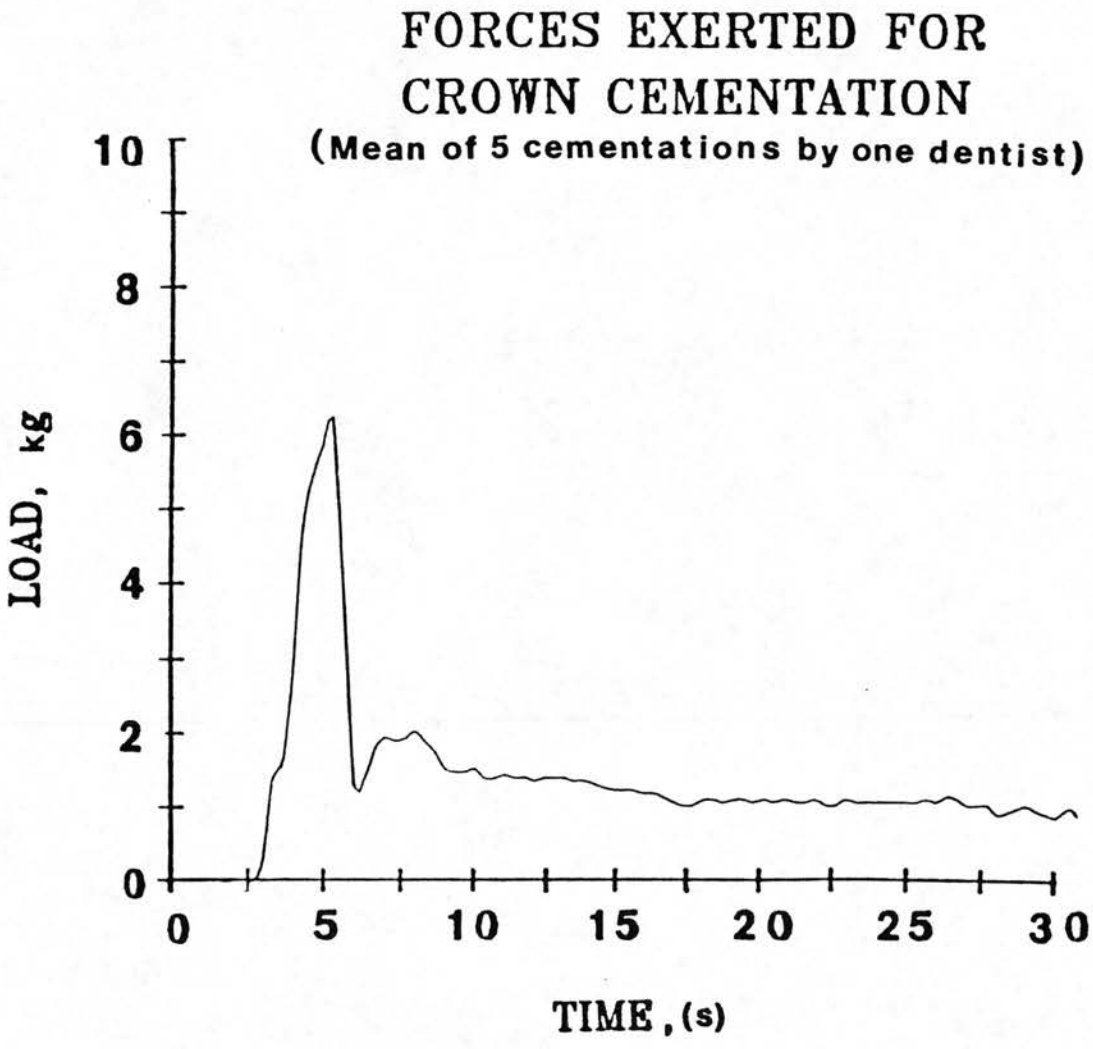
population mean to be between 4.8 kg and 6.2 kg.(mean +/- 1.96 X SE)

The maintenance load measured at 25 s into the test varied from 5.8 kg to 0 kg (a range of 5.8 kg); a mean of 2.3 kg, SD of 1.7 kg and SE of 0.21 kg (including the outlier of 0 kg). This gave a 95% probability that the mean maintenance load would lie between 1.9 kg and 2.7 kg.

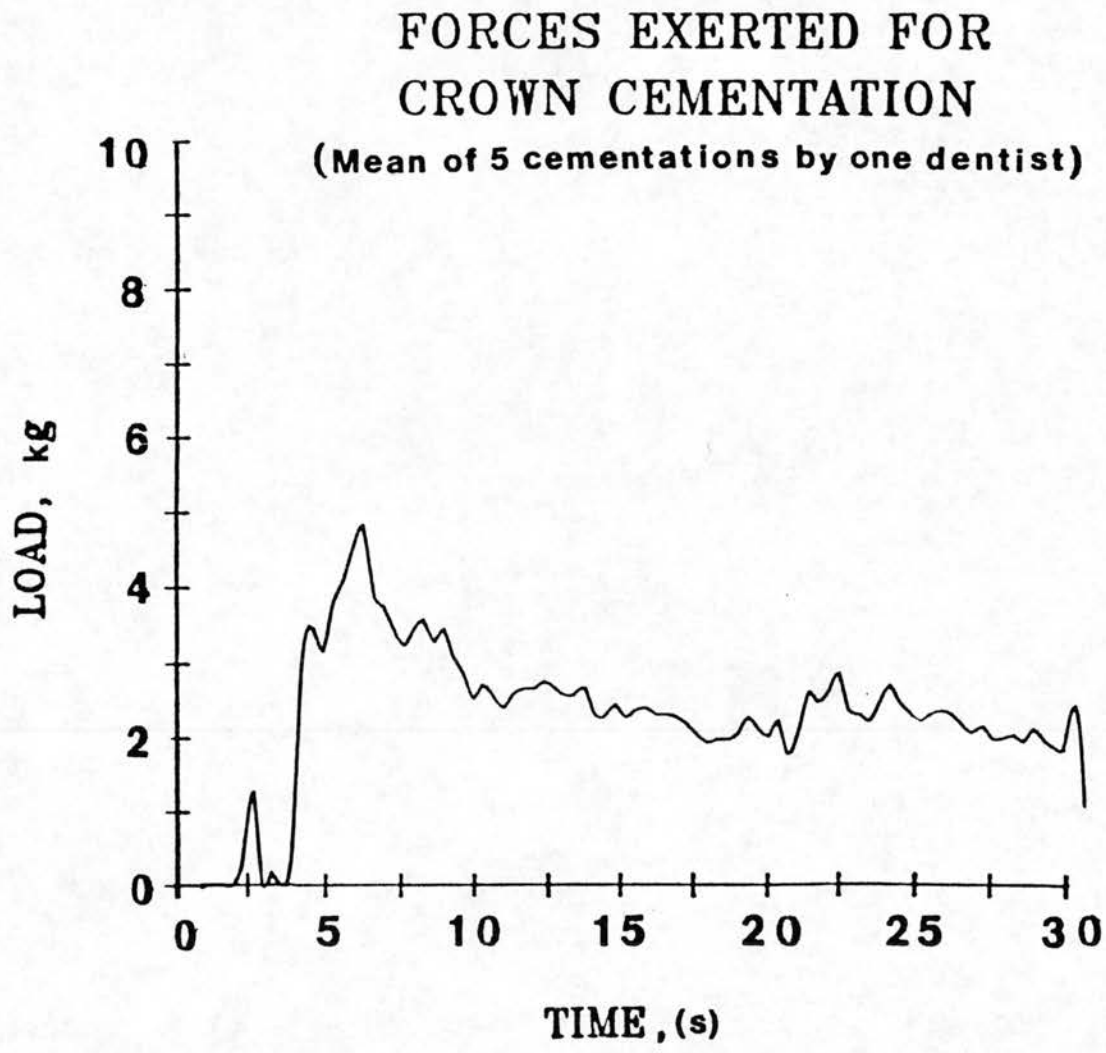
DISCUSSION

Further consideration of the results showed three different methods of crown cementation, dependent on operator variability. Firstly there were those who applied an initial seating force which they reduced to a maintenance level while the cement set (Fig 1.7). Secondly, some exerted an initial seating load which tailed off slowly (Fig 1.8). Finally, another group eased the crown into place with a force comparable with the first group's maintenance load (Fig 1.9). The second technique of allowing the pressure to tail off slowly seemed to be about half way between the other two techniques.

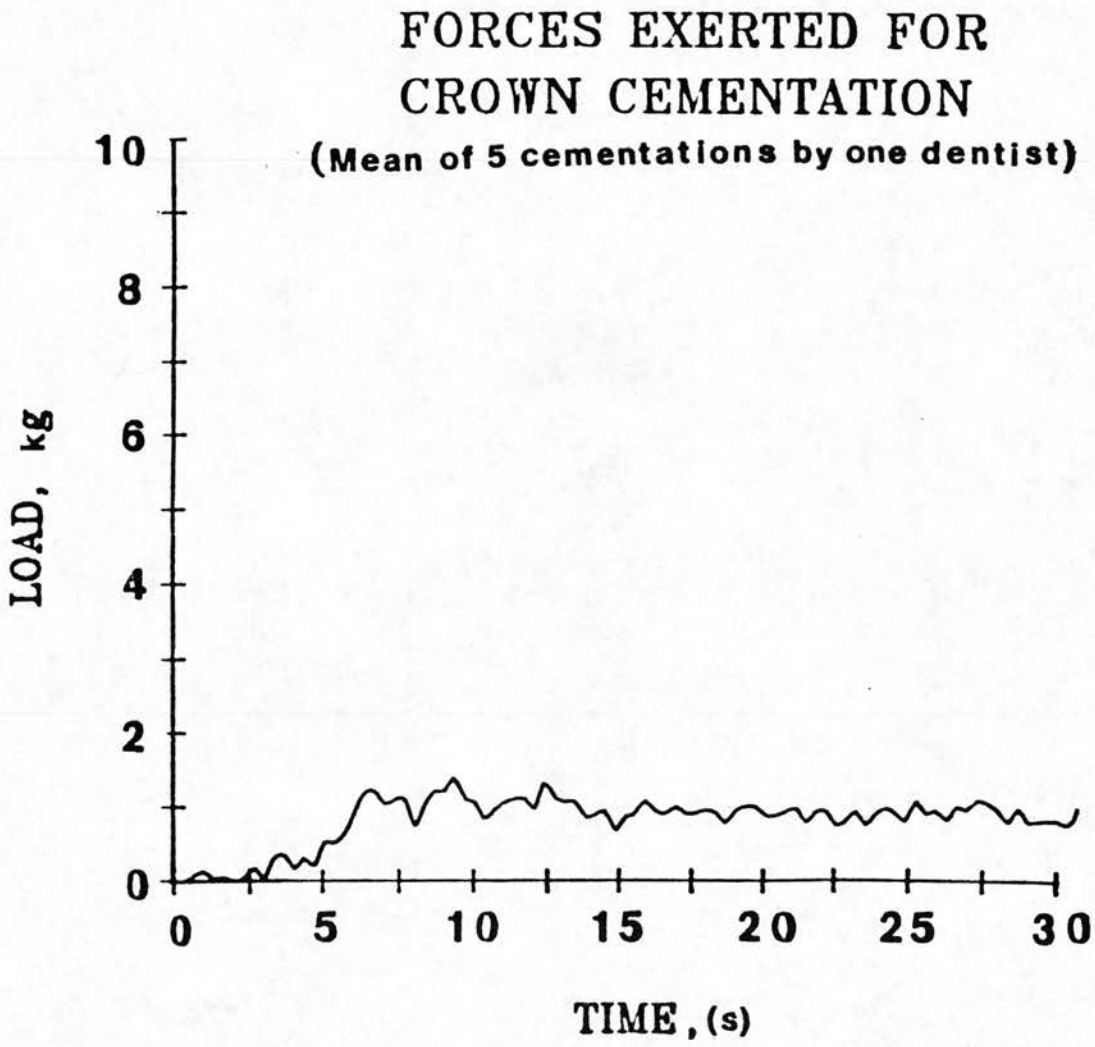
1.7 Illustration of a high initial, low maintenance force pattern used by some dentists for crown cementation.



1.8 Illustration of a high initial, high maintenance force pattern used by some dentists for crown cementation.



1.9 Illustration of a low initial, low maintenance force pattern used by some dentists for crown cementation.



While all the operators seated the crown adequately it became apparent that the disparity in force used in the seating of the crowns correlated with clinical experience, table 1.3.

Table 1.3

CEMENTATION LOAD USED IN CROWN CEMENTATION

DENTIST	MEAN LOAD IN KG	
1	9.8	
2	9.0	DENTISTS WITH
3	6.8	MORE THAN 5 YEARS
4	6.7	CLINICAL EXPERIENCE
5	5.8	
6	4.2	
7	4.3	
8	3.5	DENTISTS WITH
9	3.0	5 YEARS OR LESS
10	2.0	CLINICAL EXPERIENCE

The more experienced operators could be considered to be using more force than necessary, but it was felt that experienced dentists instinctively used the largest force

that could reasonably be used clinically.

However, such detailed interpretation of the data presented here, including statistical analysis, must be treated with caution because of the limited sample of clinicians, and the experiment should be viewed as giving a representative example of clinical practice rather than being statistically exact. The data does however permit general conclusions to be drawn regarding normal clinical practice.

The results shown in Fig's 1.7 and 1.8 indicate that dentists usually apply a high initial load which then decreases to a maintenance load, but that the rate of decrease may vary. These observations suggest that a reasonable laboratory representation of clinical cementation would involve the application of the initial mean load used by clinicians for 30 s followed by the mean maintenance load until set. Such a model would then encompass the full range of decreasing loads applied by clinicians observed in this study.

For convenience the mean figures found in this experiment were rounded up to the nearest whole number and the suggested laboratory model therefore becomes an initial pressure of 6 kg for 30 s followed by 3 kg until set.

To confirm that the laboratory study represented the clinical application it was considered necessary to confirm these observations with an equivalent clinical

study. Experiment 1.3 was therefore carried out to confirm this.

It is not known clearly from this experiment whether any or all of the clinical operators were achieving a cement film thickness within the British Standard specification. For the purpose of the work reported in this thesis it was considered more important to model the true clinical situation. The question of clinical film thickness remains a valid one however, which could be pursued in any future work.

CONCLUSION

It was concluded that a suitable laboratory model of crown cementation would involve the application of a load of 6 kg for 30 s followed by a maintenance load of 3 kg until set. However, it was also considered that the model should be confirmed by an in vivo study as described in Experiment 1.3.

Experiment 1.3

To compare the results of Experiment 1.2 with the forces used to cement crowns in clinical practice.

It was proposed in this experiment to use a small load cell in the clinical simulation, and the experiment was carried out in three parts:

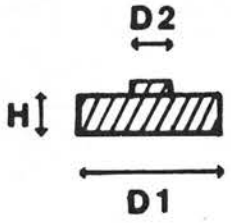
Firstly the small load cell was calibrated against the large load cell. Secondly the small load cell was incorporated into a finger stall and again calibrated against the large load cell in laboratory cementation. Finally the small load cell was used clinically.

METHOD

An R.D.P. Model 13*9 load cell was used (dimensions H=3.8mm, D1=12.7mm, and D2=3mm,). (Fig 1.10 and 1.10a). The load cell had a nominal 350 ohm strain gauge element arranged in a Wheatstone bridge (Fig 1.11). It was calibrated by the manufacturers to give an output of 1.05 mV per volt of excitation for an applied force of 22.67 kg. With an excitation voltage of 4.9 V, a strain gauge amplifier with a gain of 440 is required to give an output voltage of 0.1 V per kg.

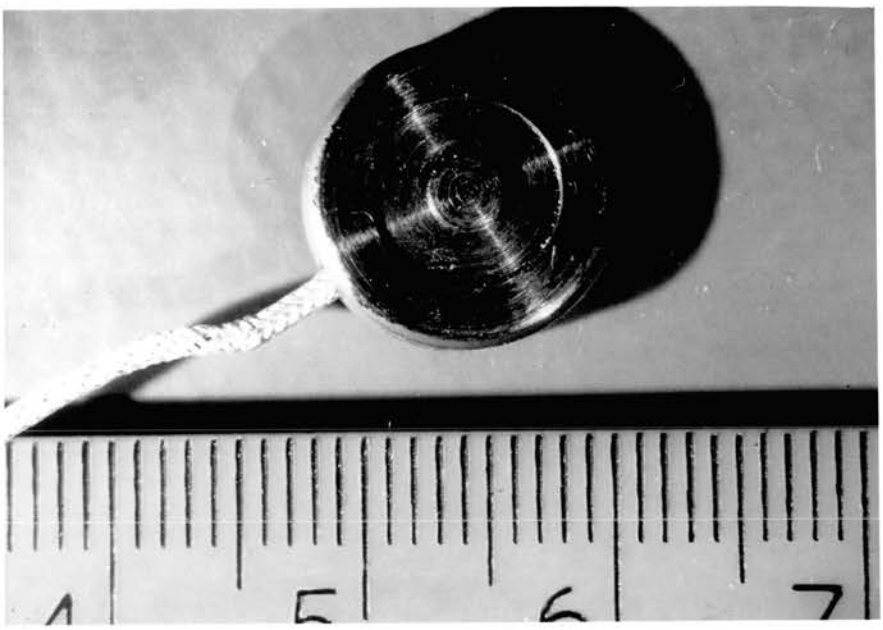
The strain gauge was small enough to be placed into a rubber finger stall (Fig 1.12) with the wires running back to the battery-operated strain gauge amplifier. An isolation amplifier was an essential safety feature to ensure complete separation of the patient and operator from the mains electricity. The data collection again used a UNILAB 532.001 analogue digital computer interface with the data held as ASCII files on floppy disc using a BBC Micro computer.

1.10 R.D.P. Model 13 load cell showing dimensions.



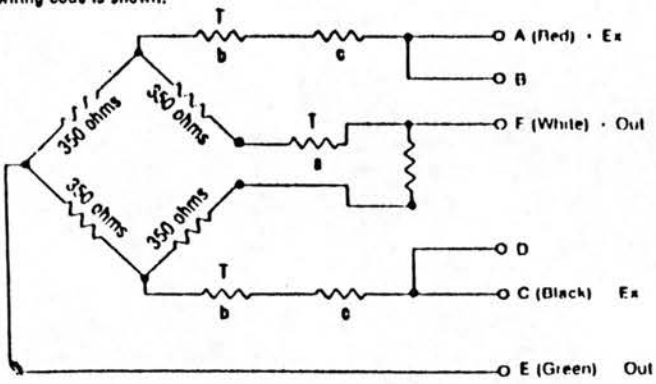
H = 3·8mm
D1 = 12·7mm
D2 = 3mm

1.10a Photograph of Model 13 load cell with scale in mm.



1.11 Diagram of electrical connections used for the small load cell.

The strain gages are wired into four active arms of a Wheatstone Bridge and bonded to the sensing element of the transducer. Optional lead wires: multi-conductor, color-coded lead wires can be provided at no additional charge. The typical wiring code is shown.



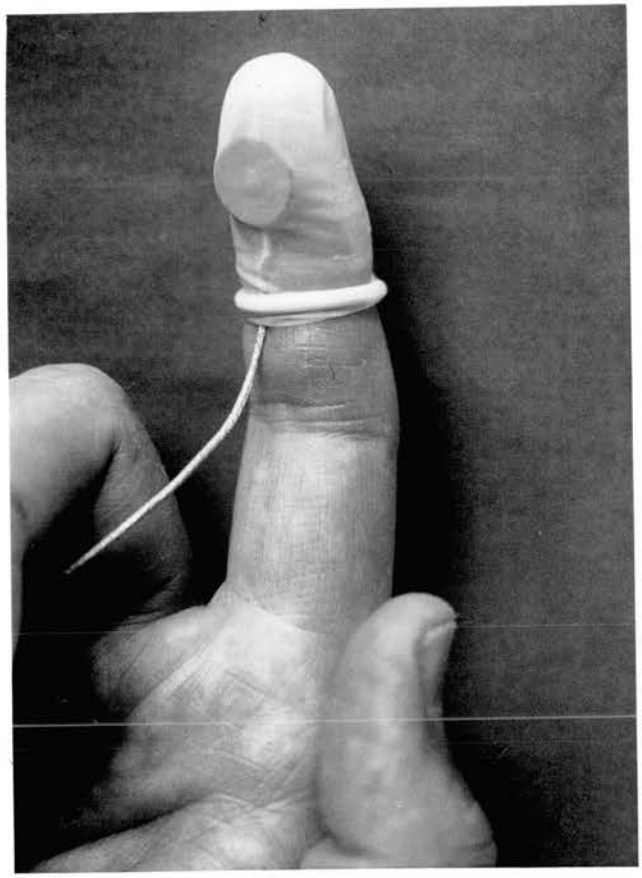
The electrical circuit illustrates a typical 350 ohm foil bridge with additional circuit components used for:

1) **Zero Temperature Compensation** - The temperature dependent resistor at (a) is placed at the open (output) corner of the bridge to offset the change of resistance in the bridge due to temperature.

2) **Span Temperature Compensation** - The temperature dependent resistors at (b) are connected in series with the input leads to compensate for the change in modulus of elasticity of the strain gages.

3) **Standardizing the Full Scale Output** - The non-temperature sensitive resistors at (c) are placed in series with the input leads to limit the input voltage, thus "standardizing" the millivolt output to a precise value.

4) **Trimming the Electrical Zero Balance** - The resistor at (d) is placed in series with the appropriate arm of the open corner bridge to electrically balance the bridge circuit.



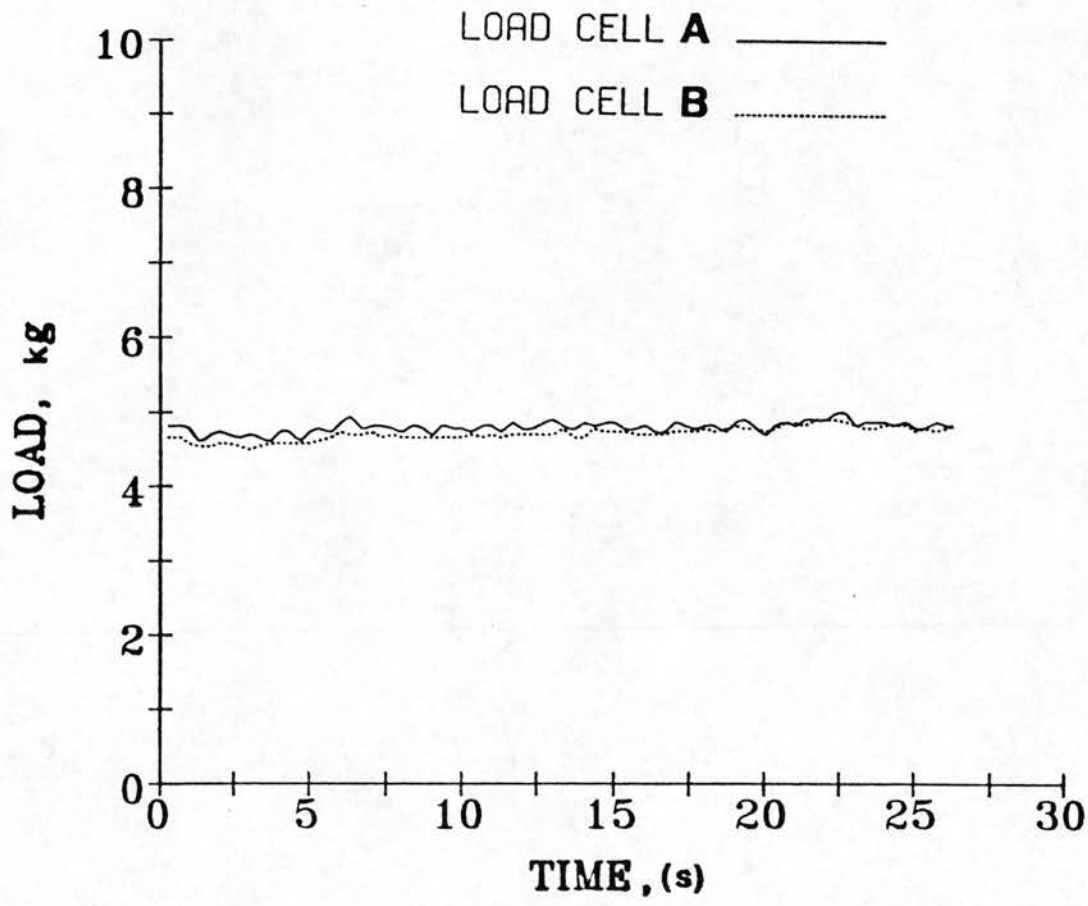
1.12 R.D.P. Model 13 load cell as used clinically.

The small load cell was calibrated by taping it to the large laboratory load cell and applying a load. Initially a static load was applied for 25 s to check the stability of the cell reading (Fig 1.13). In a separate experiment the static load was varied through a typical clinical range of 0-10 kg at a sampling rate of 3 per s. The two load cells produced consistent results (Fig 1.14).

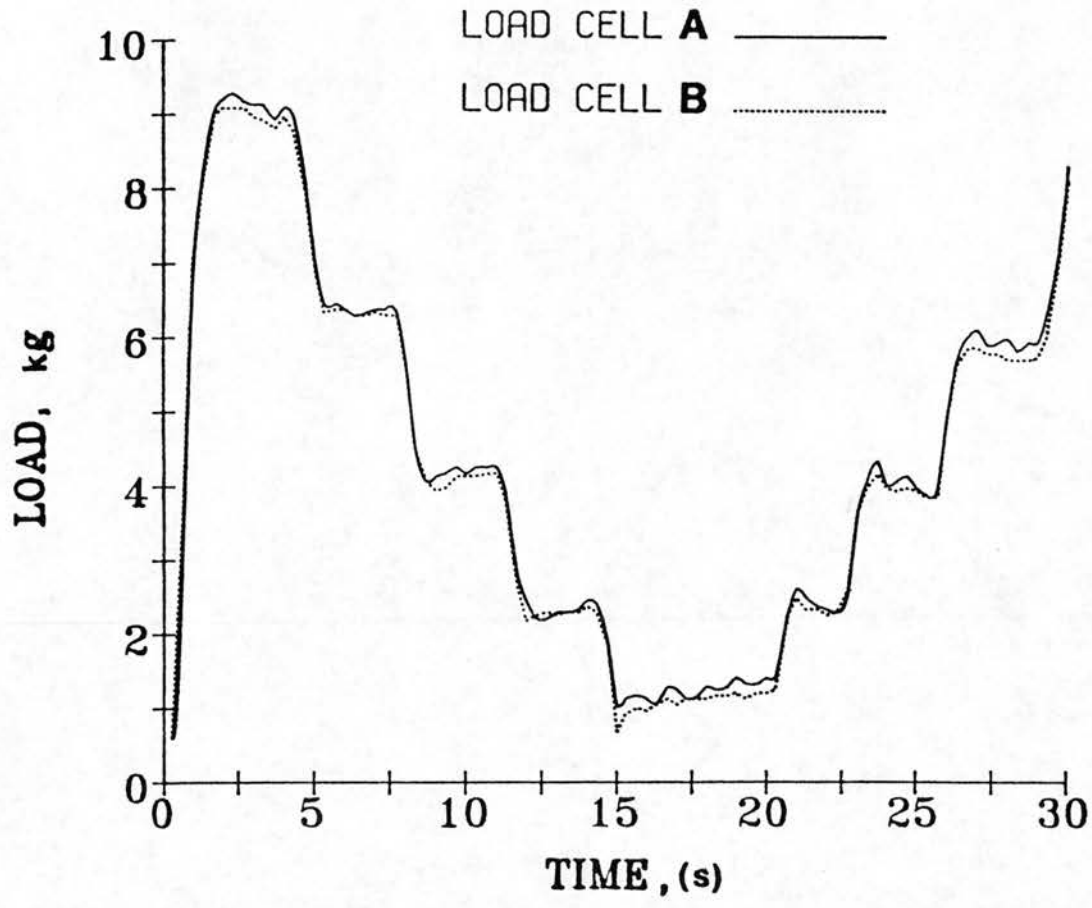
The laboratory cementation experiment 1.2 was then repeated with the small load cell incorporated in a finger stall as described above, and readings were taken from both cells simultaneously. For ease of use when cementing a crown and to ensure a good contact between the load cell's point of action and the irregular surface of the crown to be cemented, a flat-topped coping was constructed (Fig 1.15) in self-curing acrylic resin*[10] to fit the crown's occlusal/incisal surface. Five laboratory cementations were carried out using zinc phosphate cement.

Finally, a clinical study of 5 dentists using similar flat topped copings was carried out with the finger load cell above.

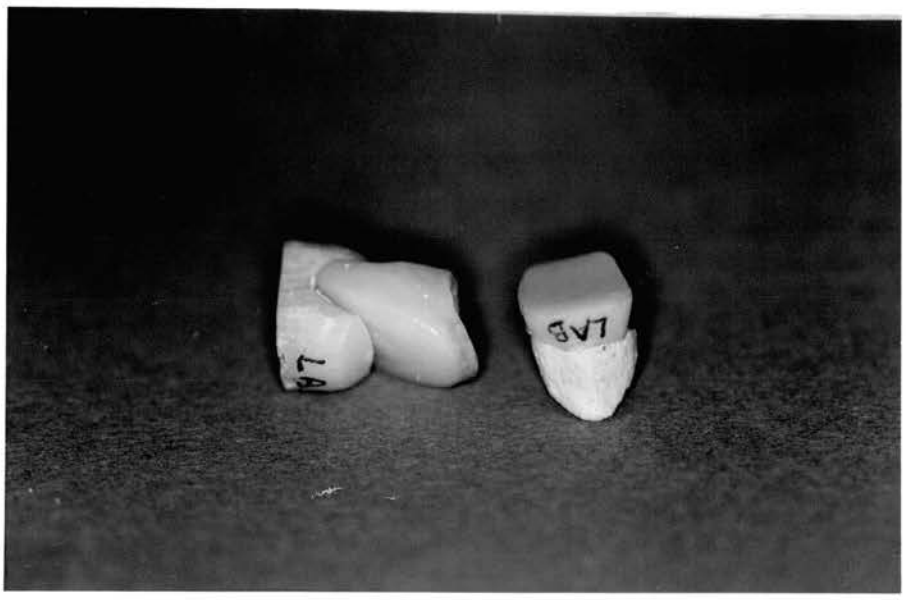
1.13 Static load test for the large and small load cells taped together (A = Sensotronic cell and B = R.D.P. Model 13 cell).



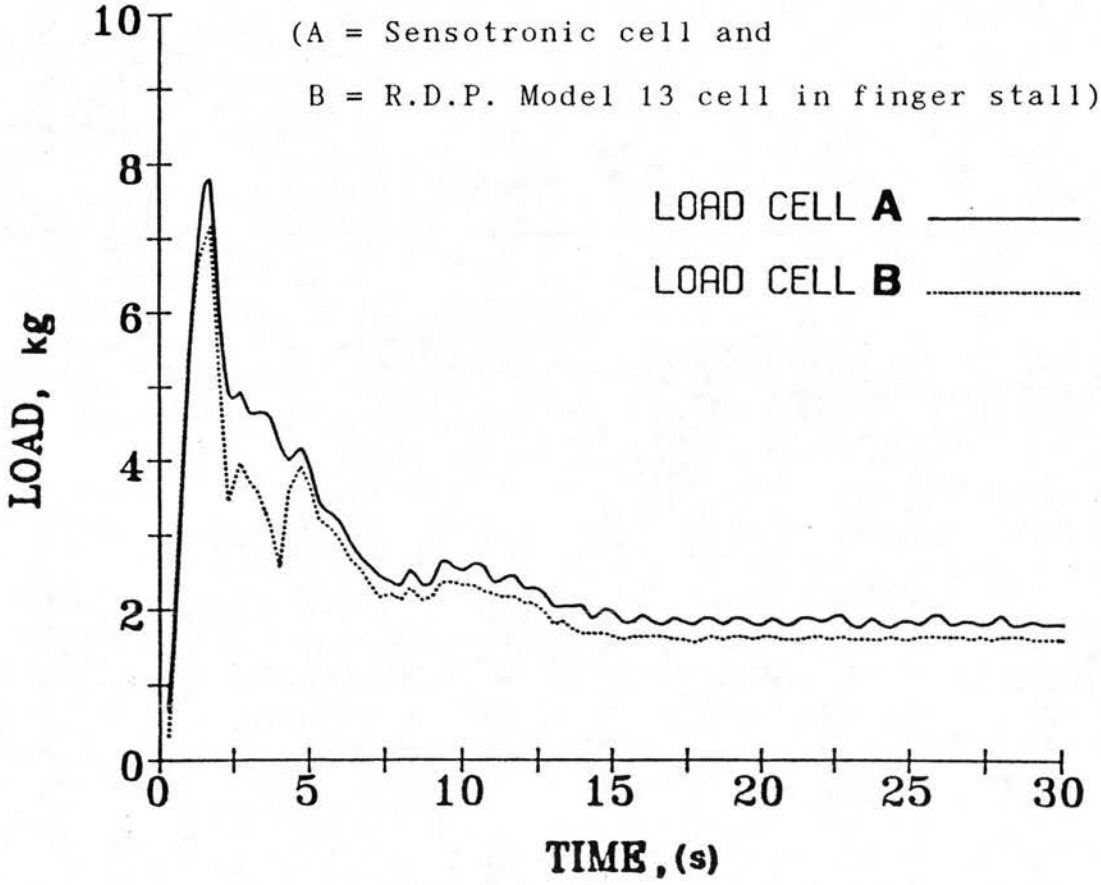
1.14 Dynamic load test for the large and small load cells taped together (A = Sensotronic cell and B = R.D.P. Model 13 cell).



1.15 Photograph of crowns with flat copings to give a good contact with the load cell.



1.16 Cementation test loads with separated load cells (A = Sensotronic cell and B = R.D.P. Model 13 cell in finger stall).



RESULTS

Initial calibration of the small load cell is shown in Figures 1.13 and 1.14. Figure 1.13 shows the application of a single static load and the stability of the reading with respect to time, and figure 1.14 shows the effect of varying the static load. The difference between the cells appears minimal.

The maximum cementation forces in the laboratory for the dual cell arrangement is shown in table 1.4 and a typical experimental result is shown in figure 1.16.

The results of the equivalent clinical studies with the finger cell above are shown in tables 1.5 and 1.6.

Table 1.4.

MAXIMUM FORCES APPLIED TO CROWNS DURING LABORATORY CEMENTATION, kg.

	1	2	3	4	5
A LARGE LOAD CELL (kg)	6.72	7.76	6.16	6.84	6.40
B SMALL LOAD CELL (kg)	5.68	7.16	5.32	5.64	5.24
A - B	1.04	0.60	0.84	1.20	1.66

MEAN OF DIFFERENCES = 0.97 SD = 0.25 SE = 0.1

Table 1.5

LOADS APPLIED TO METAL CROWNS

IN CLINICAL CEMENTATION, kg.

Dentist	B	C	D
	7.96	4.60	2.88
	6.16	5.16	3.04
	8.60	5.20	----
	8.60	6.08	----
	7.80	5.80	----
Mean	7.82	5.27	2.91
SD	1.00	0.58	0.11@
SE	0.45	0.26	0.08@

FOR ALL THE METAL CROWNS CEMENTED

MEAN = 5.99

SD = 1.97

SE = 0.57

@ The data from dentist D relates to two cementations and should only be regarded as demonstrating a trend of that practitioner.

Table 1.6

LOADS APPLIED TO PORCELAIN CROWNS IN CLINICAL CEMENTATION, kg.

Dentist	A	C	D	E
	2.50	5.52	0.56	2.88
	2.30	3.10	0.49	3.08
	----	2.92	0.64	2.60
	----	2.64	----	3.52
	----	3.92	----	----
Mean	2.4	3.62	0.56	3.02
SD	0.14@	1.16	0.07	0.39
SE	0.1@	0.52	0.04	0.20

FOR ALL THE PORCELAIN CROWNS CEMENTED

MEAN = 2.6

SD = 1.4

SE = 0.4

@ The data from dentist A relates to two cementations and should only be regarded as demonstrating a trend of that practitioner.

DISCUSSION

The initial calibration tests shown in Fig's 1.13 and 1.14, where the large and small load cells were strapped together shows that the difference between the two load cells is minimal, and that the small load cell may therefore be considered to be properly calibrated throughout the range of forces applied by clinicians (ie 0-10 kg).

However when the cells are separated for laboratory cementation studies, such that the large load cell is beneath the crown and the small load cell is in a finger stall, table 1.4 shows that the small load cell appears to give lower readings than the large cell, at least with regard to maximum applied load. Closer examination of figure 1.16 where a single cementation is followed for 30 s suggests that the two cells are still comparable under static loading, as indicated by the later part of the trace in figure 1.16.

The reason for the transient early difference is unclear but may be related to the compressibility of freshly mixed cement, the mechanical properties of the soft tissue of the finger or finger stall latex, or local deformation of the small load cell when it is no longer supported by the large cell. This could form a useful part of any further studies in this area.

The results obtained from equivalent clinical cementations of metal based crowns in table 1.5 were comparable with the results from the laboratory tests, although some variation in individual operator performance was still apparent.

These results are similar to those obtained in experiment 1.2 for cementation of crowns using the large load cell alone, and given the large variation in clinically applied pressures the laboratory conditions suggested in experiment 1.2, ie 6 kg for 30 s followed by 3 kg until set, would still appear to be a reasonable model for the clinical situation.

The data is of course only relevant to metal-based crowns. Table 1.6 relates to a separate clinical study of the pressures applied to all-porcelain crowns. A comparison of the loads applied to metal crowns (table 1.5) with those applied to all-porcelain crowns suggests that dentists intuitively apply a lower pressure when cementing the latter. This implies that a number of factors influence clinicians' behaviour in applied cementation pressures. It might be argued that a flat-topped coping is outside normal clinical experience and could therefore be introducing a bias into the cementation pressures measured in this work. Further laboratory studies should be considered to resolve this point.

The observed transient differences between the large

and small load cells could also form the basis of further studies. For example, it would be appropriate to carry out a laboratory cementation in which the small load cell was attached directly to the large load cell and not the finger, to eliminate the possibility of cell deformation.

CONCLUSIONS

These studies indicate that in both the laboratory and the clinic there is a variation among clinicians in applied cementation pressure, and support the suggestion in experiment 1.2 that a reasonable laboratory model of the clinical situation would be a static load of 6 kg applied for 30 s, followed by 3 kg until the cement has set. Further, a suitable means of monitoring this force in the clinic can be a small load cell incorporated in a finger stall.

CHAPTER 2.

INTRODUCTION

In any investigation of the effect of taper on crown retention, it is clearly necessary to determine the range of tapers achievable clinically. One method of studying this of course would be to take measurements from tooth sections, but the limitation of this is that the method is destructive and any one tooth can only be examined in a single plane.

On the other hand, a non-destructive method such as radiography allows a tooth to be examined in various planes and is therefore more relevant to the problem of three dimensional tapers. The limitation of this method however is that it involves a two dimensional representation of a three dimensional object and is therefore prone to measurement of artifacts.

Fortunately the external dimensions of teeth have been measured directly, and Wheeler in particular has published the external dimensions of teeth in book form based on measurements with calipers[83].

For the purpose of this work it was decided therefore to use the convenience of radiographic measurements to determine both internal and external dimensions of teeth

in more than one plane, and to compare the external measurements with those obtained by Wheeler as a means of demonstrating the reliability of the radiographic technique.

It was then proposed to use the radiographic measurements to determine the range of tapers achievable clinically without pulpal exposure. It was finally intended to compare these data with the range of tapers observed in actual clinical practice.

Experiment 2.1

To investigate the volume of hard tissue available at the gingival level of extracted human teeth.

METHOD

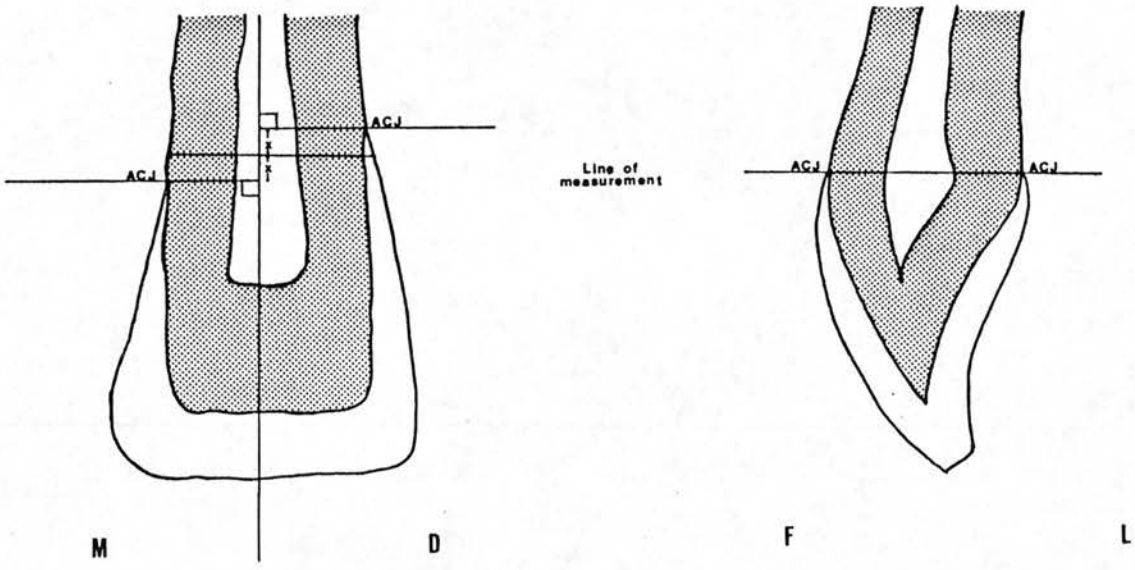
Extracted human teeth were collected by general dental practitioners in the south east of Scotland. The teeth were divided into upper molars, second premolars, first premolars, canines, lateral incisors, central incisors, and lower molars, second premolars, first premolars canines, and incisors. The first 10 (11 for upper first premolars, lateral incisors, and central incisors) of each tooth type which were not heavily filled were selected. These teeth were placed in batches on size 4 X-ray films*[11] (Kodak Dental Film ultra speed DF-50) facial surface uppermost, and the film was exposed. The process

was then repeated with the teeth rotated axially through 90^0 (mesial or distal surface uppermost). The X-ray films were processed and the films placed on the NIKON PROFILE PROJECTOR V-12 *12 where the diameter of the tooth; the diameter of the pulp; and the thickness of dentine was measured on each side of the pulp along a line from the amelo-cemental junction (ACJ) on the facial surface to the ACJ on the lingual surface. The same measurements were made from the mesial to the distal along a line from the ACJ on the mesial surface to the ACJ on the distal surface of the teeth. When the lines through ACJ's at 90^0 to the long axis were not at the same level, the measurements were made on a line at 90^0 to the long axis of the tooth equidistant from the upper and lower ACJ (Fig 2.1).

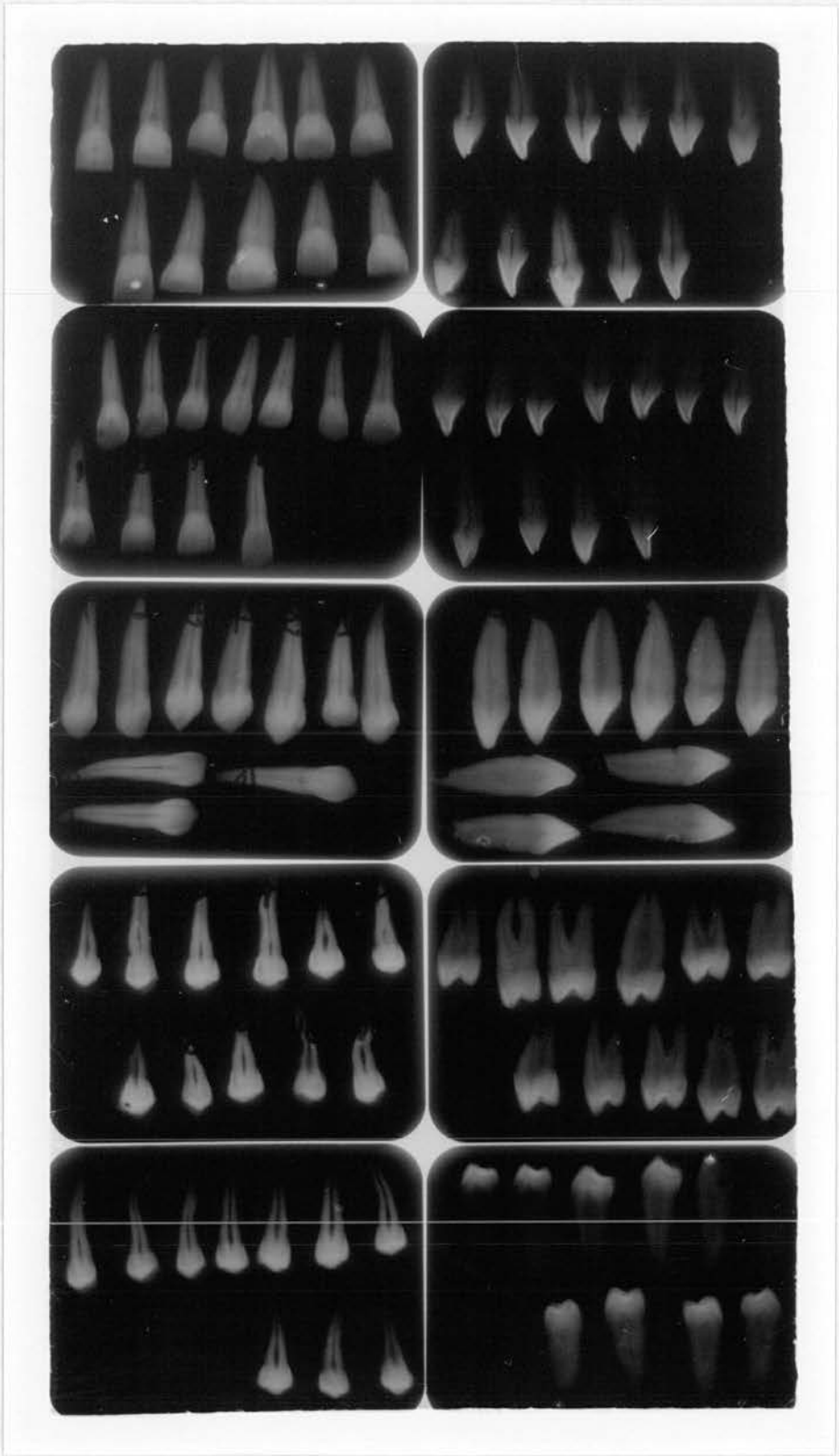
RESULTS

The results are shown in appendix 2 tables 2.1 to 2.11. and summarised in tables 2.12 and 2.13. Fig's 2.2 to 2.4 are photographic prints of the X-ray films used. It should be noted that there is a loss of definition in the photographic prints compared with the original X-ray films.

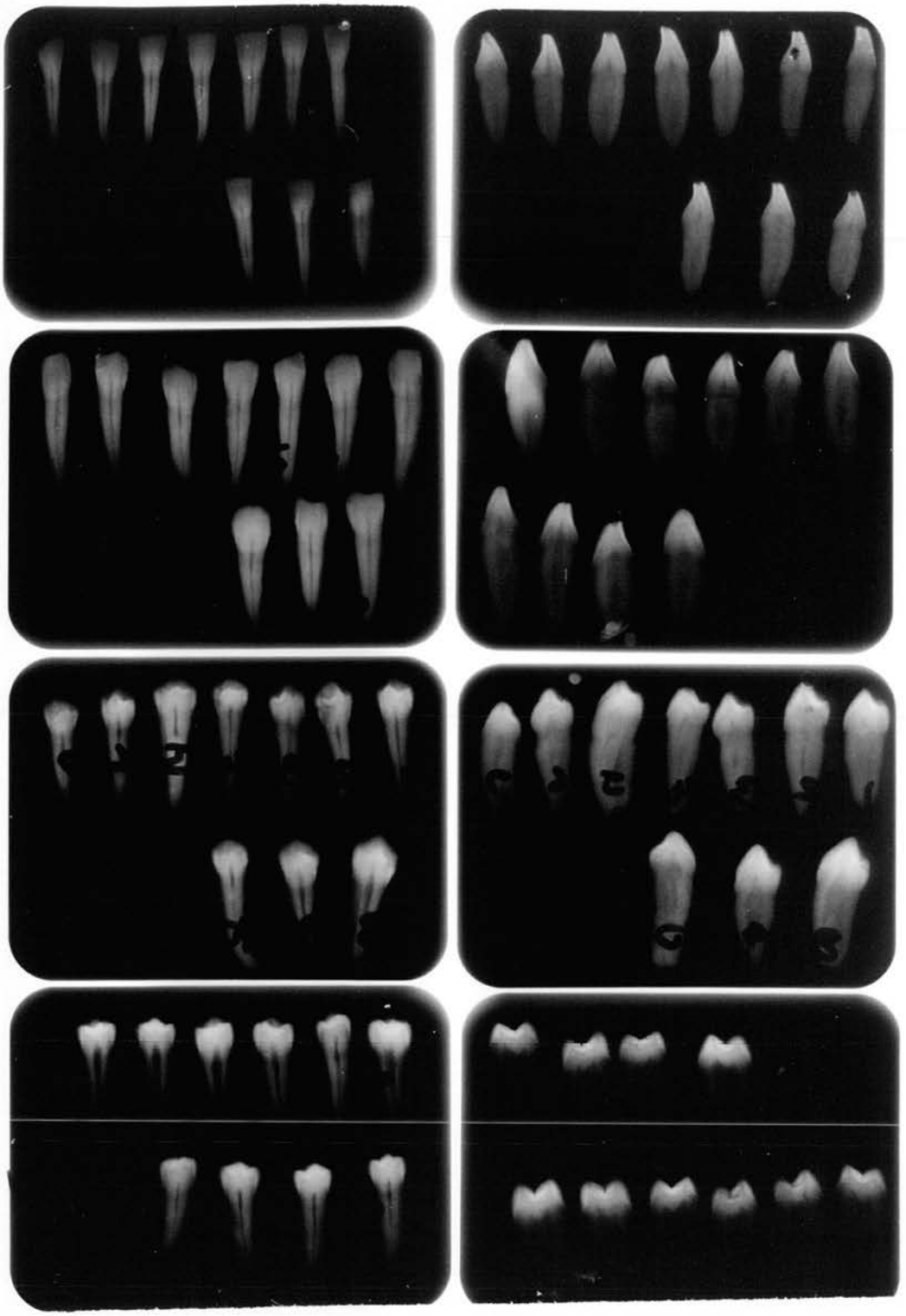
2.1 Lines used to measure available hard tissue at the gingival aspect of human teeth.



2.2 Photographic print of radiographs of upper incisors, canines, and premolars.



2.3 Photographic print of radiographs of lower incisors, canines, and premolars.



2.4 Photographic print of radiographs of molars.

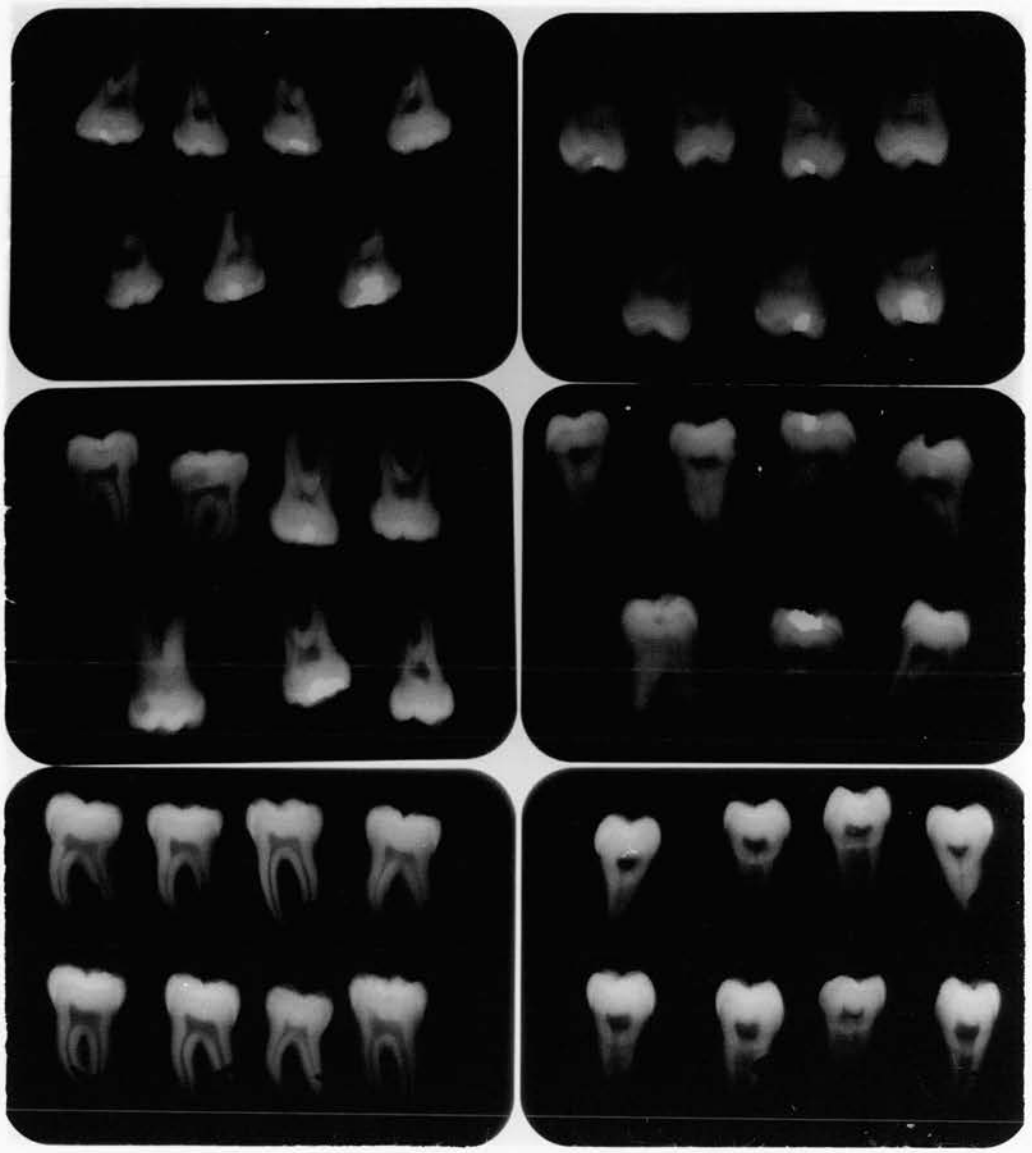


Table 2.12

SUMMARY OF MEAN THICKNESS OF DENTAL TISSUES

Measurements in mm.

	FACIAL to LINGUAL			
UPPER	FACIAL DENTINE	PULP	LINGUAL DENTINE	TOTAL
MOLARS	2.9	5.8	2.8	11.5
SECOND PREMOLARS	2.3	3.9	2.4	8.6
FIRST PREMOLARS	2.4	4.0	2.4	8.7
CANINES	3.0	2.6	2.6	8.2
LATERAL INCISORS	2.9	1.5	2.1	6.3
CENTRAL INCISORS	3.1	1.2	2.5	6.8
LOWER				
INCISORS	1.9	1.5	2.2	5.7
CANINES	2.7	1.9	2.6	7.2
FIRST PREMOLARS	2.4	2.3	2.5	7.2
SECOND PREMOLARS	2.3	2.8	2.6	7.7
MOLARS	2.5	3.8	2.8	9.2

Table 2.13

SUMMARY OF MEAN SIZE OF TEETH

Measurements in mm.

	MESIAL to DISTAL			
UPPER	MESIAL DENTINE	PULP	DISTAL DENTINE	TOTAL
MOLARS	2.3	3.9	2.9	9.0
SECOND PREMOLARS	1.8	1.0	2.1	5.0
FIRST PREMOLARS	2.0	0.9	2.0	4.9
CANINES	2.6	1.2	2.5	6.3
LATERAL INCISORS	1.8	1.5	1.9	5.2
CENTRAL INCISORS	2.5	2.0	2.4	7.0
LOWER				
INCISORS	1.6	0.7	1.5	3.7
CANINES	2.2	0.8	2.1	4.9
FIRST PREMOLARS	2.2	0.8	2.1	5.1
SECOND PREMOLARS	2.1	1.1	2.2	5.4
MOLARS	2.2	4.9	2.6	9.7

DISCUSSION AND CONCLUSIONS

The external dimensions reported here are comparable with those obtained directly by Wheeler[83] and the radiographs used here are therefore considered to be a reasonable guide to both internal and external tooth

dimensions.

Experiment 2.2

To estimate the angle of taper which would cause to exposure of the pulp in human teeth.

Clinically, for full gold crown preparations, the tapered walls of the preparations usually start near the ACJ. If the tooth has been prepared for a porcelain, or porcelain-bonded-to-gold, crown a shoulder is developed and the tapered walls are placed pulpally from the ACJ in this region. In the estimation of angle of taper to exposure it was proposed to use the radiographic technique established in experiment 2.1 to allow for the possibility of various widths of shoulder preparation.

METHOD

The X-rays of teeth used in experiment 2.1 were examined on the NIKON PROFILE PROJECTOR to measure the angles of taper which would produce a pulpal exposure.

These angles were measured from the vertical axis to six points along a line from ACJ to ACJ in both mesial-distal and facial-lingual directions. The first point was at the facial ACJ, the second 1 mm pulpally, and the third point was a further millimetre towards the pulp. The other 3 points along this line were similarly spaced

at 1 mm intervals from the lingual ACJ towards the pulp. Similarly 3 points were located from each ACJ at 1 mm intervals from the mesial ACJ and the distal ACJ. In the teeth where the ACJ's were not at the same level, the angles of taper were measured to points on lines at 90° to the long axis of the teeth running through the ACJ (Fig 2.5).

RESULTS

The data from these experiments is shown in appendix 2 tables 2.14 to 2.24 and summarised in tables 2.25 to 2.27.

Table 2.25

MEAN TAPER FROM ACJ TO EXPOSURE

Measurements in degrees.

UPPER	DISTAL	MESIAL	LINGUAL	FACIAL
CENTRAL INCISORS	48	50	49	38
LATERAL INCISORS	41	34	43	30
CANINES	41	36	42	38
FIRST PREMOLARS	43	47	52	40
SECOND PREMOLARS	47	48	52	42
MOLARS	71	57	72	64

LOWER	DISTAL	MESIAL	LINGUAL	FACIAL
INCISORS	31	35	39	38
CANINES	35	33	34	38
FIRST PREMOLARS	44	46	55	54
SECOND PREMOLARS	53	51	56	49
MOLARS	71	57	67	64

Table 2.26

MEAN TAPER FROM ACJ + 1 mm TO EXPOSURE

Measurements in degrees.

UPPER	DISTAL	MESIAL	LINGUAL	FACIAL
CENTRAL INCISORS	39	39	41	28
LATERAL INCISORS	22	22	33	19
CANINES	29	27	35	31
FIRST PREMOLARS	29	31	41	29
SECOND PREMOLARS	32	31	41	31
MOLARS	65	43	65	55

LOWER	DISTAL	MESIAL	LINGUAL	FACIAL
INCISORS	11	15	28	25
CANINES	21	19	26	30
FIRST PREMOLARS	29	32	46	44
SECOND PREMOLARS	37	36	45	39
MOLARS	65	44	58	55

Table 2.27

MEAN TAPER FROM ACJ + 2 mm TO EXPOSURE

Measurements in degrees.

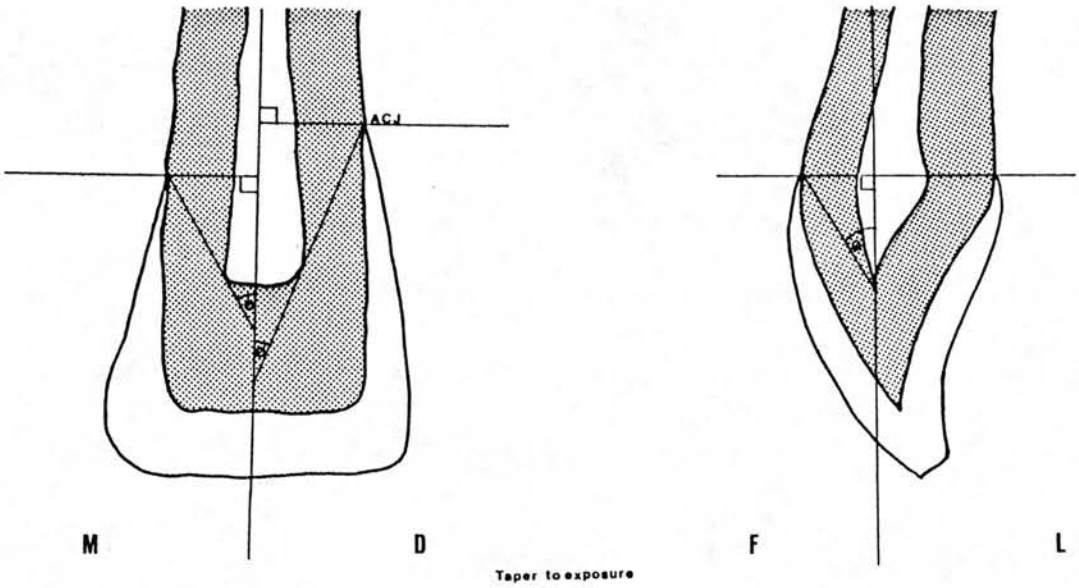
UPPER	DISTAL	MESIAL	LINGUAL	FACIAL
CENTRAL INCISORS	14	16	33	12
LATERAL INCISORS	6	0	22	4
CANINES	12	10	25	20
FIRST PREMOLARS	5	9	20	14
SECOND PREMOLARS	5	3	15	12
MOLARS	53	15	54	40

LOWER	DISTAL	MESIAL	LINGUAL	FACIAL
INCISORS	0	0	10	3
CANINES	2	1	13	20
FIRST PREMOLARS	3	5	24	30
SECOND PREMOLARS	3	8	19	19
MOLARS	49	19	33	37

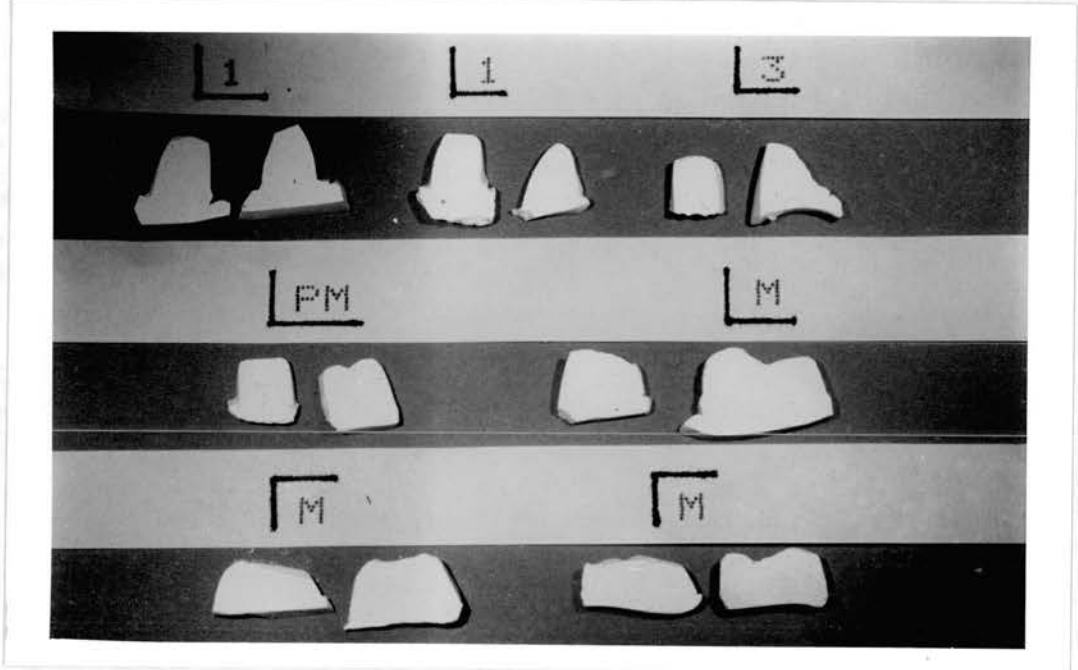
CONCLUSIONS

Extrapolation from these tables allows one to postulate a series of worst-case tapers for particular types of teeth. (e.g. A crown preparation with a 1 mm shoulder on an upper canine could not have a taper greater than 29^0 facialy.)

2.5 Reference points used to measure taper to pulpal exposure of human teeth.



2.6 Photograph of dies sectioned in the mesio/distal and bucco/palatal planes.



The taper available for different teeth can be estimated and compared with the mean sizes of preparations produced in clinical practice.

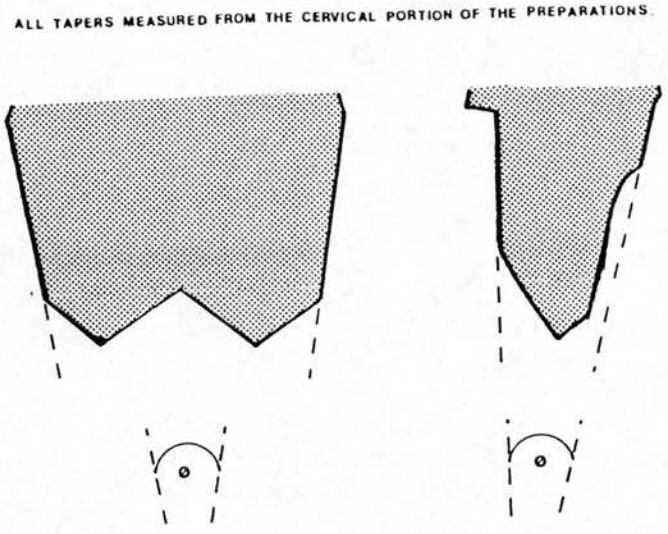
Experiment 2.3

To find the mean taper of dies for clinical crown preparations at Edinburgh Dental Hospital.

METHOD

Impressions taken to make crowns at Edinburgh Dental Hospital were collected after the crowns had been cemented. Two plaster dies were poured for each crown preparation. A section about 1 mm thick was with a scalpel cut from the centre of one of the two dies, in the mesial-distal plane, and another similar section was cut from the centre of the other die in the facial-lingual plane (Fig 2.6). The sections were ground flat on abrasive paper and the angles of taper were measured with the NIKON PROFILE PROJECTOR, from the cervical margins of the preparation (Fig 2.7).

2.7 Region of preparations used to measure taper.



RESULTS

The results of these measurements are shown in appendix 2 table 2.28 and 2.29.

The data is summarised in table 2.30. The taper was found to vary in different areas of the mouth, as also described by Eames et al[84].

Table 2.30

TAPER OF CLINICAL CROWN PREPARATIONS

(Measurements in degrees.)

UPPER

	INCISORS		CANINES		MOLARS		PREMOLARS	
	MD	FL	MD	FL	MD	FL	MD	FL
MEAN	15.8	21.0	11.8	22.6	23.6	25.3	15.4	22.0
SD	4.8	8.3	4.1	10.3	10.1	8.3	8.1	7.8
SE	0.8	1.4	1.0	2.5	2.4	2.0	2.4	2.3

LOWER

	INCISORS		CANINES		MOLARS		PREMOLARS	
	MD	FL	MD	FL	MD	FL	MD	FL
MEAN	13.2	25.7	15.4	14.2	30.9	29.8	16.0	17.6
SD	5.9	4.7	6.1	4.9	9.3	11.4	5.4	9.9
SE	1.8	1.4	1.9	1.5	2.0	2.4	1.6	3.0

The mean of the two measurements for each preparation is shown in table 2.31. This indicates the overall taper for each tooth.

Table 2.31

TAPER OF CLINICAL CROWN PREPARATIONS

(AVERAGE OF MD AND FL)

UPPER

	INCISORS	CANINES	MOLARS	PREMOLARS
MEAN	18.3	17.2	24.4	18.7
SD	7.2	9.6	9.3	8.4
SE	0.9	1.7	1.6	1.8

LOWER

	INCISORS	CANINES	MOLARS	PREMOLARS
MEAN	19.5	14.8	30.4	16.8
SD	8.3	5.5	10.3	7.8
SE	1.8	1.2	1.5	1.7

CONCLUSIONS

These figures are consistent with those of Ohme and Silness[85] who gave convergence angles of 19° to 27° for vital teeth and 12° to 37° for rootfilled teeth. Nordlander, et al[86] also gave a figure of 20° for the overall mean taper, and Shillingburg[70] found 14.7° to be the mean for clinical dies which he examined.

The tapers of crowns produced clinically are greater than the "ideal" (5° to 7°) taper quoted in most

textbooks. The evaluation of the retentive powers of cement lutes in vitro should be related to preparations with tapers in the clinical range of 10^0 to 30^0.

CHAPTER 3.

To simulate the clinical situation as closely as possible in testing the retentive strength of cement lutes, test pieces were made from human dentine and gold. The gold used was MATTICAST-R*[13] a Type III gold, British Standard 4425/1969.

As a first step, an investigation was carried out on the surface finish of crown preparations from extracted human canines. These teeth are relatively large and have strong roots which can be held in a jig. The canines also tended to have less decay and fewer defects than other available human teeth.

Simulated crown preparations were produced from these teeth on a lathe in the form of truncated cones. The surfaces were then examined for visual similarity and surface roughness, and a comparison was made with clinically prepared teeth.

Experiment 3.1

To produce the dentine core test pieces.

METHOD

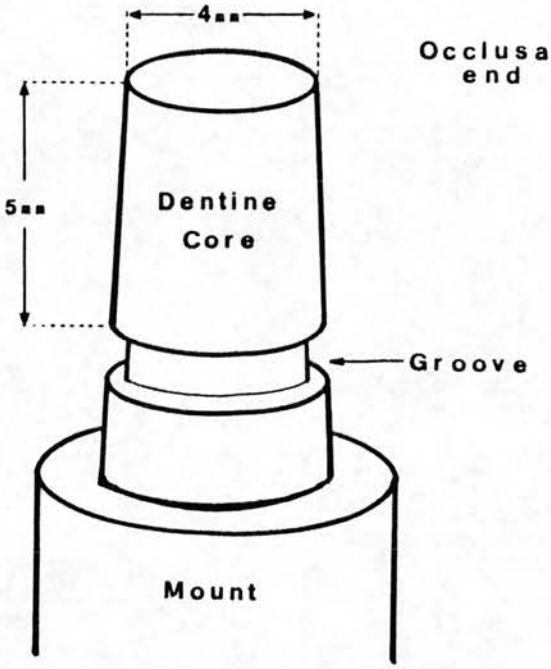
Extracted teeth were initially placed in a 10% solution

of calcium hypochlorite for 24 hours to remove contaminants, and were then stored in a 1% solution of hypochlorite until required.

The incisal tips were cut from 56 teeth, and then, the axial enamel was removed from the teeth using a tapered diamond bur in an air rotor with water coolant. This prevented the dentine from being overheated while the enamel was being removed, and also allowed inspection to ensure that there was no carious or defective dentine. The specimens were then stored in 0.85% saline solution to prevent dehydration of the dentine. Throughout the following stages the dentine was kept moist. The roots were notched buccally and palatally with a separating disc 1.25 mm thick, and two holes were drilled through the roots mesio-distally with a No 5 rosehead bur. This increased the retention of the roots when they were encased in acrylic resin in brass rings as described below.

The simulated crown preparations were produced on a lathe in the form of truncated cones (referred to in future as "cones") 5 mm high, with a diameter of 4 mm across the "occlusal" surfaces, and tapers of 5^0 which would be varied later (Fig 3.1).

3.1 Truncated cone preparation of 5^0 taper.



The test teeth were secured in brass tubing (7 mm internal and 9.6 mm external diameters). The brass tubing was cut into 20 mm sections, which were long enough to encase the root. Each ring had two 3 mm holes drilled diametrically opposite each other through the middle of its curved side, and a thread was machined the full length of the inside surface of the tube. These threads ensured good retention for the acrylic resin which was used to anchor the roots in the tubes.

K.D.Jorgensen[1] used truncated cones 8 mm high with a base diameter of 8 mm in his work on retention. The samples used in this study were smaller because human

tooth tissue as large as Jorgensen's dimensions was not available as demonstrated by the results in Chapter 2. This difference in cone size did not affect a comparison of force per unit area, and the cones in the present study were of human dentine and therefore more relevant clinically.

The cones were produced using a MYFORD ML 7 lathe*[14]. A locating rod in the form of a 4 mm diameter cylinder of brass, was mounted in the tail stock. To aid centring, the incisal tip of the tooth was temporarily attached to the locating rod with plasticine. The brass rings were secured in the self-centring chuck, and the roots were slid into the rings, ensuring that they were centred. Self-curing acrylic was poured into the rings to secure the roots. When set, the rings were removed from the chuck, and close fitting rubber tubes were placed over them to stop excess acrylic flowing out of the holes while the rest of the tube was filled. The filled rings were placed in a hydro-flask to cure the acrylic resin under pressure.

Each ring containing a canine tooth was remounted in the lathe and a tungsten carbide tool was used to produce a flat plane at right angles to the long axis of the tooth. These flat planes represented the occlusal surfaces of the "crown preparations". A tungsten carbide tool was mounted with the top slide set at 2.5^0 to the long axis. The dentine was turned with this tool to 2 mm

from the centre, thus producing 4 mm diameter occlusal surfaces on the dentine cone of 5^0 taper. To make each cone 5 mm high the locating rod was brought into contact with the occlusal end and 5 mm measured from this stop. The rod was removed from contact to avoid wear, and a parting tool was used to cut an annular groove which would provide a sharp "finishing line" for the gold crown.

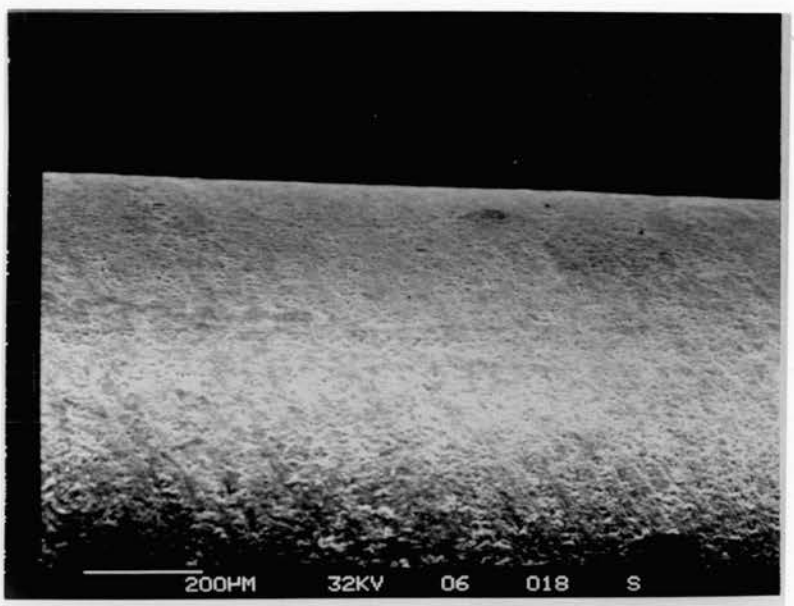
Initially 40 specimens were completed (16 teeth had been rejected during production). On closer examination a further 7 were found to be unsuitable due to small pulpal exposures, leaving 33 suitable specimens (a failure rate of 41%). The 7 rejects were kept for surface analysis by electron microscopy or TALYSURF.

The prepared specimens were stored in isotonic saline, where they were separated from each other to prevent damage by being placed in empty amalgam capsule containers. Five dentine specimens were immediately plated with gold and used for S.E.M. (scanning electron microscope*[15]) examination so that the surface of the dentine, as finished by the tungsten carbide lathe tool, could be studied (Fig 3.2).

Brass rings were chosen because they were easy to obtain and prepare. The potential for corrosion was recognized, therefore the brass rings were coated with copal-ether varnish to protect them from the solutions used in the experiments. The varnish proved to be less than perfect as a barrier and the solution was discoloured

with copper. Colonies of micro-organisms were also found to be contaminating the solution. It was decided that the rings should be electroplated with chromium to prevent corrosion. (PRECISION MACHINING EDINBURGH LTD., NEWBATTLE INDUSTRIAL ESTATE, DALKEITH) A regime of changing the storage solutions of isotonic saline three times a week (Mon 09.00, Wed 12.00, and Fri 17.00) was introduced to prevent contamination of the test pieces.

3.2 Electron-micrograph of dentine cone sent directly for S.E.M. examination (x 80).



The the surfaces of the finished test pieces were examined to ensure uniformity (quality control) of the dentine cones. This was indicated as K.D.Jorgensen[1] Oilo[62] and Felton[56] had shown that the surface texture of the cones affected the retention of crowns cemented on them.

DISCUSSION

It was necessary to store the teeth prior to use, and consideration was therefore given to literature reports of the effect of storage on retention. The work of Causton and Johnston[87] is of most concern because it suggests that teeth should be used within 20 minutes of extraction because stored teeth show a marked drop in retention. However, this is disputed by other authors. For example, Swartz and Phillips[88] showed no significant effect on the retention of acrylic cement by prolonged tooth storage. Peddey[89], and Mitchem and Gronas[90] reported no effect on bond strength related to time of storage. Beech et al in a study of phosphate and polyalkenoate cement systems[91], concluded that "time after extraction can significantly change bond strengths to dentine but the direction and magnitude of these changes depends on the adhesive systems" while Williams et al[92] demonstrated no significant differences in bond strengths using teeth stored from less then 4 months to as long as 6 years. Stackhouse et al[93], who specifically investigated storage time, stated that post-extraction age of a tooth had no consistent effect on most bond strengths.

Although no general statement can be made for all dental cements at this time, the consensus appears to be that storage has minimal effect on retention. In any event, the timescale of 20 minutes suggested by Causton et

al[87] was impractical for the experiments in the present study, and in accordance with the majority it was decided that storage would not be considered as a factor in retention for this study.

Simulated crown preparations were produced on a lathe. This introduced further factors which may affect retention, not least because it is arguable that a lathe cutting tool may not be a good model representative of dental practice. In addition, it is well established that the cutting of dentine produces a layer of proteinacious and calcific debris known generally as a dentine smear layer[24], and that this can affect retention[24,29-32]. This thesis has not investigated dentine smear layer in detail, but its possible effect is recognised and its role in retention is addressed in Chapter 8.

Experiment 3.2

To examine the surfaces of the dentine cones.

METHOD

A RANK TAYLOR HOBSON TALYSURF 5-120*[16] was used to examine non-destructively the test piece, dentine cone, surfaces. S.E.M. photographs of these areas, and S.E.M. photographs of impressions of these areas were compared with the TALYSURF results. It was hoped that the use of

impressions would remove the necessity to destroy the dentine test pieces by preparing them for an S.E.M. examination. Impressions of the experimental dentine cones would also enable comparison to be made with impressions of clinical crown preparations.

The TALYSURF has a stylus which runs along the surface of the test piece and produces a display of the full length of the surface. The machine can also produce a numerical value for surface texture - the RMS (Root Mean Square) value. To generate this value the stylus has to be travelling at a critical speed, therefore it can only survey a small section.

The dentine cones used for surface analysis were numbered, and the metal tubes were marked in two places approximately opposite each other on each tube. The first mark was a single line and the second had a cross through the line. The test pieces were placed in an engineer's V block (modified to compensate for the taper of the cone) while being surveyed by the TALYSURF. Each location was surveyed twice. First to produce the RMS reading, and then to make a pictorial record. Specimen No 8 was mounted and the surface surveyed 5 times along its full length to check whether the stylus of the machine had damaged the surface. The surface appeared to be undamaged, and on later S.E.M. examinations none of the dentine surfaces showed signs of damage from the stylus.

RESULTS

The results obtained from the Talysurf are shown in table 3.1.

Table 3.1 ROOT MEAN SQUARE VALUES FOR SURFACE TEXTURE OF DENTINE SPECIMENS.

SPECIMEN NO	RMS SITE 1	RMS SITE 2	SPECIMEN NO	RMS SITE 1	RMS SITE 2
1	22	19	2	20	18
3	17	21	4	26	31
5	23	41	6	25	20
7	17	16	8	21	31
9	22	17	10	19	12
11	16	17	12	44	25
13	27	23	14	17	19
15	25	40	16	24	25
17	69	33	18	20	20
19	18	13	20	17	19
21	29	24	22	29	29
23	16	19	24	18	16
25	31	34	26	16	16
27	19	22	28	16	21

MEAN RMS = 23. SD = 9. SE = 1.

(for both sides of all 28 samples)

Experiment 3.3

To compare the RMS values with the S.E.M. appearance of the dentine cones, and the S.E.M. appearance of impressions of the dentine cones.

METHOD

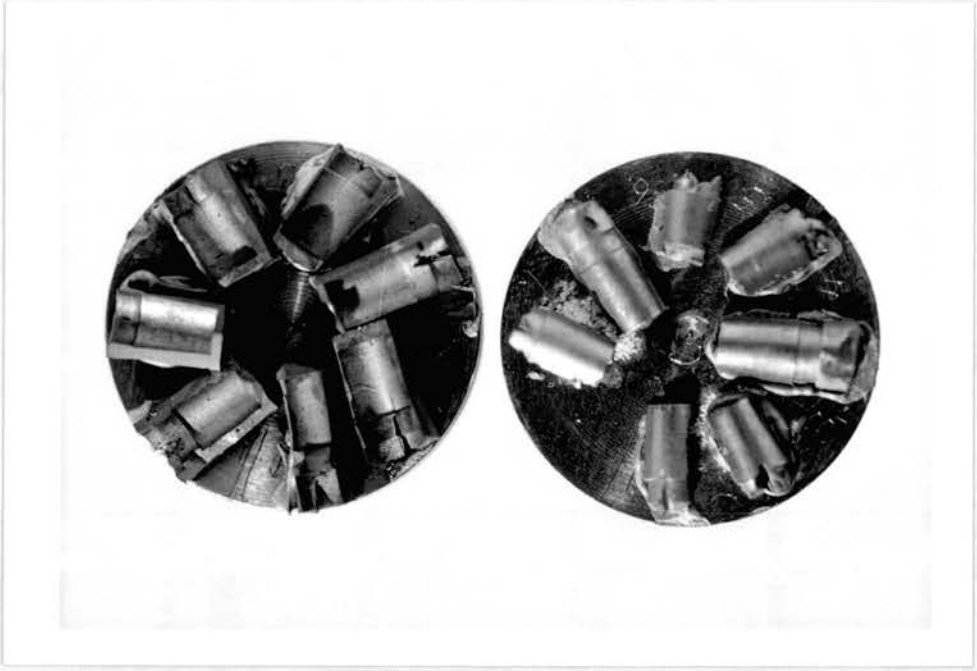
Impressions of the dentine cones were taken in REPROSIL*[17], a type II addition-cured silicone impression material, by mounting the specimens in plasticine in the small sections of an amalgam capsule box. Each of the sections was allocated a grid number corresponding to the specimen number. The top left corner of the boxes were removed to ensure correct alignment of the box with the grid. Another amalgam box was prepared to act as an "impression tray" by blocking out unused sections and removing a corner to correspond with the specimen box. Adhesive was painted in the "impression tray", light-bodied REPROSIL was mixed and loaded into the "tray" and the specimen box inverted over the "tray" immersing the test pieces in the impression material. When set the impression was examined and those with imperfections were rejected. New impressions were taken as necessary. If after the second impression the surface detail was still found to be faulty no further impressions were taken as sufficient impressions were available for comparison. On completion the test pieces were returned to the storage

bath.

A correlation was sought between the RMS values from the TALYSURF, and the S.E.M. photographs of the test pieces, and the S.E.M. photographs of the impressions of the test pieces. To this end specimens were selected with varying RMS values, for microscopy. The dentine cones were separated from the roots of the teeth with a diamond disc and divided longitudinally, midway between the two regions sampled by the TALYSURF, to produce two half cones. The bases of these half cones were smoothed to produce a surface suitable to be fixed to a conducting stub for the S.E.M., while ensuring that the regions sampled by the TALYSURF were uppermost. The impressions were removed from the "impression tray", and the bulk of the REPROSIL removed with a scalpel to make a flat base for cementation to the stub with the regions sampled by the TALYSURF uppermost.

LEIT-C*[18] conductive carbon cement was used to cement each half cone and impression to a stub. This cement has the advantage of being toluene soluble thus allowing the stubs to be reused. Each stub was numbered in the centre and had two parallel lines scribed down from the centre towards the 6 o'clock position. The first specimen on each stub was attached at the 4 o'clock position and numbered 1. Subsequent specimens were attached and numbered in an anti-clockwise direction (Fig 3.3).

3.3 Impression (left), and dentine half cone (right), mounted on a stub and gold plated for S.E.M. examination.

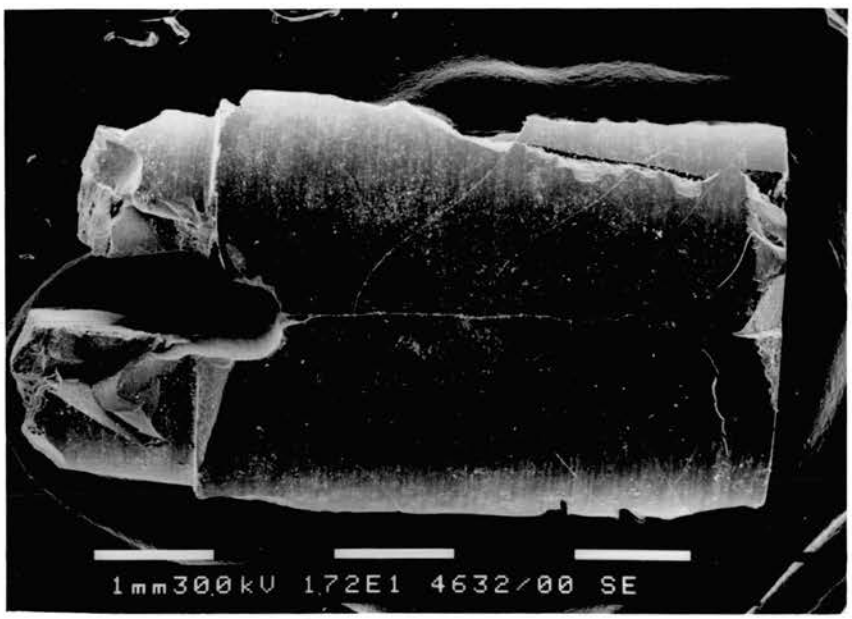


As many half cones and impressions as possible were attached to each stub. The position of each half cone and impression on each stub was recorded and the stubs were plated for electron conduction.

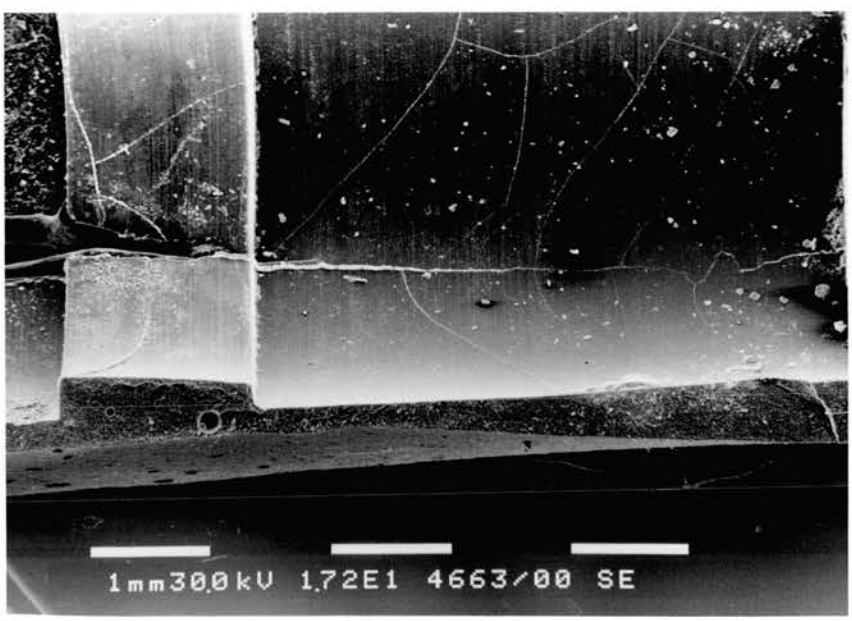
RESULTS

The electron-micrographs of half cones and their impressions showed that an impression was a good replica of a half cone and could therefore be used for SEM analysis. This would avoid destruction of the dentine cones. A typical half cone and its impression are shown

3.4a Electron-micrograph of dentine cone after talysurf measurement. Specimen 3 (x 15.5). Signs of storage damage can be seen.



3.4b Electron-micrograph of impression of specimen specimen 3 above (x 15.5).



in Fig 3.4a and 3.4b. Incidental damage to the dentine cone during sectioning for SEM study can be seen in Fig 3.4a.

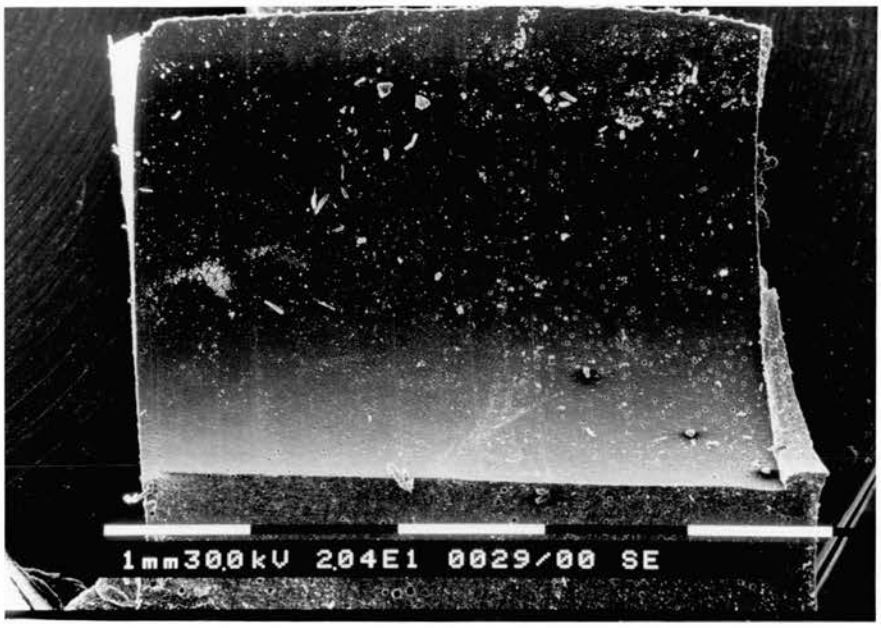
The surfaces of these dentine cones were cracked and of poor quality but when compared with electron-micrographs of dentine cones sent directly to the S.E.M. (Fig 3.2) and impressions of dentine cones made later (Fig 3.5a and Fig 3.5b) it was shown that the surfaces of the original and the later dentine cones were in good condition and free from cracks. The damage noted on the first test pieces may have been caused by a combination of prolonged storage; drying out for the TALYSURF; and/or changes in the storage medium made to reduce corrosion and infection.

To avoid this occurring to the dentine cones to be used for the crown retention tests, it was decided that the time from preparation to testing must be kept as short as possible, therefore only small numbers of dentine cones would be produced at any one time.

The correlation between the S.E.M. photograph and the RMS values obtained from the TALYSURF were poor. This was exemplified by comparing dentine cones 2 (Fig 3.6a and Fig 3.6b) and 17 (Fig 3.7a and Fig 3.7b) which had RMS values of 18 and 69 respectively (a difference in value of 41) yet there was little surface variation. Comparison of dentine cone 2 with dentine cone 3 (Fig 3.4a and 3.8), having RMS values of 18 and 17 respectively (a variation

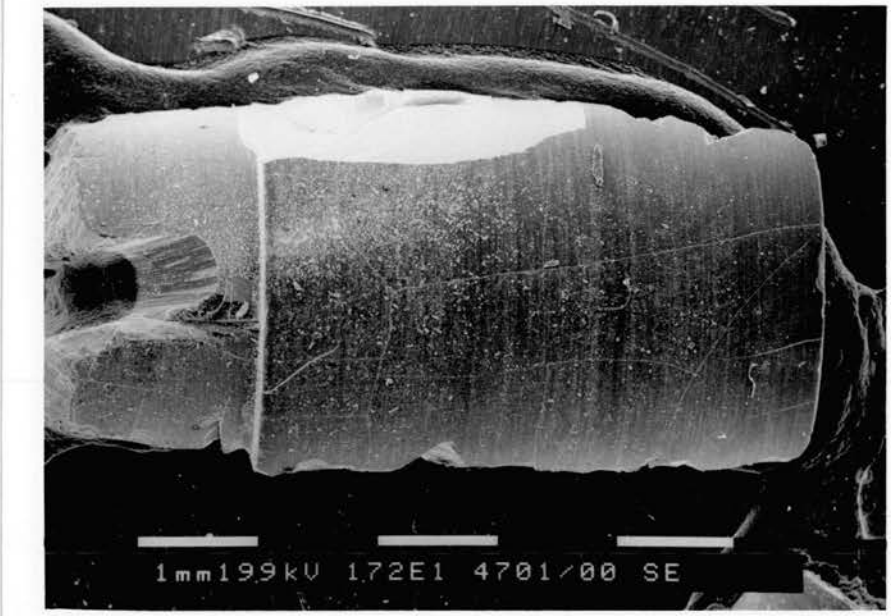
of only 1 unit) showed a more marked variation in surface quality.

3.5a Electron-micrograph of impression of dentine cone used for retention test (x 19.5).



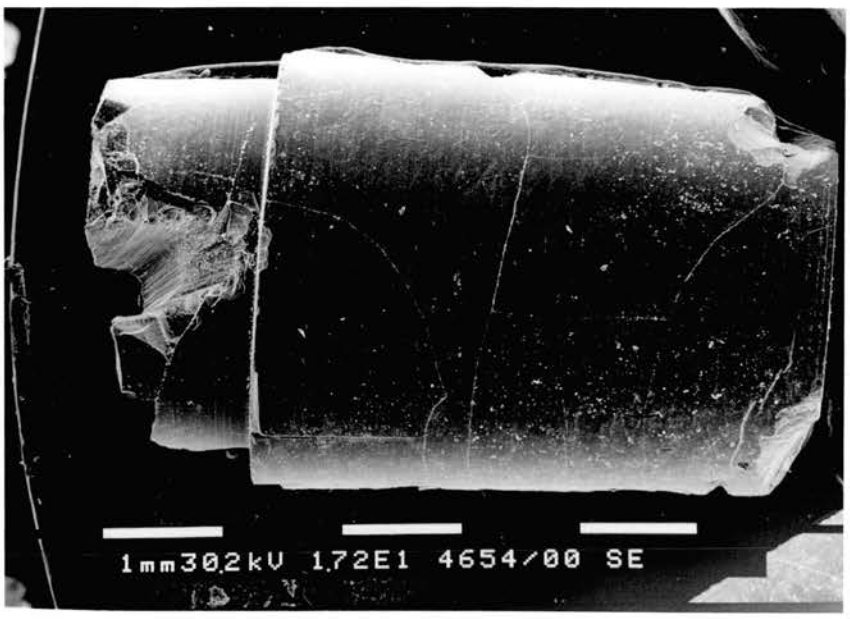
3.5b Electron-micrograph of impression of dentine cone used for retention test (x 95).

3.6a Electron-micrograph of dentine cone after talysurf measurement. Specimen 2 (x 15.5).

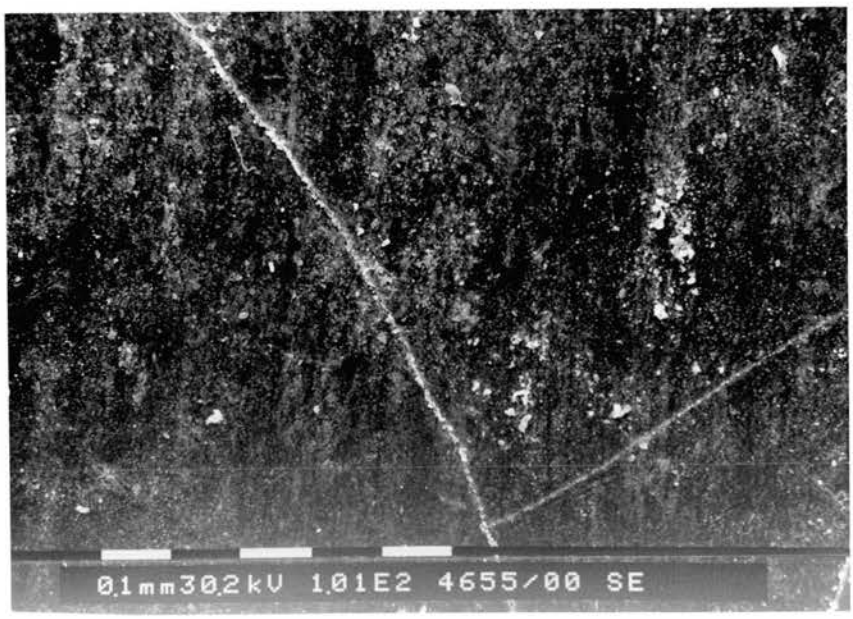


3.6b Electron-micrograph of dentine cone after talysurf measurement. Specimen 2 (x 95).

3.7a Electron-micrograph of dentine cone after talysurf measurement. Specimen 17 (x 15.5).



3.7b Electron-micrograph of dentine cone after talysurf measurement. Specimen 17 (x 95).



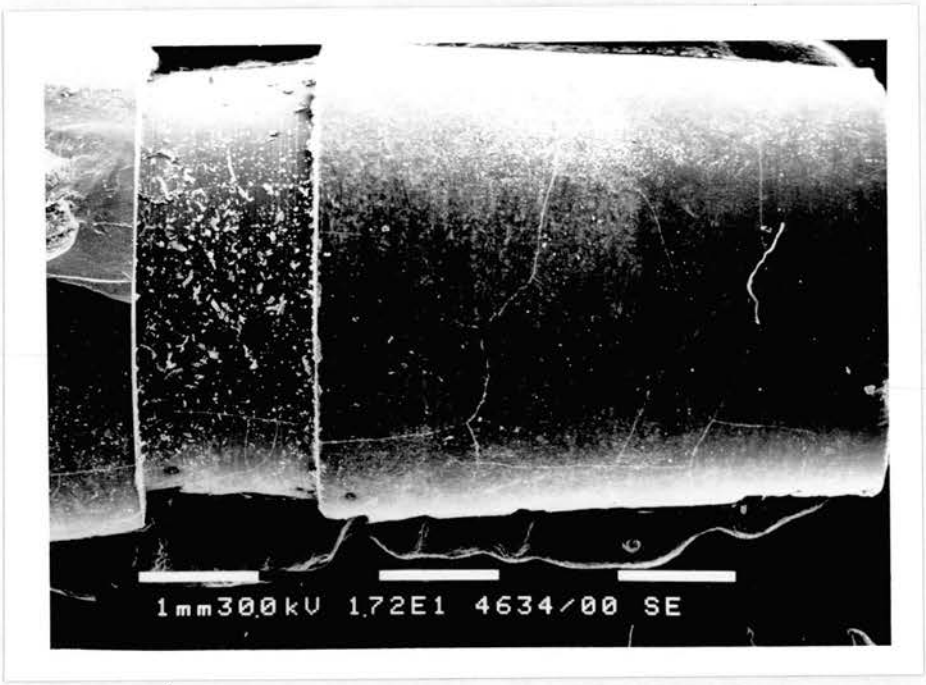
The unreliability of the TALYSURF results for the dentine cones is demonstrated by comparing the two RMS values obtained from individual test pieces shown in table 3.1 and summarised in table 3.2.

For test piece 5, the S.E.M. photographs of the first side (Fig 3.9a and Fig 3.9b) (RMS value 23) looks similar to the S.E.M. photographs of the opposite side (Fig 3.10a and Fig 3.10b) (RMS value 41). The difference of 18 in RMS values is not endorsed by the S.E.M. photographs.

This could be the result of the TALYSURF only sampling a small region which contained an abnormality as shown in the pictorial display of test pieces 12 (Fig 3.11). Side (12/1) of this test (RMS of 44) and the opposing side (12/+) (RMS of 25) show a difference of 19, unlike test piece 16 (Fig 3.12) where the RMS values differ by only 1 unit.

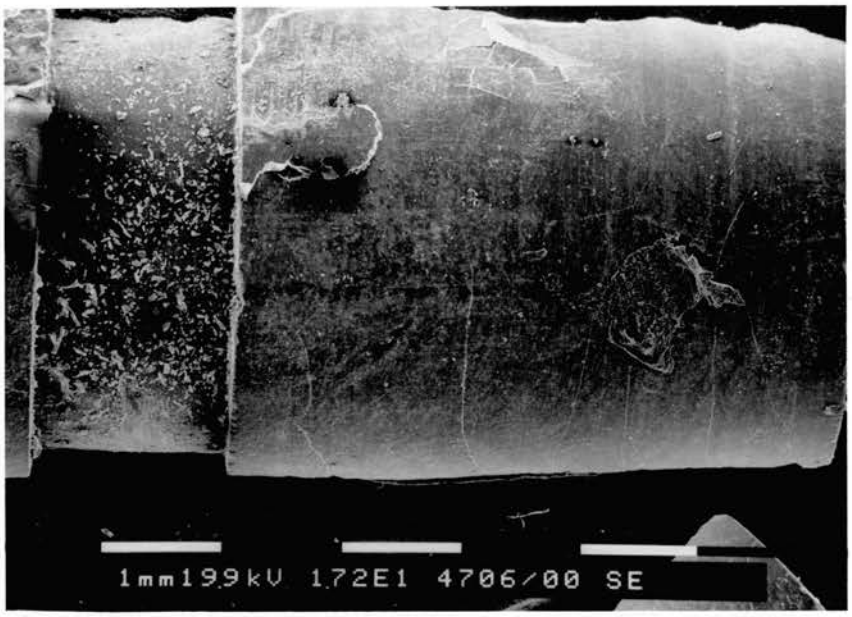
3.8 Electron-micrograph of dentine cone after talysurf measurement. Specimen 3 (x 95).

3.9a Electron-micrograph of specimen 5 (x 15.5).



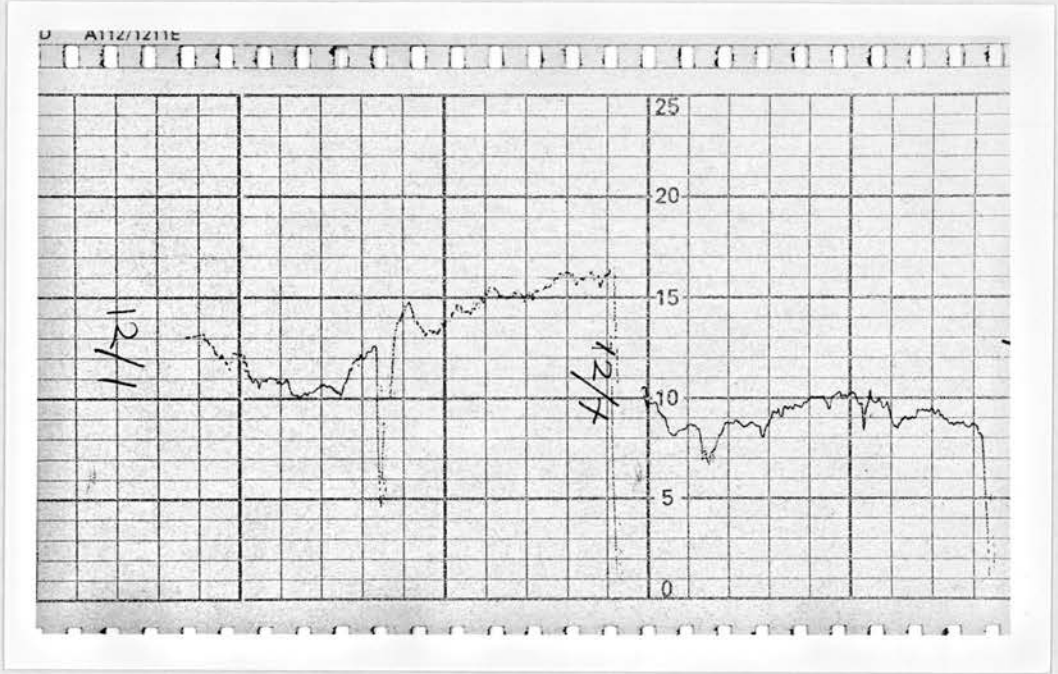
3.9b Electron-micrograph of specimen 5 (x 92).

3.10a Electron-micrograph of opposite surface of specimen 5 (x 15.5).



3.10b Higher power electron-micrograph of opposite surface of specimen 5 (x 88.6).

3.11 Pictorial representation of full length trace from TALYSURF specimen 12.



3.12 Pictorial representation of full length trace from TALYSURF specimen 16.

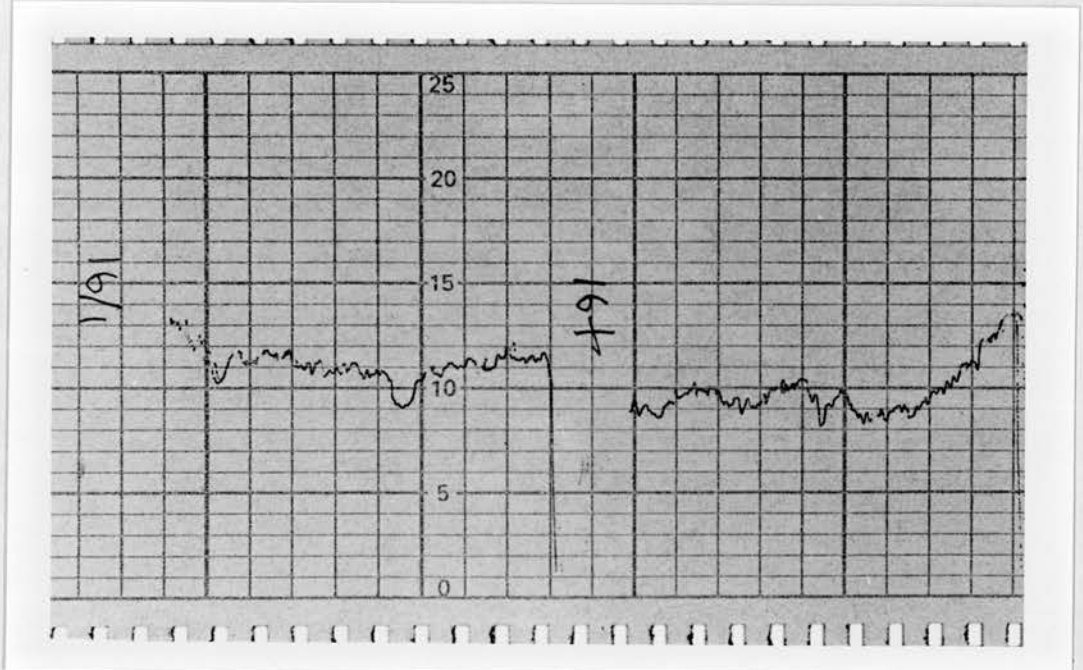


Table 3.2.

DIFFERENCES IN TALYSURF RMS VALUES

FOR INDIVIDUAL TEST PIECES

DIFFERENCE	FREQUENCY	%	DIFFERENCE	FREQUENCY	%
0	3	11	7	1	4
1	3	11	10	1	4
2	4	14	15	1	4
3	4	14	18	1	4
4	2	7	19	1	4
5	6	21	36	1	4

MEAN = 5.9 SD = 7.7 SE = 1.5

DISCUSSION AND CONCLUSIONS

The TALYSURF is in general a useful tool for the measurement of surface irregularities. However, in this study the results obtained for the profile of dentine surfaces by the TALYSURF did not correlate with those obtained by scanning electron microscopy. On the other hand, SEM studies were in better agreement with the visual appearance of the dentine surfaces, and it was therefore considered that the TALYSURF is probably not an

appropriate technique for studies of this type. A possible reason for this is that the TALYSURF may simply be to sensitive for the current project. In any event the damage caused to dentine by prolonged storage while awaiting TALYSURF measurements mitigates against its use.

Experiment 3.4

To compare the surface of the dentine cones with the surface of teeth prepared using clinical techniques.

METHOD

Four extracted human premolar teeth were prepared for a crown preparation by four experienced dental surgeons, each used the method they employed clinically (high speed tapered rotary instruments and water-coolant). These operators finished their preparations with:

1. a pink mounted stone*19,
2. a Paul lustig bur*20,
3. a Komet # 8863 diamond bur*21,
4. a medium diamond bur*22.

The prepared surfaces were then examined under the scanning electron microscope.

RESULTS

The SEM appearance of dentine prepared with clinical

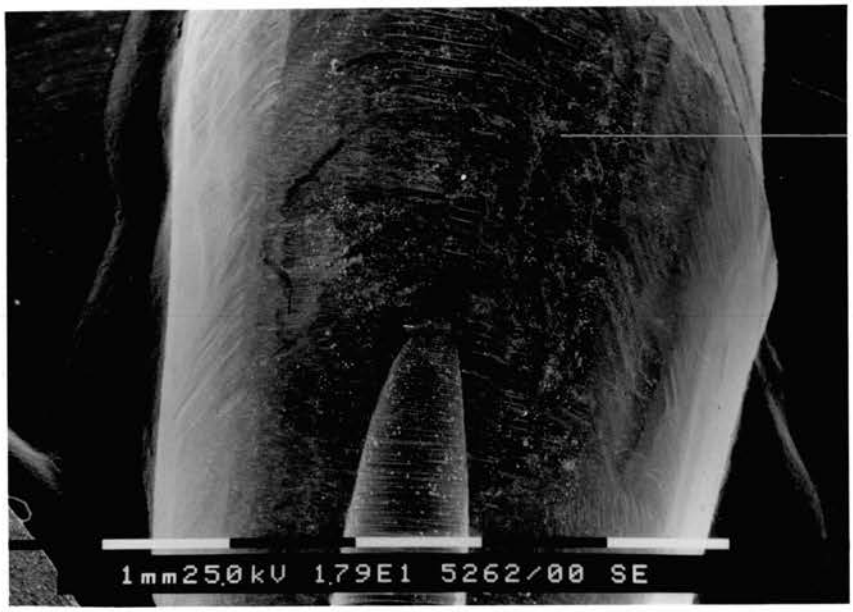
instruments is shown in figures 3.13a to 3.16b as follows:

1. Finished with a pink mounted stone. Fig 3.13a, b.
2. Finished with a Paul lustig bur. Fig 3.14a, b
3. Finished with a Komet # 8863 diamond bur. Fig 3.15a, b
4. Finished with a medium diamond bur. Fig 3.16a, b.

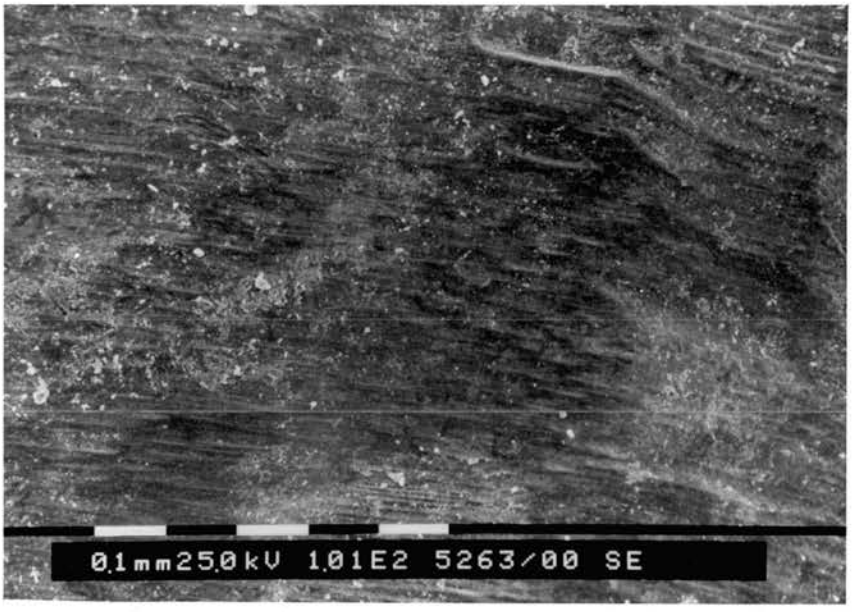
DISCUSSION AND CONCLUSIONS

The surface finish of the dentine cones prepared on a lathe shows a moderate similarity when compared at the same microscopic scale with crowns prepared with clinical instruments. However, the lathe-prepared dentine is visually smoother and less irregular with only a small interspecimen variation. The lathe-prepared surface appears to be relatively reproducible and and is therefore considered to be appropriate for the experiments in this study, although it is recognised that the lathe tool will produce a different surface in absolute terms to that normally prepared clinically

3.13a Electron-micrograph of tooth finished with a pink stone (x 17.2).

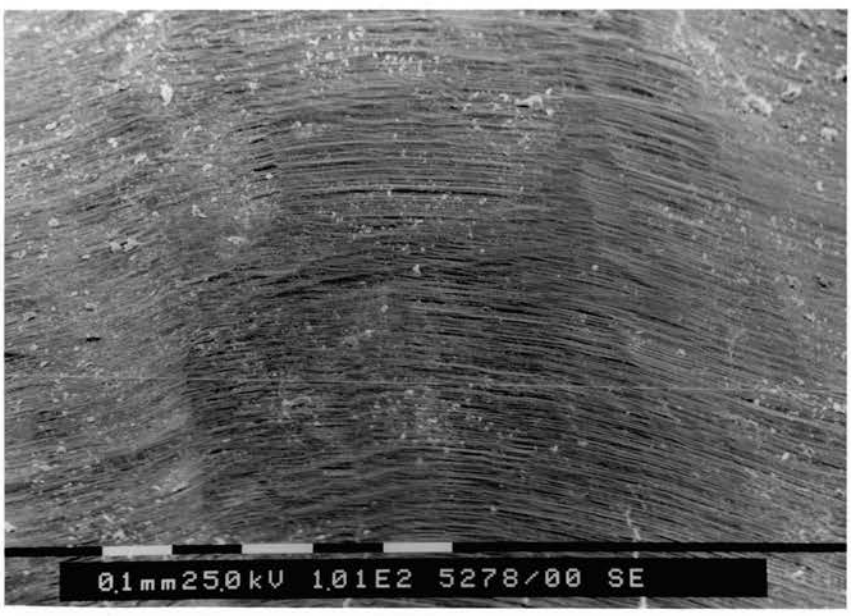


3.13b Electron-micrograph of tooth finished with a pink stone (x 95).

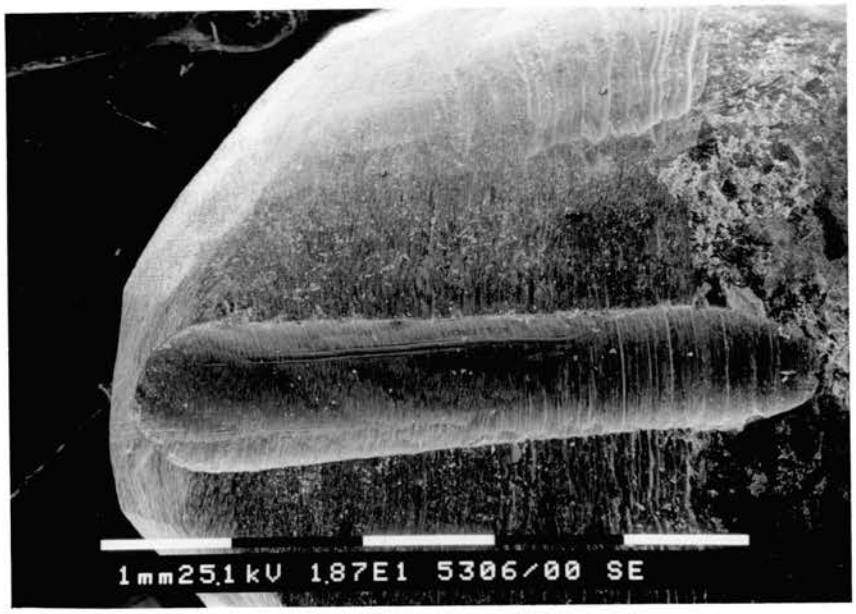


3.14a Electron-micrograph of tooth finished with a Paul lustig bur (x 17.2).

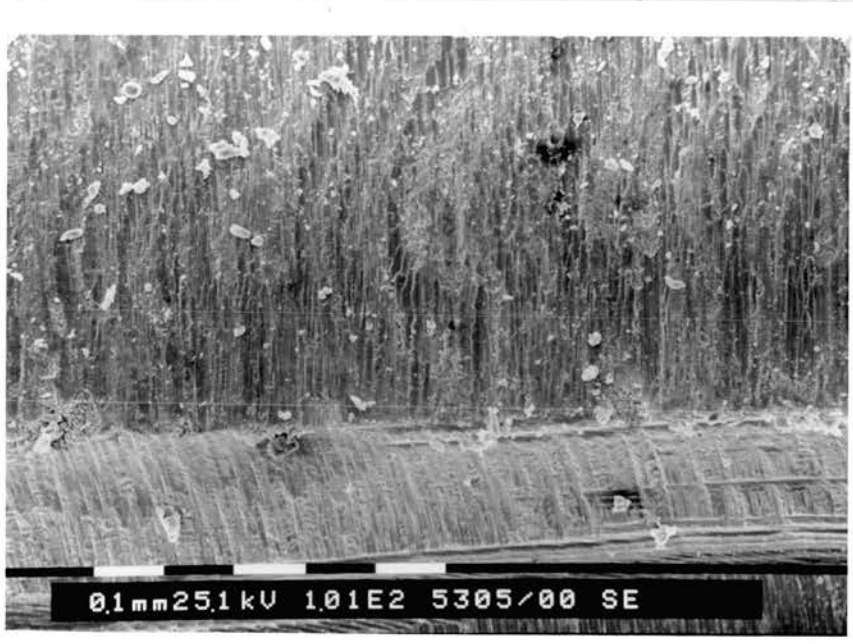
3.14b Electron-micrograph of tooth finished with a Paul lustig bur (x 95).



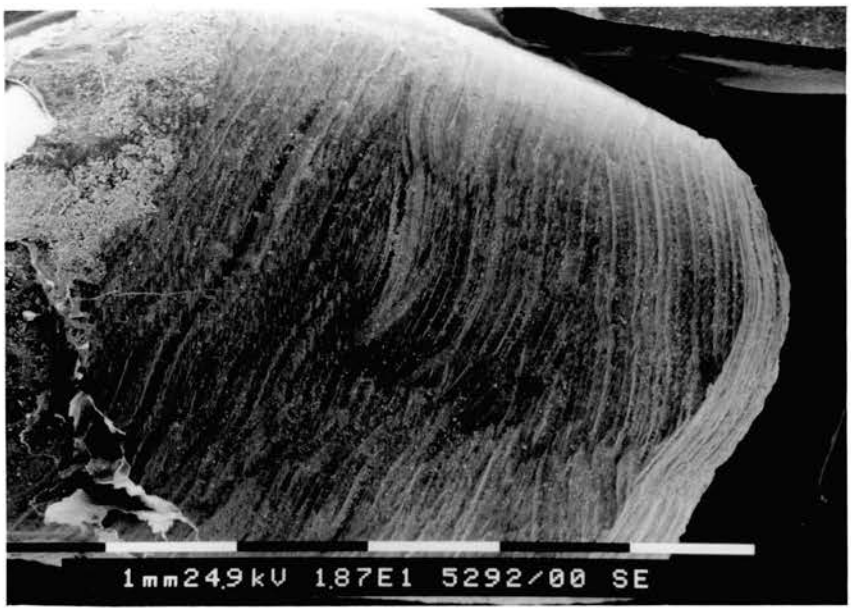
3.15a Electron-micrograph of tooth finished with a Komet # 8863 diamond (x 17.2).



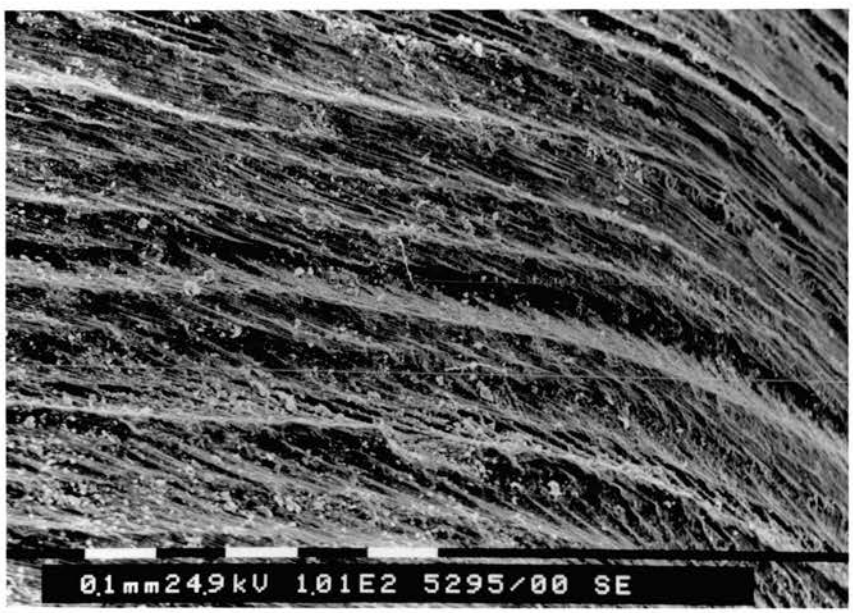
3.15b Electron-micrograph of tooth finished with a Komet # 8863 diamond (x 95).



3.16a Electron-micrograph of tooth finished with a medium diamond bur HI-DI 556 (x 17.2).



3.16b Electron-micrograph of tooth finished with a medium diamond bur HI-DI 556 (x 95).



CHAPTER 4.

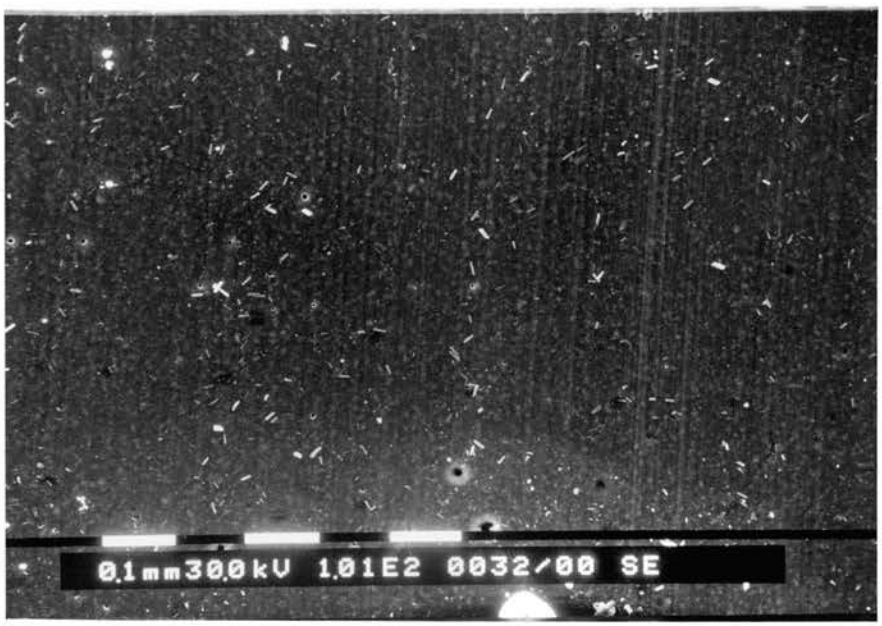
The reproducibility of dentine cone test pieces each having a standard surface finish has already been demonstrated.

The first specimens produced on the MYFORD ML7 lathe, and kept for a pilot retention test, were examined using a NIKON PROFILE PROJECTOR V-12, and were found to differ by as much as 1.5^0 in taper and 0.7 mm in the length of the cone. The SEM photographs also showed that the dentine cones had fine cracks which rendered them unusable as test pieces. These dentine cones had been produced by a technician in a mechanical workshop so it was decided that, in order to improve the quality of the test pieces, I (S. M. Black) would have to make all the dentine cones.

A HOBBYMATT precision lathe*[23] was purchased. It was decided that the taper should be 7^0 rather than 5^0 after noting Richter, Mitchem, and Brown's work[23]. It was likely that this larger taper would reduce the force required to displace the cemented crowns and hence the chance of fracture of the dentine cores under test conditions. The dentine surface shown on the electron-micrograph (Fig 4.1) was produced on this lathe using the techniques described later and is of similar quality to all subsequent surfaces which were produced

using the same method.

4.1 Electron-micrograph of dentine surface (x 95).



Experiment 4.1

To produce dentine cones of the determined size and shape to acceptable tolerances.

METHOD

The enamel was removed from the crowns of four test teeth as previously described (Experiment 3.1) (Fig 4.2

and 4.3). For retention, grooves and holes were made in the roots (Fig 4.4). It was found that the roots of canine teeth jammed when the root apices could be seen through the holes half-way up the side of the tubes. The buccal and lingual of the very large roots were reduced with a bur until they became jammed when pushed the same distance into the tubes (Fig 4.5).

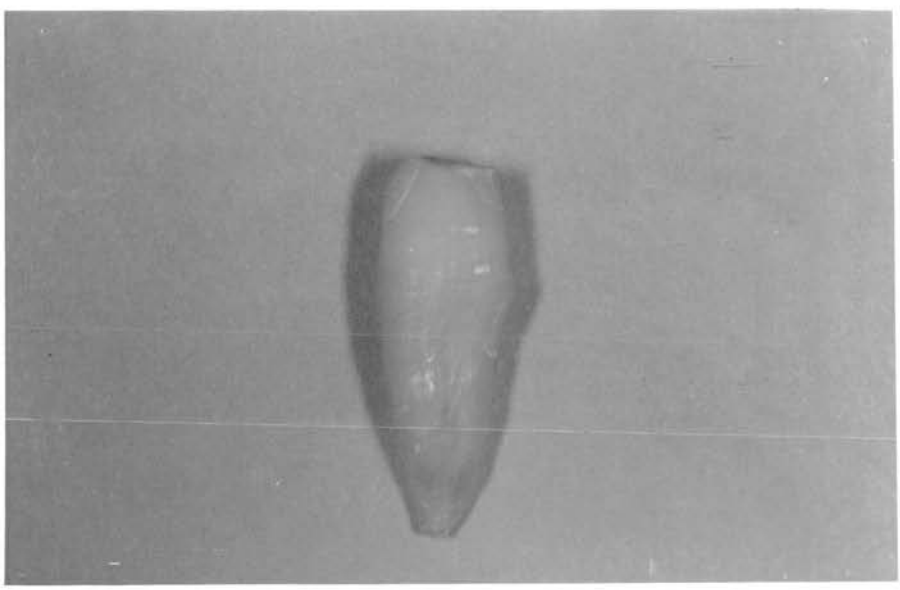
The centre of the partially prepared "occlusal" surfaces of the canines were marked with pencil and the specimen teeth were pushed into the tubes with firm hand pressure. The tubes were fixed in the self-centring chuck in the head stock of the lathe and the centre marks on the canines were aligned with the tail-stock. This ensured that the tooth was held in the approximate centre of the tube.

To speed up the process of filling the tubes with self-curing acrylic, "wells" were made in blocks of REPROSIL putty to fit the tubes. Freshly mixed putty was put into a small box, 5 tubes were pushed into the putty, and put aside to set. Five of these "well blocks" were made, 2 for filling the tubes, and 3 blocks for use as specimen holders.

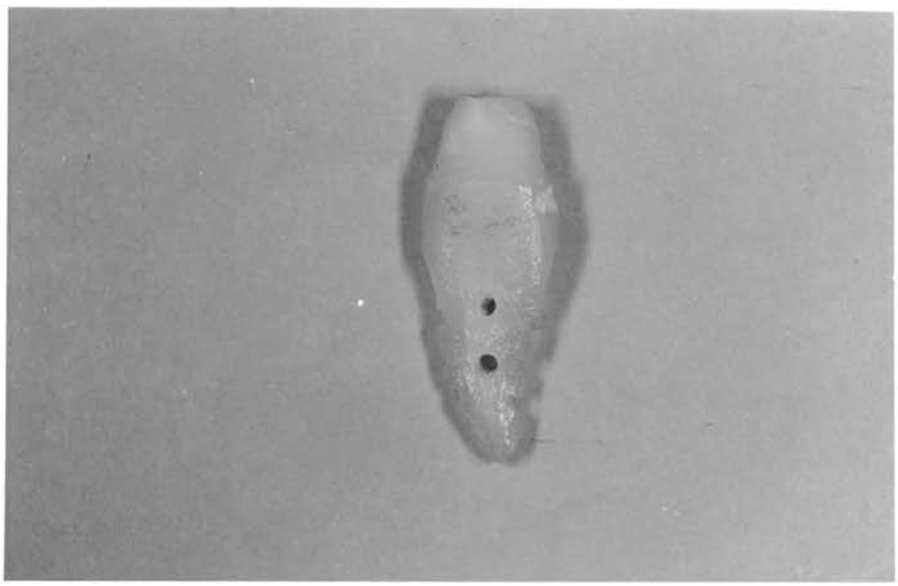
To secure the teeth in the tubes 5 wells were filled with self-curing acrylic resin and the tubes with the teeth in position were pushed slowly into the wells until the acrylic flowed out of the top of the tube.

4.2 Specimen tooth before preparation.

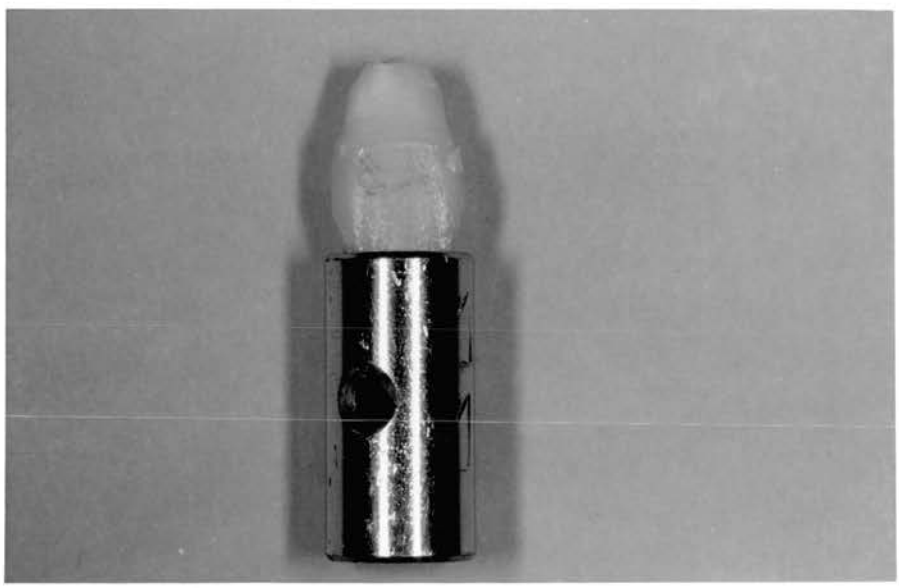
4.3 Specimen tooth with enamel removed.



4.4 Specimen tooth with retention devices cut in the root.



4.5 Specimen tooth "jammed" into the holding tube.



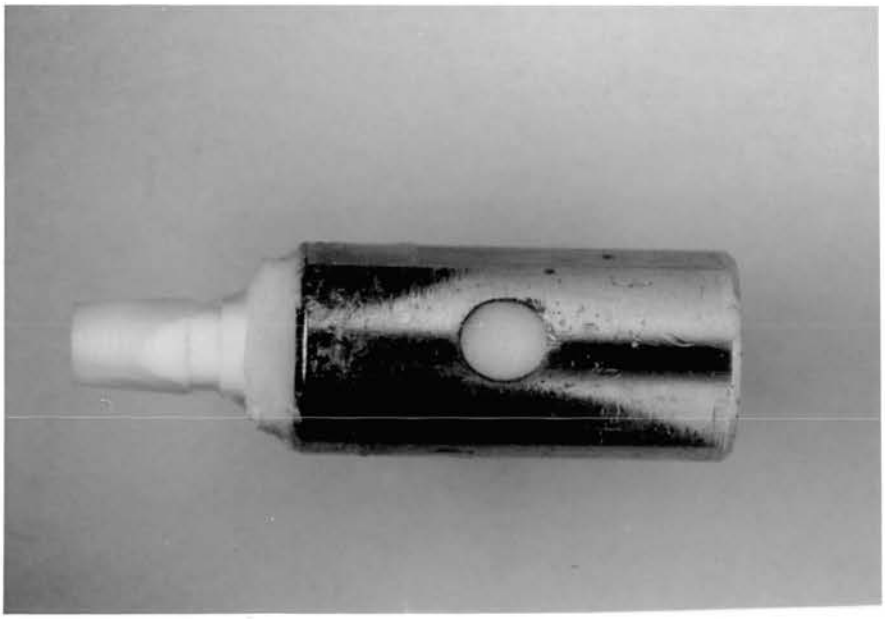
The excess acrylic was removed and the specimens were set aside to allow the acrylic resin to cure (Fig 4.6). This technique was adopted to allow the acrylic to flow into all the retention areas in and around the root while permitting any trapped air to vent. There were no subsequent failures caused by a root being pulled from a tube.

The test pieces were stored in 60 ml specimen bottles filled with isotonic saline at room temperature. The saline was changed 3 times a week.

The specimens were prepared in two further stages. In the first each was fixed in the lathe and the coronal portion was turned to a 7^0 taper with two tungsten-carbide lathe tools using water coolant, by dripping water from a 100 ml burette onto two paint brushes in contact with the dentine. The first tool was used to remove most of the tissue and changed for a special sharp tool which was kept for fine finishing only. When the taper was completed the "occlusal" portion of the preparation was reduced until a diameter of 4 mm was produced. For the second stage the lathe was equipped with a parting-off tool 1 mm wide which was used to cut a groove 5 mm from the "occlusal" end to act as a finishing margin for the preparation (fig 4.7). This sharp dividing edge was also used to check that the crown was properly seated after cementation.

4.6 Specimen tooth mounted with retention devices filled with self-curing acrylic resin.

4.7 Finished specimen tooth with 7º taper on the dentine cone and 1 mm groove to act as a margin for the crown preparation.



On completion the test pieces were stored at 37°C and 100% humidity. They were placed in the REPROSIL holders above the water level in a GRIFFIN*[24] student water bath.

The finished preparations were examined with the NIKON PROFILE PROJECTOR V-12. This gave an image of the surface (Fig 4.8) with a magnification which allowed defects of 10 mm^{-6} to be discerned, and allowed the cone height, the taper, and the diameter of the occlusal end to be measured.

RESULTS

The results are shown in table 4.1.

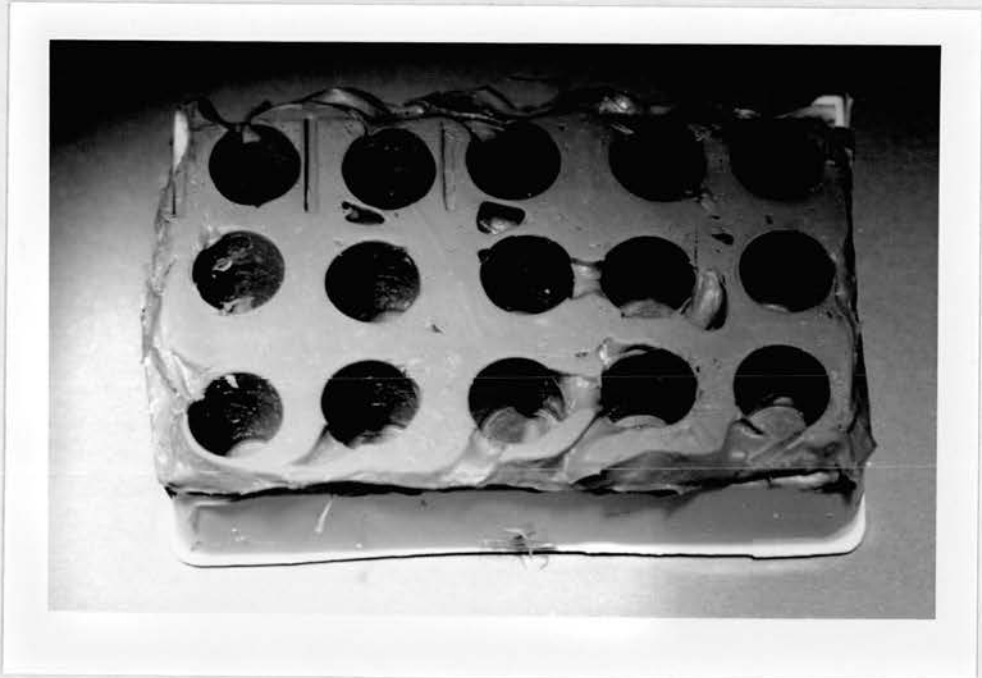
Table 4.1

DIMENSIONS OF DENTINE CONES OF 7° TAPER

Specimen no	occlusal diameter	taper degrees	height mm
1	3.89	6.8	5.03
2	3.92	7.3	5.03
3	3.97	7.3	4.96
4	3.91	7.0	5.05
Mean	3.92	7.1	5.01
S D	0.03	0.2	0.04
S E	0.02	0.1	0.02

4.8 Surface of specimen as seen on the NIKON PROFILE PROJECTOR x 100 magnification the cursor lines are superimposed.

4.9 Specimen holder for impression taking.



CONCLUSIONS

The revised method for the preparation of dentine cones allowed for the production of test pieces with readily reproducible dimensions.

Experiment 4.2

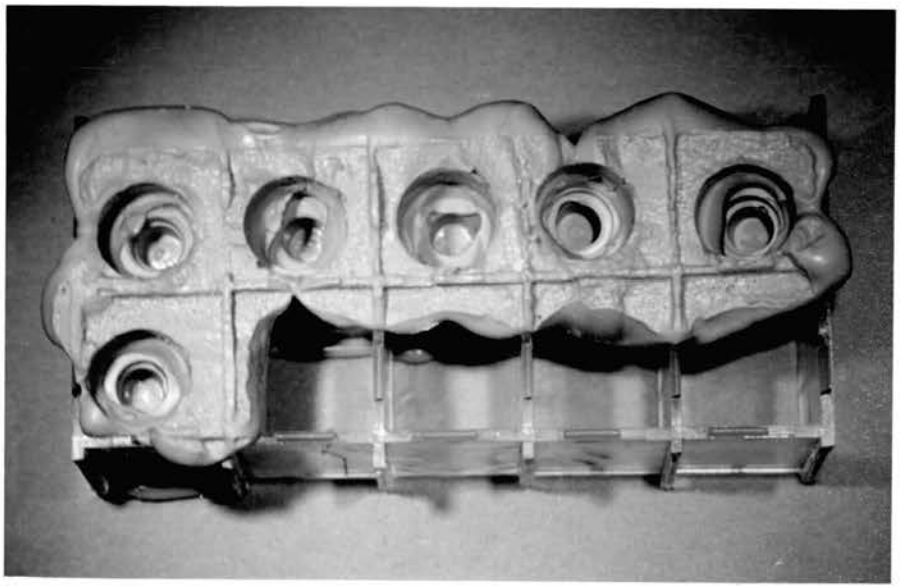
To produce cast gold "crowns" and to evaluate the cementation and retention testing techniques.

METHOD

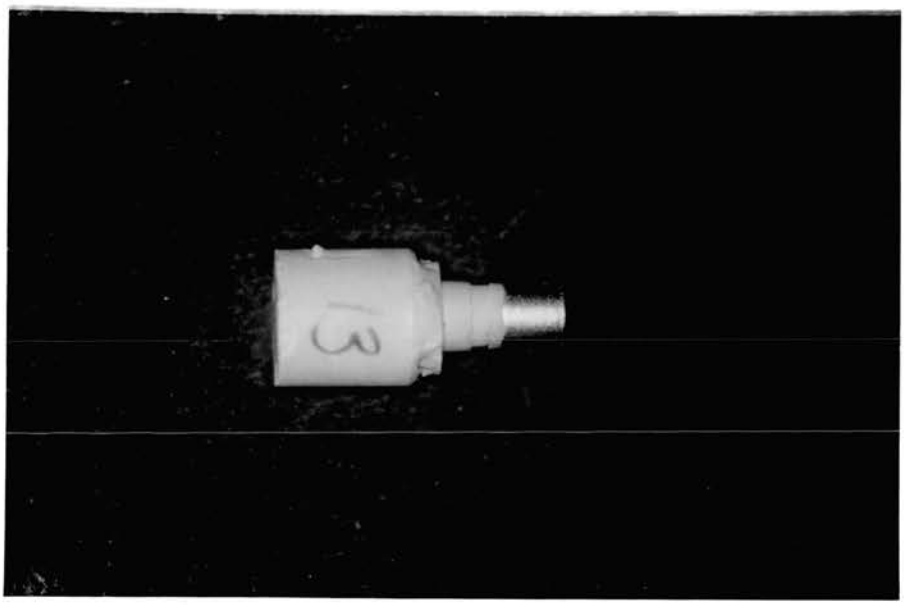
The crowns were made to fit the specimen dentine cones with a high degree of accuracy. Dies were poured in polyether impressions (IMPREGUM)*[25] of the dentine cones. The impressions were taken after making a holding device for the test specimens. Fifteen small holders were made with IMPREGUM by pushing specimen tubes into the impression material and putting it aside until set (Fig 4.9). This jig was re-usable, and the specimens were aligned so that amalgam box "cells" could be used as "impression trays" (Fig 4.10).

REPROSIL impressions had often had to be repeated, so IMPREGUM F was substituted. This was an improvement but it did not flow well into the "tray", tending to allow air to be trapped and it required a thick layer of petroleum

4.10 Impressions of dentine cones for crown production.



4.11 Stone die with die-spacer applied.



jelly to stop it reacting with impression material used to make the holding jig.

These problems were overcome for subsequent experiments by using EXTRUDE*[26], an addition-cured polysiloxane impression material which is automatically mixed in a dispensing syringe. The syringe was placed at the bottom of each cell before dispensing the impression material so that air entrapment was reduced.

Stone dies were poured in SILKEY-ROCK*[27] stone die material. Four layers of die-spacer ADAPT-RITE*[28], claimed to be equivalent to 25 mm^{-6}, were applied to the die leaving 1 mm uncoated above the finishing groove to ensure a close marginal fit (Fig 4.11). The die-spacer was painted in the order: silver, gold, silver, gold, as described by Rieger et al[94]. This was done by one operator, using the manufacturer's recommended brushes, to reduce the variability described by Olivar, Lowe, Ozaki[95]. The thickness achieved was not measured however, and its reproducibility was therefore not evaluated.

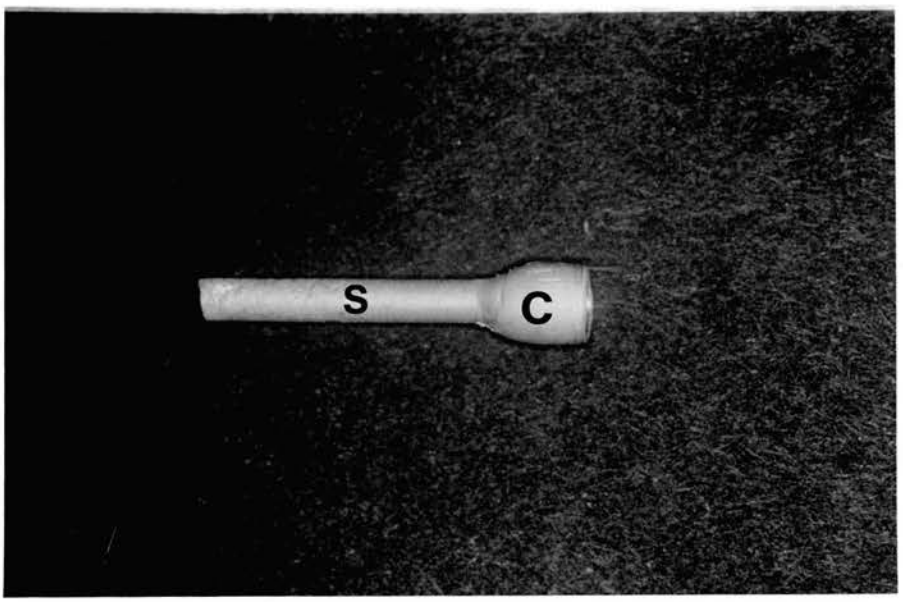
Crowns were waxed on the dies using the following method. Separating medium was applied to the dies (MICROFILM*[29]) and they were dipped into yellow MASTER WAX*[30], then repeatedly into blue inlay wax*[31] until about 1 mm thickness of wax had been applied. The wax was not allowed to overheat as this would have affected its properties. After dipping, a 3 mm diameter plastic sprue was attached to the occlusal surface of the crown.

This sprue was aligned with the long axis of the dentine core using a dental surveyor. These sprues (when they were cast in gold) were used as the means by which the displacing forces (via the grips on the testing machine) could be applied to the gold crowns. These forces would therefore be in the line of the long axis of the dentine cones. This holding method was similar to that of Kaufman et al[2]. The crowns were produced using standard clinical and laboratory techniques. In retrospect, a ring of gold cast on the occlusal surface of the casting, through which a wire could have been passed to provide an axial pull, would probably have been a more simple method. However as this model had been used successfully at the beginning of the study it was decided to continue with it.

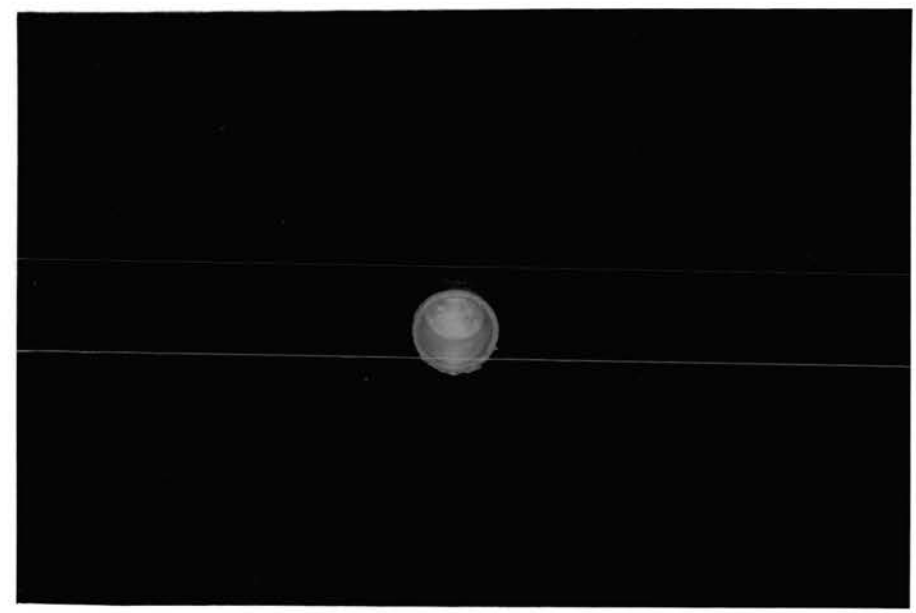
The samples were invested in a crystobalite investment (SHINY-BRITE*[32]) and cast in MATTICAST-R gold.

After casting, devesting, and finishing (Fig 4.12), the fitting surfaces of the crowns were cleaned with propan-2-ol (Fig 4.13). Any sample with a discernable imperfection on the fitting surface, using a x 5 hand magnifier, was rejected. The accuracy of fit was checked by ensuring that each crown margin was within 0.4 mm of the groove at the base of the dentine core. The crowns were cleaned again with propan-2-ol and the fitting surfaces of the crowns were dried with an air jet.

4.12 Finished gold showing crown (C) casting and 3 mm diameter sprue (S).



4.13 Fitting surface of the crown.



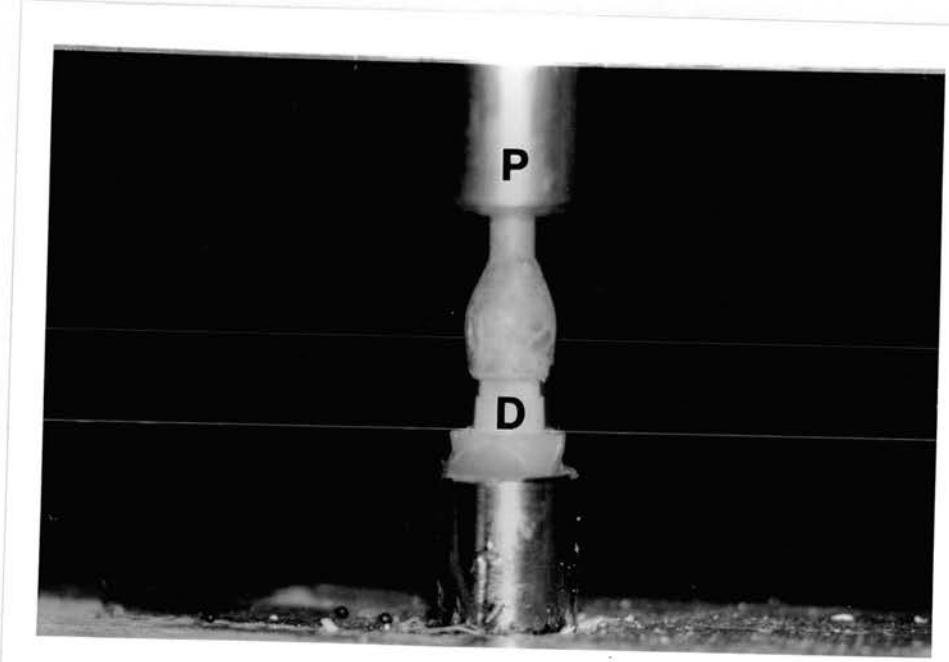
The crowns were cemented with capsule-mixed zinc phosphate cement (PHOSPHACAP). Initial cementation loads of 6 kg were were applied for 30 s followed by maintenance loads of 3 kg until set. Surplus cement was removed from the margins of the gold crowns and the edges of the dentine grooves. The crown margins were examined using x5 magnification to check the fit of the crowns. When the cement had set the specimens were returned to the 37°C, 100% humidity, environment for 24 hours.

To apply the required cementation loads a jig was made (Fig 4.14) consisting of five cementation stands, each consisting of a base to hold the sample directly under a piston which transmitted the cementation load. Each piston had a hole 3 cm deep (diameter 3.1 mm) drilled into it to create a sliding fit for the sprue extension from the occlusal of the crown to ensure that the cementation load was axial (Fig 4.15). The piston passed through a hole in the upper part of the jig to align it correctly. The piston top had a platform for the placement of weights (Fig 4.16). The piston and platform were weighed and pots of lead shot and brass weights were taped together to make up the 3 kg maintenance load. Another group of weights were taped together to provide the load of 6 kg for the initial cementation.

The optimum number of samples for cementation from any one mix was found by trial and error to be 3.

4.14 Jig for crown cementation showing the five weight platforms (W) above the pistons (P).

4.15 Crown cemented to the dentine specimen (D) with sprue extension being held in the piston (P) to ensure axial loading.



After 24 h the crowns were pulled off the dentine cores using an RDP HOWDEN Universal Servo-hydraulic testing machine (UM5/2)*[33] with a range of 0 to 200 N over 30 s (Fig 4.17 and 4.18). The output from the test machine was collected in the same way as the cementation load experiments (i.e. passed via a load amplifier to a micro computer as described in Experiment 1.2). The data could then be transferred to a main frame computer for storage and statistical analysis.

After the cemented crowns had been displaced, they were examined both for dentine fractures and to ascertain the amount of cement left on the preparation (expt. 4.3 below).

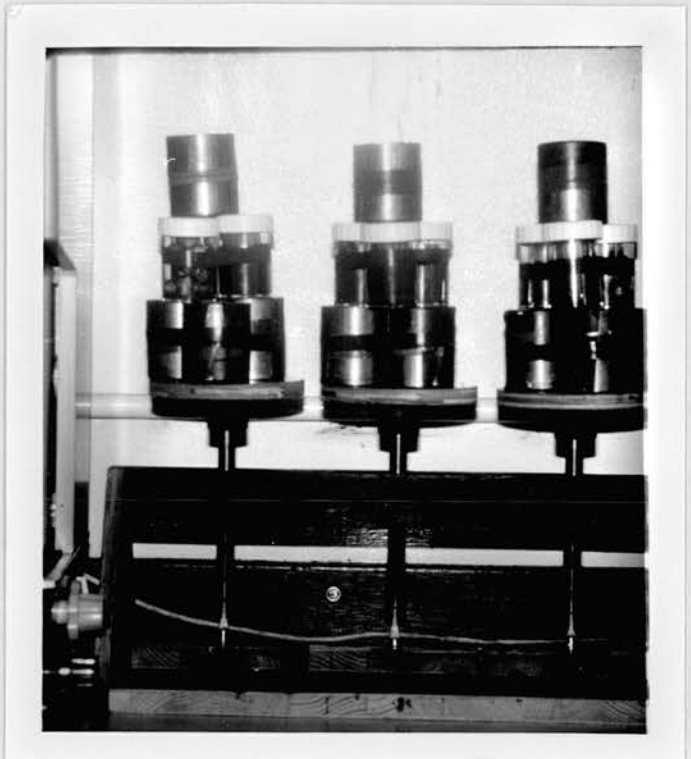
RESULTS

The results are shown in table 4.2.

Table 4.2. PHOSPHACAP CEMENT (retentive value).

1	=	104 N	cement on preparation	0-10%
2	=	128 N	cement on preparation	10-20%
3	=	176 N	cement on preparation	5-15%

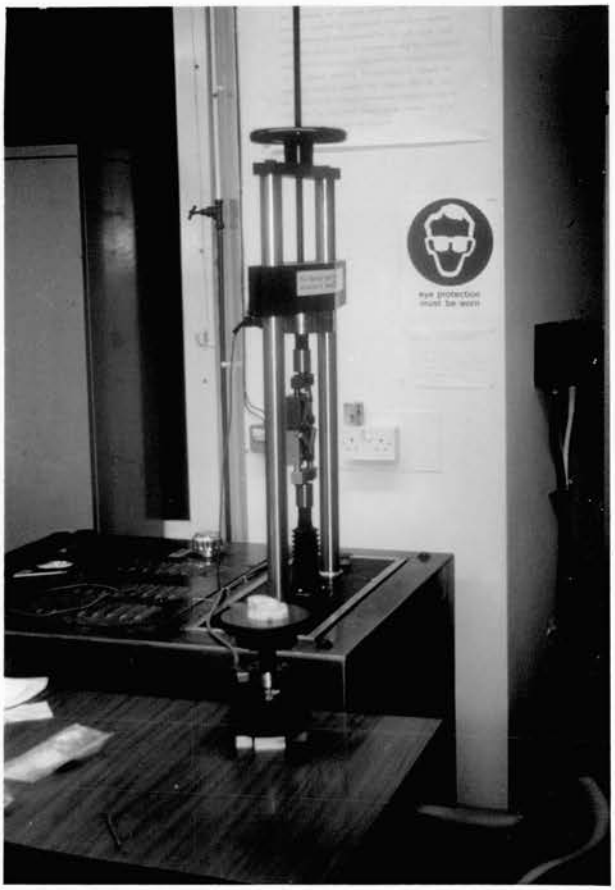
The cement was removed from the crowns and the crowns were recemented with zinc phosphate cement as before and returned to the 37°C, 100% humidity, environment for a



4.16 Jig with 6 kg loads on the weight platforms for initial cementations.

4.17 Specimens held in the grips of the RDP HOWDEN testing machine by the sprue (S) and specimen holding tube (T).

4.18 RDP HOWDEN universal servo-hydraulic testing machine (UM5/2).



further 24 hours. While pulling these crowns off, Nos. 1 and 2 dentine cores were broken, and No 4 required such a high displacing load it was off the scale before the crown separated from the dentine cone.

DISCUSSION AND CONCLUSIONS

It had been found that 30 s was too short a time for complete data collection, and that a maximum of 200 N was too small a force to cater for the more retentive crowns

It was therefore decided to have an application of the displacing force for 60 s and to allow for a maximum force of up to 500 N.

Tensile tests by their nature are prone to errors and a large scatter of results is to be expected. One reason for this is that a misalignment of the test piece will result in a non-axial load being applied. This causes a stress concentration at one side of the cone and an early failure as the tensile test becomes a tear test.

To minimise this problem great care was taken over sprue alignment, and the sprue diameter was of a similar magnitude to the "occlusal" surface of the crown. The experimental scatter was relatively small, and it was considered therefore that misalignment was not a significant problem in this work.

Experiment 4.3

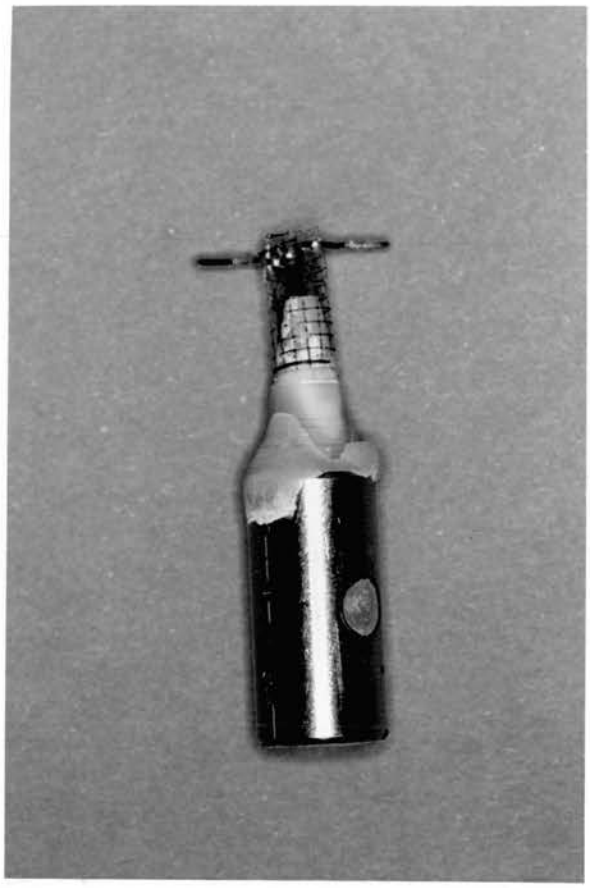
To investigate the position of failure of the cement lutes.

METHOD

The amount of cement left on the dentine preparation was estimated using a cellulose film with a 1 mm grid printed on it. The film was adapted to a dentine cone of appropriate taper, stapled into a cone shape, and then used to measure the amount of cement left on the preparations (Fig 4.19). The figure is accurate to the nearest 5% (0-10 and 90-100 at the extremes). When the mean was calculated for each different cement lute the mid point from each test was taken (5% for 0-10).

This method has been used throughout this thesis, and the conclusions of all experiments are drawn in Chapter 7.

4.19 Sample after retention test with grid to measure cement on preparation in position.



CHAPTER 5.

Experiments were devised to compare the retentive power of 8 cements by cementing gold crowns on dentine cones of 7^0 taper[17]. The cements chosen to be tested are listed in table 5.1.

Table 5.1.

LUTING CEMENTS USED IN THE EXPERIMENTS

1. Zinc oxide/eugenol, alumina, EBA. (Opotow EBA*[34])
2. Zinc phosphate (PHOSPHACAP encapsulated*[1])
3. Zinc phosphate (DeTrey*[35])
4. Polycarboxylate (POLY-F PLUS*[36])
5. Polycarboxylate (BONDALCAP encapsulated*[2])
6. Glass-ionomer (KETAC-BOND*[37])
7. Glass-ionomer (AQUACEM*[38])
8. Composite (PANAVIA-EX*[39])

Two examples each of zinc phosphate, polycarboxylate, and glass-ionomer cements were chosen as they are used most often in clinical practice. One example of each of the less commonly used reinforced ZOE cements and composite cements were chosen. Encapsulated cements were chosen for one of the zinc phosphate and one of the polycarboxylate cements and these were mixed with a

SILAMAT (S3) capsule vibrator*40.

Experiment 5.1

To find the powder : liquid ratio for hand-mixed cements

METHOD

To ensure that the consistency of the hand-mixed cements was constant, the powders were weighed on a scientific balance*41 (UNIMATIC SN1) capable of measuring to a tolerance of 0.001 g. The liquid was dispensed with a 1 ml syringe which was accurate to 0.01 ml.

The powder:liquid ratios recommended by the manufacturer of:
0.38 ml liquid : 1 g powder (OPOTOW ALUMINA EBA cement)
0.5 ml liquid : 0.20 - 0.25 g powder [zinc phosphate cement (DeTrey)] were used.

Other manufacturers did not give accurate weight:volume ratios for the powders and liquids, therefore these values were ascertained experimentally. The amounts of powder and liquid to be used in hand-mixed cements were calculated by finding the average weights of 1 scoop of powder and 1 drop of liquid, from the manufacturers dispensers, using the scientific balance. The average weight of the liquid dispensed was converted back to an accurate volume by weighing known volumes of liquid

dispensed with a pipette (PIPETMAN P 1000*[42]). The manufacturers' instructions were followed in the dispensing of the powders and liquids in this experiment. The powders were shaken, the scoops filled, and the powder levelled. The liquid dispensers were held vertically, and cleaned between drops.

RESULTS

The calculations and results for individual cements are as follows:

1. Poly-F Plus

Weight of powder in manufacturers' scoop

a. 10 scoops = 2.046 g

b. 10 scoops = 1.905 g

c. 10 scoops = 1.962 g

Mean for 1 scoop = 0.197 g

Weight of liquid (water) from manufacturers' dropper

a. 50 drops = 0.864 g

b. 50 drops = 0.824 g

c. 50 drops = 0.832 g

Mean for 1 drop = 0.017 g.

As the liquid used was deionised water, at STP

1 ml weighs 1 g.

The accuracy of the dispensing of the liquid was confirmed by using the PIPETMAN P 1000 pipette to dispense drops of 0.100 ml and weighing them with the scientific balance. As each drop was dispensed it was weighed. The resulting weights differed by a maximum of 0.008 g. After measuring 4 drops the average weight was found to be 0.101 g. The experiment was repeated and the average weight was again 0.101 g.

The average drop of water from the manufacturers dispenser had a volume of 0.017 ml.

A ratio of 1 scoop of powder : 2 drops from the dropper is recommended by the manufacturer, to produce the correct consistency for a luting cement.

Three times this amount was mixed to provide sufficient material for the cementation of 3 crowns at a time.

This represented a powder : liquid ratio of -

0.60 g : 0.10 ml (accurate to 2 places of decimals).

2.AquaCem

Weight of powder in manufacturers' scoop

a. 10 scoops = 1.309 g

b. 10 scoops = 1.212 g

c. 10 scoops = 1.188 g

Mean of 1 scoop = 0.124 g

The volume of liquid (water) in 1 drop was the same as

for POLY-F PLUS (0.017 ml), because the dropper was of exactly the same design as the dropper used for POLY-F PLUS.

A ratio of 2 scoops of powder : 3 drops from the dropper is recommended by the manufacturer to produce the correct consistency for a luting cement.

Twice this amount was mixed to provide sufficient material for the cementation of 3 crowns at a time.

This represented a powder : liquid ratio of-

0.48 g : 1 ml (accurate to 2 places of decimals).

3. Ketac-Bond

Weight of powder in the manufacturers' scoop

a. 10 scoops = 1.220 g

b. 10 scoops = 1.302 g

c. 10 scoops = 1.261 g

Mean for 1 scoop = 0.126 g

Weight of a drop of liquid from manufacturers' dropper (polymaleic acid)

a. 20 drops = 0.773 g, volume = 0.58 ml

b. 20 drops = 0.793 g, volume = 0.72 ml

c. 20 drops = 0.778 g, volume = 0.65 ml

Mean for 1 drop = 0.039g, volume = 0.033 ml

A ratio of 1 scoop of powder : 1 drop from the dropper is recommended by the manufacturers as the consistency for a luting cement.

Four times this amount was mixed to provide sufficient material for the cementation of 3 crowns at a time.

This represented a powder : liquid ratio of-

0.5 g : 0.13 ml (accurate to 2 places of decimals).

4.Panavia-Ex

The manufacturers gave a powder : liquid ratio of 3.2 : 1 by weight. The same technique of weighing the liquid (16 measurements) gave a mean of 1.05 g/ml for a single drop (SD = 0.03).

The manufacturers' ratio of 3.2 g : 1 g equates to 3.2 g : 0.95 ml.

This represented a powder : liquid ratio of:

0.65 g : 0.20 ml (accurate to 2 places of decimals).

Experiment 5.2

To find the retentive power of 8 cement lutes

METHOD

Human dentine cones were prepared as previously described (Chapter 4). Three out of 12 dentine cones were rejected before completion because of obvious

macroscopic visual defects and the remaining 9 were examined with the Nikon Profile Projector. Their dimensions are shown in Appendix 2 table 5.2.

The reproducibility of the dentine cone specimens was considered to be satisfactory. A further 2 samples were later rejected due to the presence of small pulpal exposures. The other 7 specimens were reproduced in stone, as previously described. Only 1 cement was used for this first group as there were not sufficient specimens for 2 cements at this stage.

A 7 character alphanumeric cementation code was designed to differentiate the samples.

The first 2 characters define the cement type and the third character defines the brand.

ZP1 = Phosphacap

ZP2 = DeTrey Zinc phosphate

PC1 = Bondalcap

PC2 = Poly-F Plus

GI1 = AquaCem

GI2 = Ketac-Bond

ZE1 = Opotow EBA

CO1 = Panavia-Ex

The fourth character defined the taper in degrees.

The fifth character uses letters of the alphabet for; initial cementation (A); subsequent re-cementations

(B,C,E). The letter (R) indicated the result of a re-cementation using the same dentine cone but with a new crown. The letter (Y) indicated a test in which there was a fracture of the specimen. It soon became apparent that the dentine preparation and the fitting surface of the crown were damaged during testing or when the cement was removed. Therefore this re-cementation was abandoned because of the variability which would be introduced.

The last two characters indicated the numbers which were on the specimen mounting tubes (01 to 30).

The gold crowns were produced in the manner previously described. When cast, the first crowns were cleaned and tried on the preparations and the fit was poor (too loose). However, they were cemented on to the preparations with PHOSPHACAP (ZP1), stored in 100% humidity at 37°C, and tested for retention 24 h after the cement had set. The amount of cement left on the dentine cone was calculated by placing a grid over each specimen after crown removal. This is described in Chapter 7 (Experiment 7.4). The results are shown in table 5.3.

Table 5.3 PHOSPHACAP CEMENT (Retentive value).

ZP17A01 = 46 N	cement on preparation	0-10%
ZP17A02 = 30 N	cement on preparation	0-10%
ZP17A03 = 40 N	cement on preparation	45-55%
ZP17A05 = 60 N	cement on preparation	5-15%
ZP17A07 = 30 N	cement on preparation	0-10%
ZP17AO8 = 42 N	cement on preparation	0-10%
ZP17A09 = 38 N	cement on preparation	0-10%

These results were lower than expected, probably as a result of the loose fit of the crowns, therefore a second set of impressions was taken of the preparations and another set of castings were made. The fit of the second castings was better than the fit of the first group but they were still rather too loose. The results using the second castings is shown in table 5.4.

Table 5.4 PHOSPHACAP CEMENT (Retentive value).

ZP17R01 = 58 N	cement on preparation	0-10%
ZP17R02 = 46 N	cement on preparation	0-10%
ZP17R03 = 72 N	cement on preparation	60-70%
ZP17R05 = 36 N	cement on preparation	20-30%
ZP17R07 = 48 N	cement on preparation	10-20%
ZP17YO8 = 50 N	dentine fractured	
ZP17R09 = 30 N	cement on preparation	0-10%

The specimens which fractured invariably did so at the finishing groove where the dentine was weaker. Since the exact failure path was unknown for any of the specimens tested it was considered necessary to include any case of dentine fracture in the overall results.

There was an improvement in retention with the second group of crowns but the retention values were still considered to be low. The improvement on the first result could have been a function of the slightly better fit of the crowns, or could have been due to the roughening of the dentine cone surfaces caused by the removal of the cement after the first cementations. It was also possible that the surface had been damaged by the prolonged storage of the samples while the second crowns were made.

The rather loose fit of the crowns was investigated, and it was found that the technicians were overheating the gold alloy to the extent that after the arm of the centrifugal casting machine had stopped rotating, the alloy was often still fluid and flowed back out of the sprue hole. The technicians had tried to counter this unwanted effect by spinning the casting rings by hand. The results of the first 2 groups were deemed to be unreliable. A complete review of the casting technique was undertaken (with the technicians) to ensure greater accuracy for future castings.

Another group of gold crowns was prepared. The

dimensions of which are shown in Appendix 2 table 5.5.

The third group of gold crowns were examined and found to be close-fitting on the dentine cones and therefore satisfactory for the experiments. They were cemented on to the dentine cones with PHOSPHACAP and POLY-F PLUS. The retention tests were carried out after the specimens had been stored for 24 h in 100% humidity at 37°C.

Similarly, further groups were prepared. The results of the quality control tests are shown in Appendix 2 tables 5.6 to 5.8. The means and standard deviations of the results in Appendix 2 clearly show that they are all of one population of mean occlusal diameter 3.91 mm (SD 0.08), Taper 6.98° (SD 0.09) and height 5.06 mm (SD 0.05).

These dentine cones had crowns made and cemented as previously described but using the other cements to be tested.

RESULTS

The results of all the retention tests are shown in Appendix 2 tables 5.9 to 5.16.

The results show that the glass-ionomer cements failed at the cement/metal interface leaving the cement mostly on the dentine. BONDALCAP had cement both in the crown and on the dentine after the crown had been pulled off the dentine cone. All the other cements failed at the cement/dentine interface leaving the cement in the crown.

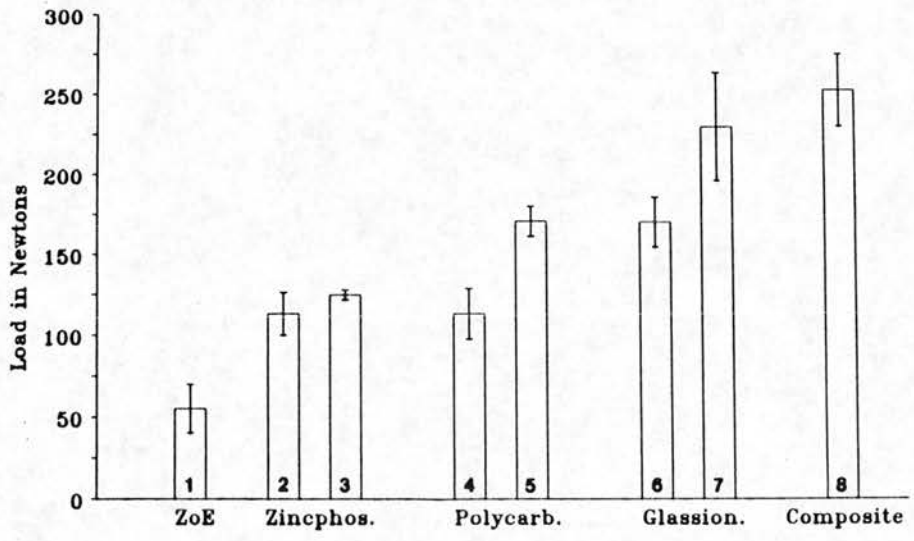
The results of the retention tests are summarised in table 5.17. and Fig 5.1.

Table 5.17.

RETENTION OF GOLD CROWNS CEMENTED ON HUMAN DENTINE CORES

CEMENT	NO. OF SPECIMENS	RETENTION MEAN(N)	STANDARD DEVIATION	STANDARD ERROR
1. OPOTOW EBA	5	55	33	15
2. PHOSPHACAP	5	113	29	13
3. DE TREY ZINC	5	125	7	3
4. POLY-F PLUS	5	113	35	15
5. BONDALCAP	5	170	21	9
6. KETAC-BOND	5	170	35	16
7. AQUACEM	5	229	75	34
8. PANAVIA-EX	5	252	50	22

5.1 The retention of gold crowns on human dentine using eight cements.



The dentine core (crown preparation) was completely fractured off at the level of the finishing groove leaving the preparation still cemented in the crown of 6 specimens (1 POLY-F PLUS; 2 KETAC-BOND; and 3 PANAVIA-EX).

Using a Wilcoxon rank sum test with a significance level of $p = 0.05$.

The sample sets 2 and 3 which both involved zinc phosphate cements showed no significant differences in their retentions.

The sample sets 6 and 7 which both involved glass-ionomer cements showed no statistical differences in their retentions.

The sample sets 4 and 5 which both involved polycarboxylate cements were significantly different from each other.

The crowns cemented with the zinc oxide/eugenol EBA cement were significantly less retentive than the other cements.

The crowns cemented with the zinc phosphate cements showed no significant difference in retention from POLY-F PLUS, but were significantly less retentive than BONDALCAP; the glass-ionomers; and the composite cement.

The crowns cemented with the BONDALCAP were significantly more retentive than those cemented with phosphate cements, or POLY-F PLUS; but were not significantly different from those cemented with the

glass-ionomer cements. They were less retentive than the composite cement.

The crowns cemented with the PANAVIA-EX proved to be significantly more retentive than all except the crowns cemented with the AQUACEM. The composite cement specimens had the largest number of fractures of the dentine (3 out of 5). This suggests that this cement was more retentive than the experimental results reported here would indicate.

The results are shown in table 5.18 for the cement types. The 2 phosphate cements; the 2 polycarboxylate cements; and the 2 glass-ionomer cements are combined to give 3 generic groups.

Table 5.18.

RETENTION OF GOLD CROWNS CEMENTED ON HUMAN DENTINE CORES

CEMENT TYPE	NO. OF SPECIMENS	RETENTION MEAN(N)	STANDARD DEVIATION	STANDARD ERROR
1. ZOE/EBA	5	55	33	15
2. ZINC PHOSPHATES	10	119	21	7
3. POLYCARBOXYLATES	10	141	41	13
4. GLASS-IONOMERS	10	199	54	20
5. COMPOSITE RESIN	5	252	50	22

DISCUSSION AND CONCLUSIONS

The ranking of the cements by retentive power in these experiments appears to be as follows:

1. Composite (adhesive type) - highest.
2. Glass-ionomer.
3. Polycarboxylate.
4. Zinc phosphate.
5. Zinc oxide/eugenol EBA - lowest.

These results are interesting because they appear to follow the same order as the known adhesive properties of the cements studied. For example, the first three types of cement are known to adhere to dentine, whereas the last two types are retained solely by mechanical interlocking[96]. Within the adhesive cements, glass-ionomers are well known to have a greater adhesion to dentine than polycarboxylate cements[12,97], even though the adhesive agent in both cases is a polyalkenoic acid such as polyacrylic acid or polymaleic acid. Further, resin cements such as PANAVIA-EX, which contain a complex mix of adhesive agents, are believed to adhere to dentine with a stronger bond than either glass-ionomer or polycarboxylate cements[12,55]. The relative power of adhesive cements in this study appears therefore to be consistent with their known bond strengths to dentine.

In a similar way, zinc oxide/eugenol cements are known to be mechanically inferior to zinc phosphate cements[12],

and it is therefore not surprising that they exhibit inferior retention in this study where they have similar flow and retention is believed to be through mechanical means only.

It is tempting therefore to imply from these studies that crown retention depends partly on the adhesive properties of any given cement. However a similar ranking would have resulted from considering tensile strength alone[12,98]. Of course, crown separation may involve both tensile and shear failure, and until the precise mode of failure is established it is in fact impossible to draw any firm conclusions regarding the relative contributions of adhesive and "mechanical" failures to crown separation. Investigation of the failure mode could form a suitable basis for future work in this area.

CHAPTER 6.

In clinical practice, teeth which have been prepared for crowns are protected with temporary crowns. Experiments were designed to investigate the effect of the materials used in the making and cementing of temporary crowns on to dentine cones, on the retentive power of 5 types of dental cement.

To this end only one cement of each type was required. Although the consistency of mix obtained with encapsulated cements is probably superior to that of hand-mixed cements in clinical practice, encapsulated cements were not used in this study. It was considered to be necessary for all the cements to be mixed in the same way, and only 2 types were available in the encapsulated form. The proportions of powder:liquid were strictly controlled, as described in Experiment 5.1.

Eames et al[84] showed the retention of a cast gold crown to be related to the size of the cement space and hence to the cement film thickness. The optimum thickness of die relief for maximum retention is unclear but 25 m^{-6} is advocated by Eliasson and Lund[99] and 35 m^{-6} by Cherberg and Nicholls[100].

Fusayama and Iwamoto[81] recommend a cement film thickness of 31 to 38 m^{-6} for optimal shear strength for

zinc phosphate.

Most investigators have found that the film thickness of cement lutes under the occlusal surface of crowns was greater than 38 m^{-6}, ranging from 60 m^{-6} to 435 m^{-6} Pilo et al[101].

Windeler[102] proposed an equation to relate occlusal and axial film thicknesses:

$$\text{occlusal discrepancy} = \frac{\text{film thickness on axial walls minus space available for cement}}{\text{sine 1/2 taper angle of the preparation}}$$

If Windeler's equation were applied to the mean taper of 17.20 for upper canines (Ref Chapter 2, table 2.31); if the die relief were Eliasson and Lund's[99] 25 m^{-6}; and if the cement thickness were 60 m^{-6} to 435 m^{-6} on the occlusal surface; then the axial thickness would be 34 m^{-6} to 90 m^{-6}.

The crown preparations in the present study had cement spacing of 25 m^{-6} (achieved by coating the dies with ADAPT-RITE*[28]) with a margin of 1 mm left uncoated (as described in Experiment 4.2). From previous experiments it was expected that the forces used for cementation in the following experiments would produce a cement film thickness of about 40 m^{-6}.

Experiment 6.1

To investigate the film thicknesses achieved using the method previously described Chapter 4.

METHOD

Four dentine cones of 7° taper were produced as described in Experiment 4.1. The dimensions of the dentine specimens are shown in table 6.1.

Table 6.1

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
52	3.86	7.0	5.15
53	3.96	7.0	5.02
54	4.01	7.0	5.03
55	3.81	6.9	5.06
Max	4.01	7.0	5.15
Min	3.81	6.9	5.02
Mean	3.91	6.98	5.07
SD	0.09	0.05	0.06

The technique previously used for devesting the gold

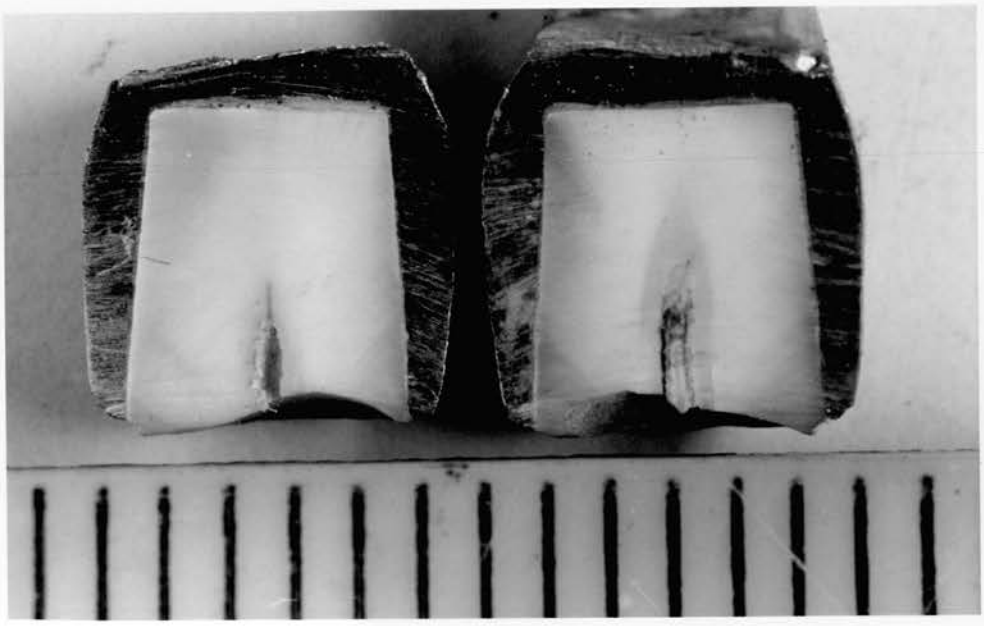
crowns had been to place the crowns in an ultrasonic bath containing water, and then to wash out excess investment with a jet of water before a final cleaning with cotton-wool and propan-1-ol. After this the fitting surface was sometimes dark grey, so Felton, Kanoy and White's[103] technique of air abrading of the gold surface with a 25 m^{-6} aluminium oxide powder (ALPHABLAST M 25*[43]) for 10 s was used to remove the surface discolouration. This fine abrasive was chosen as it would cause very little abrasion of the gold surface while providing a uniform finish. This technique was used henceforth for the cleaning of all the gold crowns.

After devesting, the crowns were cemented using zinc phosphate*[35], polycarboxylate*[36], glass-ionomer*[37], and composite*[39] cements, as previously described in Chapter 4.

The sprues were removed using a cut-off disk. The specimen-holding tube was mounted with self-cured acrylic resin in plastic cuvette tubes (12.5 by 12.5 mm in cross section and 46 mm high). The dentine cones were clear of the acrylic-resin. This method allowed the specimen to be mounted in a lathe. A cut-off disk was used to cut through the centre of the crown and the dentine cone along the axial plane. The two halves of the crown were separated from the root just below of the finishing groove (Fig 6.1). The crown sections were embedded in acrylic-resin and the cut surfaces were polished on a flat

bed polisher*44 with silicon carbide papers of progressively finer grit.

6.1 Gold crown cemented and sectioned axially through the centre.



A polishing cloth was used with progressively finer abrasives*45 finishing with a particle size of 0.1 m $^{-6}$. The crown sections were removed from the acrylic-resin by squeezing the resin in a vice (clear of the specimens) until it fractured, releasing the crown sections. The sections were mounted on SEM stubs, plated, and examined in the SEM. The mean cement thickness on the axial walls of the crowns was calculated by measuring the cement thickness at 5 points (1 mm apart starting 0.5 mm above the crown margin) along the full length of each axial

wall. The cement thickness between the occlusal end of the preparation and the under-surface of the crown was also measured.

RESULTS

The measurements of the film thicknesses on the axial walls are shown in table 6.2.

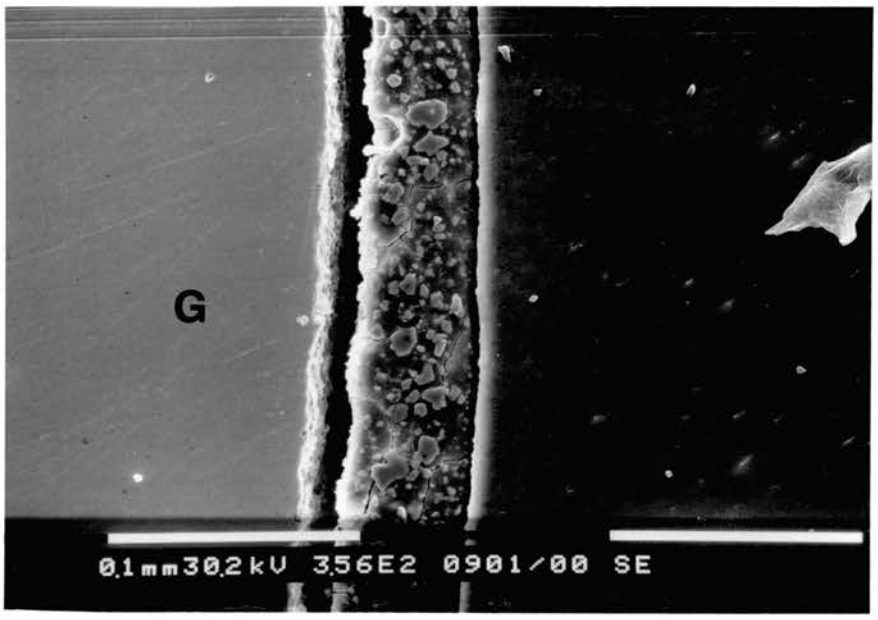
Figs 6.2 to 6.9 show a selection of the SEM pictures of cement lutes.

Table 6.2.

FILM THICKNESS OF CEMENT LUTES FROM 5 SITES ON EACH OF THE 2 AXIAL WALLS m^{-6}

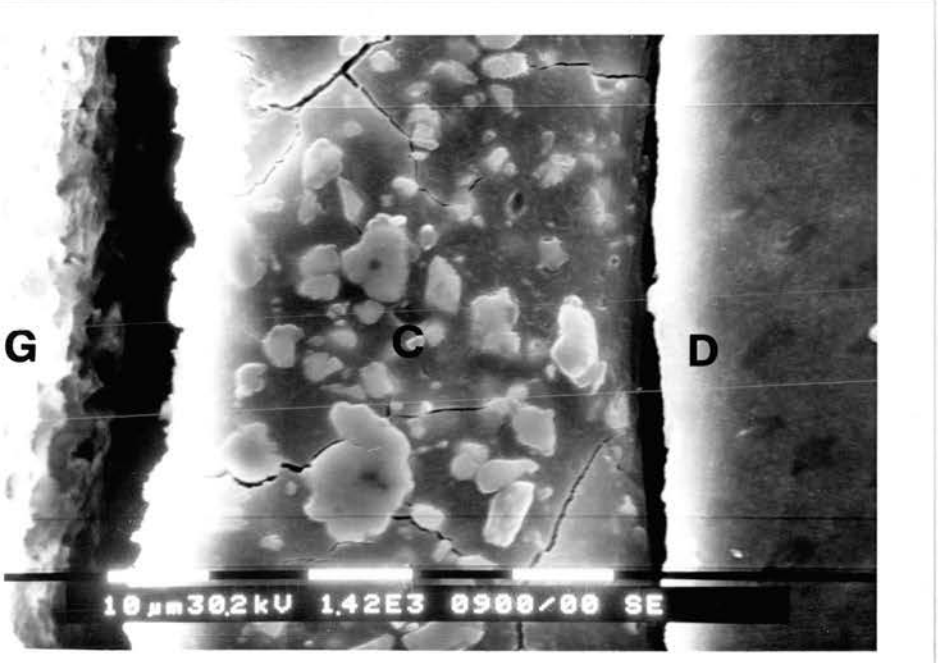
Measu-rement	Zinc phosphate	Poly-carboxylate	Glass-ionomer	Composite
1	47	40	39	39
2	40	32	44	40
3	52	45	50	38
4	44	43	50	39
5	43	31	37	36
6	43	44	47	42
7	48	32	48	51
8	47	36	43	42
9	50	36	39	40
10	44	39	43	43
MEAN	46	38	44	41
SD	3.7	5.2	4.7	4.1
SE	1.2	1.6	1.5	1.3

6.2 Electron-micrograph of zinc phosphate cement lute (x 330).

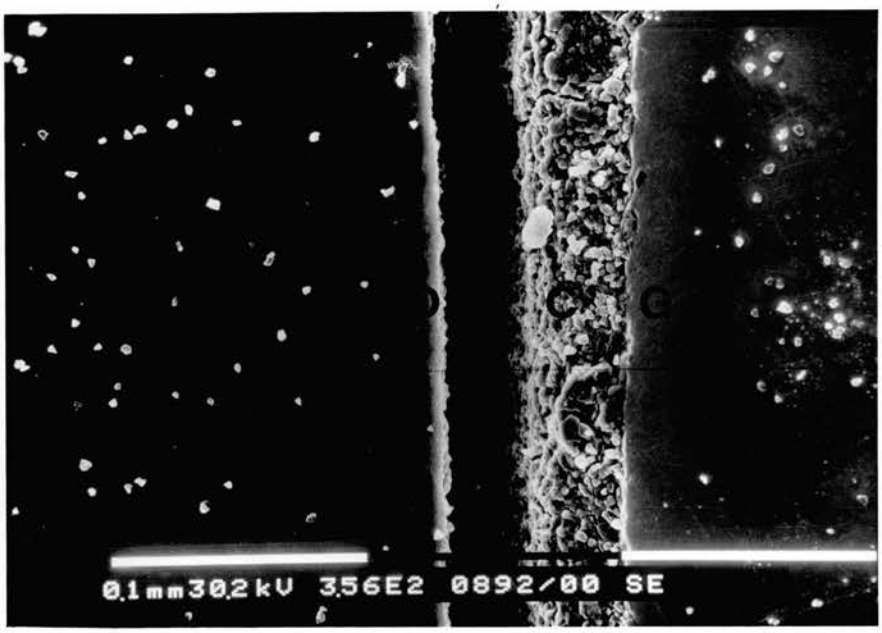


D = Dentine G = Gold C = Cement

6.3 Higher power electron-micrograph of zinc phosphate cement lute (x 1300).

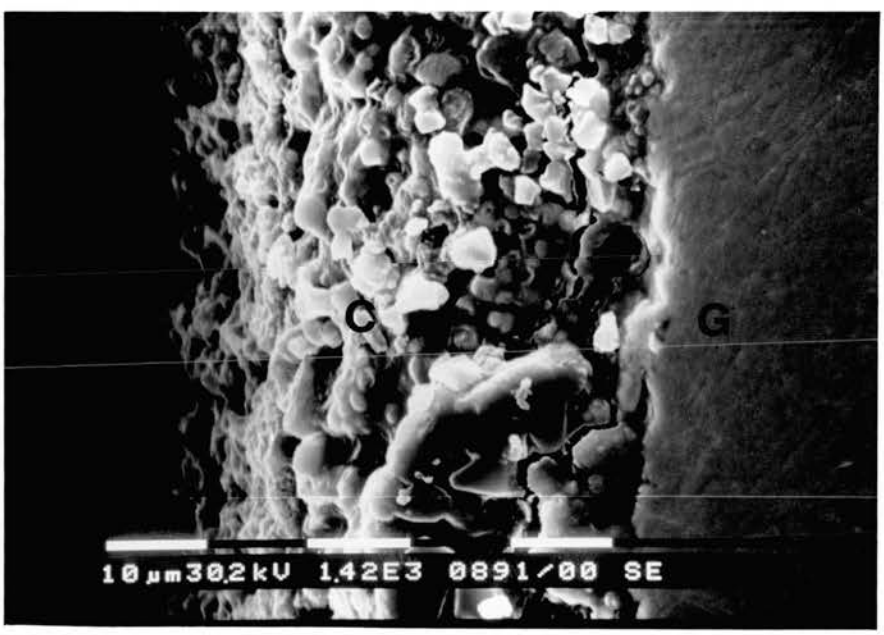


6.4 Electron-micrograph of polycarboxylate cement lute (x 330).

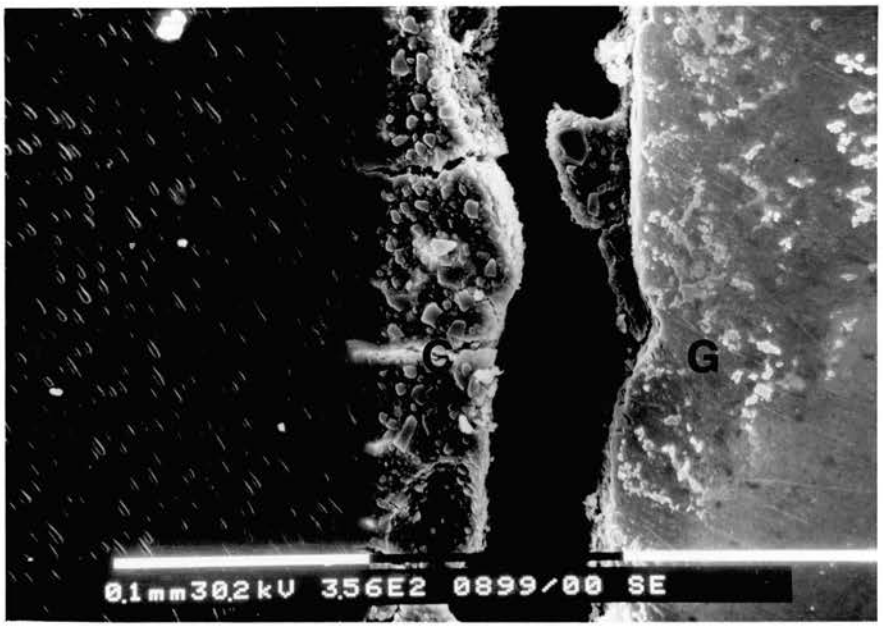


D = Dentine G = Gold C = Cement

6.5 Higher power electron-micrograph of polycarboxylate cement lute (x 1300).

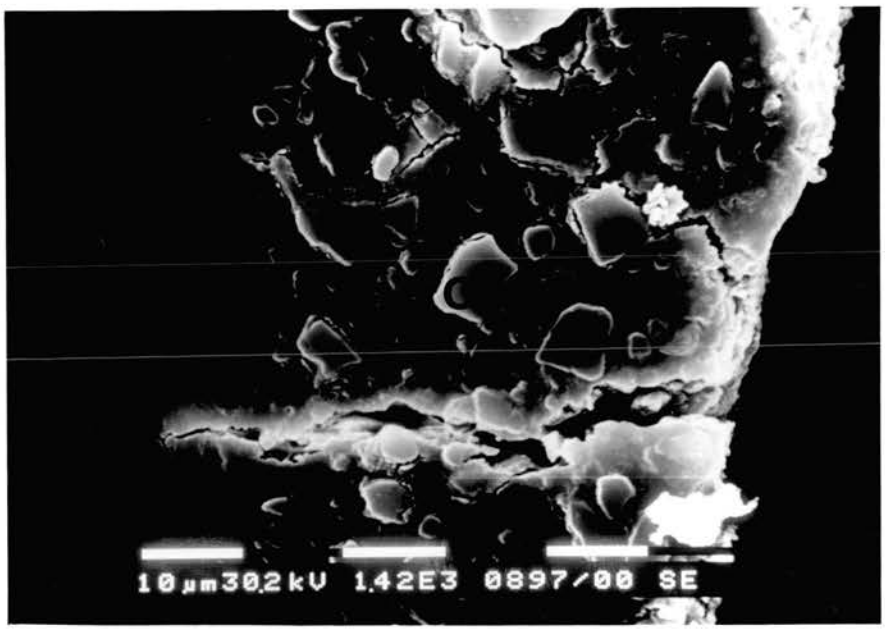


6.6 Electron-micrograph of glass-ionomer cement lute (x 330).

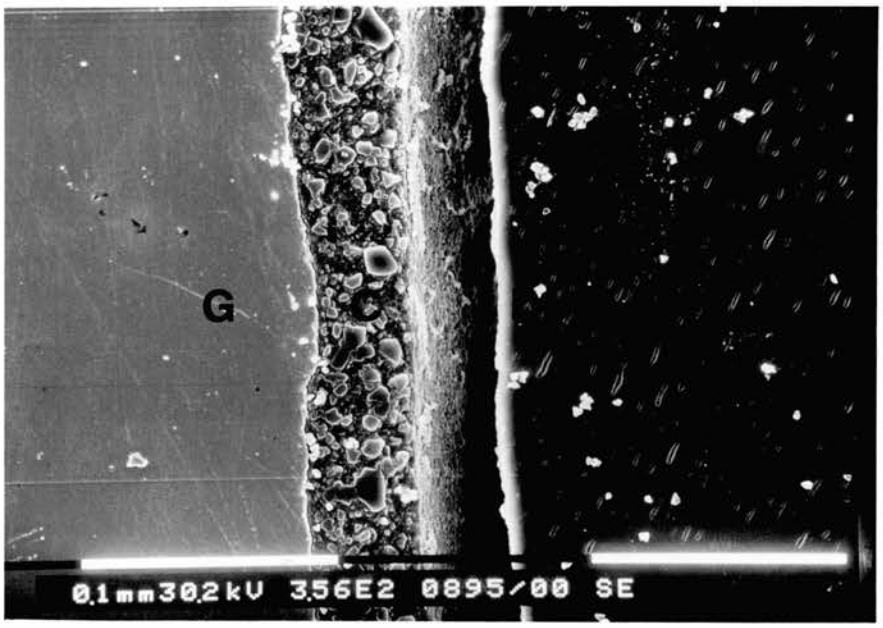


D = Dentine G = Gold C = Cement

6.7 Higher power electron-micrograph of glass-ionomer cement lute (x 1300).

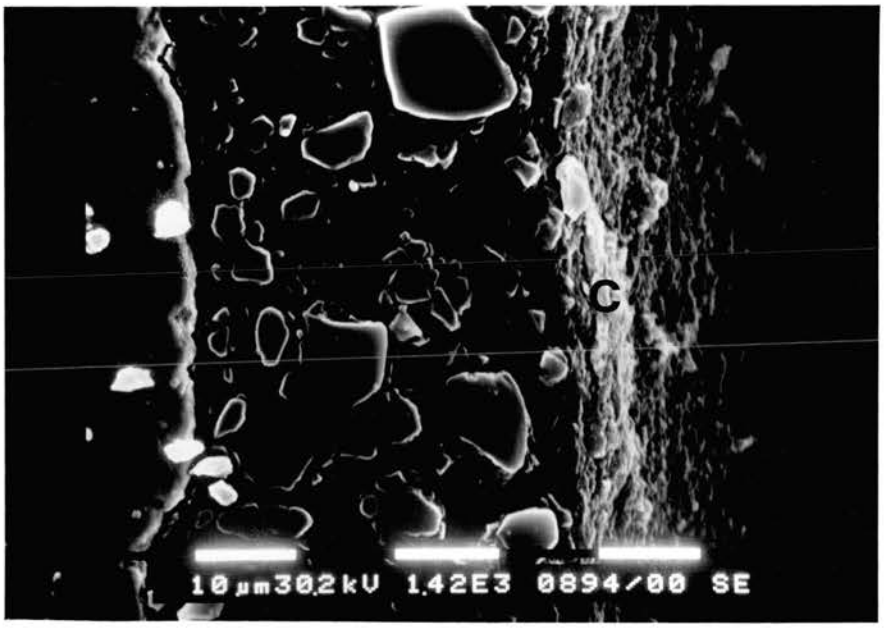


6.8 Electron-micrograph of composite cement lute (x 300).



D = Dentine G = Gold C = Cement

6.9 Higher power electron-micrograph of composite cement lute (x 1300).



DISCUSSION AND CONCLUSION

The mean cement film thicknesses were from 3% to 17% greater than the higher optimum (38 m^{-6}) recommended by Fusayama[81], but within the expected range derived from Windeler's[102] equation.

Although table 6.2 indicates that the film thickness at the axial wall is relatively reproducible, it was also observed in these studies that cement thickness under the occlusal aspect of crowns varied from 30 m^{-6} to 149 m^{-6} in spite of the control over the loading regime adopted. Similar variations have however been reported elsewhere by Pilo et al[101] and Fusayama et al[104].

Although the reason for this variation is unclear, the work of Jorgensen and Esbensen[105] who studied film thicknesses in the range 20 m^{-6} and 140 m^{-6}, suggests that any such variation would have only a moderate effect on retention. For the purposes of the work reported here this variation was considered to be acceptable for the satisfactory retention of crowns in clinical practice and hence for the specimens used in the tests.

Button et al[106] showed that different methods of cleaning dentine prior to cementing crowns varied the retention of some cements. It was postulated that either the dentine, or the cements, could be affected by the materials used to make temporary crowns, or by the temporary cements used to fix the temporary crowns in

place. Some clinicians also use volatile cleansing agents on dentine preparations (after removing temporary crowns) and these cleansing agents could affect the retention of the permanently cemented crowns.

The following experiments were devised to investigate the effects of these materials.

Experiment 6.2

To find the retentive power of different types of dental cements after the construction and cementation of temporary crowns on the dentine preparations.

METHOD

Twenty six dentine cones were produced as previously described (Experiment 4.1). The dimensions of the dentine preparations from these first two groups of cones are shown in Appendix 2 tables 6.3 and 6.4. and summarised below:

Summary of Table 6.3.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	3.89	7.1	5.10
Min	3.70	6.9	4.92
Mean	3.79	6.99	5.05
SD	0.05	0.06	0.05

Summary of Table 6.4.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.04	7.0	5.11
Min	3.71	6.8	4.79
Mean	3.85	6.95	5.04
SD	0.09	0.06	0.08

To simulate the clinical situation, acrylic-resin temporary crowns, slightly larger than the dentine cone preparations, were made for each of the dentine specimens. After impressions were taken for crown construction,

the dentine cones had a layer of petroleum jelly smeared over them. Each temporary crown-form had the appropriate specimen number written on the side in water-proof ink, and was filled with a fresh mix of TRIM (an N Iso-Butyl Methacrylate temporary crown material*[46]). When the TRIM had lost it's surface shine the temporary crown was pushed into place on the preparation. While the TRIM was at the rubbery stage of set the temporary crown was removed and replaced twice (to compensate for polymerization shrinkage) and then put into hot water (60°C) to accelerate the set. The petroleum jelly was removed from each dentine cone and from each temporary crown with wet cotton-wool and air/water spray from a three-in-one syringe. The temporary crowns were tried on and the excess TRIM was removed from the margins using an acrylic cutting bur.

The temporary crowns were cemented with TEMP BOND (a zinc oxide/eugenol temporary cement*[47]), and stored in 100% humidity at 37°C for a week. The gold crowns were constructed as previously described in Experiment 6.1.

The temporary crowns were removed from the dentine specimens and the dentine surfaces were washed with water, using a cotton wool pledget. The dentine cones were dried with an air jet and the crowns were cemented with different cements, using the technique previously described in Experiment 4.2. The specimens were returned to storage at 100% humidity for 24 hours before being used

for the retention tests.

The cementation of the glass-ionomer and composite cements had to be repeated because they set too rapidly, and the margins of the cemented crowns were not quite flush with the coronal edges of the finishing grooves.

Retention tests were carried out on these test pieces as described in Experiment 4.2. The displacing force was applied for 60 s (or until the maximum force of 500 N had been reached).

The dimensions of the dentine cones used in the repeat of the glass-ionomer and composite tests, are shown in Appendix 2 table 6.5. and summarised below.

Summary of Table 6.5.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone	occlusal diameter	taper degrees	height mm
Max	4.01	7.0	5.07
Min	3.89	6.8	5.01
Mean	3.93	6.92	5.05
SD	0.04	0.13	0.03

RESULTS

The results of the retention tests are shown in full in

Appendix 2 tables 6.6 to 6.12. and summarised below. Appendix 2 tables 6.9 and 6.10 show the results for test specimens where the cemented crown margins were not flush with the coronal edge of the dentine groove and are marked with ++ below. This experiment was repeated and the results are shown in Appendix 2 table 6.11 and 6.12. and are summarised as the last two results below.

ZINC PHOSPHATE	= 105 N
POLYCARBOXYLATE	= 238 N
ZINC OXIDE EBA	= 86 N
GLASS-IONOMER++	= 167 N
COMPOSITE++	= 20 N
GLASS-IONOMER	= 200 N
COMPOSITE	= 279 N

CONCLUSIONS

There was an increase in the retentive value of the fully seated crowns, but this was not significant in either case ($p > 0.05$).

The technique used in this experiment (listed in Annex 1) was satisfactory and was used for all other experiments of this type.

Experiment 6.3

To investigate the effect of re-cementing, with zinc

phosphate cement, the gold crowns which had been pulled from the the dentine cores in the tests previously described in Experiment 6.2.

METHOD

Some workers in this field have described experiments in which crown forms have been recemented one, or more, times[57,107,108]. It was thought that the damage done to the crown and the dentine specimens during testing might alter the retentive power of the cements used. Therefore this experiment was designed to test this hypothesis. The specimens which had been cemented with zinc phosphate appeared to have little damage, therefore most of the cement from the first test was removed from the fitting surfaces of the gold crowns by placing them in an ultrasonic bath containing water. Tenacious cement was carefully removed using a dental excavator. The cement on the preparation was also removed with great care using a blunt Wards carver no. 2. The crowns were recemented with zinc phosphate cement, stored in 100% humidity for 24 h, and tested for retention.

RESULTS

The rather surprising results are shown in table 6.13. The mean retentive value had significantly increased from 105 N for the initial cementation to 175 N after re-cementation ($p = 0.01$ using the Wilcoxon rank sum test).

Table 6.13 ZINC PHOSPHATE (Retentive value).

ZP27B01 = 178 N	cement on preparation	5-15%
ZP27B02 = 188 N	cement on preparation	15-25%
ZP27B03 = 164 N	cement on preparation	10-20%
ZP27B05 = 174 N	cement on preparation	0-10%
ZP27B06 = 172 N	cement on preparation	0-10%

MEAN = 175 N S.D. = 9 S.E. = 4

DISCUSSION AND CONCLUSION

The reason for the statistically significant increase in retention of the recemented gold crowns in this experiment is unclear. Possible contributing factors include damage to the dentine and micromechanical locking of phosphate cement into roughnesses on the fitting

surfaces of the recemented crowns, where the degree of damage and the size of the undercuts could be critical. Other factors may also be involved however, and the subject is pursued further in Chapter 8.

Experiment 6.4

To find the retentive power of different cements after the construction and cementation of temporary crowns on the dentine preparations which were then cleaned with PREP-DRY*[48].

METHOD

The technique was the same as before (Experiment 6.2) except that a drying and cleansing agent PREP-DRY (containing volatile solvents including ethyl ether and an unknown ketone) was used instead of water to clean the dentine cones after the removal of the temporary crowns. The dimensions of the first group of dentine cones are shown in Appendix 2 table 6.14 and summarised below.

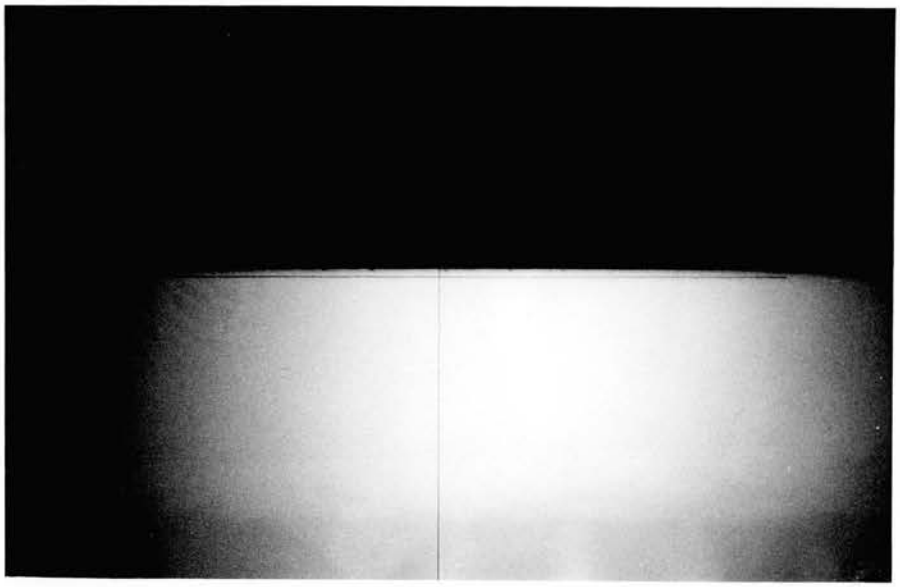
Summary of Table 6.14.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.00	7.0	5.09
Min	3.90	6.8	4.84
Mean	3.93	6.97	5.02
SD	0.03	0.06	0.07

Comparing the reproducability of the dimensions of the dentine cones from different groups showed that the tolerance was good. It was therefore considered to be acceptable to measure only a random sample from each group to ensure that quality control was maintained. All of the dentine cones were viewed on the NIKON PROFILE PROJECTOR V-12 (Fig 6.10) to ensure that the surface quality was good and that there were no irregularities on the preparations. The dimensions of the randomly selected dentine cones are shown in Appendix 2 tables 6.15 and 6.16 and summarised below. These dimensions were within acceptable limits.

6.10 Dentine surface viewed on the profile projector magnification X 100.



Summary of Table 6.15.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.05	7.0	5.14
Min	3.92	6.8	5.02
Mean	3.98	6.93	5.07
SD	0.06	0.09	0.05

Summary of Table 6.16.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.02	7.0	5.08
Min	3.82	6.9	5.02
Mean	3.92	6.98	5.05
SD	0.08	0.05	0.03

RESULTS

The crowns cemented on the dentine cones cleaned with PREP-DRY were tested as previously described in Experiment 6.2. The results of these retention tests are shown in Appendix 2 tables 6.17 to 6.21 and summarised below.

ZINC PHOSPHATE = 155 N
POLYCARBOXYLATE = 236 N
GLASS-IONOMER = 307 N
COMPOSITE = 165 N
ZINC OXIDE EBA = 84 N

CONCLUSIONS

PREP-DRY, the volatile agent, appeared to have had no effect on the polycarboxylate cement, but improved the retention of the zinc phosphate and glass-ionomer cements.

Cleaning the dentine with PREP-DRY appeared to have a deleterious effect on the composite cement, reducing the retention by 59%.

Experiment 6.5

To find the retention of gold crowns cemented on dentine cones which had had no previous temporary cementation.

These specimens could act as a control group for comparison with the test pieces which had had temporary crowns cemented on them. This experiment was necessary as the results from Experiment 5.2 which was initially designed to act as a control, were not completely relevant to this experiment because the divesting technique was altered in Experiment 6.2.

METHOD

The technique described in Experiment 6.2 was used. The results of the quality control for these groups are shown in tables 6.22 and 6.23.

Table 6.22.

COMBINED RESULTS FOR THE DIMENSIONS OF ALL THE DENTINE CONES USED FOR CEMENTATION WITH POLYCARBOXYLATE CEMENT.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.00	7.0	5.09
Min	3.90	6.9	4.95
Mean	3.93	6.98	5.03
SD	0.04	0.05	0.05

Table 6.23.

COMBINED RESULTS OF THE DIMENSIONS OF A RANDOM SAMPLE OF 10 OF THE 20 DENTINE CONES USED TO TEST THE RETENTION OF ZINC OXIDE EBA, ZINC PHOSPHATE, GLASS-IONOMER, AND COMPOSITE CEMENTS.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	4.00	7.0	5.15
Min	3.87	6.9	5.01
Mean	3.90	6.98	5.07
SD	0.06	0.04	0.04

RESULTS

Gold crowns cemented on dentine cones (which had not previously had temporary crowns fitted) were tested for retention as previously described (Experiment 6.2). The results of the retention tests are shown in Appendix 2 tables 6.24 to 6.28 and summarised below.

ZINC PHOSPHATE	= 123 N
POLYCARBOXYLATE	= 233 N
GLASS-IONOMER	= 288 N
COMPOSITE	= 235 N
ZINC OXIDE EBA	= 71 N

In the groups of crowns cemented with composite cement, the control group (235 N), and the group where water was used to clean the temporary cement off the dentine (279 N), had similar retention. However, the mean retention of the crowns was reduced where PREP-DRY had been used to clean the dentine (165 N).

The difference in retention of the specimens in which PREP-DRY was used; the control group; and those where water cleaning was used; were not statistically significant ($p = 0.15$ and $p = 0.10$ respectively). Further investigation into the effect of cleaning dentine with PREP-DRY when a temporary crown had not previously been cemented was considered to be necessary.

Experiment 6.6

To investigate the effect on the retentive power of composite cement when PREP-DRY was used to clean dentine cones before cementing gold crowns.

This experiment was designed to investigate any change in retention when PREP-DRY (volatile agent) was used. It was possible that the volatile agent alone might have a different effect from a combination of PREP-DRY with the materials used for temporary crown production and cementation.

METHOD

A set of 5 dentine cones and gold crowns were made as described previously (Experiment 6.2). The dentine was cleaned with PREP-DRY and the crowns cemented with composite cement and stored in 100% humidity for 24 h.

RESULTS

The retention of the gold crowns cemented to dentine cones which had been cleaned with PREP-DRY was tested as previously (Experiment 6.2). The results are shown in table 6.29.

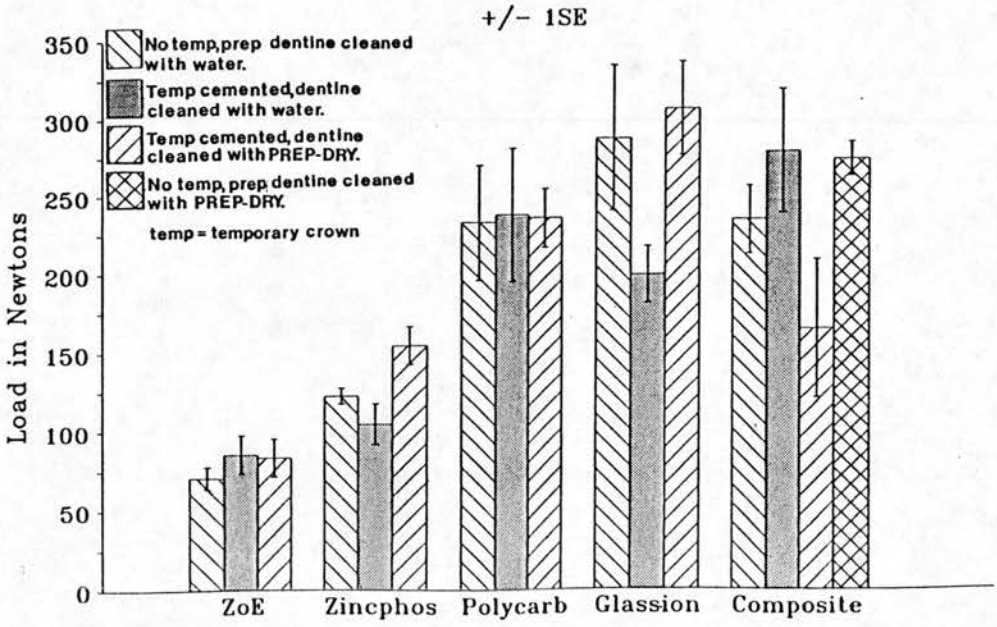
Table 6.29 COMPOSITE CEMENT (Retentive value).

CO17A12 = 258 N	cement on preparation	10-20%
CO17A21 = 270 N	cement on preparation	15-25%
CO17A14 = 300 N	dentine fracture	
CO17Y16 = 296 N	dentine fracture	
CO17Y20 = 246 N	dentine fracture	

MEAN = 274 N S.D. = 24 S.E. = 11

The results of these experiments are summarised in the bar chart (Fig 6.11).

6.11 Retentive power of gold crown cemented on human dentine cones: with and without temporary cementation.



In this histogram the first bar in each cement group represents cementation on dentine which had had no previous temporary crowns, i.e. the control. The second bar shows the effect of temporary crowns cemented with TEMP BOND, followed by the cleansing of the preparations with water. The third bar shows the effect of temporary crowns cemented with TEMP BOND, followed by the cleansing of the preparations with PREP-DRY. The fourth bar (composite cement group only) shows the effect of swabbing the dentine with PREP-DRY when a temporary crown had not previously been cemented.

The Zinc oxide eugenol EBA cement showed no statistically significant difference in retention irrespective of whether the dentine cones had had no temporary crowns; temporary crowns and water cleaning; or temporary crowns and PREP-DRY cleaning.

Similarly, the Polycarboxylate cement showed no statistically significant difference in retention irrespective of the pre-cementation treatment of the dentine cones.

The Glass-ionomer group showed no statistical difference between the control specimens and either of the groups with temporary crowns. However of the 2 groups which had had temporary crowns, the one which had been cleaned with the volatile agent was significantly more retentive ($p = 0.02$)

The zinc phosphate cement showed no difference between

the retention of the crowns cemented without previous temporary cover, and those where temporary cover had been fitted and the dentine washed with water, which is in accord with Worley, Hamm, and von Fraunhofer[109]. There was, however, a significant improvement in retentive power after the dentine had been cleaned with the PREP-DRY after temporary cementation, when compared with the control and those cleaned with water after temporary cementation ($p = 0.02$ for both).

When the composite cement was used there was no statistically significant difference between any of the results. The tendency for reduced retention when PREP-DRY was used after the cementation of temporary crowns, was not apparent when the volatile agent was used without previous temporary cementation.

CONCLUSIONS

These experiments showed that cementing a temporary crown using a eugenol based temporary cement had no significant effect on the retention of any cement tested. When after temporary cementation the volatile cleansing agent was used, there was no significant effect on the retention of polycarboxylate or EBA cements.

The use of the volatile cleansing agent appeared to increase the retentive power of zinc phosphate and glass-ionomer cements after temporary crowns had been

cemented.

Most of the zinc phosphate cement remained in the gold crowns after the retention tests, indicating little chemical reaction between dentine and cement. Therefore the improved retention after cleansing of the dentine with PREP-DRY could be a result of the removal of contaminants and/or drying of the dentine.

Similarly, the improvement in retention of the glass-ionomer cement following cleansing of the dentine with PREP-DRY may also have been due to removal of possible contaminants or moisture.

Composite cement showed no significant differences in the tests. The frequency of dentine fractures was high (35% of all specimens) indicating higher values of retention.

The interaction between eugenol and composite cement is well documented[110,111]. Therefore it seemed likely that traces of eugenol left after temporary cementation and water washing would have affected the retentive value of the composite cement, but this did not occur. When PREP-DRY was used after temporary cementation there was a tendency for the retention to decrease. This reduced retention did not occur when PREP-DRY was used alone on the dentine, which implied that the effect was not related to the PREP-DRY, but to a reaction between it and the materials used in the production and cementation of a temporary crown.

Perhaps any residual eugenol was in discrete islands on the dentine and the PREP-DRY had spread this eugenol in a thin film across the surface. This could slow the set of the composite and reduce the strength of the composite cement at the dentine/cement interface. Alternatively, eugenol may have penetrated into the dentinal tubules and have been drawn back to the surface by the PREP-DRY.

It would probably be prudent to avoid the use of PREP-DRY if a composite cement were to be used for the final cementation of a crown.

CHAPTER 7.

It is generally accepted in clinical practice that the "ideal" taper for a crown preparation is 5^0 to 7^0. However, this ideal is seldom achieved. The taper in fact varies between different sections of a tooth and also from one area of the mouth to another, as shown in table 2.30. For each region of the mouth the figures reported in this investigation agree with those of Nordlander, et al[86] whose results were achieved by instructing dentists, who were specialists in fixed prosthodontics, to attempt to achieve tapers in the range of 4^0 to 10^0. The figures are also in accord with those of Ohme and Silness[85] who noted convergence angles of 19^0 to 27^0 for vital teeth and 12^0 to 37^0 for root-filled teeth.

Eames et al[84] while noting the difference between mesio-distal and facio-lingual tapers in preparations, found a 20^0 taper to be the mean. Mack[112] measured a mean taper of 17^0 and Shillingburg[70] quotes averages of 8.6^0 to 26.6^0 with an overall mean of 14.7^0.

The concept of an "ideal" taper is in fact based on a paper by Jorgensen[1] in which it was claimed that as tapers were reduced below 5^0 the increase in retention was very large, and as tapers were increased over 30^0 the reduction in retention was relatively small.

This paper of Jorgensen[1] is perhaps the most widely

cited reference in studies relating retention of crowns to preparation taper. It is surprising therefore that it has rarely, if ever, been challenged, particularly since a close examination reveals that Jorgensen's interpretation of his results relied on extrapolated data. In addition, not only were his model crown preparations made in a synthetic material (a polymer galalith), but the crowns used had open tops and therefore had no contribution to retention from their "occlusal" aspects. They therefore bore little resemblance to clinically prepared teeth.

It was therefore decided in this study to investigate the question of optimum clinical taper in more detail, using prepared human tooth tissue and gold crowns more representative of those used in normal clinical practice. On the basis of the known range of clinically achieved tapers as described above, it was decided that a variation in taper over the range 7-30^0 would be appropriate for study, since it would include not only the expected clinical variation but also the range of tapers investigated by Jorgensen[1].

Experiment 7.1

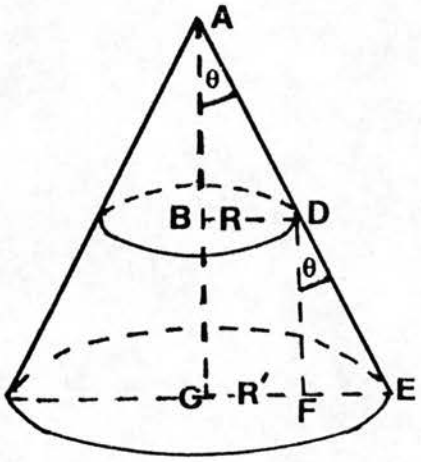
To investigate the effect of taper on the retentive power of different cements.

Alteration of the taper would affect other parameters of the preparation, and therefore make it difficult to

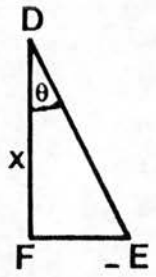
ensure that changes in retention were due to the variation in the taper alone. It was considered that a suitable model would be one in which the area of the occlusal surface was constant. Further, the axial surface area was also kept constant by varying the height and the base diameter. The calculations showing how the dimensions of dentine cones of constant surface area could be produced are shown in Fig 7.1. Unfortunately this design of dentine cone would be impractical clinically as the base of the preparation would be too large (5.76 mm for a cone of 23^0 taper and 6.19 mm for a cone of 30^0 taper) to be cut in the dentine of human canines (mean diameter mesio-distaly 6.3 mm, table 2.13; or 5.5 mm Wheeler [25] (1969). Theoretically dentine cones of base 6.19 mm can be made from teeth 6.3 mm wide, but in practice when the teeth were mounted on the lathe they were invariably slightly off centre before turning began. This design of dentine cone would also have precluded the use of larger tapers.

An alternative model as described below was therefore adopted, and the formulae for calculating the total surface areas, and the curved surface areas, used in this thesis, are found at III and IV in Fig 7.1.

7.1 Calculations used to determine the dimensions of a truncated cone.



BC = x
BÂD = θ
FE = R'-R



$R'-R = x\text{Tan}\,\theta$

The surface area of a cone $= \frac{2\pi R'}{2\pi (AE)} \times \pi(AE)^2$

$= \frac{\pi R'AE}{(AE)}$ but $\frac{R'}{(AE)} = \text{Sin}\theta$

=> SURFACE AREA OF CONE ACE $= \frac{\pi R'^2}{\text{Sin}\theta}$ ----- I

=> SURFACE AREA OF CONE ABD $= \pi R(AD)$

$= \frac{\pi R^2}{\text{Sin}\theta}$ ----- II

=> CURVED SURFACE AREA OF TRUNCATED CONE IS I - II

$= \frac{\pi}{\text{Sin}\theta} (R'^2-R^2)$

$= \frac{\pi}{\text{Sin}\theta} (R'-R)(R'+R)$

$= \frac{\pi}{\text{Sin}\theta} (x\text{Tan}\theta)(x\text{Tan}\theta+2R)$

$= \frac{\pi x}{\text{Cos}\theta} (x\text{Tan}\theta+2R)$ ----- III

=> TOTAL SURFACE AREA OF TRUNCAED CONE
IS CURVED SURFACE AREA + TOP SURFACE AREA.

$\frac{\pi x}{\text{Cos}\theta} (x\text{Tan}\theta+2R) + \pi R^2$ ----- IV

TO FIND THE HEIGHT OF A TRUNCATED CONE OF CONSTANT CURVED SURFACE AREA.

$$A = \frac{\pi x}{\text{Cos}\theta}\,(x\text{Tan}\theta+4) \qquad \text{----- III'}$$

$$\Rightarrow \quad \frac{A\text{Cos}\theta}{\pi} = x^2\text{Tan}\theta + 4x$$

$$\Rightarrow \quad \text{Tan}\theta x^2 + 4x - \frac{A\text{Cos}\theta}{\pi} = 0$$

$$\Rightarrow \quad x = \frac{-4 \pm \sqrt{\left\{16 + \frac{4A\text{Cos}\theta\text{Tan}\theta}{\pi}\right\}}}{2\text{Tan}\theta}$$

THE NEGATIVE IS UNACCEPTABLE

$$\Rightarrow \quad x = \frac{-4 + 2\sqrt{\left\{4 + \frac{A\text{Cos}\theta\text{Tan}\theta}{\pi}\right\}}}{2\text{Tan}\theta}$$

$$\Rightarrow \quad x = \frac{\sqrt{\left\{4\pi + \frac{A\text{Cos}\theta\text{Tan}\theta}{\pi}\right\}} - 2}{\text{Tan}\theta} \qquad \text{----- V}$$

CALCULATE THE AREA A FROM III' AND SUBSTITUTE IN V TO FIND x.

KNOWING x THE BASE DIAMETER R' IS AS FOLLOWS.

$$R' = 2R+2x\text{Tan}\theta \qquad \text{----- VI}$$

METHOD

To keep the size of the preparation suitable for the human dentine available, and to allow a range of tapers to be studied, it was decided that the height and base of the dentine cones should be kept constant in a similar manner to Jorgensen's work[1], and to apply a correction factor to compensate for alterations in surface areas. A taper of 7^0 has already been described in this thesis, and for this additional work tapers of 15^0, 23^0, and 30^0 were chosen, dentine cones for testing being prepared with height 5 mm, and base diameter 4.4 mm. As the production technique required the diameter of the occlusal surface of the preparation to be known this was calculated from the formula:

$$TD = BD - 2\,(h\mathrm{Tan}\theta)$$

Where TD is the occlusal (top) diameter; BD is the base diameter; h is the height of the dentine cone; and θ is half the angle of taper.

These calculations were based on the original prototype model with a 5^0 taper rather than the final 7^0 model. This resulted in the 15^0, 23^0, and 30^0 dentine cones all having the standard height and base diameter above, whereas the 7^0 dentine cones had the standard height but a base diameter oversized by 0.2 mm. Since all the results were calculated as a force per unit area, it was considered that this variation would not significantly

affect any comparison of the data on retention.

The dentine cones of 15^0 taper were prepared in two batches as described in Appendix 1, and their dimensions are shown in Appendix 2 tables 7.1 and 7.2 and summarised below.

Summary of Table 7.1

DIMENSIONS OF DENTINE CONES OF 15^0 TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	3.35	15.1	5.07
Min	3.05	14.8	5.00
Mean	3.17	14.9	5.04
SD	0.08	0.1	0.02

Summary of Table 7.2

DIMENSIONS OF DENTINE CONES OF 15⁰ TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	3.45	15.3	5.06
Min	3.10	14.6	4.96
Mean	3.24	15.0	5.02
SD	0.11	0.2	0.03

The cones were then divided into 4 groups of 5. Gold crowns were made and cemented with zinc phosphate cement, polycarboxylate cement, glass-ionomer cement, and composite cement as described in Appendix 1, one cement being used for each group. Temporary crowns were not used, and the specimens were subsequently tested for retention as also described in Appendix 1.

The lathe was then set to a taper of 23⁰ and a further 20 dentine cones were produced with occlusal diameter 2.4 mm, height 5 mm, and base diameter 4.4 mm. As the reproducibility of the samples was good, a random sample of the dimensions of the dentine cones was taken to check the quality control. The results are shown in Appendix 2 table 7.3. and summarised below.

Summary of Table 7.3

DIMENSIONS OF A RANDOM SAMPLE FROM A GROUP OF 20 DENTINE CONES OF 23° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	2.42	23.1	5.07
Min	2.35	23.0	5.03
Mean	2.38	23.0	5.05
SD	0.03	0.04	0.02

Gold crowns were cemented on to the dentine cones of 23° taper with the test cements in 4 groups of 5 as above, and tested for retention using the standard technique in Appendix 1.

The process was then repeated with dentine cones of taper of 30°, with occlusal diameter 1.76 mm, height 5 mm, and base diameter 4.4 mm. A random sample of the preparations used in this experiment is shown in Appendix 2 table 7.4. and summarised below.

Summary of Table 7.4

DIMENSIONS OF A RANDOM SAMPLE FROM A GROUP OF 20 DENTINE CONES OF 30° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	1.82	30.2	5.08
Min	1.74	30.0	5.00
Mean	1.78	30.0	5.04
SD	0.03	0.08	0.03

It should be noted that a reinforced zinc oxide / eugenol EBA cement was not included at this point because previous experiments suggested that it was not a sufficiently retentive luting medium for permanent crown cementation.

RESULTS

The results for the specimens with 7° taper are shown in tables 6.24 to 6.27, the individual cements being denoted by an alphanumeric code described earlier in Chapter 5.

For the cements used in this experiment however, the first 4 characters of the 7 character code were

modified in the following manner because there was only one of each cement type being tested, and the tapers were greater than 10^0:

The first 2 characters were used to designate the cement type as:

ZP = zinc phosphate cement.

PC = polycarboxylate cement.

GI = glass-ionomer cement.

CO = composite cement.

and the second 2 characters showed the taper. The other characters remained as before.

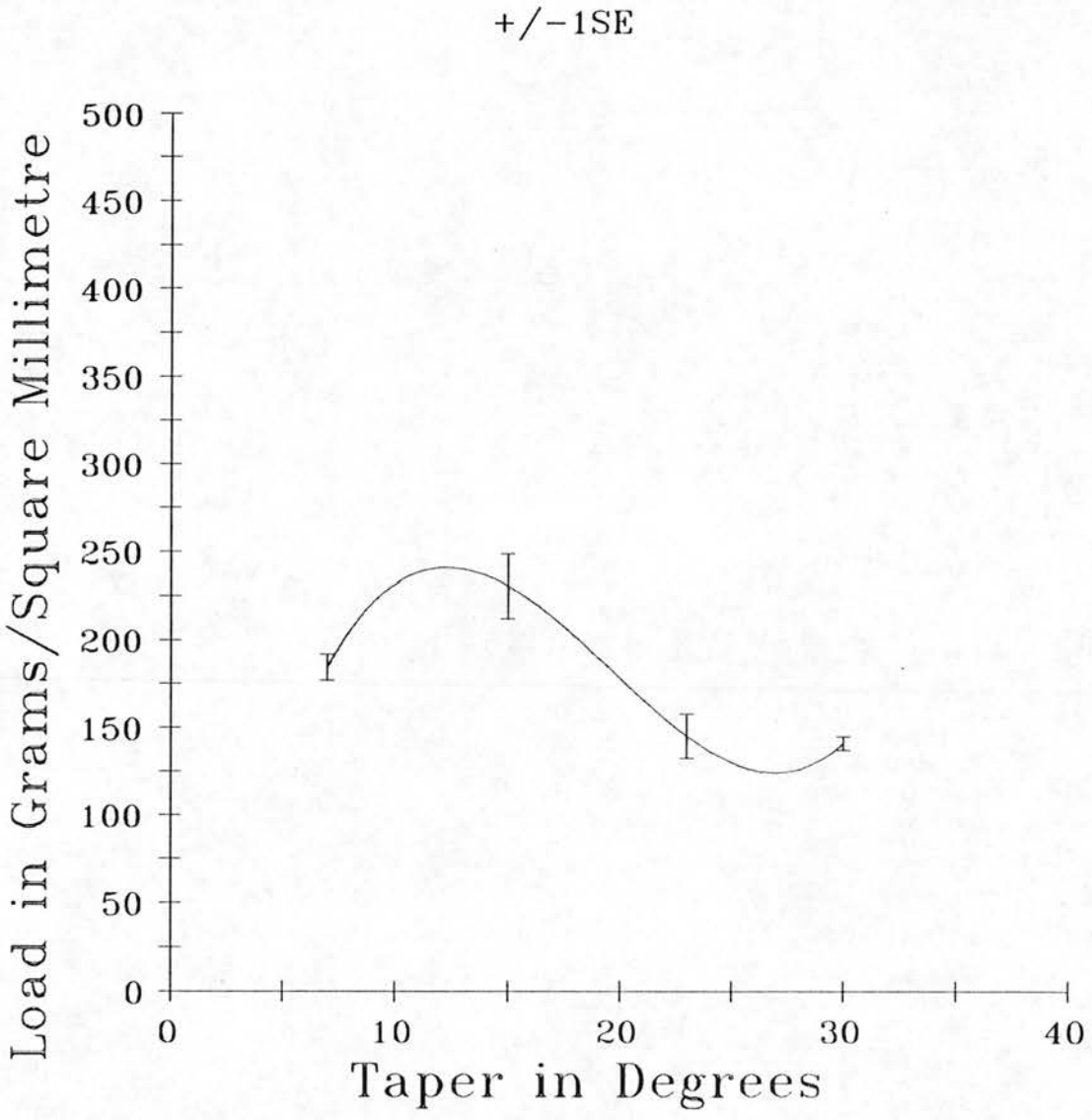
The results of the retention tests for the specimens with $15-30^0$ tapers are summarised below as failure strengths in Newtons. The full data set is given in Appendix 2 tables 7.5 to 7.16 with standard deviations and standard errors.

TAPER	15^0	23^0	30^0
ZP	135	78	70
PC	202	174	140
GI	184	132	96
CO	248	216	141

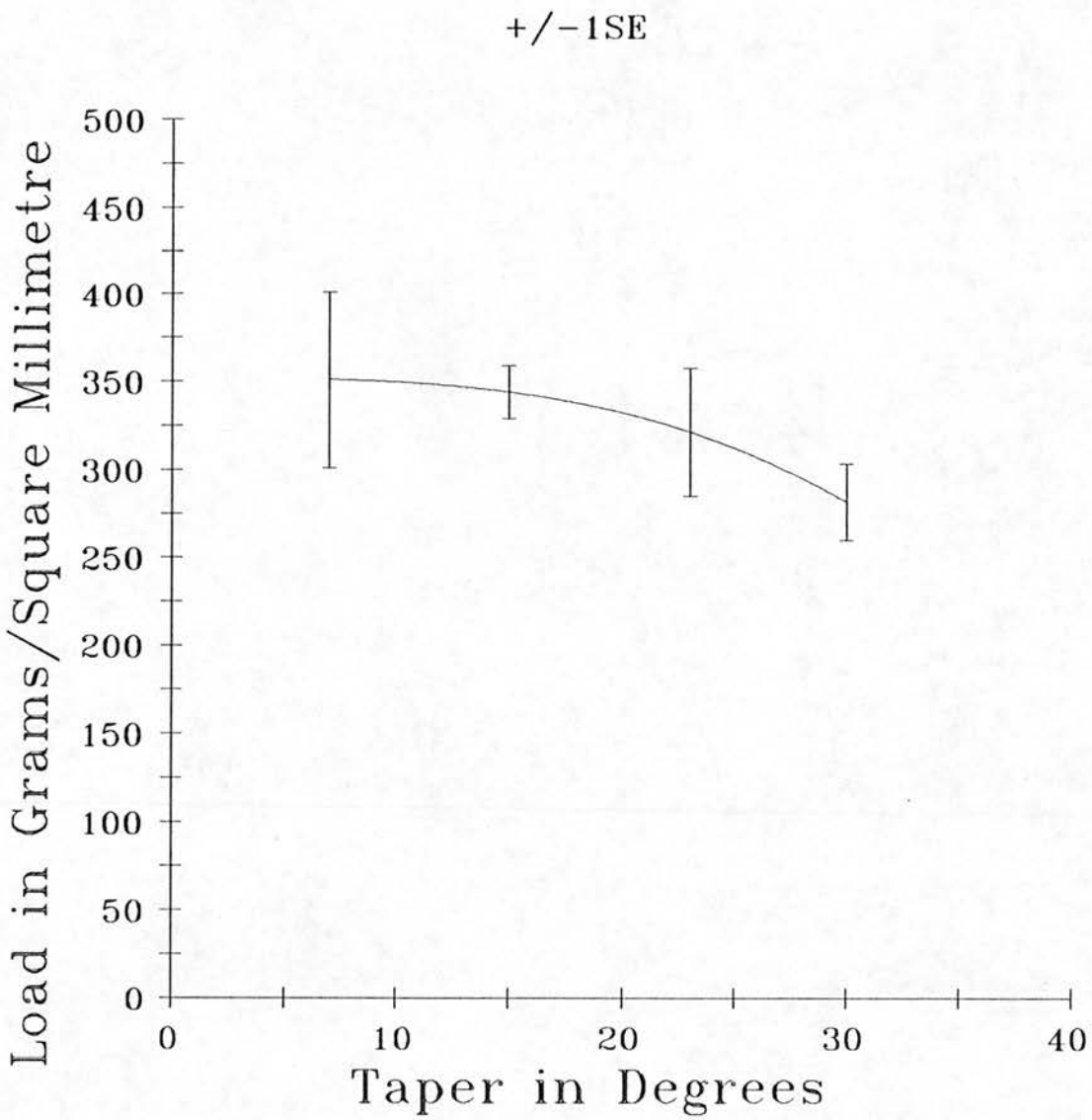
The results are also shown graphically in Figs 7.2 to 7.5 as the retentive force per unit axial (curved) surface area, and in Figs 7.6 to 7.9 as the retentive force per

unit total surface area.

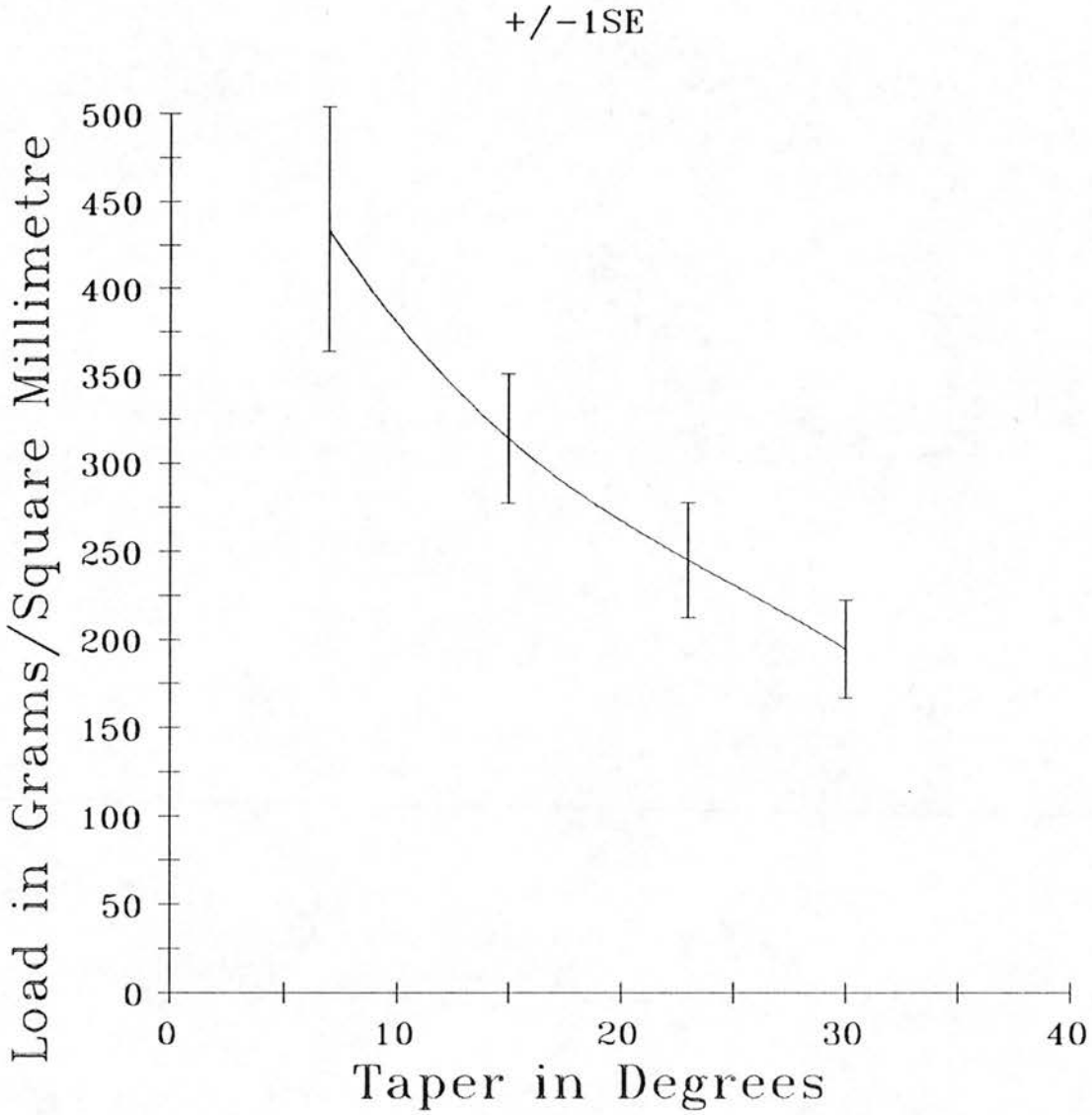
7.2 Mean retentive power of zinc phosphate cement related to axial surface area.



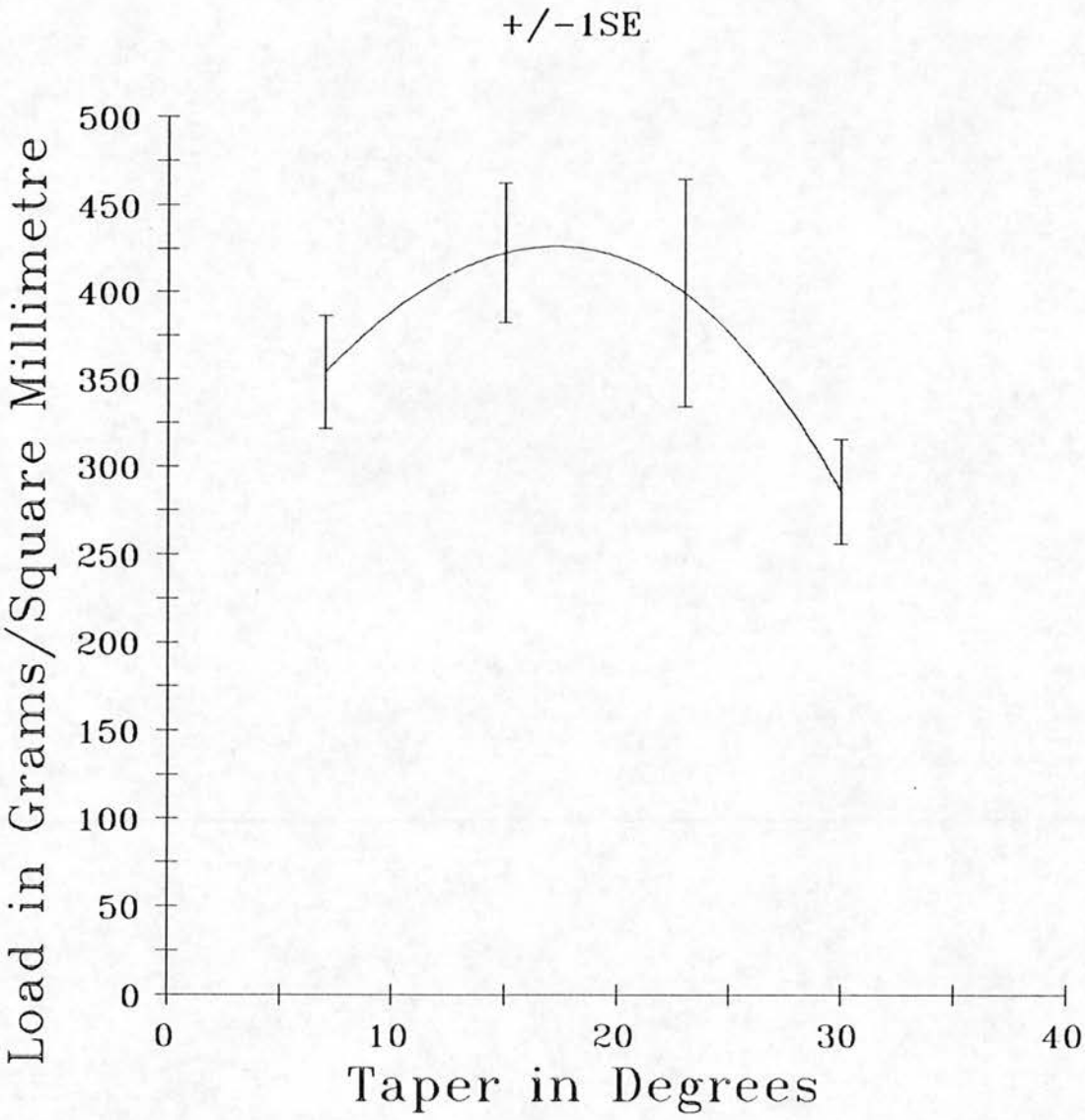
7.3 Mean retentive power of polycarboxylate cement related to axial surface area.



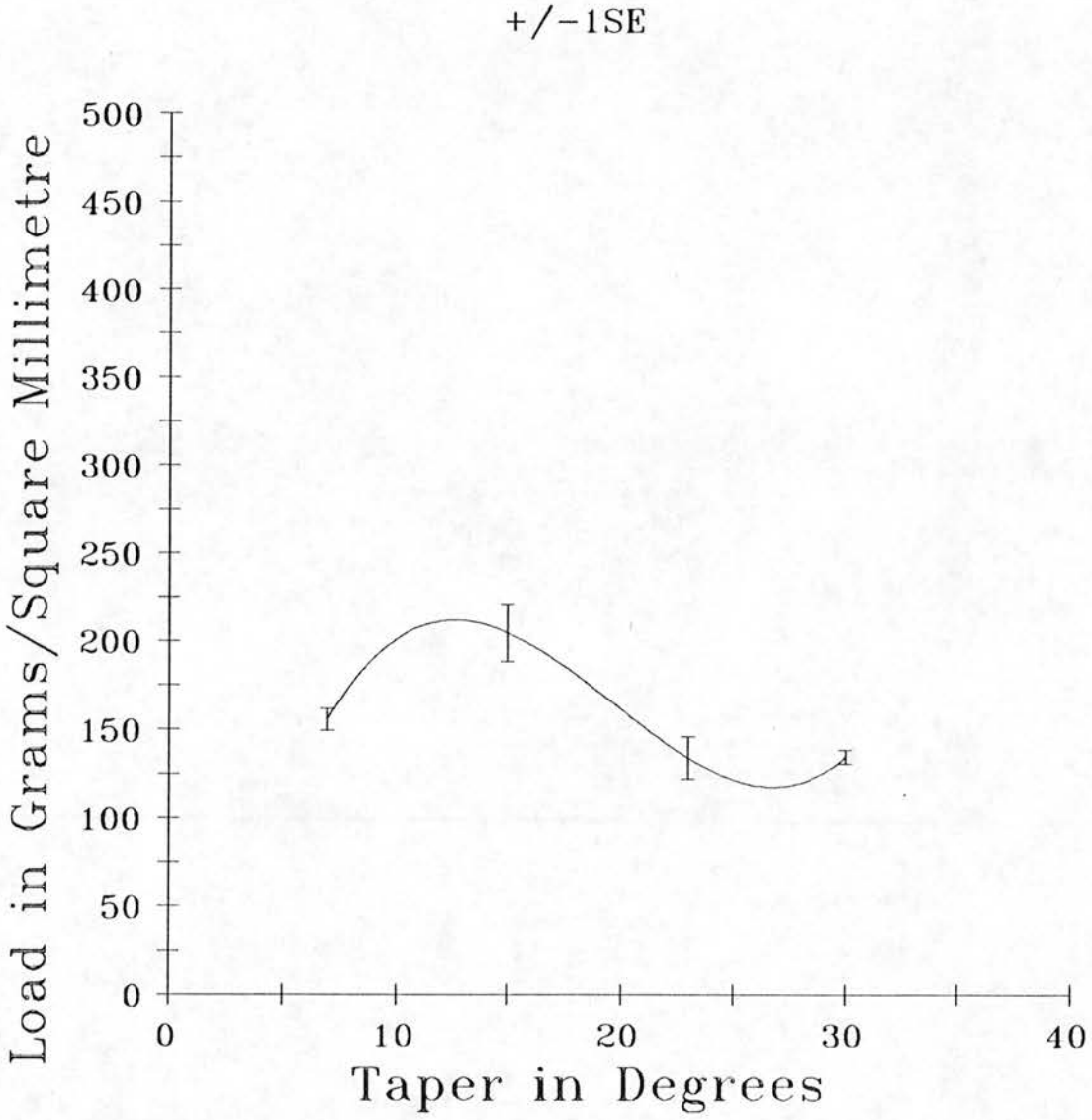
7.4 Mean retentive power of glass-ionomer cement related to axial surface area.



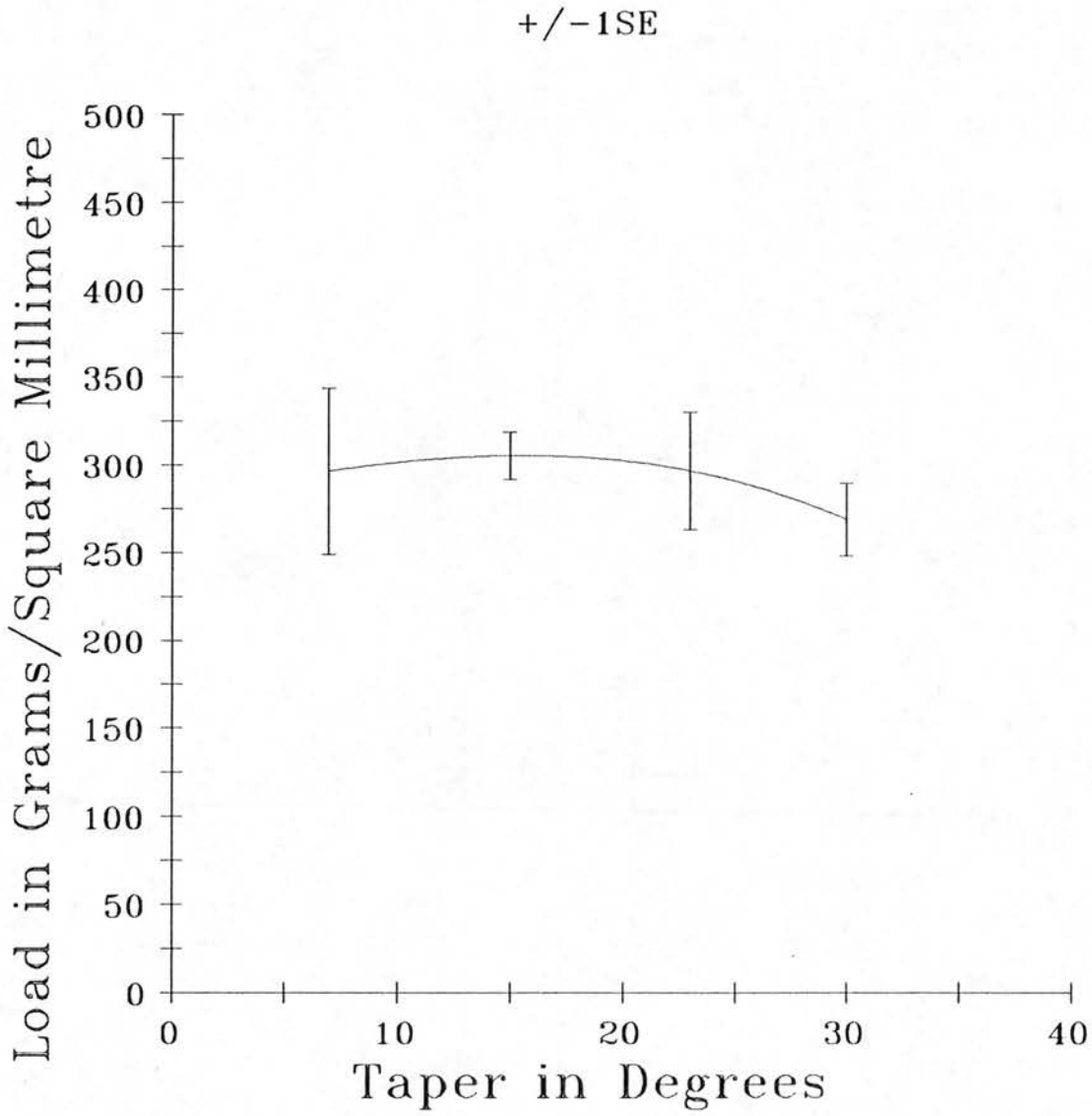
7.5 Mean retentive power of composite cement related to axial surface area.



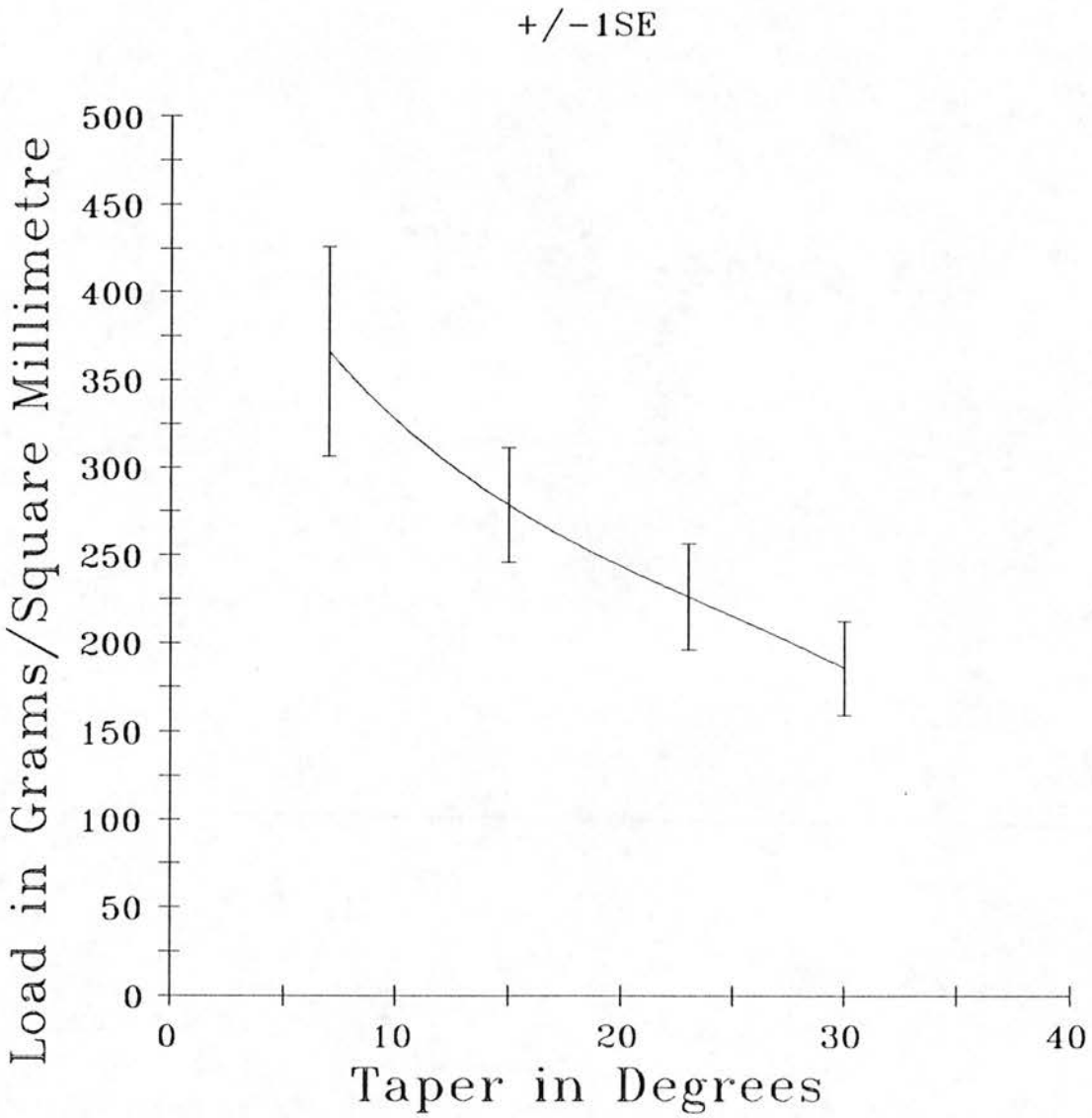
7.6 Mean retentive power of zinc phosphate cement related to total surface area.



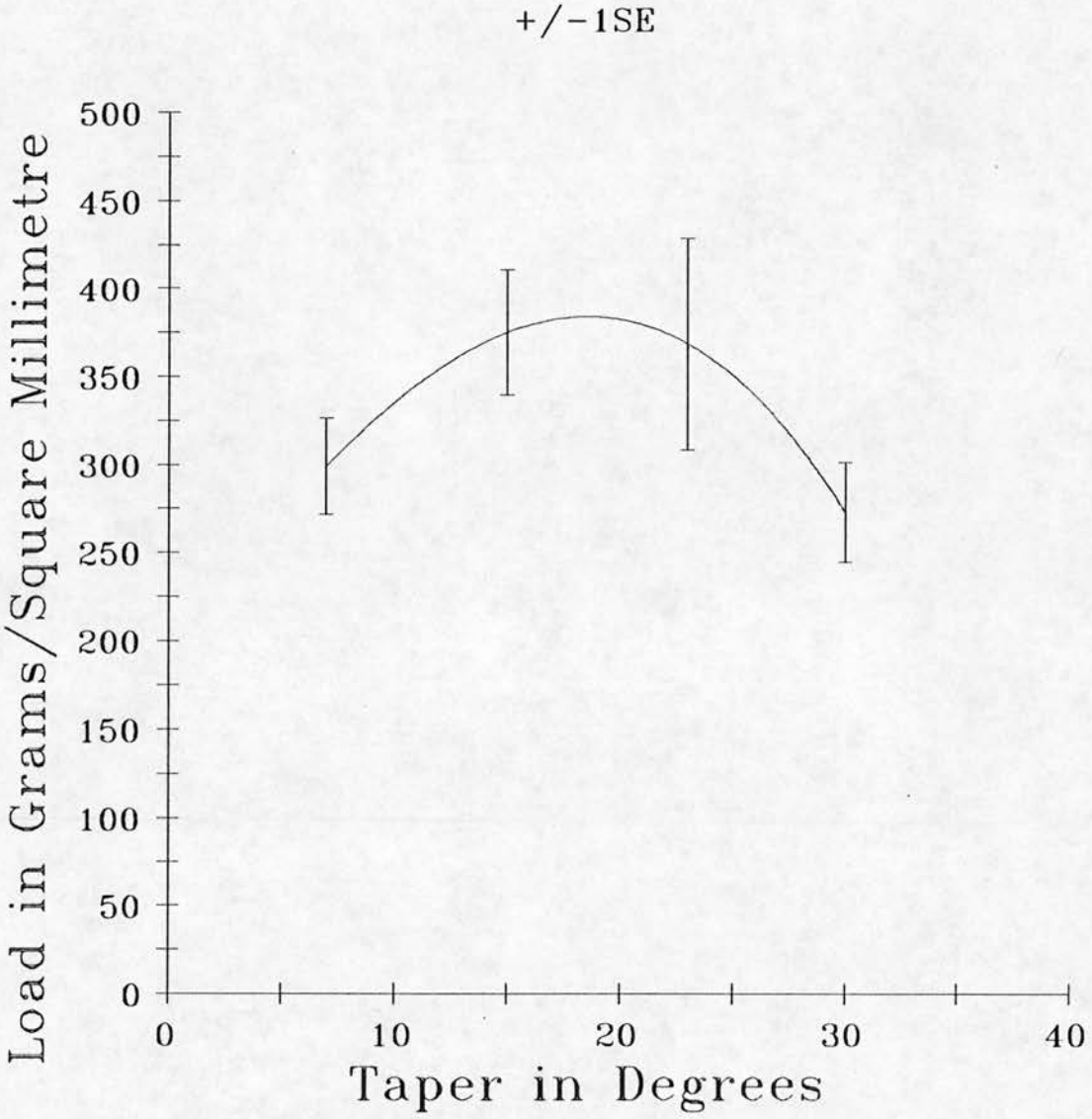
7.7 Mean retentive power of polycarboxylate cement related to total surface area.



7.8 Mean retentive power of glass-ionomer cement related to total surface area.



7.9 Mean retentive power of composite cement related to total surface area.



DISCUSSION

In contrast to Jorgensen's work[1], for certain cement lutes there would appear to be an optimum taper giving maximum retention. The most direct comparison with Jorgensen's data is Figs 7.2-7.5 where retention is related to axial surface area alone. It can be seen that both zinc phosphate cement (Fig 7.2) and composite cement (Fig 7.5) appear to show such an optimum, and further that the value of the optimum taper is cement-dependent. As has already been discussed elsewhere in this thesis, the model used by Jorgensen is open to question because no account was taken of any contribution to retention from the "occlusal" aspect of crown preparations.

For this reason, the results of this experiment are further shown in Figs 7.6-7.9 as a function of total surface area (i.e. including "occlusal" aspect). An optimum taper can still clearly be seen in Figs 7.6 and 7.10 for zinc phosphate cement and composite cement respectively, but in addition Fig 7.7 for polycarboxylate cement now shows evidence of a possible optimum taper. Interestingly however, Figs 7.4 and 7.8 for glass-ionomer cement show no optimum, and the reason for this is unclear. However, glass-ionomer and polycarboxylate cements share the same adhesive mechanisms and have similar polyacid components, it is possible therefore that the observation of an optimum taper may be

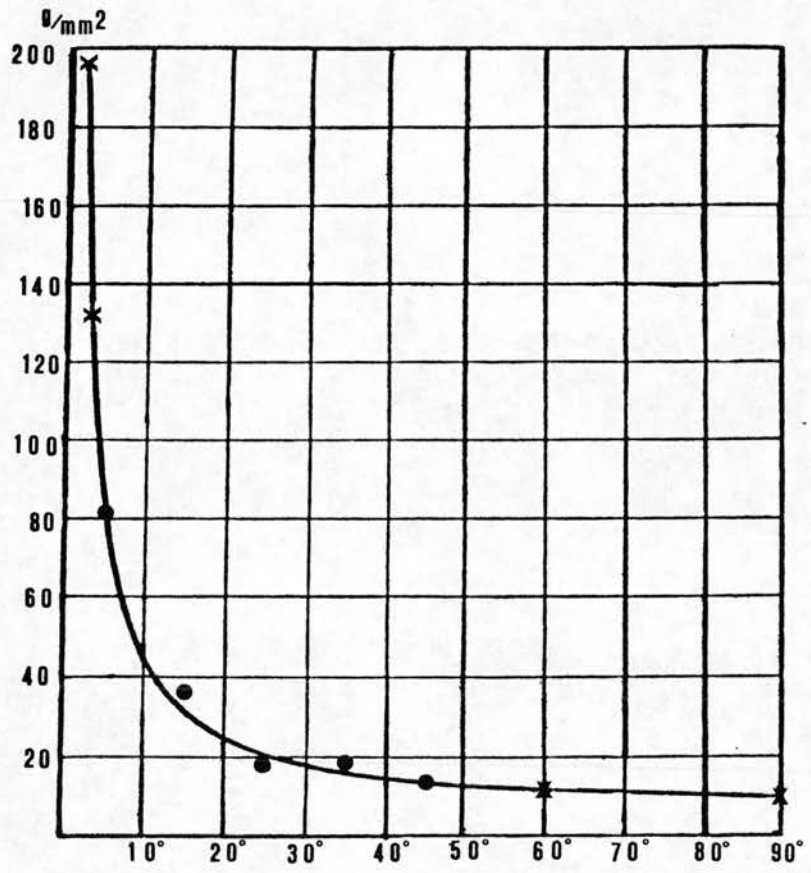
material-related. Fore example, it may be that in the case of these adhesive cements the predominant mode of failure is cohesive, and that their results are simply reflecting cement strength rather than any effect of taper. It might therefore be advantageous to concentrate any immediate further work on non-adhesive zinc phosphate cement to avoid any such difficulties in the interpretation of data.

The results may be summarised as follows:

CEMENT	OPTIMUM TAPER
Zinc Phosphate	7-15
Polycarboxylate	7-23 (or possibly none?)
Glass-ionomer	none
Composite	7-23

Jorgensen[1] suggested that there might be a hyperbolic relationship between retention and taper, such that retention increased as taper was reduced. However, this conclusion was supported in part by "extrapolated" (i.e. mathematically generated) additional data as shown in Fig 7.10 (original data shown in Appendix 2 table 7.17), and it is possible to draw other curves through his actual experimental data.

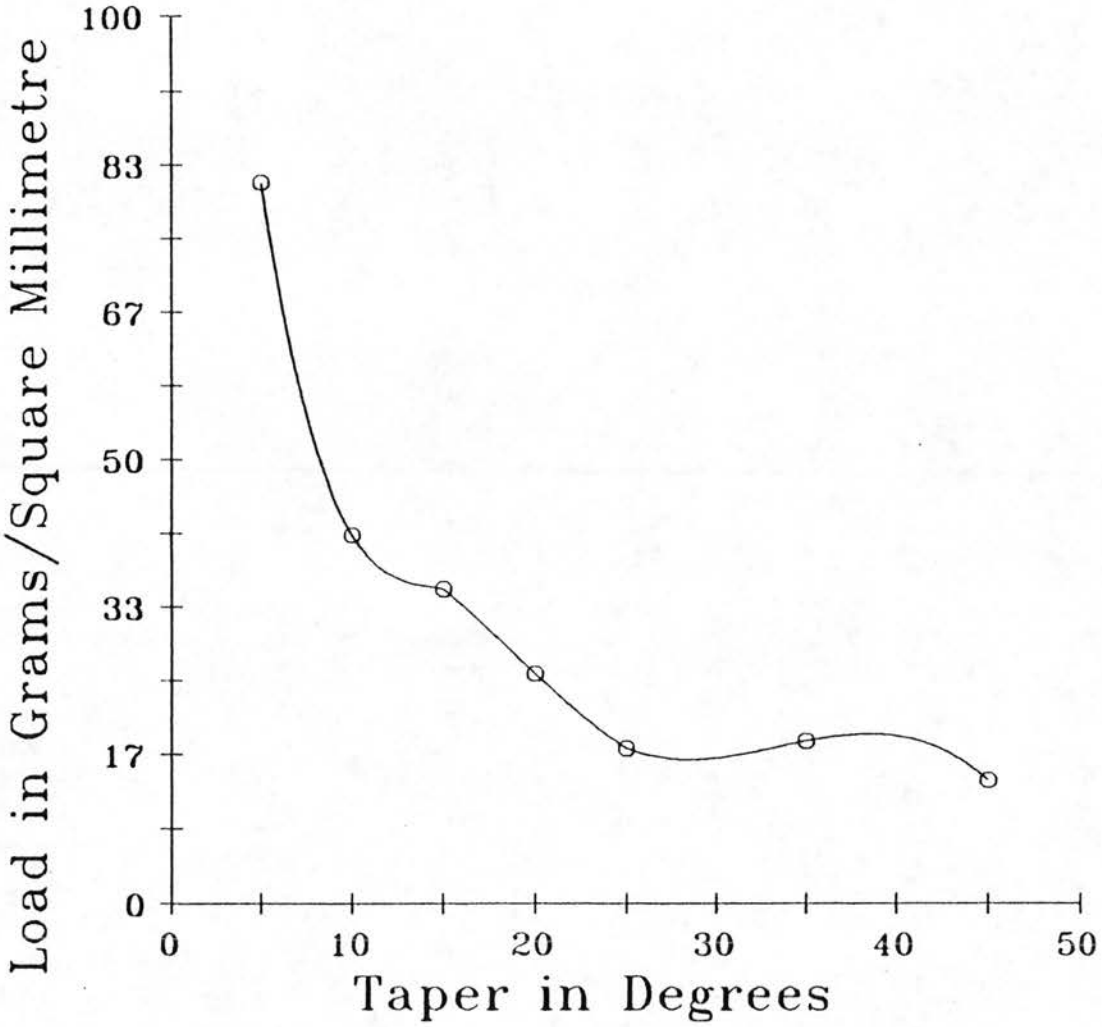
7.10 " The relationship between the retention and convergence angle in cemented veneer crowns " taken from Jorgensen[1] and including original extrapolated points (x).



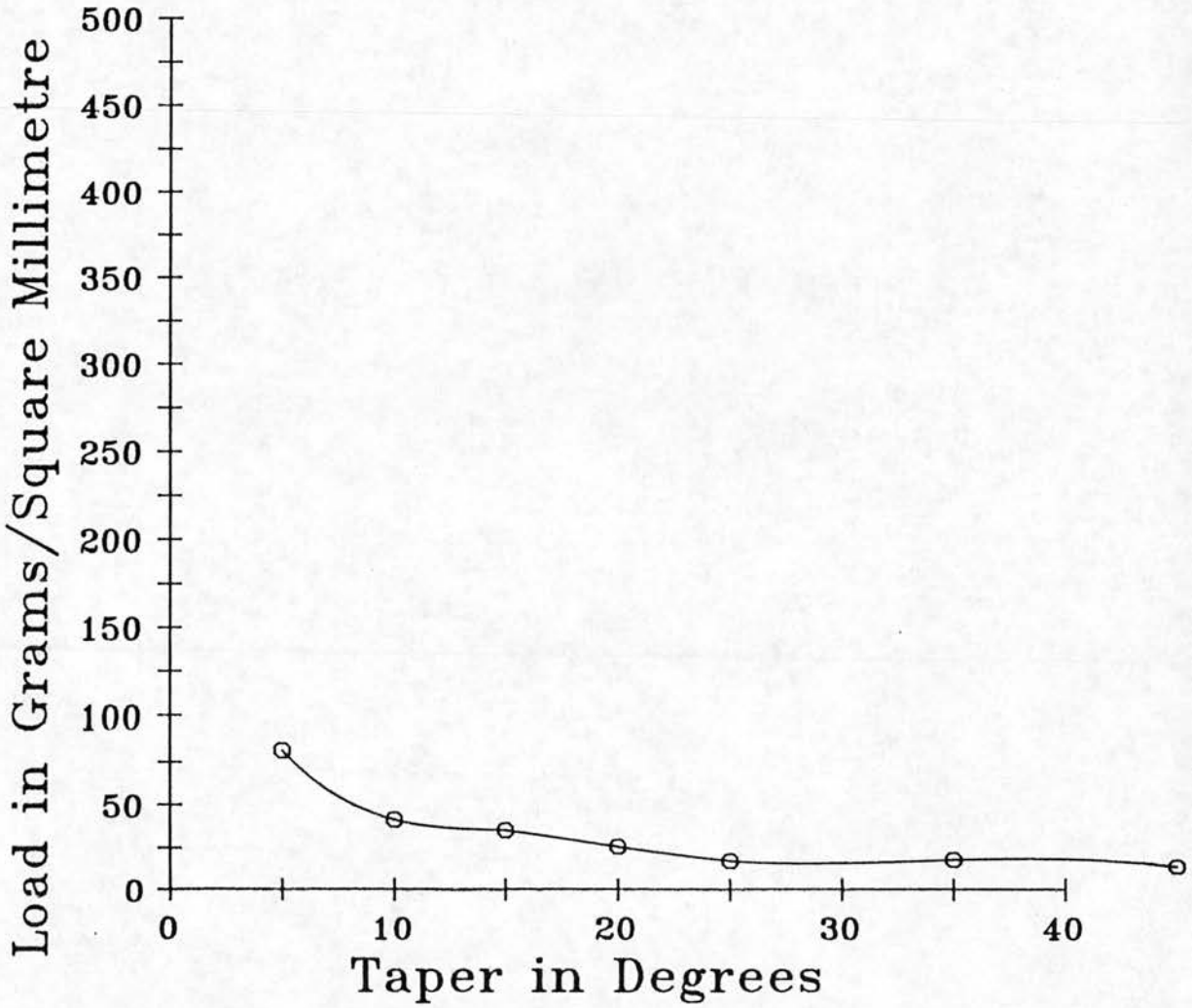
For example, Jorgensen's actual data[1] is shown in Fig 7.11 with expanded vertical axis, and in Fig 7.12 with a compressed vertical axis. One interpretation of Fig 7.12 would be that with the exception of the first data point there is a linear relationship between retention and taper. Interpretation of Jorgensen's data in the manner that Jorgensen himself adopted relies heavily therefore on a single data point. In view of this it is surprising

that Jorgensen's work has been so little challenged and so readily accepted by the dental profession.

7.11 Mean retentive power of zinc phosphate cement using Jorgensen's experimental data[1].
(ie without extrapolated points)



7.12 Mean retentive power of zinc phosphate cement using Jorgensen's data[1] on the axes of the current study.



However, the same criticism could also be applied to the work reported here, which in a similar way relies on limited data sets. The findings reported here, and the observation of a possible optimum taper for retention, should therefore be treated with caution, particularly since the curves through the points have been computer-fitted. If further work confirms these results however, it would draw the currently accepted hyperbolic relationship between retention and taper into question. Further research into this relationship is therefore urgently required.

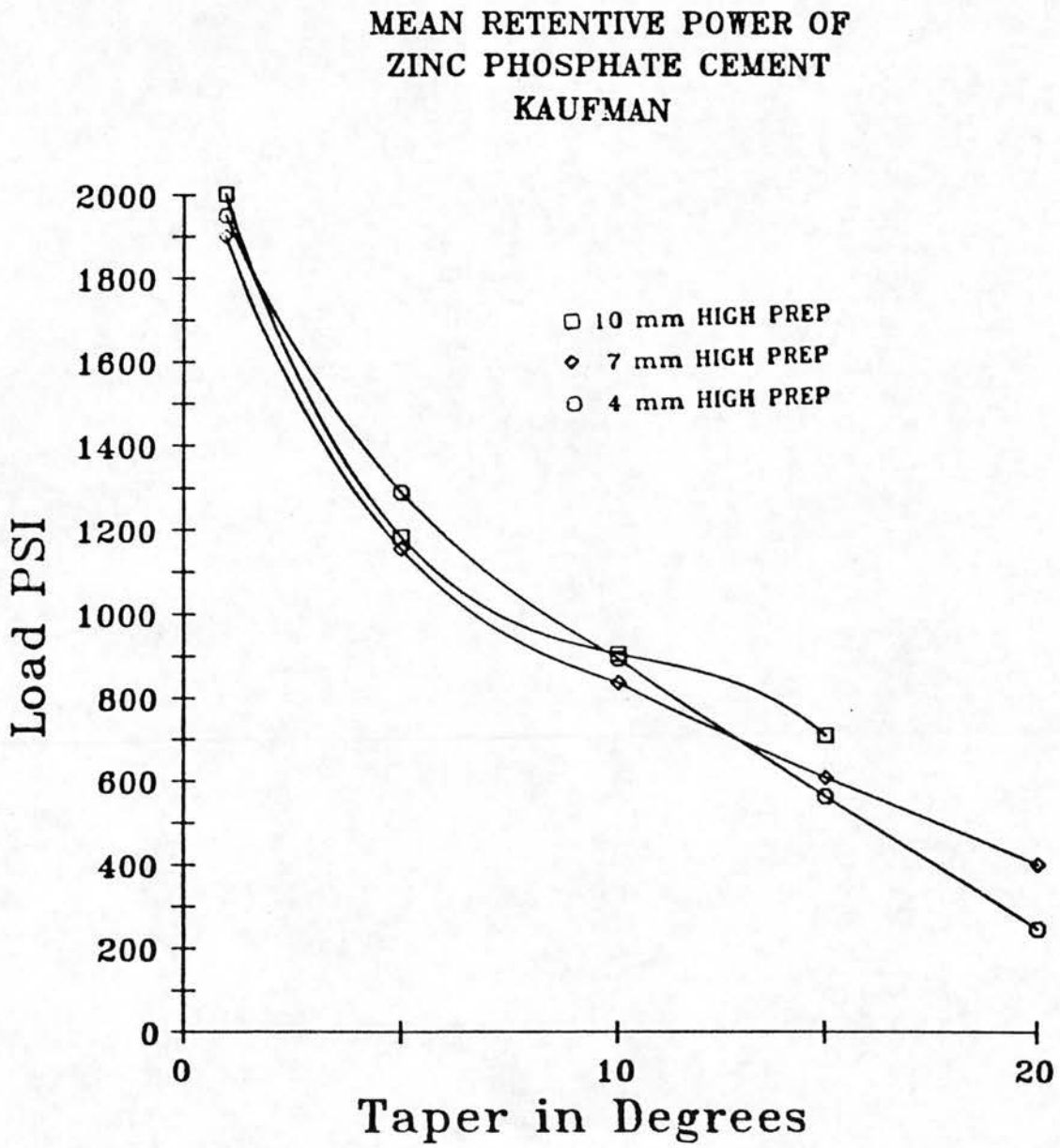
As has already been mentioned, this hyperbolic relationship was based on truncated cones in which no account was taken of any contribution to retention from the "occlusal" cone surface. The work reported here however, in which the data has been related to both axial and total surface areas, suggests that it may be wrong to ignore the "occlusal" aspects of crowns. The effect of including "occlusal" surface area in Figs 7.6-7.9 is to alter the shape of the diagram slightly compared with Figs 7.2-7.5. This does not affect the overall shape for zinc phosphate and composite cements, which display an optimum taper whether or not the "occlusal" surface area is included. However, polycarboxylate cement is particularly interesting (Fig 7.3 and 7.7) because it suggests that inclusion of "occlusal" surface area can turn an apparently monotonic relationship into one with a

maximum value.

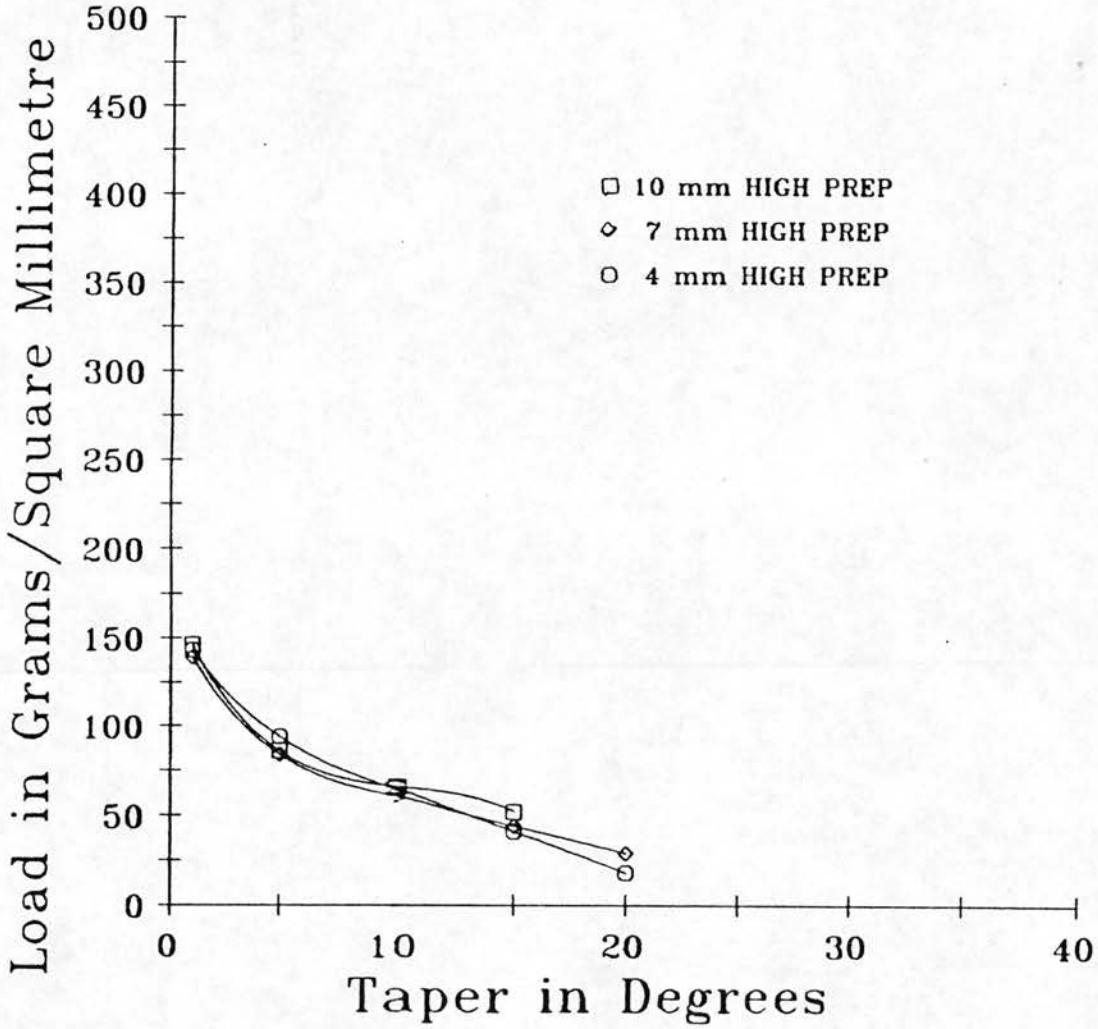
Again, this conclusion should be treated with caution until these experiments have been further verified. However, if the observation of optimum taper is indeed confirmed, the result for polycarboxylate would suggest that the contribution of the "occlusal" surface to overall retention may be a significant factor, and that it may be wrong to ignore it.

Doubt is also cast on Jorgensen's[1] hyperbolic relationship by the work of Kaufman et al[2], who investigated the retention of gold castings as a function of taper (Original data in Appendix 2 table 7.18). Although they did not themselves question Jorgensen's interpretation, and presented their data with different axes to those of Jorgensen so that direct comparison would have been difficult, their results are shown in Fig 7.13 using Jorgensen's format, and in Fig 7.14 on the scale of the work reported in this thesis. The relationship between retention and taper in their work does not appear to be hyperbolic.

7.13 Mean retentive power of zinc phosphate cement taken from Kaufman et al[2].



7.14 Mean retentive power of zinc phosphate cement using the data of Kaufman et al[2] on the axes of the current study.



Nor of course is there evidence of any optimum taper, but in common with Jorgensen[1] their model preparations were made in a synthetic material and may not be properly representative of clinical practice. The importance of their work is to call into question the hyperbolic relationship suggested by Jorgensen, a view which is also supported by the data in this thesis. Interestingly, their results are more consistent with Figs 7.4 and 7.8 for glass-ionomer cement although the similarity may be fortituous.

CONCLUSIONS

For 3 out of the 4 cements studied there appears to be an optimum taper for maximum retention of gold crowns on human dentine as follows:

CEMENT	OPTIMUM TAPER
Zinc Phosphate	7-15
Polycarboxylate	7-23 (or possibly none?)
Glass-ionomer	none
Composite	7-23

The optimum taper appears to vary among cements, although the results should be regarded as preliminary until confirmed by further work. Such confirmation would draw the currently accepted hyperbolic relationship between retention and taper into question and could have a significant effect on future clinical practice. Further research is therefore urgently required.

In addition, the work reported here suggests that the contribution to retention from the "occlusal" aspects of crowns cannot be ignored. The effect of including "occlusal" surface area is to alter the shape of the failure strength versus taper diagram slightly, and in critical cases such as that of polycarboxylate cement may turn an apparently monotonic relationship into one exhibiting a maximum value.

The reason for the presence of an optimum taper is unclear, but it may be speculated that it could for example have resulted from difficulty in extruding excess cement as the taper reduced, surface roughness effects at low taper, or changes in the site of cement failure, among others.

It was therefore considered necessary to investigate these possibilities by a series of experiments in which firstly the extrusion of excess cement was facilitated, secondly the surfaces of the dentine cones were examined

in detail, and finally the cement failure site was determined.

Experiment 7.2

To investigate the effect of facilitated cement extrusion on the retention of gold crowns with zinc phosphate cement.

In this experiment, cement extrusion was facilitated by a combination of die spacer and venting. The selected taper was 7^0 because it was considered to be the most critical in determining the presence or otherwise of an optimum taper, and was in least agreement with the data of Jorgensen[1] and Kaufman et al[2]. The cement chosen was zinc phosphate because it showed the most marked optimum taper. The results of the phosphate cement specimens also had the lowest standard deviation (SD = 12).

METHOD

The lathe was reset to 7^0, and 10 dentine cones were produced. Impressions were taken and dies produced in the standard way (Appendix 1). The first 5 dies had 4 coats of ADAPT-RITE die-spacer painted over the whole of the fitting surfaces. Gold crowns were constructed on these dies in the standard manner (Appendix 1). The other 5 dies were relieved in the conventional way leaving

1 mm at the margin uncoated. Gold crowns were cast and cleaned as described in Appendix 1. Each of the second group of crowns was vented by a hole drilled through the occlusal surface of the casting with a No 2 round bur. All of the crowns were then cemented and tested in the standard manner (Appendix 1).

RESULTS

The tolerances of the prepared dentine cones are shown in Appendix 2 table 7.19, and the complete data on retention is displayed in Appendix 2 tables 7.20 and 7.21. and summarised below:

Whole surface coated	Mean = 108 N	S.D. = 32	S.E. = 14
Vented	Mean = 119 N	S.D. = 37	S.E. = 16

DISCUSSION AND CONCLUSION

These results are not significantly different (p=0.05) from the previous retention tests for crowns cemented with zinc phosphate cement, and the presence of an optimum taper does not therefore appear to be the result of difficulty in extruding excess cement.

Experiment 7.3

To examine the prepared dentine cones for possible surface roughness effects at low taper.

METHOD

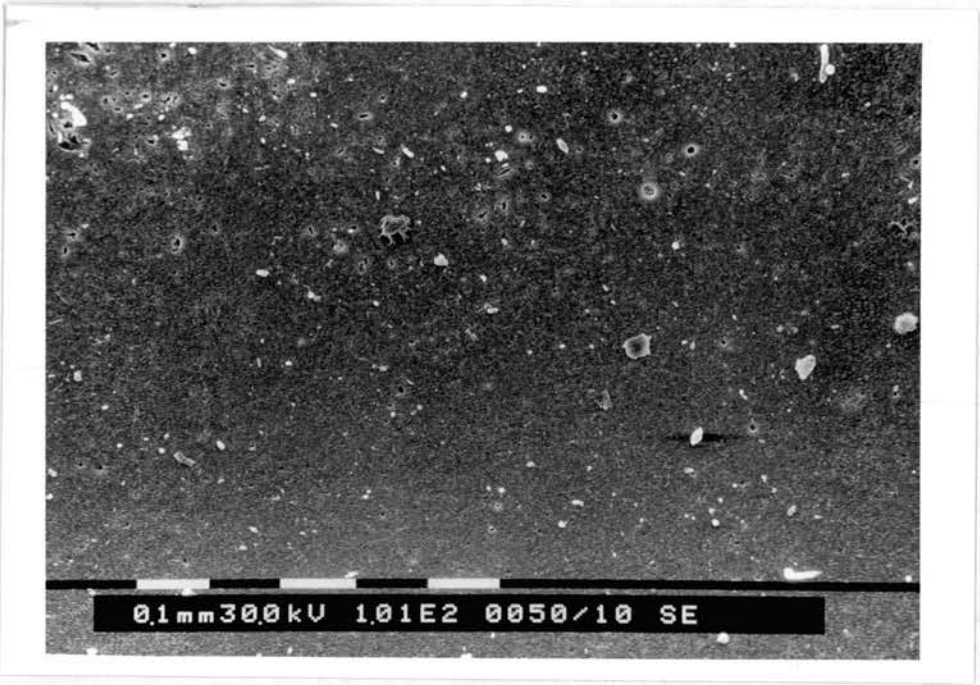
It has already been demonstrated elsewhere in this thesis that impressions of dentine cones are a good replica of the original, and may be used as reference models of the dentine surface (Experiment 3.3). A comparison was therefore made between cone surfaces of 7^0 and 15^0 taper by taking their impressions, prepared earlier in this thesis for crown construction, and sectioning, mounting, and examining them with a scanning electron microscope.

RESULTS

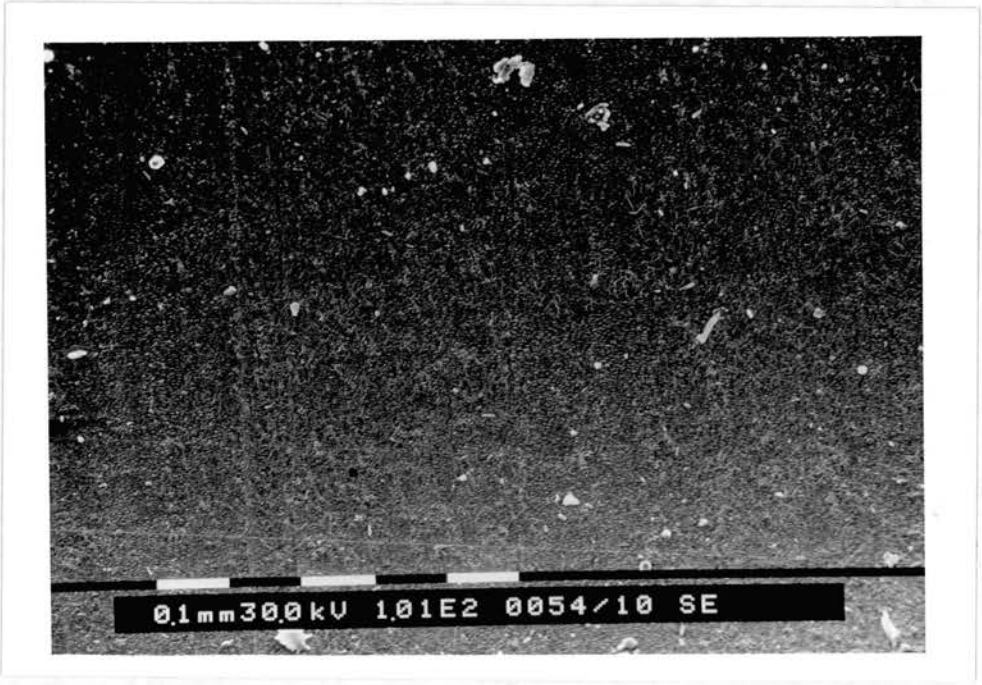
The S.E.M. photomicrographs are shown in Figs 7.15-7.18 and appear to be comparable with each other regardless of taper angle.

7.15 Electron-micrograph of a 7^0 taper sample (X95)

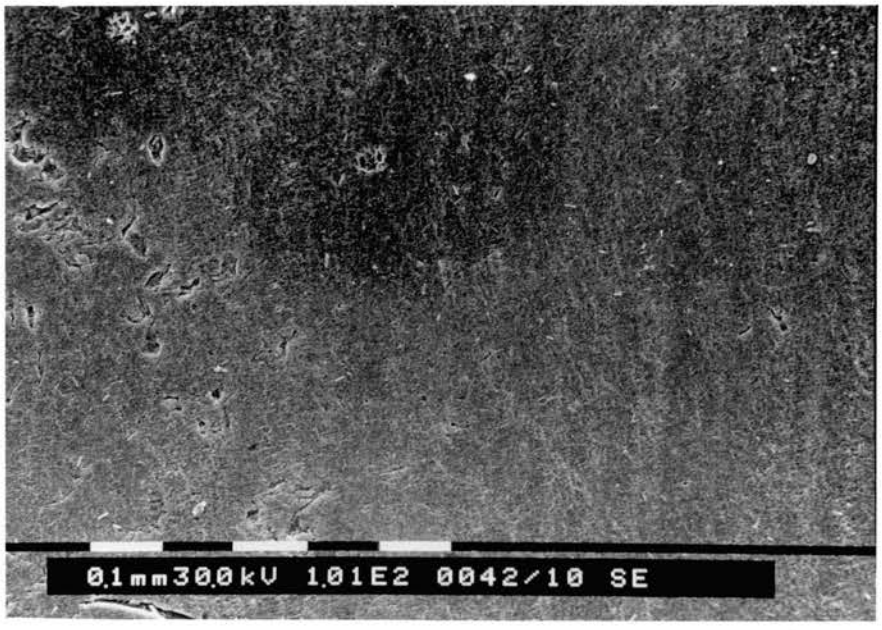
7.16 Electron-micrograph of a 15^0 taper sample (X95)



7.17 Electron-micrograph of a 23^0 taper sample (X95)



7.18 Electron-micrograph of a 30^0 taper sample (X95)



CONCLUSION

There do not appear to be any obvious surface anomalies which could account for the difference in retentive power with varying taper.

Experiment 7.4

To investigate the significance of cement failure site in the observation of optimum taper for gold crown retention

METHOD

The method is described in experiment 4.3.

RESULTS

The results of all experiments on failure site in this thesis are summarised in table 7.22.

Table 7.22

MEAN % OF CEMENT LEFT ON THE DENTINE AFTER THE REMOVAL OF THE GOLD CROWNS.

CEMENT	TAPER				ALL TAPERS COMBINED	
	7^0	15^0	23^0	30^0		
Zinc Phosphate	05%	07%	09%	09%	8%	SD = 5
Polycarboxylate	68%	34%	34%	36%	43%	SD = 25
Glass-ionomer	44%	81%	79%	73%	68%	SD = 26
Composite	05%	08%	18%	16%	11%	SD = 13

DISCUSSION

It would appear from table 7.22 that the composite and zinc phosphate cements failed predominantly at the cement/dentine interface.

The polycarboxylate cement was more variable but also tended to fail at the cement/dentine interface, leaving more cement on the dentine.

The glass-ionomer was more variable than the other

cements but tended to fail at the cement/gold interface.

These results are particularly interesting because they follow the same pattern as the observations on retention vs taper angle. For example, the evidence for an optimum taper is most pronounced in composite and zinc phosphate cements, and the same cements appear here to show the most pronounced failure at the cement/dentine interface. Glass-ionomer cement, on the other hand, shows no optimum taper and failure appears here to be more likely at the cement/gold interface.

The result for polycarboxylate cement is consistent with this pattern. In experiment 7.1 it was shown that in the case of polycarboxylate cement the inclusion of the "occlusal" surface in the calculation of total surface area turned an apparently monotonic relationship between retention and taper into one with an apparent maximum, and it was suggested that polycarboxylate cement might be a critical case in the evidence for an optimum taper. In the experiment reported here polycarboxylate cement again appears to be an intermediate case in which the evidence for predominance of one failure site is somewhat equivocal, but tends to favour the cement/dentine interface in keeping with composite and zinc phosphate cements.

It is tempting to infer from this that the site of failure is in some way connected to the appearance of an optimum taper for retention, and that there is no optimum

when failure occurs at the cement/gold interface. This view is supported by the work of Kaufman et al[2] who studied the retention of gold crowns on aluminium crown preparations and therefore inevitably had cement/metal failure. It is interesting to observe that when their results are shown on axes used in this thesis (Fig 7.14), the shape of the graph is very similar to that of glass-ionomer cement (Figs 7.4 and 7.8).

There may of course be other factors such as cement thickness involved, and failure site and taper may only be related indirectly through one or more of these factors. Further work is therefore required to determine these factors and their possible significance for future dental practice.

CONCLUSION

There may be a relationship between failure site and the observation of an optimum taper, such that the latter is associated with failure at the cement/dentine interface. The precise nature of this relationship is unclear however, and should form part of any further investigation in this field.

Comparison of the present results for zinc phosphate cement with previous literature reports.

The results presented in this thesis cast doubt on an accepted part of current dental practice, which was based largely on work by Jorgensen[1]. A question however arises as to why the results on retention presented here are several times greater than those of Jorgensen (and in deed Kaufman et al[2]), and the answer can be found in a comparison with some of the many literature reports in this subject by various workers. The most common cement studied has been zinc phosphate cement, and it is most relevant therefore to compare previous data for this cement with the data in this thesis.

In the present study the mean retentive force for dentine cones of 7^0 to 15^0 taper was found to be 184.4-230.4 g/mm^2 for the axial surface area, and 155.7-204.4 g/mm^2 for the total surface area. Jorgensen[1] however reported a retentive force of 41.1 g/mm^2 for a 10^0 taper with only an axial surface involved.

Kaufman et al[2], who similarly to Jorgensen[1] took no account of the "occlusal" surface, quoted retentive values for cones of 10^0 taper, and heights of 4, 7, and 10 mm, which convert to 65.1, 60.9, and 65.9 g/mm^2. The results of Kaufman et al are therefore are slightly higher than those of Jorgensen, but are of the same order of magnitude.

The most obvious difference between these reports and the current work is that neither Jorgensen[1] nor Kaufman et al[2] used crown preparations made from human dentine.

Jorgensen used cones of Galalith (a plastic moulding substance made of casein and formaldehyde) and crowns of turned brass, while Kaufman used aluminium cones and cast gold crowns. A better comparison of the current results would therefore be with reports of other workers who also used dentine specimens in the investigation of retention of dental restorations, as shown in table 7.23 for zinc phosphate cement.

Table 7.23

RETENTION OF DENTAL RESTORATIONS CEMENTED ON TO DENTINE PREPARATIONS WITH ZINC PHOSPHATE CEMENT (FOR TOTAL SURFACE AREA).

Taper	retention g/mm^2		reported by	year	
7^0	219	*!	RICHTER[23]	1970	
7^0	308/384		McCOMB[58]	1982	(INLAYS)
8^0	113		ARFIED[68]	1987	
10^0	212		OMAR[69]	1988	
10^0	370/610	*	OILO[62]	1978	
15^0	285.5		DHAL[67]	1986	

* = It is not clear if this was for axial or total surface area.

! = Extrapolated from a graph.

The results of the present study are of the same order of magnitude as the mean of these previous reports, supporting not only the data but also the view that experiments on retention should always involve human dental tissues, and casting further doubt on earlier work with non-biological materials.

A comment on the geometry of conic models for studies of retention

It is apparent that a number of workers in the field have ignored the contribution to retention from the "occlusal" surface of crown preparations. Of course, an idealised model for investigating the influence of taper would be a full cone as there would be no "occlusal" factor, but this would be impractical for human dentine due to the position of the pulp.

Examination of the work of Kaufman et al[2], where aluminium truncated cones were used, indicates that the "occlusal" surface may have an effect on retention. Kaufman et al claimed that "every unit of area on a prepared tooth surface having the same degree of convergence has the same retentiveness, regardless of the height of the inclined surface". This was derived from an experiment in which the base diameter and taper were kept constant and the height varied. Increase in height consequently reduced the "occlusal" area and hence reduced

the significance of any retention derived from the occlusal portion of the truncated cone.

If the calculations are repeated for total surface area the statement still holds as the component of retention from the "occlusal" portion of the preparation became less as the component of retention derived from the axial wall increases.

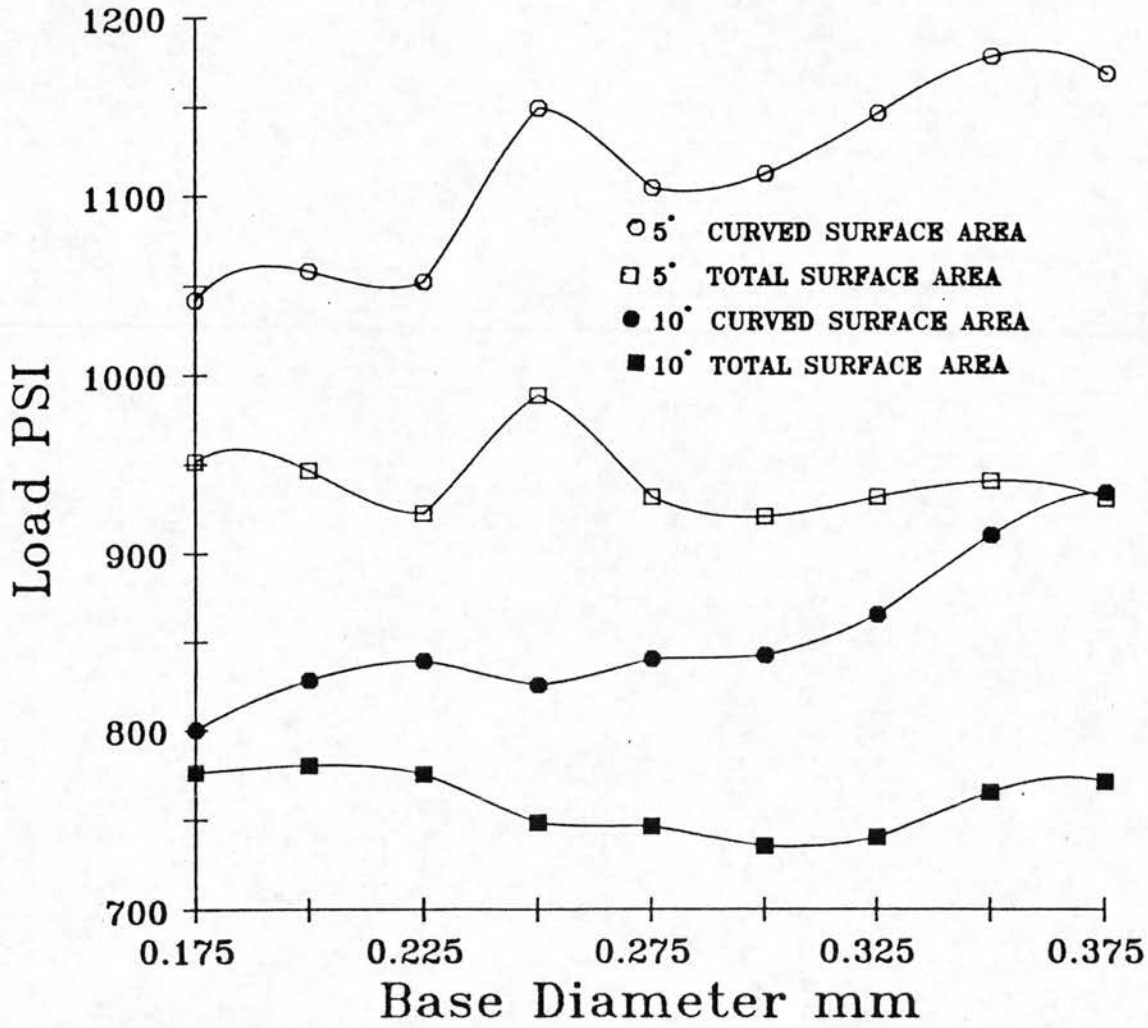
Kaufman et al[2] also state that "There is a linear increase in retention as the preparation increases in diameter" which was derived from comparing the retention of test pieces where the height and taper were kept constant and the diameter of the base (and therefore the "occlusal" surface) was increased. These two statements do not seem to be consistent and do not take into account the effect of the "occlusal" surface area.

If the calculations leading to the second statement are repeated using total surface area the "linear increase" is no longer apparent. The relationship between total surface area and retention becomes constant for each taper (Fig 7.19) in agreement with the first statement.

There remains considerable scope for manipulating cone geometry to shed further light on this important area of dental research. For example, although it is not feasible to prepare full cones from human dentine, it should be possible to control the geometry so that, for example, a parameter such as "occlusal" surface area is kept constant while axial area is varied. Alternatively,

it might be possible to keep axial surface area constant for a given taper while varying "occlusal" area, then extrapolating the data to zero "occlusal" area to simulate a full cone. In this way it might ultimately be possible to determine the separate contributions of axial and "occlusal" surfaces to the overall retention, and thereby their relative significances.

7.19 Mean retentive power of zinc phosphate cement using the data of Kaufman et al[2] to examine the effect of comparing axial and total surface area.



CHAPTER 8.

Felton, Kanoy and White[103] investigated the change in retention when cast crowns were recemented on to human dentine crown preparations of 5^0 taper using zinc phosphate cement. After removal of the crowns they cleaned the specimens with a solution of sodium bicarbonate in an ultrasonic cleaner for 30 minutes, and then with flour of pumice in a rubber cup. They reported no significant change in retention after one recementation.

The next experiments were designed to investigate the the effect of recementation on retention. The taper of the human dentine crown preparations chosen for these experiments was 23^0. This was felt to be a good taper for cement testing (and comparison) because it was within the clinical range (plus or minus 1 Standard Deviation) for all preparations where a gold casting could be used, except for those on lower canines (Chapter 2 table 2.31).

This taper is less than the mean taper which would produce exposure of the pulp of all teeth (Chapter 2 table 2.25). It is also less than the mean taper of those preparations with a 1 mm shoulder on the facial aspect of the teeth, except the upper lateral incisors (Chapter 2 table 2.26). Therefore a 23^0 taper would be consistent with clinical crown preparations.

The taper was considered to be adequate as a test of the cement while also reducing the number of fractures, of the dentine cones.

Experiment 8.1

To investigate the effect of recementing gold crowns to dentine cones using different cements.

METHOD

Seven dentine cone preparations (taper of 23^0) and gold crowns were produced for the phosphate cement, and 5 preparations for each of the polycarboxylate, glass-ionomer, and composite cements. The crowns were cemented, stored, and tested for retention in the standard manner (Appendix 1). The dimensions of the dentine cones, to which gold crowns were cemented with zinc phosphate and polycarboxylate, are shown in Appendix 2 table 8.1. The dimensions of those cemented with glass-ionomer and composite are shown in Appendix 2 table 8.2. and a summary of both tables is shown below.

Summary of Table 8.1 and 8.2

DIMENSIONS OF DENTINE CONES OF 23° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
Max	2.45	23.1	5.09
Min	2.22	22.8	4.99
Mean	2.40	23.0	5.03
SD	0.04	0.1	0.03

After the first retention tests cement was found in varying amounts on the dentine cones and on the fitting surfaces of the crowns. The cement was removed from the inside of the crowns using an ultrasonic bath filled with a solution of "TARTAR, LIGHT STAIN AND PERMANENT CEMENT REMOVER"*[49]. The cement was carefully removed from the dentine of the preparation with a Wards No 2 carver (simulating clinical practice).

The dentine cone was washed with deionised water and the inside of the crown cleaned with Propan-1-ol. The crowns were recemented with the same cement, stored for 24 h, and the retention test repeated in the standard manner (Appendix 1). This recementation regime was repeated 6 times.

RESULTS

The results of the retention tests are shown in Appendix 2 tables 8.3 to 8.30. and are summarised below in tables 8.31 to 8.34 and plotted in Figs 8.1 to 8.4.

Table 8.31

THE MEAN RETENTIVE VALUE (N) OF GOLD CROWNS REPEATEDLY CEMENTED TO 23° TAPER DENTINE CONES WITH ZINC PHOSPHATE CEMENT.

	MEAN	No	SD	SE
CEMENTATION	79	7	15	6
RECEMENTATION 1	86	7	29	11
RECEMENTATION 2	127	7	28	10
RECEMENTATION 3	96	7	25	9
RECEMENTATION 4	112	7	25	10
RECEMENTATION 5	116	7	32	12
RECEMENTATION 6	103	7	22	9

No = Number of specimens tested.

Table 8.32

THE MEAN RETENTIVE VALUE IN NEWTONS OF GOLD CROWNS REPEATEDLY CEMENTED TO 23° TAPER DENTINE CONES WITH POLYCARBOXYLATE CEMENT.

	MEAN	No	SD	SE
CEMENTATION	201	5	43	19
RECEMENTATION 1	217	5	68	31
RECEMENTATION 2	223	5	42	19
RECEMENTATION 3	233	4	27	13
RECEMENTATION 4	282	4	62	31
RECEMENTATION 5	272	4	40	20
RECEMENTATION 6	293	3	15	9

No = Number of specimens tested.

Table 8.33

THE MEAN RETENTIVE VALUE IN NEWTONS OF GOLD CROWNS REPEATEDLY CEMENTED TO 23° TAPER DENTINE CONES WITH GLASS-IONOMER CEMENT.

	MEAN	No	SD	SE
CEMENTATION	184	5	49	22
RECEMENTATION 1	290	5	74	33
RECEMENTATION 2	205	3	82	47
RECEMENTATION 3	230	1	--	--
RECEMENTATION 4	68	1	--	--
RECEMENTATION 5	116	1	--	--
RECEMENTATION 6	182	1	--	--

No = Number of specimens tested.

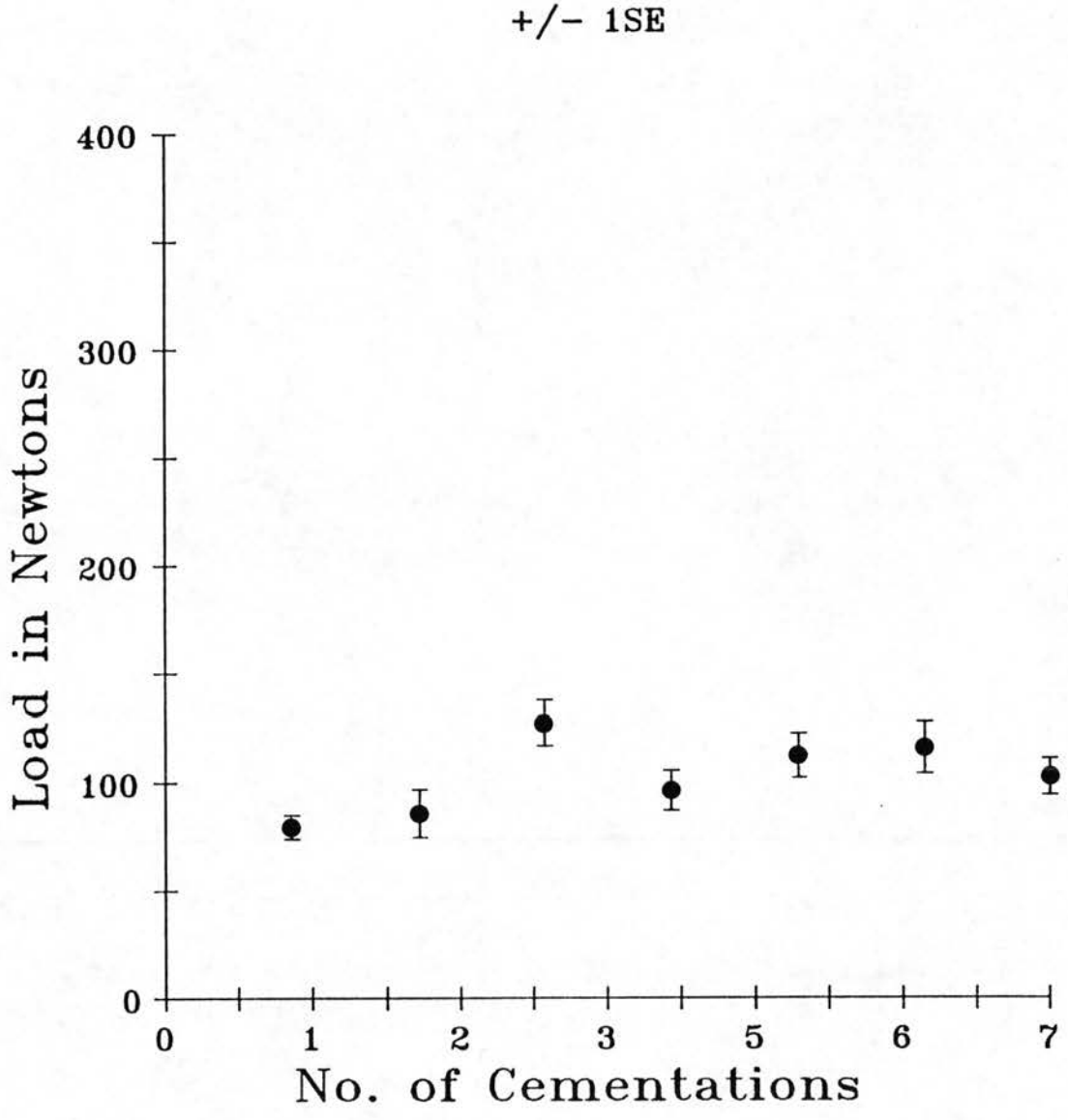
Table 8.34

THE MEAN RETENTIVE VALUE IN NEWTONS OF GOLD CROWNS REPEATEDLY CEMENTED TO 23° TAPER DENTINE CONES WITH COMPOSITE CEMENT.

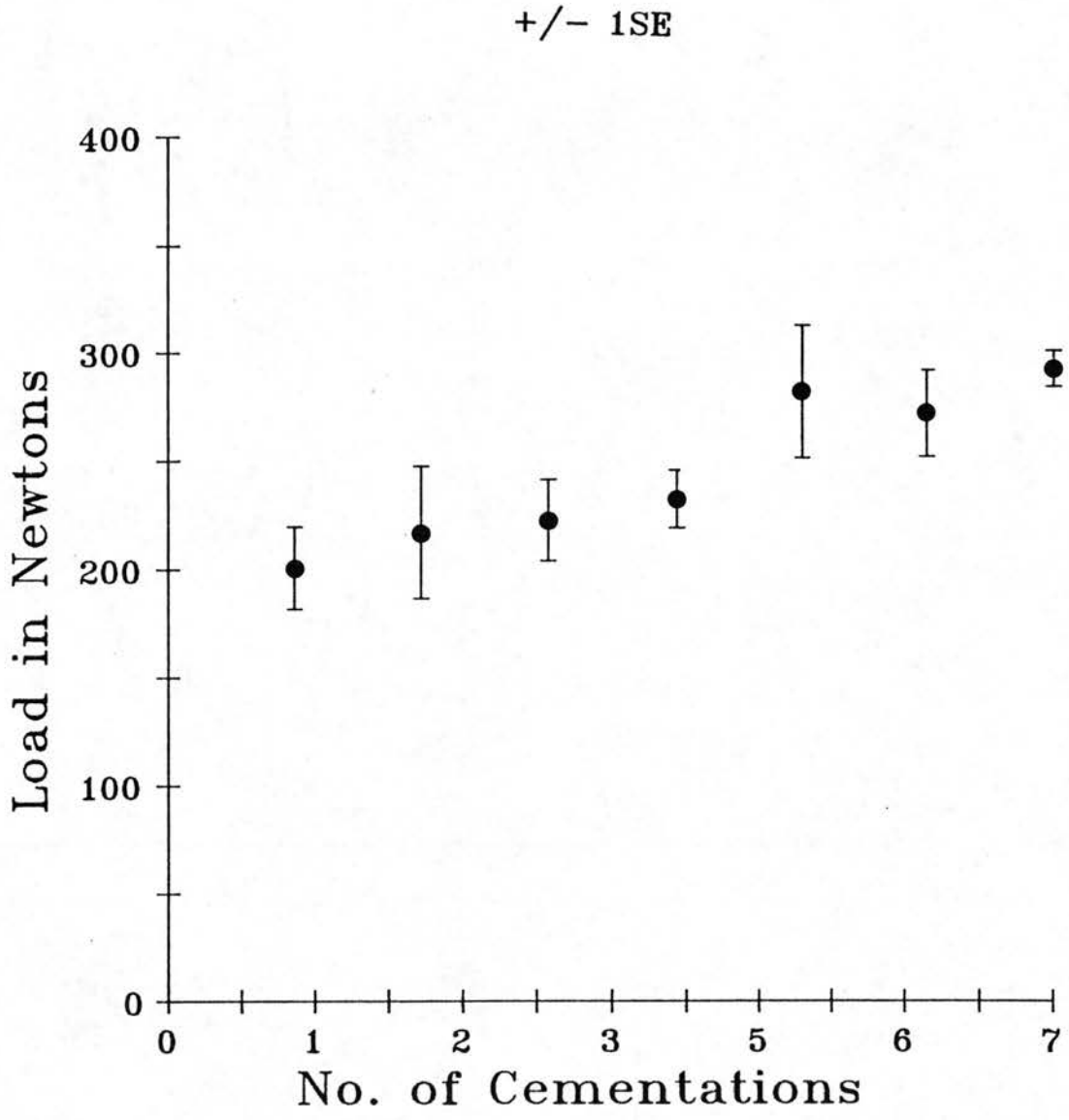
	MEAN	No	SD	SE
CEMENTATION	292	5	58	26
RECEMENTATION 1	357	3	84	49
RECEMENTATION 2	225	2	72	51
RECEMENTATION 3	295	2	140	99
RECEMENTATION 4	262	2	133	94
RECEMENTATION 5	128	2	37	26
RECEMENTATION 6	181	2	117	83

No = Number of specimens tested.

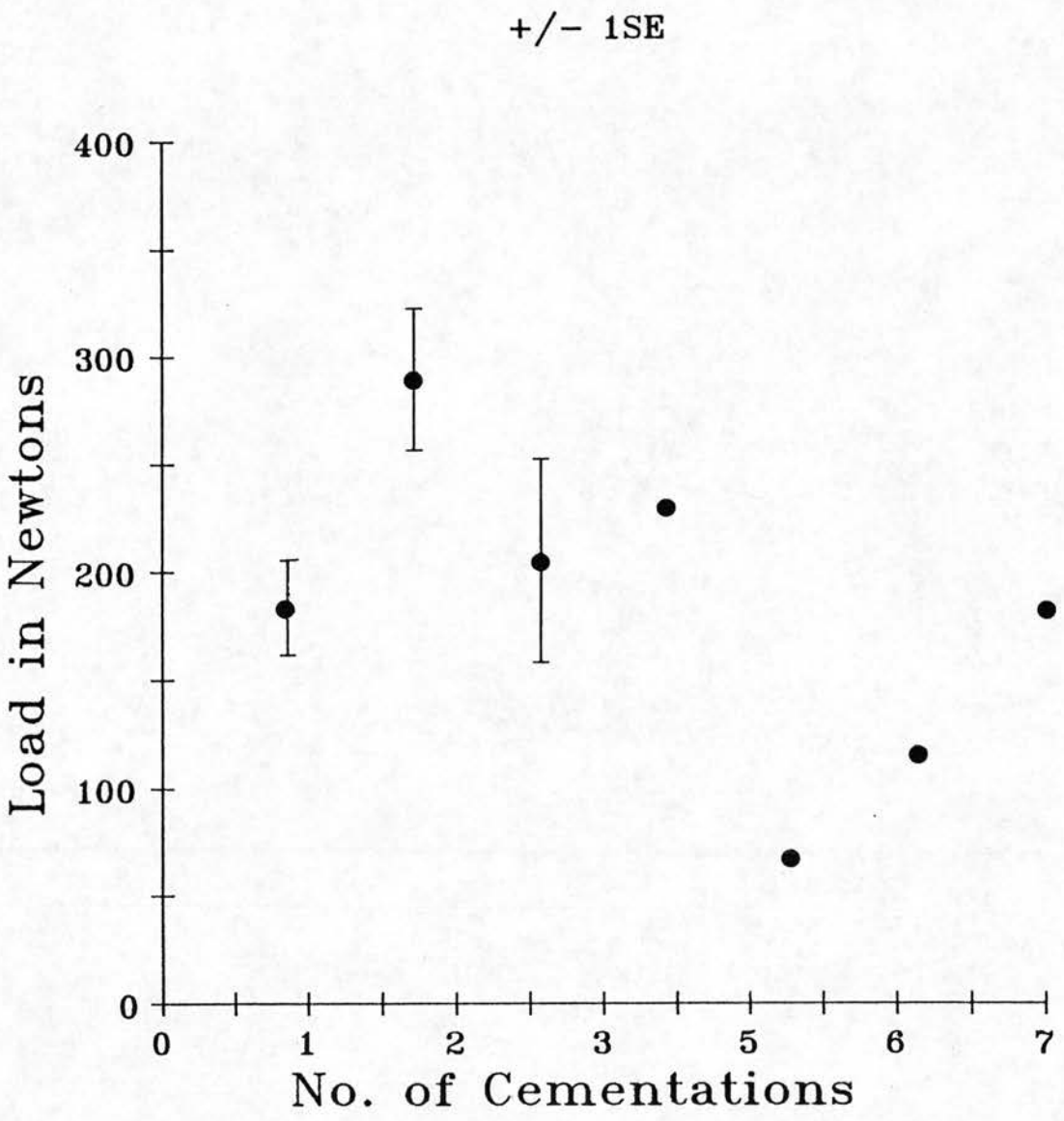
8.1 Mean retentive power of zinc phosphate cement related to recementation.



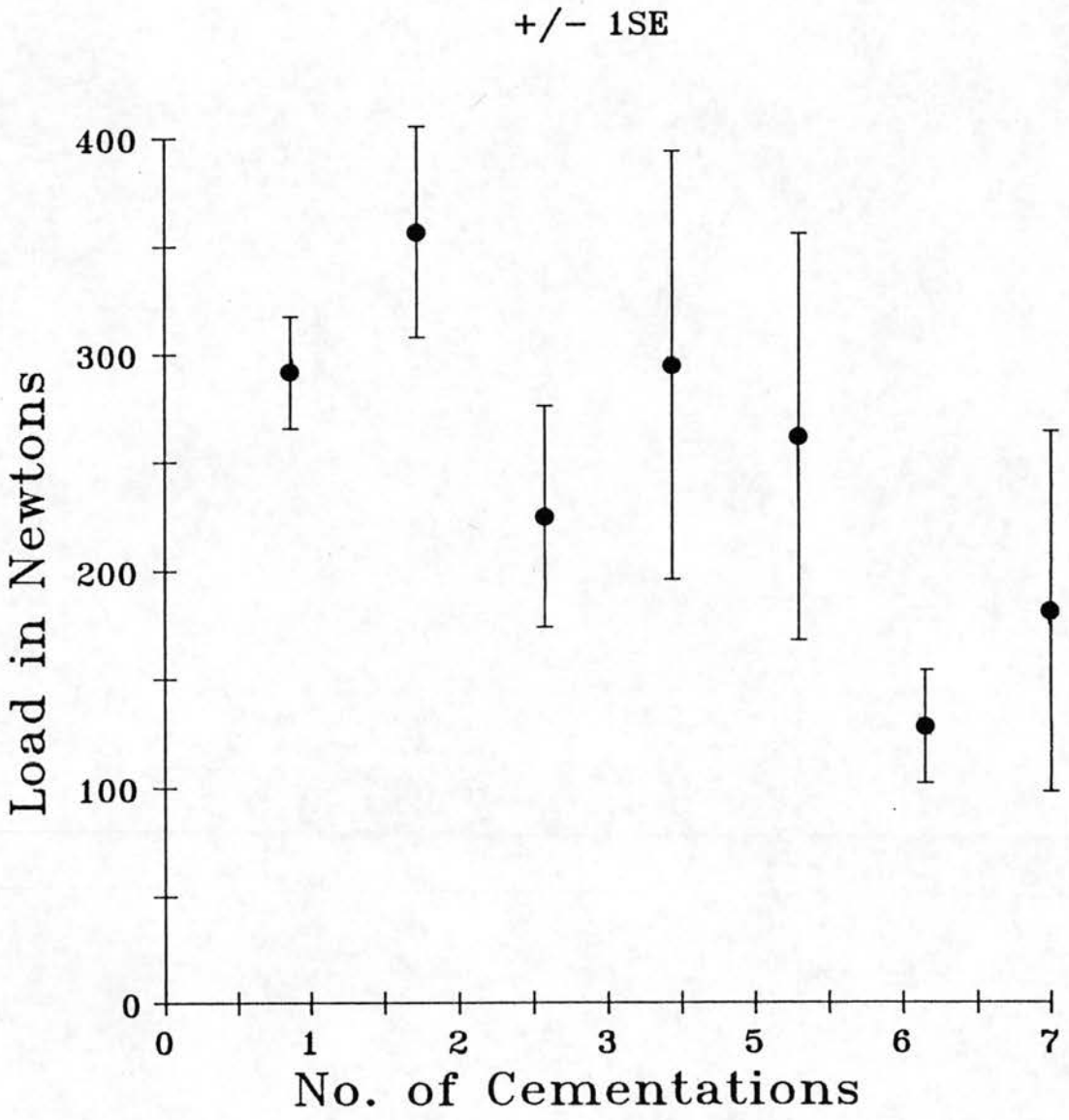
8.2 Mean retentive power of polycarboxylate cement related to recementation.



8.3 Mean retentive power of glass-ionomer cement related to recementation.



8.4 Mean retentive power of composite cement related to recementation.



DISCUSSION

The retentive power of all the cements tested showed an initial increase in retention with the first recementation although none of these increases in retention were of statistical significance.

The specimens cemented with glass-ionomer and composite cements after the initial increase in retention both showed a reduction in retention but none of these values are significantly different from the retentive value of the first cementation. This is partly due to the large number of sample failures producing relatively large standard errors.

The specimens cemented with polycarboxylate cement showed a steady increase in the retentive power of the cement with the sixth recementation significantly more retentive than the initial cementation ($p = 0.036$ using Wilcoxon rank sum test).

In the zinc phosphate recementation Experiment 7, extra tests were done to use the extra dentine cones which had been made to compensate for the expected loss of cones due to exposure of the pulps. Experience had also shown that the results from the zinc phosphate cements were more consistent and therefore the increase in sample size was likely to enhance the chance of showing significant differences between the cementations.

The retentive power of the zinc phosphate cement

continued to increase with the second recementation achieving a level significantly more retentive than the initial cementation. The increased retentive value dropped below a significant increase with the third recementation, before climbing into significantly more retentive values with the fourth and fifth recementations. The retentive value of the sixth recementation dropped to value not significantly higher than the initial cementation.

There are many factors such as dentine smear layer or surface roughness which could potentially affect crown retention on recementation, although the variations reported here are in fact quite small. It is difficult to determine which of the factors are actually involved, although it is possible to speculate that any increase in retention on recementation may be linked to the problem of dentine smear layer. If such a layer were present in part or in whole on the original crown preparation, it could well interfere with the retentive process. Subsequent crown removal might also remove part or all of this smear layer so that recementation is on a cleaner dentine surface. This is however only one possible explanation of any rise in retention on recementation. An equally valid explanation would be that the removal of cement from the dentine surface increases its roughness and results in improved micro-mechanical retention. In any event, the reason for the apparent decrease in retention in some

recementations remains unclear. The resolution of this problem would form an excellent basis for any further work in this area.

Experiment 8.2

To examine the surface of dentine samples after the removal of luting cements prior to recementation.

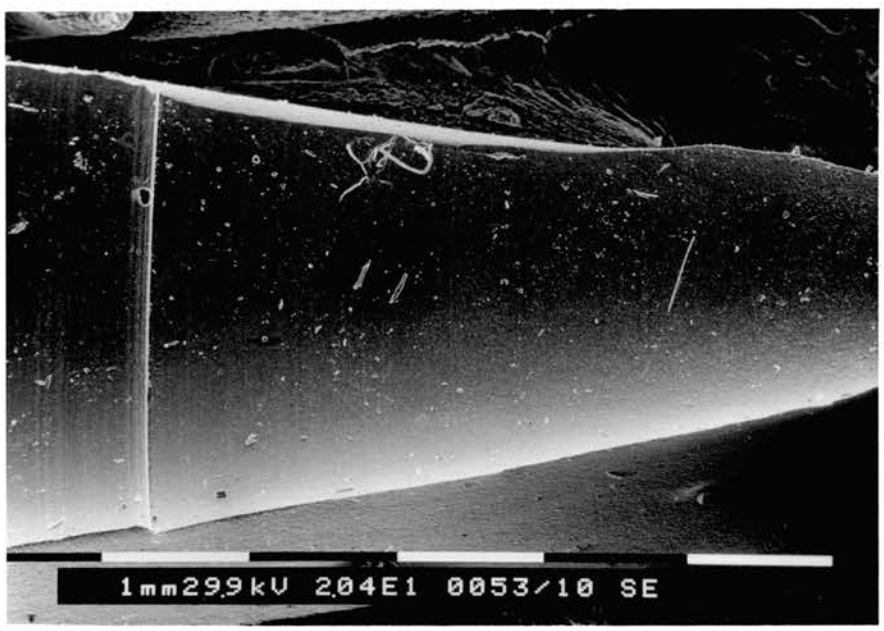
METHOD

The EXTRUDE impressions of the dentine cones were prepared and examined with a S.E.M. as described in Experiment 3.3.

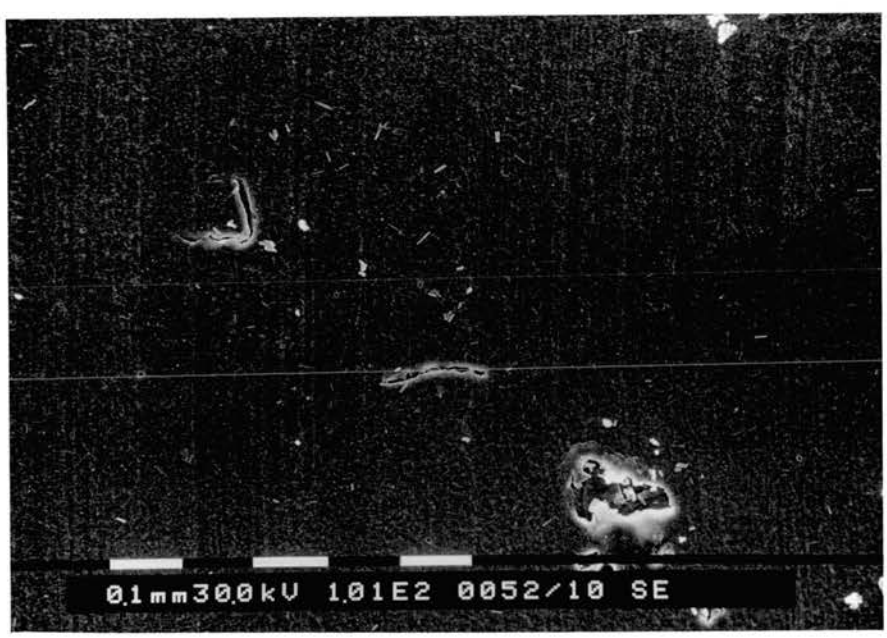
RESULTS AND DISCUSSION

Figures 8.5 and 8.6 show the typical S.E.M. appearance of dentine cones prior to cementation. Figures 8.7 to 8.10 show the appearance of dentine cones after cement removal, and Figs 8.11 to 8.14 show the appearance of the dentine after repeated removal of cement.

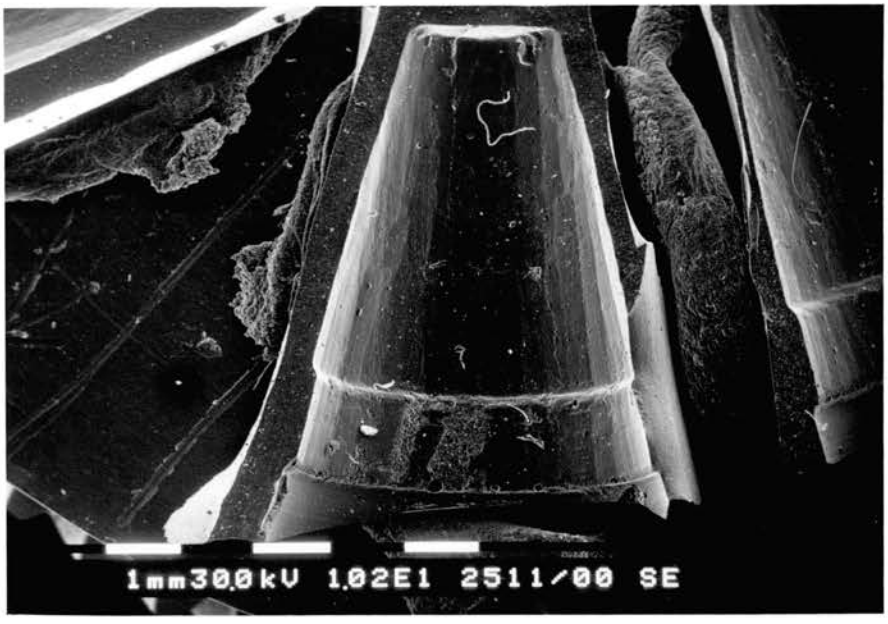
8.5 Electron-micrograph of a 23° taper dentine cone before cementation (x 19.5).



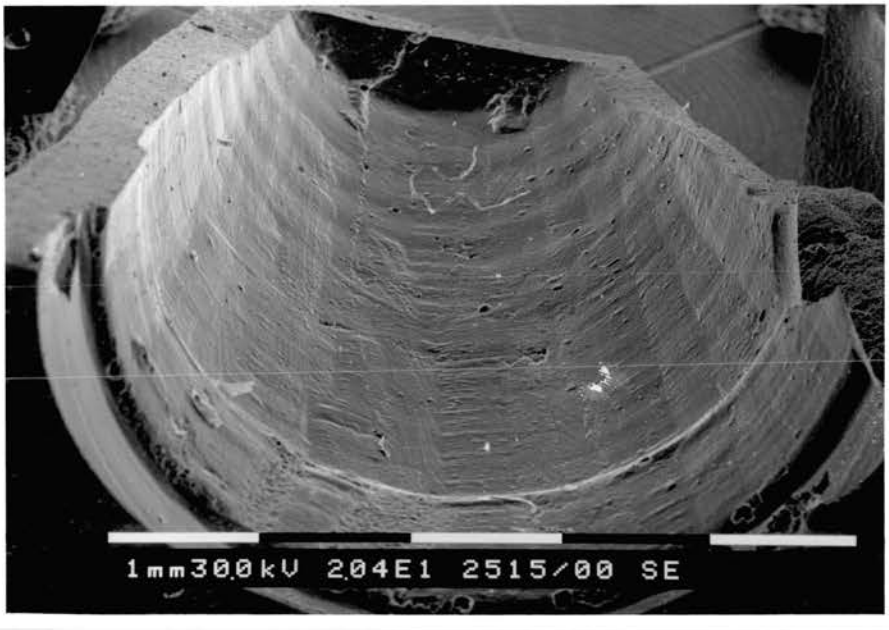
8.6 Electron-micrograph of a 23° taper dentine cone before cementation (x 95).



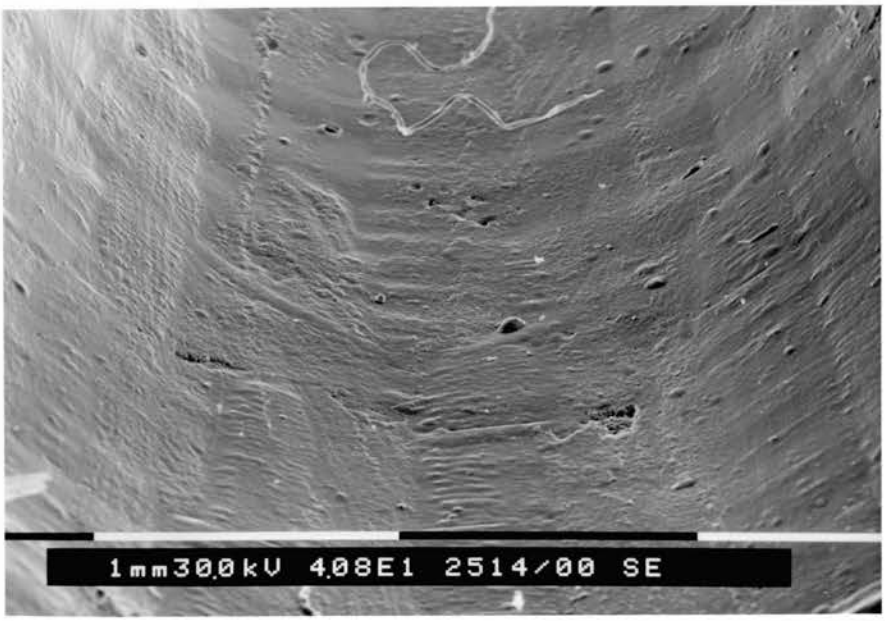
8.7 Electron-micrograph of a 23° taper dentine cone after cementation and cement removal (x 9.7).



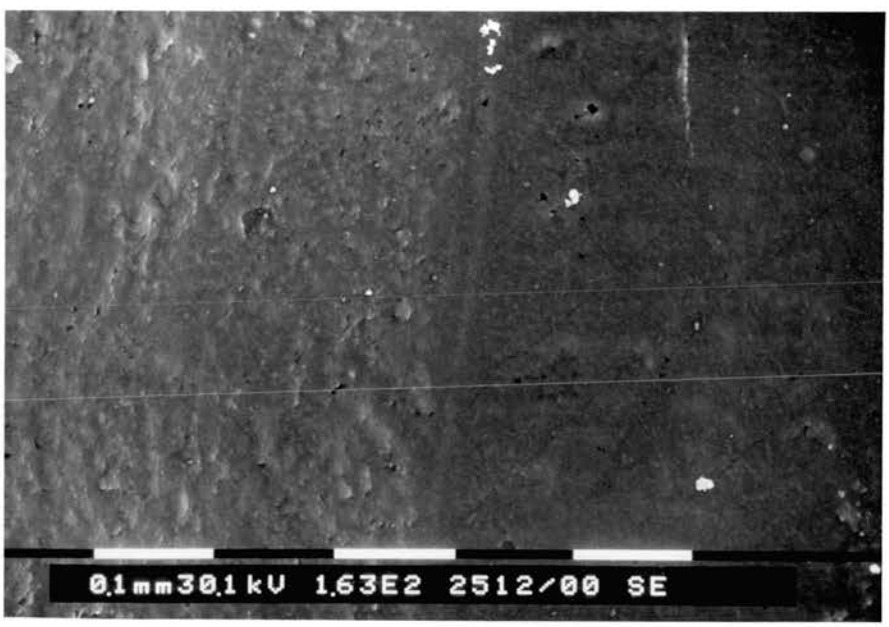
8.8 Electron-micrograph of a 23° taper dentine cone after cementation and cement removal oblique view (x 19.3).



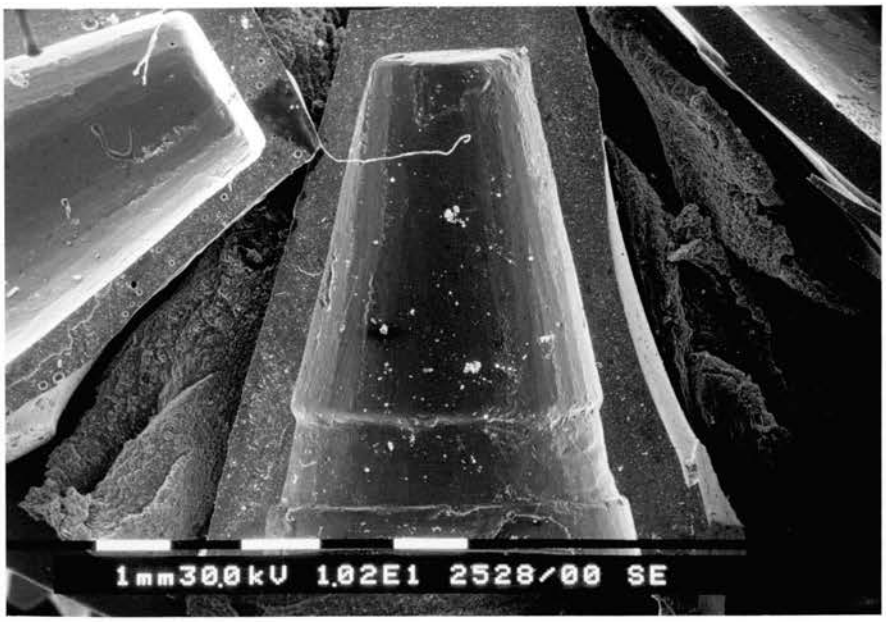
8.9 Electron-micrograph of a 23° taper dentine cone after cementation and cement removal oblique view (x 38.6).



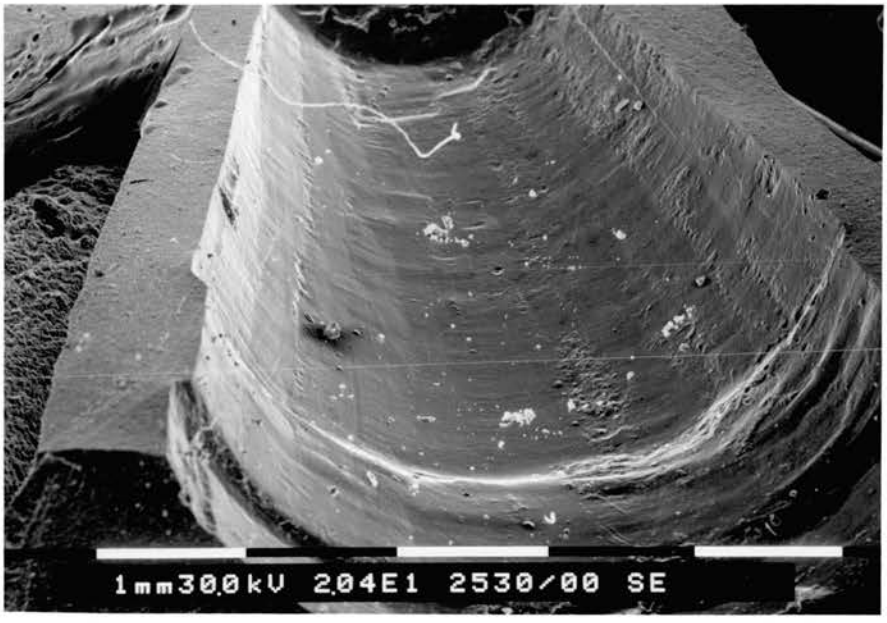
8.10 Electron-micrograph of a 23° dentine cone taper after cementation and cement removal oblique view (x 150).



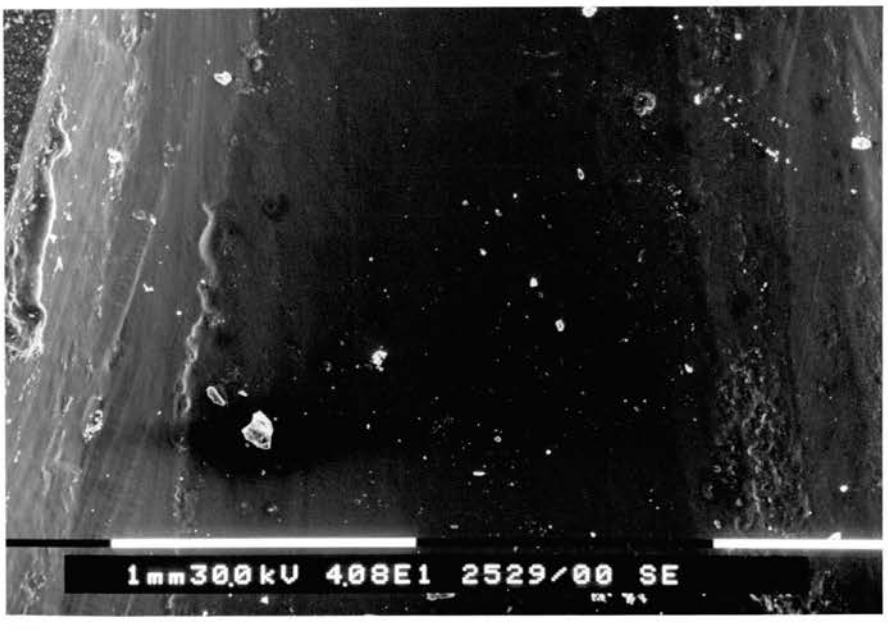
8.11 Electron-micrograph of a 23º taper dentine cone after repeated cementations and cement removal (x 9.7).



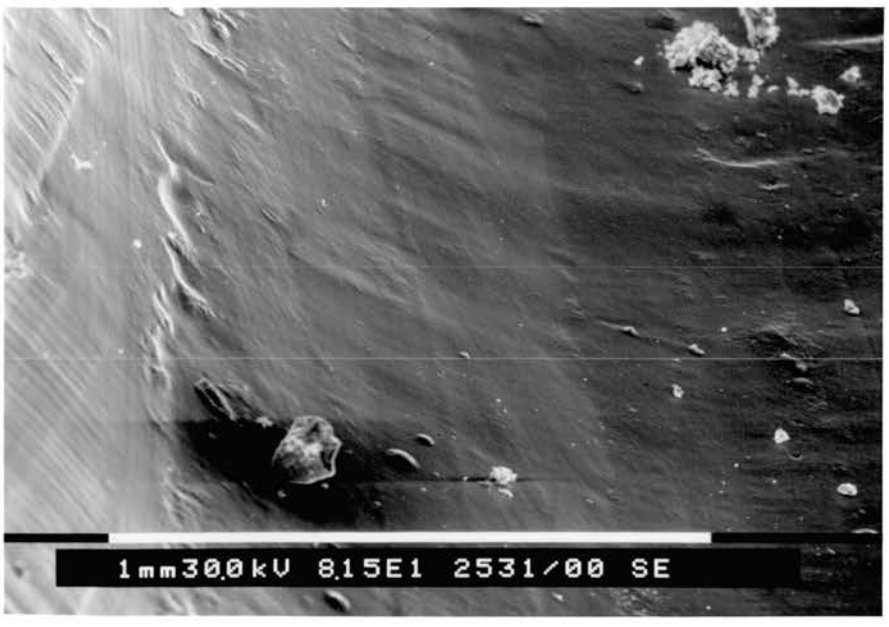
8.12 Electron-micrograph of a 23º taper dentine cone after repeated cementations and cement removal oblique view (x 19.5).



8.13 Electron-micrograph of a 23° taper dentine cone after repeated cementations and cement removal oblique view (x 38.6).



8.14 Electron-micrograph of a 23° taper after repeated cementations and cement removal oblique view (x 76.1).



These micrographs showed that the first removal of cement altered the surface of the dentine but subsequent removals of cement did not appear to have much effect. This would support the view that surface roughness is involved in alteration in retention. Any dentine smear layer may then also be important because its removal would affect surface roughness and hence retention. This may not be the only effect of any dentine smear layer however, and the contributions of surface roughness and smear layer to retention should be clarified by further study.

CONCLUSIONS (Experiments 8.1 and 8.2)

The reasons for the apparent initial increase in retentive power of all cements remains unclear, but if it were due to the roughening of the dentine surfaces it would be in accord with Oilo and Jorgensen[62] who reported an increase in retention with an increase in surface roughness.

While the reasons for the changes in retention remain a subject for speculation, what is clear is that recementation is acceptable in the absence of any obvious clinical contraindication.

Experiment 8.3.

Collation of the available data from the use of dentine cones of 23° taper.

METHOD

As 23^0 taper dentine cones were considered to be suitable preparations to test the retention of gold crowns cemented with different cements, the data from all specimens of these dimensions were collated and analysed.

RESULTS

The initial retentive values from Experiment 8.1 when compared with the same cements on the 23^0 taper preparations in Experiment 7.1. (tables 7.8 to 7.11) showed no significant differences between the two sets of results.

The order of ranking for retentive power from both experiments was the same, (highest composite, second polycarboxylate, third glass-ionomer, and worst zinc phosphate) as shown in tables 8.35 and 8.36.

Table 8.35

RANKING OF THE RETENTION OF CEMENTS USED TO CEMENT GOLD CROWNS ON TO 23° TAPER HUMAN DENTINE CONES (CHAPTER 7).

CEMENT	MEAN	SD	SE
Composite	216 N	78	35
Polycarboxylate	174 N	44	20
Glass-ionomer	132 N	39	18
Zinc phosphate	78 N	17	7

Table 8.36

RANKING OF THE RETENTION OF CEMENTS USED TO CEMENT GOLD CROWNS ON TO 23° TAPER HUMAN DENTINE CONES (CHAPTER 8).

CEMENT	MEAN	SD	SE
Composite	292 N	58	26
Polycarboxylate	201 N	43	19
Glass-ionomer	184 N	49	22
Zinc phosphate	79 N	15	6

Statistical analysis of the results from Chapter 7 show the zinc phosphate cement to be less retentive than all the other cements, but fails to show any other significant differences (table 8.37).

Table 8.37

SIGNIFICANCE AND P STATISTIC PRODUCED WHEN COMPARING THE RETENTION OF DIFFERENT CEMENTS USED TO CEMENT GOLD CROWNS TO HUMAN DENTINE CONES OF 23° TAPER (CHAPTER 7).

	Zinc phosphate	Poly carboxylate	Glass-ionomer	Composite
Zinc phosphate	\\	Sig	Sig	Sig
Polycarboxylate	.008	\\	NSig	NSig
Glass-ionomer	.016	.151	\\	NSig
Composite	.016	.426	.151	\\

Sig = Statistically significant difference.

NSig = No Statistically significant difference.

Statistical analysis of the results from Chapter 8 also shows the zinc phosphate cement to be significantly less retentive than all the other cements used.

It also shows the composite cement to be significantly more retentive than all the other cements used (table 8.38).

There was no significant difference between the polycarboxylate and glass-ionomer cements.

Table 8.38

SIGNIFICANCE AND P STATISTIC PRODUCED WHEN COMPARING THE RETENTION OF DIFFERENT CEMENTS USED TO CEMENT GOLD CROWNS TO HUMAN DENTINE CONES OF 23° TAPER (CHAPTER 8).

	Zinc phosphate	Poly carboxylate	Glass-ionomer	Composite
Zinc phosphate	\\	Sig	Sig	Sig
Polycarboxylate	.003	\\	NSig	Sig
Glass-ionomer	.003	.691	\\	Sig
Composite	.003	.032	.016	\\

Tables 8.39 and 8.40 show the effect of pooling the results from the two sets of experiments to increase the sample size. This confirmed the results obtained from the final experiment because the p statistic was slightly more significant (table 8.40). Pooling did not however demonstrate any further significances.

Table 8.39

RANKING OF THE RETENTION OF CEMENTS USED TO CEMENT GOLD CROWNS ON TO 23° TAPER HUMAN DENTINE CONES (CHAPTERS 7 AND 8).

CEMENT	MEAN	SD	SE
Composite	254	76	24
Polycarboxylate	187	43	14
Glass-ionomer	158	50	16
Zinc phosphate	79	15	4

Table 8.40

SIGNIFICANCE AND P STATISTIC PRODUCED WHEN COMPARING THE RETENTION OF DIFFERENT CEMENTS USED TO CEMENT GOLD CROWNS TO HUMAN DENTINE CONES OF 23° TAPER (CHAPTER 7 AND 8).

	Zinc phosphate	Poly carboxylate	glass-ionomer	composite
Zinc phosphate	\\	Sig	Sig	Sig
Polycarboxylate	.000	\\	NSig	Sig
Glass-ionomer	.000	.190	\\	Sig
Composite	.000	.023	.005	\\

These experiments showed that the best of these cement types to use as a lute for gold crowns to human dentine was composite. The next best were polycarboxylate or glass-ionomer, and the worst was zinc phosphate cement.

CHAPTER 9.

A comparison of the results from the in-vitro experiments reported in this thesis, with the survival of crowns, cemented with different materials, from a clinical study by Black and Charlton[113].

Experiment 8.1

To assess the clinical life expectancy of crowns and bridges cemented with 4 different cement types.

METHOD

The records of crown and bridge patients treated at Edinburgh Dental Hospital from 25/3/83 to 20/2/85 were scrutinized. All the patients included in this study had regular follow-up appointments from 6 months up to almost 7 years. Those patients who did not attend for a dental examination during the last 6 months of the investigation were sent a questionnaire, which was as simple as possible (Fig 9.1), together with a stamped addressed envelope.

9.1. Questionnaire sent to patients who had crowns and/or bridges cemented at Edinburgh Dental Hospital 1980-88.

Our records show that you had a crown fitted onto your tooth or teeth (described in lay terms)

ON ___/___/___(date)

I would be most grateful if you could answer the following questions.

1. Is the crown all right as far as you know

Yes/No

2. If the crown failed when did it fail. Please give month and year if possible.

..... Month .....Year

3. If you would like a dental inspection please delete as appropriate.

I would/would not like to have a dental inspection

During the last 6 months of the study;

430 (51.5 %) restorations were examined.

169 (21.6 %) Restorations were reported by questionnaire.

210 (26.9 %) Restorations were lost from the study at this stage.

This investigation followed a total of 132 bridges, 534 crowns, 116 post crowns; cemented with polycarboxylate, glass-ionomer, zinc phosphate, or zinc oxide/eugenol reinforced EBA cements over an 8 year period, with patients entering and leaving the study at different

times. The periods of study for each of the cements were:

1. Polycarboxylates . . . . 84 months
2. Glass-ionomers . . . . 70 months
3. Zinc phosphates . . . . 84 months
4. Zinc oxide/eugenol, EBA . . . 89 months

The data was stored in a database on a main-frame computer and was examined using a survival analysis technique described by Brown et al[114], to allow for the loss of patients from the study and of those entering at different times.

RESULTS

The results are listed in Tables 9.1 to 9.4. and shown in the graphs Figs 9.2 to 9.5.

Table 9.1.

ESTIMATED PERCENTAGE SURVIVAL FOR ALL RESTORATIONS AT 1, 2 AND 5 YEARS. STANDARD ERROR IN BRACKETS

	YEAR 1	YEAR 2	YEAR 5
Polycarboxylate . .	96.9 (0.9)	91.4 (1.5)	81.7 (2.4)
Glass-ionomer . .	92.7 (2.0)	87.1 (2.7)	74.8 (4.2)
Zinc phosphate . .	91.9 (2.3)	85.9 (2.9)	68.7 (4.8)
Zinc oxide/eugenol EBA.	57.1 (1.9)	57.1 (1.9)	42.9 (1.9)

Table 9.2.

ESTIMATED PERCENTAGE SURVIVAL FOR BRIDGES AT 1, 2 AND 5 YEARS. STANDARD ERROR IN BRACKETS

	YEAR 1	YEAR 2	YEAR 5
Polycarboxylate . .	98.5 (1.50)	95.2 (2.7)	87.6 (5.0)
Glass-ionomer . .	96.6 (3.4)	96.6 (3.4)	91.6 (5.8)
Zinc phosphate . .	100 (0.0)	86.7 (8.8)	60.5 (1.4)
Zinc oxide/eugenol EBA.	50.0 (2.5)	50.0 (2.5)	50.0 (2.5)

Table 9.3.

ESTIMATED PERCENTAGE SURVIVAL FOR CROWNS AT 1, 2 AND 5 YEARS. STANDARD ERROR IN BRACKETS

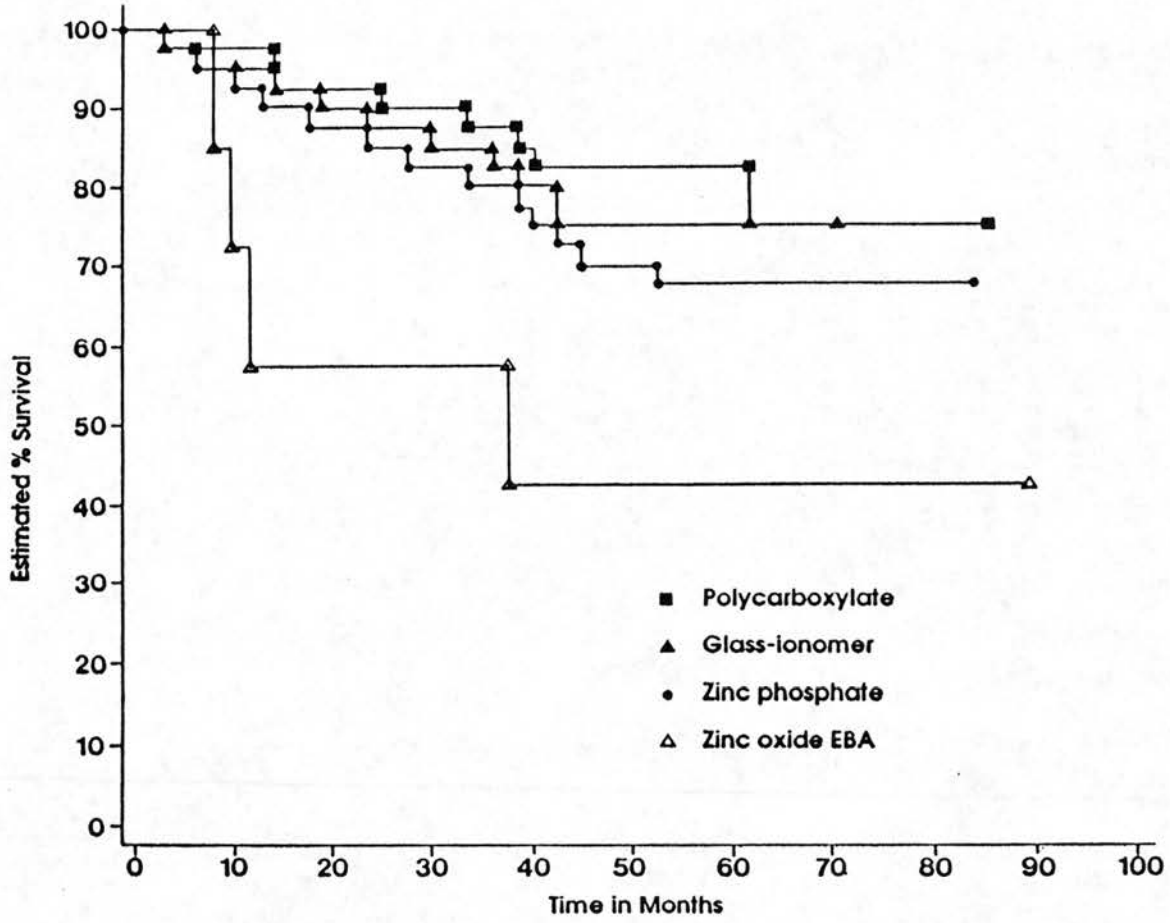
	YEAR 1	YEAR 2	YEAR 5
Polycarboxylate . .	97.4 (1.6)	92.8 (1.7)	83.8 (2.7)
Glass-ionomer . .	95.7 (1.9)	89.9 (2.9)	77.4 (4.9)
Zinc phosphate . .	91.9 (2.9)	89.5 (3.3)	73.1 (6.0)
Zinc oxide/eugenol EBA.	100 (0.0)	100 (0.0)	50.0 (3.5)

Table 9.4.

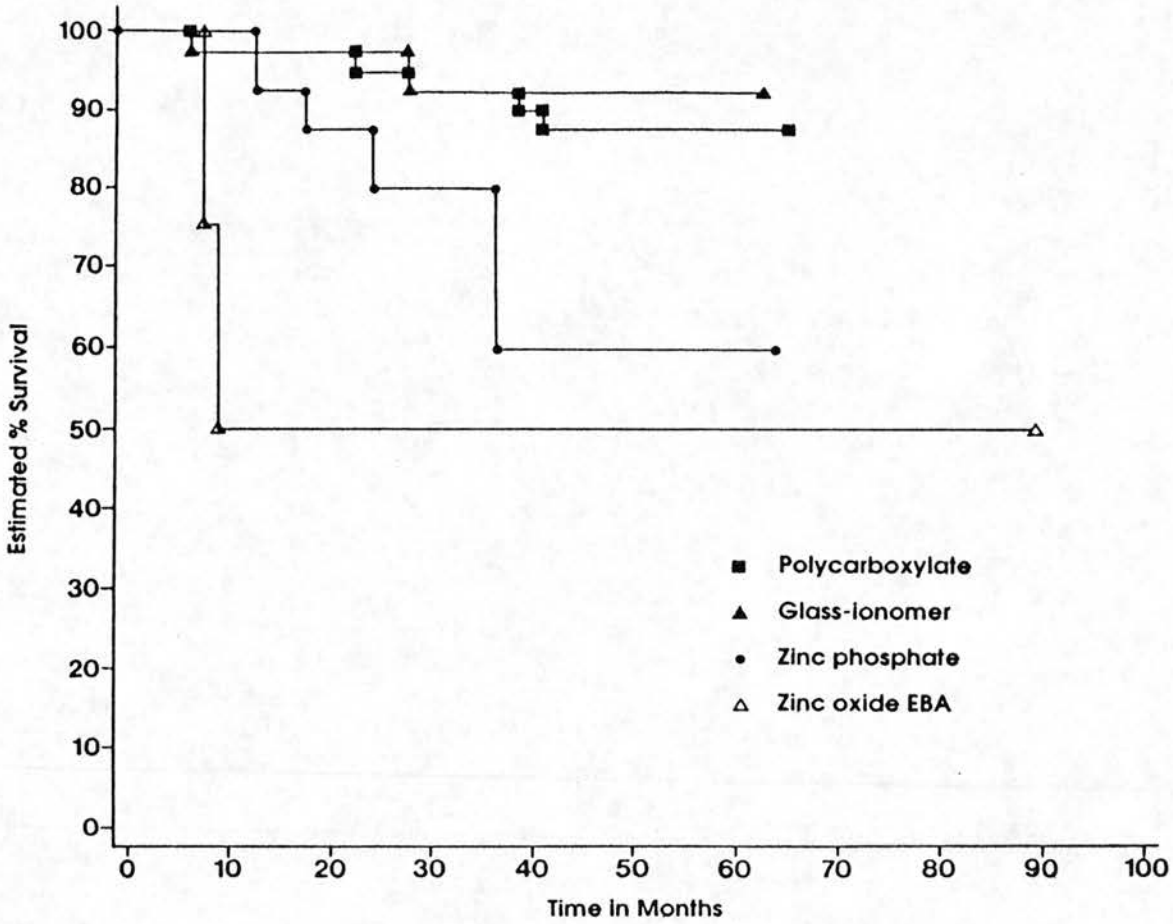
ESTIMATED PERCENTAGE SURVIVAL FOR POST CROWNS AT 1, 2 AND 4.6 YEARS. STANDARD ERROR IN BRACKETS

	YEAR 1	YEAR 2	YEAR 4.6
Polycarboxylate . .	83.2 (5.8)	78.2 (6.4)	53.9 (1.1)
Glass-ionomer . .	65.2 (1.2)	51.0 (1.3)	25.5 (1.4)
Zinc phosphate . .	88.4 (4.9)	77.0 (6.8)	65.7 (4.8)

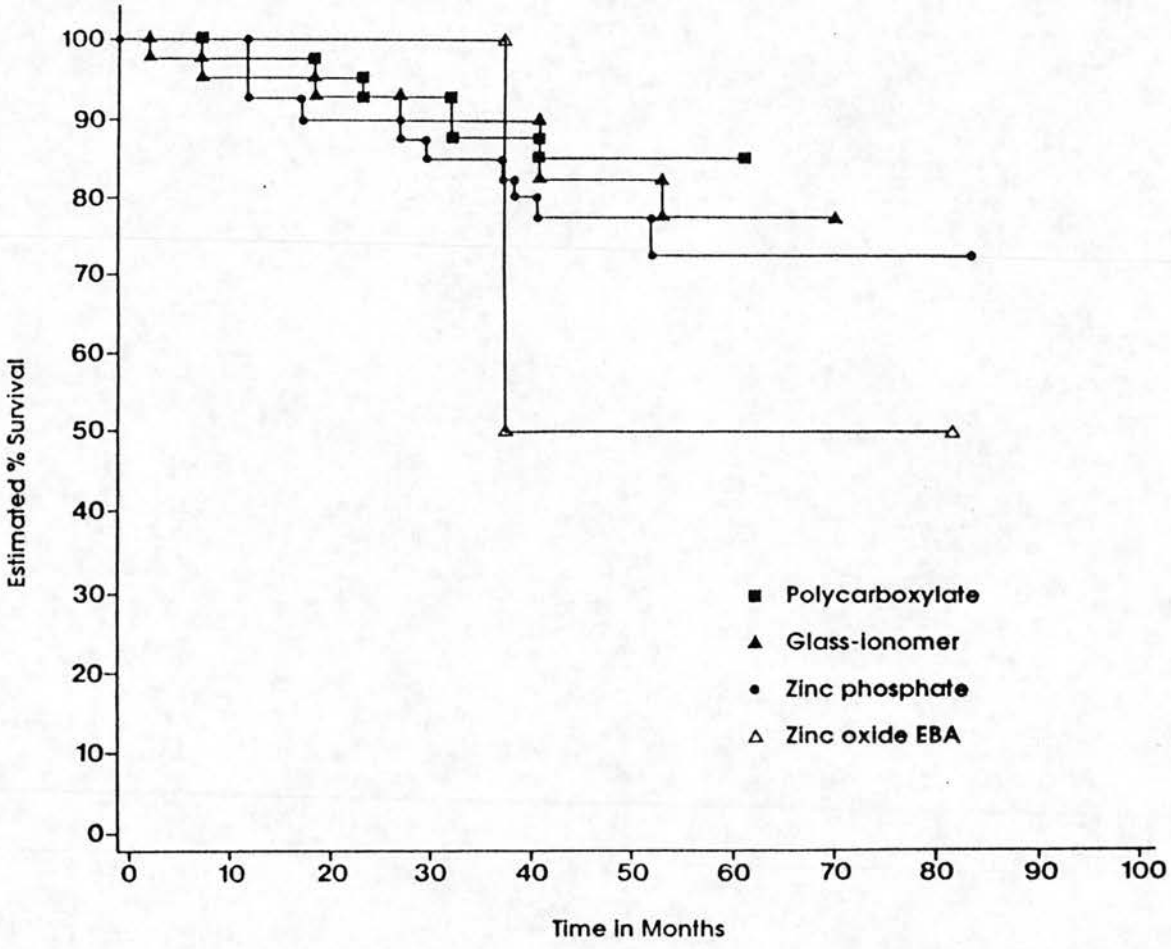
9.2. Estimated percentage survival for all restorations at 1, 2 and 5 years.



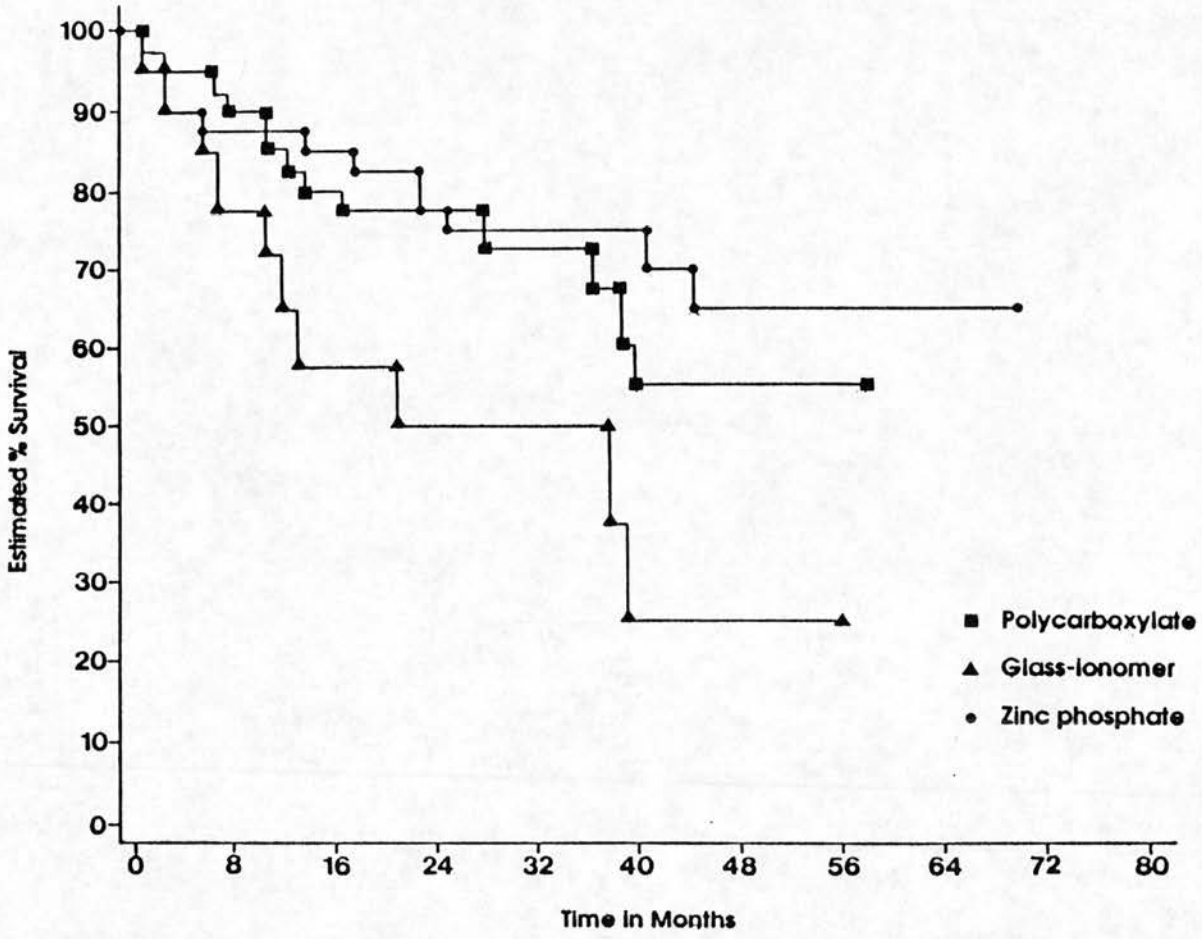
9.3. Estimated percentage survival for bridges at 1, 2 and 5 years.



9.4. Estimated percentage survival for crowns at 1, 2 and 5 years.



9.5. Estimated percentage survival for post crowns at 1, 2 and 4.6 years.



The ranking of the cements when all restorations were compared was first polycarboxylate; glass-ionomer; zinc phosphate; and last zinc oxide/eugenol reinforced EBA cement.

A pairwise comparison of survival of all the restorations using the lee-desu statistic to generate 'p' values, showed that restorations cemented with zinc oxide/eugenol reinforced EBA cements had significantly shorter survival rates than all other cements ($p > 0.05$). There was no significant difference between the survival rates of restorations cemented with zinc phosphate and glass-ionomer cements ($p = 0.5$), or between those with glass-ionomer and polycarboxylate cements ($p = 0.15$). The restorations cemented with polycarboxylates showed a significantly longer survival rate than the zinc phosphate cements ($p = 0.02$).

Pairwise comparisons of crowns alone shows the same ranking as for all restorations but with with no significant differences.

In the analysis of the bridges glass-ionomer is ranked first; polycarboxylate second; zinc phosphate third; and zinc oxide/eugenol reinforced EBA cement last. With p at the significance level of 0.05 glass-ionomer is significantly more retentive than zinc phosphate cement and the zinc oxide/eugenol reinforced EBA cement is less retentive than both the glass-ionomer and polycarboxylate cements. There are no other significant differences.

The ranking for survival of post crowns was zinc phosphate first; polycarboxylate second; and glass-ionomer cement third. No post crowns were cemented with zinc oxide reinforced EBA cement. The survival of zinc phosphate cemented post crowns was significantly better than those cemented with glass-ionomer.

DISCUSSION

Schwartz et al[115] showed that crowns and bridges fail (in order of frequency) because of caries, cement failure, defective margins, excessive wear, periodontal disease, mobility, lost veneer, poor aesthetics, periapical involvement, broken solder joint, broken pontic, and other reasons. In this study there was no specific record of any crown or bridge failing as a result of trauma, periodontal problems, or bridge fracture.

The cement lute is not the only factor involved in the retention of crowns or bridges;

Surface roughness [Button, Barnes and Moon[116] and Felton, Kanoy, and White[56]];

Taper Jorgensen[1];

Film thickness Fusayama and Iwamoto[81];

Size and shape of the tooth preparation Roberts[117] are also important.

However, in this retrospective clinical investigation it was not possible to assess the influence of these other

variables, and therefore the assumption had to be that the causes of failure (other than failure of the cement lute) were randomly distributed. Torabinejad[118] observed that retrospective studies can be criticized because the data to be analysed is restricted and all the information about each case is not available. However this type of study is less prone to investigator bias; allows for random selection of cases with large sample sizes; and the results are readily extrapolated to the population in general.

Although the number of crowns and bridges cemented with zinc oxide/eugenol reinforced EBA cements was small (a reflection of clinical practice) this was allowed for in the analysis of the data as the statistical method used is capable of coping with samples of varying sizes.

CONCLUSIONS

1. Restorations cemented with zinc oxide/eugenol reinforced EBA cements were significantly more liable to clinical failure than those cemented with the other materials investigated when all restorations were considered together. This is in accord with the results of the retention tests in this thesis where zinc oxide/eugenol reinforced EBA cements were shown to have poor retentive properties.

2. When comparing all restorations together those with cement lutes of polycarboxylate survived significantly longer than those in which zinc phosphates were used. The ranking of the cements is the same as the ranking for retention found in the 23^0 taper model. The only difference between these results and the 23^0 taper model is that no significant difference is shown between zinc phosphate cements and glass-ionomer cements.

3. Restorations cemented with glass-ionomer showed no significant difference from those cemented with polycarboxylate cements. This was similar to the results of the 23^0 taper model.

4. When only crowns were considered, the ranking stayed the same as that of the retention tests, but there was no significant difference between the cements.

5. When only bridges were considered the glass-ionomer cements were better than the polycarboxylates and were ranked first. Bridges cemented with glass-ionomer survived significantly longer than those cemented with zinc phosphate. The glass-ionomer and polycarboxylate survival rates showed no significant difference.

6. Post crowns cemented with zinc phosphate survived significantly longer than those cemented with

glass-ionomer cements. Zinc phosphate was ranked first; then polycarboxylate; and lastly glass-ionomer.

SUMMARY OF FINDINGS

1. For 3 out of the 4 cements studied in this thesis there appears to be an optimum taper for maximum retention of gold crowns on human dentine. The value of this optimum taper appears to vary among cements, and further work is now required to confirm its presence as indicated by this preliminary study.

A summary of the findings is:

CEMENT	OPTIMUM TAPER
Zinc Phosphate	7-15
Polycarboxylate	7-23 (or possibly none?)
Glass-ionomer	none
Composite	7-23

Confirmation of these findings would draw the currently accepted hyperbolic relationship between retention and taper into question. This is an important area for further research.

2. Experimental method.

A dentine truncated cone with a 23^0 taper is suitable for the testing dental cements because:

a) it is similar to the shape of many clinical crown

preparations.

b) it can be produced on many extracted human canines without pulpal exposure.

c) the taper is sufficiently large to ensure rigorous test for a luting cement.

e) the taper is also sufficiently large to minimise the number of fractures of the dentine cones.

3. The currently accepted hyperbolic relationship between retention and taper[1] was based on truncated cones in which no account was taken of any contribution to retention from the "occlusal" cone surface. The work reported in this thesis, in which the data has been related to both axial surface area and total surface area, suggests that "occlusal" aspects of the crowns cannot be ignored. The effect of including "occlusal" surface area is to alter the shape of the failure strength versus taper diagram slightly. The overall shape of the diagram for zinc phosphate and composite cements, which display an optimum taper, is not affected whether the "occlusal" surface area is included or not. However, the case of polycarboxylate cement is of particular interest (Fig 7.4 and 7.8) because it indicates that inclusion of "occlusal" surface area can turn an apparently monotonic relationship into one exhibiting a maximum value.

If further work confirms the observation of optimum taper suggested by the data presented in this thesis, the

result for polycarboxylate indicates that the contribution of the "occlusal" surface to overall retention may be a significant factor in producing an optimum taper.

4. The in-vitro experiments showed:

a) the composite cement (PANAVIA-EX) was significantly more retentive than all other cements tested in-vitro.

b) glass-ionomer and polycarboxylate cements showed no significant difference in retention (23^0 taper).

c) zinc phosphate cements were less retentive than composite, glass-ionomer and polycarboxylate cements.

d) zinc oxide eugenol EBA cements were less retentive than all other cement types tested.

Composite cements are considered to have low pulpal irritation Mjor[119] and Inokoshi et al[54] and therefore they may prove to be the best luting cement in the future (Clinical Research Associates[120]).

5 The clinical survival of crowns and bridges showed:

a) glass-ionomer and polycarboxylate cements to have no significant difference in survival rate.

b) bridges cemented with glass-ionomer cements survived significantly longer than those cemented with zinc phosphate cements.

c) all restorations cemented with polycarboxylate

cements survived significantly longer than those cemented with zinc phosphate cements.

d) zinc oxide eugenol EBA survived for significantly less time than all other cement types tested.

6. The use of a eugenol-based cement (TEMP BOND) for the cementation of temporary crowns had no subsequent adverse effect on the retention of permanent gold crowns cemented with any of the cement types used in this study.

7. After temporary cementation with a eugenol based cement, cleaning the preparation with a volatile cleaning /drying agent (PREP-DRY) appears to improve the retentive power of zinc phosphate and glass-ionomer cements but may reduce that of composite cement.

8. There is no contraindication to the recementation of gold crowns as this study showed:

a) no significant decrease in retention over in any cement over 6 recementations.

b) an increase in the retentive power of polycarboxylate and zinc phosphate with repeated recementations.

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APPENDIX 1.

TECHNIQUE

The standard technique devised for the retention testing of different cements.

1. The dentine cones (of specified dimensions) were produced on a HOBBYMATT precision lathe as described in Experiment 4.1.

2. Impressions were taken of the dentine cones with EXTRUDE, an addition-cured polysyloxane impression material as described in Experiment 4.2.

3. Stone dies were poured in SILKEY-ROCK die material as described in Experiment 4.2.

4. The stone dies were relieved with 4 coats of ADAPT-RITE die-spacer as described in Experiment 4.2.

5. The gold crowns were produced as described in Experiment 4.1 and the fitting surfaces air abraded with ALPHABLAST M 25 as described in Experiment 6.1.

6. The cements were hand mixed in the ratio's described in Experiment 5.1.

7. The crowns were cemented three at a time with initial cementation loads of 6 kg for 30 s followed by maintenance load of 3 kg using the cementation jig as described in Experiment 4.2.

8. The cemented specimens were stored at 37°C, 100% humidity, for 24 h before retention testing as described in Experiment 4.1.

9. The retention testing was carried out using an RDP HOWDEN universal testing machine as described in Experiment 4.2. The displacing force was applied for 60 s (or until the maximum force of 500 N was reached).

10. The data was collected from the RDP SENSOTEC load cell and processed as described in Experiment 1.2.

APPENDIX 2.

Table 2.1a UPPER CENTRAL INCISORS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	6.7	0.4	3.8	2.5
2	8.2	1.8	3.0	3.4
3	6.2	0.6	3.3	2.3
4	7.4	2.1	2.9	2.4
5	6.2	1.1	2.7	2.4
6	7.0	1.3	3.5	2.2
7	6.2	1.6	2.4	2.2
8	6.8	0.9	3.3	2.6
9	6.8	1.1	2.9	2.8
10	6.2	0.9	2.9	2.4
11	6.7	1.3	2.8	2.6
MEAN	6.8	1.2	3.1	2.5
SD	0.6	0.5	0.4	0.3
SE	0.2	0.2	0.1	0.1

Table 2.1b UPPER CENTRAL INCISORS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	7.0	-	-	-
2	6.9	1.8	2.5	2.6
3	5.7	1.1	1.6	3.0
4	7.1	2.5	2.3	2.3
5	6.9	2.0	2.5	2.4
6	7.4	-	-	-
7	7.0	1.3	3.5	2.2
8	6.8	2.3	2.3	2.2
9	7.8	2.6	2.9	2.3
10	7.1	2.3	2.4	2.4
11	6.7	2.5	2.2	2.0
MEAN	7.0	2.0	2.5	2.4
SD	0.5	0.5	0.5	0.3
SE	0.2	0.2	0.2	0.1

Table 2.2a UPPER LATERAL INCISORS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	5.9	1.8	2.6	1.5
2	4.7	1.6	2.0	1.1
3	6.2	1.5	2.2	2.5
4	6.4	1.3	2.7	2.4
5	6.2	1.7	2.4	2.1
6	6.4	1.4	2.7	2.3
7	7.0	0.6	3.6	2.8
8	6.6	3.2	2.2	1.2
9	6.2	0.6	3.3	2.3
10	6.9	1.3	3.9	2.3
11	6.9	1.2	3.7	2.0
MEAN	6.3	1.5	2.9	2.1
SD	0.6	0.7	0.7	0.6
SE	0.2	0.2	0.2	0.2

Table 2.2b UPPER LATERAL INCISORS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	6.2	1.8	2.0	2.4
2	5.0	2.2	1.8	1.0
3	4.4	1.2	1.2	2.0
4	5.1	1.3	1.7	2.1
5	4.9	1.2	1.9	1.8
6	5.1	1.2	1.9	2.1
7	5.0	-	-	-
8	4.4	1.0	1.7	1.7
9	5.7	-	-	-
10	5.3	-	-	-
11	6.0	1.9	2.0	2.1
MEAN	5.2	1.5	1.8	1.9
SD	0.6	0.4	0.3	0.4
SE	0.2	0.2	0.1	0.2

Table 2.3a UPPER CANINES FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	8.2	2.1	3.2	2.9
2	8.0	2.8	3.2	2.0
3	8.8	1.9	4.0	2.9
4	8.6	2.9	3.1	2.6
5	8.1	3.3	2.4	2.4
6	7.7	1.5	3.3	2.9
7	7.9	2.1	3.1	2.7
8	8.7	3.0	2.8	2.9
9	7.8	2.7	2.3	2.8
10	7.9	3.2	2.7	2.0
MEAN	8.2	2.6	3.0	2.6
SD	0.4	0.6	0.5	0.4
SE	0.1	0.2	0.2	0.1

Table 2.3b UPPER CANINES MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	6.5	1.1	2.7	2.7
2	5.9	0.8	2.6	2.5
3	7.6	1.0	3.6	3.0
4	6.8	1.8	2.4	2.6
5	6.4	2.0	2.0	2.4
6	6.4	1.2	2.6	2.6
7	6.5	1.5	2.4	2.6
8	5.9	0.7	2.9	2.3
9	5.3	0.7	2.5	2.1
10	6.0	1.1	2.5	2.4
MEAN	6.3	1.2	2.6	2.5
SD	0.6	0.5	0.4	0.2
SE	0.2	0.1	0.1	0.1

Table 2.4a UPPER FIRST PREMOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	7.9	3.8	1.9	2.2
2	8.5	3.1	2.8	2.6
3	9.7	4.3	2.6	2.8
4	9.3	3.9	2.7	2.7
5	9.2	4.6	2.3	2.3
6	8.8	3.5	2.5	2.8
7	8.4	3.7	2.2	2.5
8	8.4	4.0	2.1	2.3
9	8.8	4.1	2.4	2.3
10	8.4	4.1	2.4	2.1
11	7.9	4.4	2.3	1.2
MEAN	8.7	4.0	2.4	2.4
SD	0.6	0.4	0.3	0.5
SE	0.2	0.1	0.1	0.1

Table 2.4b UPPER FIRST PREMOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	4.3	0.7	1.5	2.1
2	5.0	0.2	2.3	2.5
3	5.5	1.1	2.1	2.3
4	5.9	0.6	3.2	2.1
5	4.9	1.1	1.8	2.0
6	5.2	1.0	2.4	1.9
7	4.1	0.8	1.5	1.8
8	4.4	0.6	2.1	1.7
9	5.3	0.7	2.3	2.3
10	4.0	1.7	1.3	1.0
11	4.7	0.8	1.8	2.1
MEAN	4.9	0.9	2.0	2.0
SD	0.6	0.4	0.5	0.4
SE	0.2	0.1	0.2	0.1

Table 2.5a UPPER SECOND PREMOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	8.8	3.7	2.4	2.7
2	8.4	3.6	2.7	2.1
3	8.0	3.9	2.0	2.1
4	8.6	4.4	1.9	2.3
5	8.8	3.4	2.6	2.8
6	9.2	3.9	2.6	2.7
7	8.5	4.3	2.1	2.1
8	9.3	4.3	2.5	2.5
9	8.1	4.0	1.9	2.2
10	7.9	3.7	2.0	2.2
MEAN	8.6	3.9	2.3	2.4
SD	0.5	0.3	0.3	0.3
SE	0.2	0.1	0.1	0.1

Table 2.5b UPPER SECOND PREMOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	5.8	0.9	2.2	2.7
2	4.9	1.1	1.6	2.2
3	4.2	0.9	1.6	1.7
4	4.8	1.0	1.7	2.1
5	5.1	1.2	1.7	2.2
6	5.5	1.0	2.2	2.3
7	4.8	1.1	2.0	1.7
8	4.7	0.9	1.8	2.0
9	5.1	1.0	1.9	2.2
10	4.8	1.1	1.6	2.1
MEAN	5.0	1.0	1.8	2.1
SD	0.4	0.1	0.2	0.3
SE	0.1	0.0	0.1	0.1

Table 2.6a UPPER MOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	11.0	5.7	2.8	2.5
2	10.4	5.0	2.6	2.8
3	10.9	5.5	2.8	2.6
4	11.2	5.8	2.6	2.8
5	12.1	6.0	3.2	2.9
6	11.6	5.9	2.8	2.9
7	11.2	4.8	3.3	3.1
8	12.6	7.1	2.8	2.7
9	12.1	5.6	3.2	3.3
10	11.8	6.2	2.8	2.8
MEAN	11.5	5.8	2.9	2.8
SD	0.7	0.6	0.3	0.2
SE	0.2	0.2	0.1	0.1

Table 2.6b UPPER MOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	9.1	4.4	2.2	2.5
2	7.9	2.7	2.3	2.9
3	7.9	3.8	1.3	2.8
4	9.2	4.2	2.3	2.7
5	9.6	4.1	2.5	3.0
6	8.7	2.9	2.7	3.1
7	9.4	4.2	2.4	2.8
8	9.2	4.1	2.2	3.2
9	-	-	-	-
10	10.4	4.8	2.6	3.0
MEAN	9.0	3.9	2.3	2.9
SD	0.8	0.7	0.4	0.2
SE	0.3	0.2	0.1	0.1

Table 2.7a LOWER INCISORS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	5.6	2.5	1.0	2.1
2	5.5	1.5	1.9	2.1
3	6.1	1.7	2.0	2.4
4	5.9	1.7	1.9	2.3
5	5.9	1.4	2.1	2.4
6	5.2	1.6	1.8	1.8
7	5.3	0.8	2.3	2.2
8	5.8	1.4	2.1	2.3
9	6.0	1.3	2.2	2.5
10	5.7	1.4	2.0	2.3
MEAN	5.7	1.5	1.9	2.2
SD	0.3	0.4	0.4	0.2
SE	0.1	0.1	0.1	0.1

Table 2.7b LOWER INCISORS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	3.1	0.5	1.3	1.3
2	3.6	0.7	1.4	1.5
3	3.6	0.7	1.5	1.4
4	3.5	0.7	1.4	1.4
5	4.3	0.7	1.8	1.8
6	3.5	0.6	1.4	1.5
7	3.2	-	-	-
8	3.7	0.7	1.5	1.2
9	4.0	0.5	1.8	1.7
10	4.3	0.8	2.0	1.5
MEAN	3.7	0.7	1.6	1.5
SD	0.4	0.1	0.2	0.2
SE	0.1	0.0	0.1	0.1

Table 2.8a LOWER CANINES FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL @	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	7.0	1.6	2.7	2.7
2	7.3	1.3	3.4	2.6
3	7.2	2.3	2.4	2.5
4	7.0	2.2	2.3	2.5
5	7.3	1.9	2.7	2.7
6	6.9	2.1	2.2	2.6
7	6.8	1.9	2.4	2.5
8	6.6	1.7	2.5	2.4
9	8.5	2.1	3.6	2.8
10	7.2	2.1	2.5	2.6
MEAN	7.2	1.9	2.7	2.6
SD	0.5	0.3	0.5	0.1
SE	0.2	0.1	0.2	0.0

Table 2.8b LOWER CANINES MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	4.8	0.8	2.1	1.9
2	4.5	0.7	1.8	2.7
3	4.7	0.8	1.9	2.0
4	4.9	1.0	1.9	2.0
5	5.0	0.6	3.1	1.5
6	5.1	0.9	2.1	2.1
7	5.3	0.9	2.1	2.3
8	4.8	0.8	2.1	1.9
9	5.0	0.8	2.0	2.2
10	5.1	0.7	2.4	2.0
MEAN	4.9	0.8	2.2	2.1
SD	0.2	0.1	0.4	0.3
SE	0.1	0.0	0.1	0.1

Table 2.9a LOWER FIRST PREMOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	7.3	2.7	2.2	2.4
2	7.2	1.8	2.5	2.9
3	6.7	2.0	2.1	2.6
4	6.8	2.4	2.5	1.9
5	8.2	2.7	2.4	3.1
6	6.6	1.9	2.3	2.4
7	6.4	1.2	2.6	2.6
8	7.4	3.0	2.1	2.3
9	7.1	2.4	2.5	2.2
10	7.9	2.7	2.5	2.7
MEAN	7.2	2.3	2.4	2.5
SD	0.6	0.6	0.2	0.4
SE	0.2	0.2	0.1	0.1

Table 2.9b LOWER FIRST PREMOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	4.7	0.7	2.2	1.8
2	4.8	0.9	1.7	2.2
3	5.2	1.3	2.1	1.8
4	5.1	0.5	2.5	2.1
5	6.1	0.6	2.7	2.8
6	4.7	0.6	2.1	2.0
7	4.4	0.7	1.8	1.9
8	5.9	1.1	2.2	2.6
9	4.9	0.9	2.0	2.0
10	5.2	0.9	2.2	2.1
MEAN	5.1	0.8	2.2	2.1
SD	0.5	0.3	0.3	0.3
SE	0.2	0.1	0.1	0.1

Table 2.10a LOWER SECOND PREMOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	7.4	3.3	2.0	2.1
2	7.7	3.4	2.2	2.1
3	8.0	2.9	2.2	2.9
4	7.2	3.0	2.1	2.6
5	8.0	3.2	2.3	2.5
6	-	-	-	-
7	7.2	1.6	2.8	2.8
8	8.0	2.0	2.6	3.4
9	8.0	2.6	2.3	2.3
10	7.5	2.8	2.3	2.4
MEAN	7.7	2.8	2.3	2.6
SD	0.4	0.6	0.3	0.4
SE	0.1	0.2	0.1	0.1

Table 2.10b LOWER SECOND PREMOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	5.1	1.4	1.9	1.8
2	5.4	1.5	2.0	1.9
3	5.8	1.3	2.3	2.2
4	5.4	1.1	2.1	2.2
5	5.4	0.6	2.4	2.4
6	6.0	1.9	1.8	2.3
7	5.4	0.5	2.4	2.5
8	5.2	0.7	2.3	2.2
9	5.1	0.9	2.1	2.1
10	4.8	0.8	1.9	2.1
MEAN	5.4	1.1	2.1	2.2
SD	0.4	0.5	0.2	0.2
SE	0.1	0.1	0.1	0.1

Table 2.11a LOWER MOLARS FACIAL to LINGUAL

Measurements in mm.

NO	TOTAL	PULP	FACIAL DENTINE	LINGUAL DENTINE
1	7.7	1.7	2.4	3.6
2	8.9	2.9	2.4	3.6
3	9.3	4.7	2.4	2.2
4	8.8	4.3	2.6	1.9
5	8.5	4.1	2.0	2.4
6	9.6	2.8	2.2	4.6
7	9.5	4.0	3.0	2.5
8	9.2	3.8	2.6	2.8
9	10.0	5.1	3.0	1.9
10	10.1	4.8	2.6	2.7
MEAN	9.2	3.8	2.5	2.8
SD	0.7	1.0	0.3	0.9
SE	0.2	0.3	0.1	0.3

Table 2.11b LOWER MOLARS MESIAL to DISTAL

Measurements in mm.

NO	TOTAL	PULP	MESIAL DENTINE	DISTAL DENTINE
1	10.3	5.4	2.2	2.7
2	8.4	3.4	2.5	2.5
3	9.8	4.8	2.3	2.7
4	9.4	5.0	2.1	2.3
5	9.8	4.7	2.3	2.8
6	9.2	4.8	2.2	2.2
7	9.6	4.2	2.5	2.9
8	10.0	5.3	2.2	2.5
9	11.0	6.0	2.4	2.6
10	9.9	5.0	1.6	2.5
MEAN	9.7	4.9	2.2	2.6
SD	0.7	0.7	0.3	0.2
SE	0.2	0.2	0.1	0.1

Table 2.14

UPPER CENTRAL INCISORS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	68	60	29	79	76	73	--	--	--	--	--	--
2	30	23	13	35	27	18	37	24	5	40	29	9
3	74	68	40	80	79	76	--	--	--	--	--	--
4	21	16	6	33	27	19	27	17	2	25	13	0
5	34	21	7	45	35	21	64	49	27	62	52	18
6	31	18	4	51	44	34	--	--	--	--	--	--
7	29	20	6	28	18	10	40	28	7	29	27	9
8	39	28	14	46	39	28	58	47	20	60	53	30
9	30	18	2	51	44	33	63	57	31	61	53	27
10	21	12	1	33	25	17	32	17	0	26	13	0
11	42	28	4	55	41	35	80	72	39	83	71	19
MEAN	38	28	12	49	41	33	50	39	16	48	39	14
SD	18	18	12	18	20	22	19	20	15	21	21	11
SE	5	6	4	5	6	7	7	7	5	8	8	4

Note: Measurement 0 indicates that the pulp was exposed on the line from the ACJ to ACJ or the taper was -ve as a result of a pulp horn.

Table 2.15

UPPER LATERAL INCISORS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	21	12	0	32	29	20	13	1	0	47	4	0
2	29	15	0	45	36	0	--	--	--	--	--	--
3	24	12	0	43	35	24	44	27	0	37	22	0
4	28	19	8	35	27	17	32	13	0	31	17	0
5	21	11	0	39	31	19	33	23	0	40	24	0
6	25	15	1	39	31	20	39	24	0	41	22	0
7	47	33	14	62	27	45	--	--	--	--	--	--
8	29	23	15	23	16	7	19	15	0	20	4	0
9	52	39	9	67	61	46	--	--	--	--	--	--
10	26	16	0	32	23	13	--	--	--	--	--	--
11	27	14	0	51	44	33	61	48	0	68	61	41
MEAN	30	19	4	43	33	22	34	22	0	41	22	6
SD	10	9	6	13	12	14	16	15	--	15	19	16
SE	3	3	2	4	4	4	6	6	--	6	7	6

Table 2.16

UPPER CANINES (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	41	34	24	44	35	28	38	29	13	39	28	10
2	51	41	26	58	49	33	59	47	17	64	49	28
3	42	34	24	51	43	33	42	32	16	51	41	26
4	35	28	20	38	29	22	32	29	13	34	23	13
5	32	26	17	34	27	19	25	18	8	29	22	0
6	35	27	17	38	40	22	36	25	12	36	25	11
7	34	26	17	37	30	20	28	20	8	40	29	14
8	40	32	21	46	39	29	28	17	4	38	24	3
9	33	25	16	36	32	22	40	30	5	35	17	0
10	38	33	22	35	27	19	33	20	4	41	30	14
MEAN	38	31	20	42	35	25	36	27	10	41	29	12
SD	6	5	4	8	7	6	10	9	5	10	10	10
SE	2	2	1	3	2	2	3	3	2	3	3	3

Table 2.17

UPPER FIRST PREMOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	34	20	6	48	37	8	49	26	20	59	47	10
2	53	39	26	47	31	4	64	56	27	63	53	35
3	47	33	17	66	56	35	53	43	9	50	38	9
4	43	31	18	56	51	45	44	32	4	40	26	0
5	46	35	18	55	44	16	40	28	0	47	32	0
6	49	35	15	67	59	43	63	51	35	48	30	0
7	28	19	7	44	30	10	49	23	0	39	21	0
8	34	25	6	44	30	11	40	23	2	20	14	0
9	33	23	8	46	34	13	40	23	0	44	30	5
10	37	28	13	43	32	12	26	8	0	25	0	0
11	39	35	16	57	48	24	46	29	0	40	31	0
MEAN	40	29	14	52	41	20	47	31	9	43	29	5
SD	8	7	6	9	11	15	11	14	13	13	15	11
SE	2	2	2	3	3	4	3	4	4	4	4	3

Table 2.18

UPPER SECOND PREMOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	46	36	14	60	51	32	56	42	15	46	28	0
2	45	34	18	49	37	11	49	33	0	47	30	0
3	43	30	5	59	51	21	38	19	0	33	15	0
4	44	31	6	35	24	0	46	28	0	49	33	4
5	35	22	10	43	33	4	49	34	2	48	35	7
6	41	32	16	51	39	12	39	30	9	44	34	15
7	37	25	10	49	36	13	53	39	0	49	33	0
8	45	35	19	62	54	26	47	25	0	47	33	0
9	50	38	15	66	57	26	53	33	0	58	45	23
10	35	25	9	45	30	0	--	--	--	--	--	--
MEAN	42	31	12	52	41	15	48	31	3	47	32	5
SD	5	5	5	10	11	11	6	7	5	7	8	8
SE	2	2	2	3	4	4	2	2	2	2	3	3

Table 2.19

UPPER MOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	44	34	12	54	45	30	38	22	0	54	43	19
2	82	66	47	78	73	63	73	56	27	84	82	76
3	73	64	49	77	71	56	56	37	0	78	75	59
4	61	51	32	70	62	52	63	51	11	78	74	69
5	70	62	52	77	70	61	65	50	25	74	67	61
6	54	46	27	69	59	46	69	60	31	77	73	64
7	60	50	39	73	64	53	58	45	17	60	48	30
8	61	54	42	70	60	51	32	16	0	72	60	49
9	67	61	48	73	68	62	--	--	--	--	--	--
10	69	57	47	75	73	66	56	46	24	66	60	48
MEAN	64	55	40	72	65	54	57	43	15	71	65	53
SD	11	10	13	7	9	11	14	15	13	10	13	19
SE	3	3	4	2	3	3	5	5	4	3	4	6

Table 2.20

LOWER INCISORS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	39	26	0	39	27	1	44	13	0	47	17	0
2	28	18	0	28	19	0	17	3	0	16	4	0
3	37	26	0	40	29	15	31	11	0	23	2	0
4	38	28	0	34	23	9	35	13	0	32	8	0
5	29	19	8	30	21	10	29	13	0	25	9	0
6	32	15	0	41	31	0	21	6	0	17	2	0
7	48	33	9	53	40	19	--	--	--	--	--	--
8	40	27	7	40	29	14	38	17	0	38	16	0
9	43	29	9	43	30	7	55	35	0	50	24	0
10	41	25	0	44	35	20	44	27	0	32	13	0
MEAN	38	25	3	39	28	10	35	15	--	31	11	--
SD	6	6	4	7	6	8	12	10	--	12	8	--
SE	2	2	1	2	2	2	4	3	--	4	3	--

Table 2.21

LOWER CANINES (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	44	36	23	43	32	18	26	15	1	38	19	0
2	37	30	21	29	21	11	29	12	0	30	15	0
3	33	26	18	30	21	12	34	19	0	32	20	0
4	37	29	17	37	27	16	37	22	0	37	22	0
5	42	35	26	33	22	10	23	11	0	27	16	0
6	37	28	19	32	30	12	25	12	0	34	20	2
7	31	22	14	31	23	14	41	25	3	45	33	14
8	38	30	20	28	17	5	29	18	2	27	15	0
9	51	44	31	40	29	10	56	40	0	45	33	8
10	27	18	7	40	33	23	28	16	0	35	19	0
MEAN	38	30	20	34	26	13	33	19	1	35	21	2
SD	7	7	7	5	5	5	10	9	1	7	7	5
SE	2	2	2	2	2	2	3	3	0	2	2	2

Table 2.22

LOWER FIRST PREMOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	52	41	24	55	46	29	47	30	1	38	22	0
2	62	54	42	59	51	36	39	21	0	39	25	0
3	47	37	24	44	34	0	37	23	2	43	29	0
4	57	44	23	64	56	0	47	33	5	47	28	0
5	65	57	38	71	66	59	48	36	16	50	35	15
6	46	37	24	48	38	25	38	21	2	36	21	0
7	75	68	58	75	67	50	70	62	0	70	59	0
8	47	38	22	46	37	15	41	28	10	41	28	10
9	45	34	22	48	29	9	38	26	0	30	14	0
10	43	33	24	43	33	21	51	36	13	47	27	0
MEAN	54	44	30	55	46	24	46	32	5	44	29	3
SD	11	12	12	12	14	20	10	12	6	11	12	5
SE	3	4	4	4	4	6	3	4	2	3	4	2

Table 2.23

LOWER SECOND PREMOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	44	33	0	49	32	3	44	27	0	49	33	0
2	49	37	22	56	39	2	45	30	0	50	35	0
3	47	38	22	52	44	33	51	38	18	47	31	2
4	43	32	14	51	43	29	47	33	2	53	38	5
5	46	38	21	52	42	15	49	36	12	44	26	1
6	--	--	--	--	--	--	45	23	0	53	39	8
7	60	47	27	66	58	43	64	52	24	63	45	9
8	50	40	16	59	43	16	54	37	0	57	38	1
9	55	45	24	61	52	16	66	53	20	67	51	0
10	49	38	22	59	48	15	48	31	0	48	30	0
MEAN	49	39	19	56	45	19	51	36	8	53	37	3
SD	5	5	8	6	8	14	8	10	10	7	7	4
SE	2	2	3	2	3	5	3	3	3	2	2	1

Table 2.24

LOWER MOLARS (measurements in degrees)

ANGLE TO EXPOSURE AT 1 mm INTERVALS FROM THE ACJ.

NO	FACIAL			LINGUAL			MESIAL			DISTAL		
	ACJ			ACJ			ACJ			ACJ		
	+0	+1	+2	+0	+1	+2	+0	+1	+2	+0	+1	+2
1	69	54	40	68	60	40	46	29	1	66	57	40
2	61	47	17	62	54	35	58	44	13	62	52	33
3	57	49	40	56	39	9	58	45	13	77	71	64
4	59	49	32	53	38	0	46	30	5	61	58	31
5	44	40	0	69	60	35	58	48	20	78	73	66
6	58	48	26	64	52	21	43	24	0	60	47	14
7	72	69	60	79	73	61	65	53	27	80	77	71
8	82	78	73	85	85	85	67	57	53	71	65	46
9	71	63	53	67	56	0	58	45	20	76	71	55
10	65	53	31	66	58	47	69	61	41	79	75	65
MEAN	64	55	37	67	58	33	57	44	19	71	65	49
SD	10	12	21	10	14	27	9	12	17	8	11	19
SE	3	4	7	3	4	9	3	4	5	3	3	6

Table 2.28 TAPER OF CLINICAL PREPARATIONS UPPERS
(Measurements in degrees.)

INCISORS		CANINES		MOLARS		PREMOLARS	
MD	FL	MD	FL	MD	FL	MD	FL
19.4	2.7	7.6	20.5	20.2	29.0	16.9	30.0
15.7	19.0	12.0	14.6	33.0	13.6	31.8	16.4
23,7	10.5	18.0	17.0	47.6	28.3	11.3	24.0
10.7	19.9	13.7	10.0	12.0	31.7	24.5	19.6
21.7	29.7	14.9	19.5	16.6	11.2	18.0	19.7
18.0	20.0	11.2	11.4	20.0	11.2	7.0	7.5
17.9	19.2	12.5	37.0	31.0	18.7	5.0	26.4
19.8	19.9	7.2	41.0	13.0	24.7	15.0	15.4
17.4	23.3	4.4	24.8	27.3	42.8	6.0	30.6
9.1	35.8	13.9	37.0	26.8	23.5	16.2	33.5
19.7	11.8	16.2	38.0	7.2	26.0	18.2	18.3
10.4	26.0	15.9	11.4	10.5	22.0		
8.3	21.5	9.6	12.2	23.0	22.6		
18.3	29.6	4.5	24.5	23.1	30.3		
15.9	28.7	10.3	24.5	29.7	26.4		
17.0	4.4	12.0	25.1	19.2	33.0		
15.9	22.9	16.2	15.0	28.5	35.7		
20.0	36.7			35.5	25.5		
15.5	18.0						
10.7	31.5						
12.7	19.0						
10.0	21.2						
18.1	20.2						
25.3	18.2						
13.3	16.0						
17.2	20.1						
6.8	10.2						
9.6	30.0						
12.3	15.7						
10.6	20.2						
21.3	35.4						
19.4	12.2						
19.5	24.1						

Table 2.29 TAPER OF CLINICAL PREPARATIONS LOWERS
(Measurements in degrees.)

INCISORS		CANINES		MOLARS		PREMOLARS	
MD	FL	MD	FL	MD	FL	MD	FL
11.5	23.0	18.8	5.0	24.5	26.2	19.4	19.9
22.4	34.4	10.3	7.2	33.8	35.7	25.5	32.0
10.6	20.5	9.7	14.4	34.7	19.7	16.0	21.2
2.2	22.8	10.0	23.0	17.3	34.5	8.4	20.7
16.6	24.0	25.4	14.2	37.3	40.8	17.5	11.3
18.5	24.2	10.7	18.1	24.6	21.5	19.5	2.0
15.3	32.2	24.4	16.0	36.1	21.4	19.4	29.2
5.6	31.3	17.2	12.9	45.3	29.3	10.2	28.7
18.7	25.0	11.7	15.2	29.7	30.2	9.0	9.7
11.3	22.2	10.4	13.6	42.5	23.3	18.3	7.4
12.1	23.2	21.1	16.7	32.7	28.1	12.4	11.3
				28.3	10.3		
				45.0	49.7		
				25.6	22.6		
				26.4	27.8		
				30.8	11.3		
				12.9	12.8		
				20.9	45.5		
				39.7	51.7		
				21.2	40.9		
				20.1	32.0		
				45.8	36.4		
				36.2	33.7		

Table 5.2.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
1	3.87	7.40	5.00
2	3.87	7.01	5.01
3	3.92	6.93	5.11
4	3.88	6.95	5.06
5	3.94	7.00	5.10
6	4.00	7.00	5.01
7	4.08	6.93	4.99
8	3.98	6.98	5.08
9	4.03	6.83	5.12
Max	4.08	7.40	5.12
Min	3.87	6.83	4.99
Mean	3.95	7.00	5.05
SD	0.08	0.16	0.05

Table 5.5.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
10	3.82	6.9	5.15
11	3.90	7.0	5.08
12	3.86	6.9	5.17
13	3.83	7.0	4.95
14	3.81	7.0	5.13
15	3.95	7.0	5.15
16	3.96	6.9	5.11
17	3.97	7.0	5.11
18	3.92	7.0	5.02
19	3.90	7.0	5.11
20	3.81	6.9	4.96
Max	3.97	7.0	5.17
Min	3.81	6.9	4.95
Mean	3.89	6.96	5.08
SD	0.06	0.05	0.08

Table 5.6.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
21	3.83	7.0	5.07
22	3.92	6.9	5.12
23	3.90	7.0	5.07
24	3.87	6.9	5.00
25	3.87	6.9	5.11
26	3.89	7.0	4.98
27	3.89	7.0	5.00
28	3.85	6.9	5.04
29	3.93	7.0	5.01
30	3.84	7.0	5.00
Max	3.93	7.0	5.12
Min	3.83	6.9	4.98
Mean	3.88	6.96	5.04
SD	0.04	0.05	0.05

Table 5.7.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
31	3.83	6.9	5.09
32	3.87	7.0	5.06
33	3.88	7.0	4.98
34	3.94	6.8	5.11
35	3.86	6.9	5.06
36	3.86	7.0	5.00
37	3 86	7.0	5.01
38	3.90	7.0	4.99
39	3.81	7.0	5.08
40	3.83	7.0	5.02
Max	3.94	7.0	5.11
Min	3.81	6.8	4.98
Mean	3.86	6.96	5.04
SD	0.05	0.07	0.05

Table 5.8.

DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
41	3.99	7.0	5.03
42	3.96	7.2	5.02
43	3.85	6.9	5.10
44	3.96	7.0	5.09
45	4.01	7.0	5.10
46	4.08	7.0	5.06
47	3.96	6.9	5.07
48	4.09	7.0	5.08
49	4.08	7.0	5.04
50	3.93	7.1	5.09
51	3.98	7.0	5.07
Max	4.09	7.2	5.10
Min	3.85	6.9	5.02
Mean	3.99	7.01	5.07
SD	0.07	0.08	0.03

Table 5.9. PHOSPHACAP CEMENT (Retentive value).

ZP17A11 = 162 N	cement on preparation	25-35%
ZP17A13 = 116 N	cement on preparation	0-10%
ZP17A14 = 88 N	cement on preparation	0-10%
ZP17A18 = 94 N	cement on preparation	0-10%
ZP17A19 = 106 N	cement on preparation	0-10%

MEAN = 113 N S.D. = 29 S.E. = 13

Table 5.10. POLY-F CEMENT (Retentive value).

PC27A11 = 70 N	cement on preparation	0-10%
PC27Y13 = 124 N	dentine fractured	
PC27A14 = 162 N	cement on preparation	0-10%
PC27A18 = 92 N	cement on preparation	0-10%
PC27A19 = 116 N	cement on preparation	0-10%

MEAN = 113 N S.D. = 35 S.E. = 15

Table 5.11. AQUACEM CEMENT (Retentive value).

GI17Y06 = 300 N	cement on preparation	80-90%
GI17A12 = 158 N	cement on preparation	90-100%
GI17A26 = 164 N	cement on preparation	90-100%
GI17A27 = 206 N	cement on preparation	90-100%
GI17A28 = 318 N	cement on preparation	90-100%

MEAN = 229 N S.D. = 75 S.E. = 34

Table 5.12. BONDALCAP CEMENT (Retentive value).

PC17A23 = 190 N	cement on preparation	85-95%
PC17A24 = 178 N	cement on preparation	10-20%
PC17A25 = 176 N	cement on preparation	35-45%
PC17A29 = 134 N	cement on preparation	80-90%
PC17A30 = 172 N	cement on preparation	90-100%

MEAN = 170 N S.D. = 21 S.E. = 9

Table 5.13. ZINC PHOSPHATE CEMENT (DE TREY) (Retentive value).

ZP27A01 = 130 N	cement on preparation	0-10%
ZP27A02 = 124 N	cement on preparation	15-25%
ZP27A03 = 124 N	cement on preparation	0-10%
ZP27A06 = 114 N	cement on preparation	0-10%
ZP27A07 = 132 N	cement on preparation	10-20%

MEAN = 125 N S.D. = 7 S.E. = 3

Table 5.14. KETAC-BOND CEMENT (Retentive value).

GI27A05 = 174 N	cement on preparation	10-20%
GI27A11 = 140 N	cement on preparation	0-10%
GI27A14 = 206 N	cement on preparation	0-10%
GI27Y17 = 200 N	dentine fractured	
GI27Y20 = 128 N	dentine fractured	

MEAN = 170 N S.D. = 35 S.E. = 16

Table 5.15. PANAVIA-EX CEMENT (Retentive value).

CO17A13 = 238 N	cement on preparation	45-55%
CO17Y14 = 228 N	dentine fractured	
CO17Y15 = 232 N	dentine fractured	
CO17Y16 = 342 N	dentine fractured	
CO17A19 = 222 N	cement on preparation	0-10%

MEAN = 252 N S.D. = 50 S.E. = 22

Table 5.16. ZINC OXIDE EBA CEMENT (Retentive value).

ZE17A09 = 92 N	cement on preparation	0-10%
ZE17A10 = 16 N	cement on preparation	0-10%
ZE17A18 = 32 N	cement on preparation	0-10%
ZE17A26 = 50 N	cement on preparation	0-10%
ZE17A30 = 86 N	cement on preparation	0-10%

MEAN = 55 N S.D. = 33 S.E. = 15

Table 6.3.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
56	3.79	6.9	5.01
57	3.78	7.0	5.09
58	3.78	7.0	5.08
59	3.79	7.0	5.04
60	3.80	7.0	5.04
61	3.76	6.9	5.06
62	3.83	7.0	5.08
63	3.70	7.0	4.92
64	3.82	7.1	5.10
65	3.89	7.0	5.08
Max	3.89	7.1	5.10
Min	3.70	6.9	4.92
Mean	3.79	6.99	5.05
SD	0.05	0.06	0.05

Table 6.4.

DIMENSIONS OF DENTINE CONES OF 7º TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
66	3.89	7.0	5.04
67	3.82	7.0	4.99
68	3.85	7.0	5.11
69	3.98	7.0	5.05
70	3.80	7.0	4.79
71	3.89	7.0	5.04
72	3.84	6.8	5.04
73	3.73	6.9	4.98
74	3.71	6.9	5.11
75	3.92	7.0	5.08
76	3.91	6.9	5.10
77	3.80	6.9	5.03
78	4.04	7.0	5.07
79	3.84	6.9	5.04
80	3.75	7.0	5.09
81	3.80	7.0	5.02
Max	4.04	7.0	5.11
Min	3.71	6.8	4.79
Mean	3.85	6.95	5.04
SD	0.09	0.06	0.08

Table 6.5.

DIMENSIONS OF DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
82	3.89	7.0	5.01
83	3.92	7.0	5.03
84	3.93	7.0	5.06
85	3.91	7.0	5.05
86	3.93	6.8	5.07
87	3.91	6.7	5 07
88	4.01	6.7	5.06
89	3.94	7.0	5.06
90	3.90	7.0	5.04
91	3.96	7.0	5.05
Max	4.01	7.0	5.07
Min	3.89	6.8	5.01
Mean	3.93	6.92	5.05
SD	0.04	0.13	0.03

Table 6.6 ZINC PHOSPHATE CEMENT (Retentive value).

ZP27A01 = 125 N	cement on preparation	0-10%
ZP27A02 = 140 N	cement on preparation	5-15%
ZP27A03 = 70 N	cement on preparation	0-10%
ZP27A05 = 110 N	cement on preparation	25-35%
ZP27A06 = 82 N	cement on preparation	0-10%

MEAN = 105 N S.D. = 29 S.E. = 13

Table 6.7 POLYCARBOXYLATE CEMENT (Retentive value).

PC27A07 = 288 N	cement on preparation	25-35%
PC27A23 = 160 N	cement on preparation	0-10%
PC27Y08 = 356 N	dentine fractured	
PC27Y09 = 124 N	dentine fractured	
PC27Y28 = 262 N	dentine fractured	

MEAN = 238 N S.D. = 95 S.E. = 43

Table 6.8 ZINC OXIDE EBA CEMENT (Retentive value).

ZE17A07 = 68 N	cement on preparation	0-10%
ZE17A09 = 68 N	cement on preparation	0-10%
ZE17A11 = 66 N	cement on preparation	0-10%
ZE17A26 = 128 N	cement on preparation	0-10%
ZE17A28 = 100 N	cement on preparation	0-10%

MEAN = 86 N S.D. = 27 S.E. = 12

Table 6.9 GLASS-IONOMER CEMENT (Retentive value).

GI27A16 = 170 N	cement on preparation	0-10%
GI27A21 = 178 N	cement on preparation	90-100%
GI27A25 = 194 N	cement on preparation	80-90%
GI27A27 = 162 N	cement on preparation	70-80%
GI27Y30 = 130 N	dentine fractured	

MEAN = 167 N S.D. = 24 S.E. = 11

Table 6.10 COMPOSITE CEMENT (Retentive value).

CO17A17 = 102 N	cement on preparation	0-10%
CO17Y18 = 224 N	dentine fractured	
CO17A19 = 240 N	cement on preparation	0-10%
CO17A22 = 180 N	cement on preparation	0-10%
CO17Y29 = 290 N	dentine fractured	

MEAN = 207 N S.D. = 71 S.E. = 32

Table 6.11 GLASS-IONOMER CEMENT (Retentive value).

GI27A02 = 190 N	cement on preparation	55-65%
GI27A05 = 226 N	cement on preparation	75-85%
GI27Y07 = 182 N	dentine fractured	
GI27A08 = 148 N	cement on preparation	55-65%
GI27A11 = 254 N	cement on preparation	90-100%

MEAN = 200 N S.D. = 41 S.E. = 18

Table 6.12 COMPOSITE CEMENT (Retentive value).

CO17Y12 = 302 N	dentine fractured	
CO17A13 = 244 N	cement on preparation	0-10%
CO17A14 = 252 N	cement on preparation	0-10%
CO17Y15 = 418 N	dentine fractured	
CO17A20 = 178 N	cement on preparation	0-10%

MEAN = 279 N S.D. = 89 S.E. = 40

Table 6.14.DIMENSIONS OF DENTINE CONES OF 7° TAPER

dentine cone no.	occlusal diameter mm	taper degrees	height mm
92	4.00	7.0	5.09
93	3.90	7.0	5.04
94	3.94	7.0	4.95
95	3.90	6.9	5.08
96	3.93	6.8	5.03
97	3.98	7.0	5.01
98	3.90	7.0	5.05
99	3.90	7.0	4.84
100	3.93	7.0	5.06
101	3.95	7.0	5.04
102	3.91	7.0	5.08
103	3.93	7.0	5.02
Max	4.00	7.0	5.09
Min	3.90	6.8	4.84
Mean	3.93	6.97	5.02
SD	0.03	0.06	0.07

Table 6.15.

DIMENSIONS OF FIRST RANDOM SAMPLE FROM A GROUP OF 10 DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
104	3.92	6.8	5.02
105	3.94	7.0	5.09
106	4.01	6.9	5.08
107	4.05	7.0	5.14
Max	4.05	7.0	5.14
Min	3.92	6.8	5.02
Mean	3.98	6.93	5.07
SD	0.06	0.09	0.05

Table 6.16. DIMENSIONS OF SECOND RANDOM SAMPLE FROM A GROUP OF 10

DENTINE CONES OF 7° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
108	3.82	7.0	5.04
109	4.02	7.0	5.05
110	3.93	7.0	5.02
111	3.91	6.9	5.08
Max	4.02	7.0	5.08
Min	3.82	6.9	5.02
Mean	3.92	6.98	5.05
SD	0.08	0.05	0.03

Table 6.17 ZINC PHOSPHATE CEMENT (Retentive value).

ZP27A01 = 156 N	cement on preparation	5-15%
ZP27A03 = 198 N	cement on preparation	0-10%
ZP27A06 = 148 N	cement on preparation	0-10%
ZP27A10 = 146 N	cement on preparation	0-10%
ZP27A16 = 128 N	cement on preparation	0-10%

MEAN = 155 N S.D. = 26 S.E. = 12

Table 6.18 POLYCARBOXYLATE CEMENT (Retentive value).

PC27A09 = 232 N	cement on preparation	0-10%
PC27A22 = 220 N	cement on preparation	0-10%
PC27A23 = 276 N	cement on preparation	0-10%
PC27Y24 = 176 N	dentine fracture	
PC27Y25 = 274 N	dentine fracture	

MEAN = 236 N S.D. = 42 S.E. = 19

Table 6.19 GLASS-IONOMER CEMENT (Retentive value).

GI27A02 = 410 N	cement on preparation	90-100%
GI27A07 = 276 N	cement on preparation	90-100%
GI27Y08 = 334 N	dentine fracture	
GI27A11 = 272 N	cement on preparation	90-100%
GI27Y27 = 244 N	dentine fracture	

MEAN = 307 N S.D. = 66 S.E. = 30

Table 6.20 COMPOSITE CEMENT (Retentive value).

CO17A15 = 150 N	cement on preparation	0-10%
CO17A17 = 136 N	cement on preparation	0-10%
CO17A19 = 152 N	cement on preparation	0-10%
CO17Y29 = 62 N	cement on preparation	0-10%
CO17Y18 = 326 N	dentine fracture	

MEAN = 165 N S.D. = 97 S.E. = 44

Table 6.21 ZINC OXIDE EBA CEMENT (Retentive value).

ZE17A01 =	128 N	cement on preparation	0-10%
ZE17A05 =	62 N	cement on preparation	0-10%
ZE17A28 =	70 N	cement on preparation	0-10%
ZE17A30 =	94 N	cement on preparation	0-10%
ZE17A04 =	68 N	cement on preparation	0-10%

MEAN = 84 N S.D. = 27 S.E. = 12

Table 6.24 ZINC PHOSPHATE CEMENT (Retentive value).

ZP27A06 =	136 N	cement on preparation	0-10%
ZP27A07 =	120 N	cement on preparation	0-10%
ZP27A20 =	128 N	cement on preparation	0-10%
ZP27A23 =	104 N	cement on preparation	0-10%
ZP27A29 =	126 N	cement on preparation	0-10%

MEAN = 123 N S.D. = 12 S.E. = 5

Table 6.25 POLYCARBOXYLATE CEMENT (Retentive value).

PC27A01 =	292 N	cement on preparation	55-65%
PC27A06 =	280 N	cement on preparation	75-85%
PC27A11 =	124 N	cement on preparation	60-70%
PC27A14 =	162 N	cement on preparation	55-65%
PC27A13 =	306 N	cement on preparation	70-80%

MEAN = 233 N S.D. = 84 S.E. = 37

Table 6.26 GLASS-IONOMER CEMENT (Retentive value).

GI27A13 = 452 N	cement on preparation	90-100%
GI27A14 = 324 N	cement on preparation	55-65%
GI27A17 = 184 N	cement on preparation	0-10%
GI27A24 = 224 N	cement on preparation	40-50%
GI27A25 = 258 N	cement on preparation	10-20%

MEAN = 288 N S.D. = 105 S.E. = 47

Table 6.27 COMPOSITE CEMENT (Retentive value).

CO17A11 = 266 N	cement on preparation	0-10%
CO17A15 = 182 N	cement on preparation	0-10%
CO17A18 = 208 N	cement on preparation	0-10%
CO17Y21 = 304 N	dentine fracture	
CO17A26 = 214 N	cement on preparation	0-10%

MEAN = 235 N S.D. = 49 S.E. = 22

Table 6.28 ZINC OXIDE EBA CEMENT (Retentive value).

ZE17A03 = 95 N	cement on preparation	0-10%
ZE17A05 = 72 N	cement on preparation	0-10%
ZE17A10 = 55 N	cement on preparation	0-10%
ZE17A12 = 64 N	cement on preparation	0-10%
ZE17A30 = 68 N	cement on preparation	0-10%

MEAN = 71 N S.D. = 15 S.E. = 7

Table 7.1

DIMENSIONS OF DENTINE CONES OF 15° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
112	3.16	15.0	5.03
113	3.25	14.8	5.05
114	3.15	14.8	5.07
115	3.18	15.0	5.04
116	3.18	15.0	5.07
117	3.15	15.1	5.04
118	3.35	14.8	5.03
119	3.10	14.9	5.05
120	3.15	15.0	5.04
121	3.05	15.0	5.00
Max	3.35	15.1	5.07
Min	3.05	14.8	5.00
Mean	3.17	14.9	5.04
SD	0.08	0.1	0.02

Table 7.2

DIMENSIONS OF DENTINE CONES OF 15° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
122	3.22	14.6	5.00
123	3.45	15.0	5.04
124	3.15	15.3	5.04
125	3.10	14.9	5.06
126	3.34	15.1	5.05
127	3.35	15.1	5.02
128	3.21	15.1	5.01
129	3.24	15.1	4.96
130	3.13	15.0	5.01
131	3.19	15.1	5.05
Max	3.45	15.3	5.06
Min	3.10	14.6	4.96
Mean	3.24	15.0	5.02
SD	0.11	0.2	0.03

Table 7.3

DIMENSIONS OF A RANDOM SAMPLE FROM A GROUP OF 20 DENTINE CONES OF 23° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
132	2.35	23.1	5.03
133	2.38	23.0	5.05
134	2.36	23.0	5.07
135	2.35	23.0	5.04
136	2.41	23.0	5.07
137	2.42	23.0	5.04
138	2.36	23.1	5.03
139	2.39	23.0	5.05
140	2.36	23.0	5.04
Max	2.42	23.1	5.07
Min	2.35	23.0	5.03
Mean	2.38	23.0	5.05
SD	0.03	0.04	0.02

Table 7.4

DIMENSIONS OF A RANDOM SAMPLE FROM A GROUP OF 20 DENTINE CONES OF 30° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
141	1.74	30.2	5.08
142	1.81	30.0	5.00
143	1.77	30.0	5.03
144	1.79	30.0	5.00
145	1.79	30.0	5.06
146	1.78	30.0	5.08
147	1.74	30.0	5.07
148	1.75	30.1	5.03
149	1.82	30.0	5.01
150	1.76	30.0	5.06
Max	1.82	30.2	5.08
Min	1.74	30.0	5.00
Mean	1.78	30.0	5.04
SD	0.03	0.08	0.03

Table 7.5 ZINC PHOSPHATE CEMENT (Retentive value, 15° taper).

ZP15A01 = 150 N	cement on preparation	10-20%
ZP15A06 = 116 N	cement on preparation	0-10%
ZP15A07 = 130 N	cement on preparation	0-10%
ZP15A08 = 112 N	cement on preparation	0-10%
ZP15A12 = 168 N	cement on preparation	0-10%

MEAN = 135 N S.D. = 24 S.E. = 11

Table 7.6 POLYCARBOXYLATE. (Retentive value, 15° taper).

PC15A05 = 222 N	cement on preparation	55-65%
PC15A06 = 222 N	cement on preparation	30-40%
PC15A08 = 174 N	cement on preparation	30-40%
PC15Y10 = 206 N	dentine fractured	
PC15A11 = 188 N	cement on preparation	0-10%

MEAN = 202 N S.D. = 21 S.E. = 9

Table 7.7 GLASS-IONOMER. (Retentive value, 15⁰ taper).

GI15YO1 = 218 N	dentine fractured	
GI15A03 = 194 N	cement on preparation	55-65%
GI15A27 = 126 N	cement on preparation	85-95%
GI15A28 = 140 N	cement on preparation	75-85%
GI15A30 = 242 N	cement on preparation	90-100%

MEAN = 184 N S.D. = 50 S.E. = 22

Table 7.8 COMPOSITE. (Retentive value, 15⁰ taper).

CO15A19 = 234 N	cement on preparation	0-10%
CO15A20 = 190 N	cement on preparation	0-10%
CO15A21 = 306 N	cement on preparation	5-15%
CO15A22 = 304 N	cement on preparation	10-20%
CO15A24 = 208 N	cement on preparation	0-10%

MEAN = 248 N S.D. = 54 S.E. = 24

Table 7.9 ZINC PHOSPHATE. (Retentive value, 23⁰ taper).

ZP23A09 = 76 N	cement on preparation	0-10%
ZP23A12 = 60 N	cement on preparation	15-25%
ZP23A13 = 70 N	cement on preparation	0-10%
ZP23A14 = 104 N	cement on preparation	5-15%
ZP23A17 = 82 N	cement on preparation	0-10%

MEAN = 78 N S.D. = 17 S.E. = 7

Table 7.10 POLYCARBOXYLATE. (Retentive value, 23° taper).

PC23A16 = 216 N	cement on preparation	45-55%
PC23A19 = 136 N	cement on preparation	50-60%
PC23A20 = 222 N	cement on preparation	?
PC23A21 = 128 N	cement on preparation	15-25%
PC23A29 = 168 N	cement on preparation	5-15%

MEAN = 174 N S.D. = 44 S.E. = 20

Table 7.11 GLASS-IONOMER. (Retentive value, 23° taper).

GI23A03 = 96 N	cement on preparation	80-90%
GI23A07 = 106 N	cement on preparation	85-95%
GI23A08 = 188 N	cement on preparation	55-65%
GI23A10 = 158 N	cement on preparation	75-85%
GI23Y15 = 112 N	dentine fractured	

MEAN = 132 N S.D. = 39 S.E. = 18

Table 7.12 COMPOSITE. (Retentive value, 23° taper).

CO23A16 = 220 N	cement on preparation	0-10%
CO23A23 = 284 N	cement on preparation	25-35%
CO23A28 = 184 N	cement on preparation	?
CO23Y24 = 102 N	dentine fractured	
CO23Y25 = 290 N	dentine fractured	

MEAN = 216 N S.D. = 78 S.E. = 35

Table 7.13 ZINC PHOSPHATE. (Retentive value, 30° taper).

ZP30A17 = 74 N	cement on preparation	0-10%
ZP30A20 = 69 N	cement on preparation	0-10%
ZP30A21 = 68 N	cement on preparation	0-10%
ZP30A26 = 64 N	cement on preparation	5-15%
ZP30A29 = 76 N	cement on preparation	15-25%

MEAN = 70 N S.D. = 5 S.E. = 2

Table 7.14 POLYCARBOXYLATE. (Retentive value, 30° taper).

PC30A12 = 118 N	cement on preparation	45-55%
PC30A14 = 168 N	cement on preparation	75-85%
PC30A16 = 114 N	cement on preparation	10-20%
PC30A27 = 156 N	cement on preparation	20-30%
PC30A30 = 142 N	cement on preparation	5-15%

MEAN = 140 N S.D. = 24 S.E. = 11

Table 7.15 GLASS-IONOMER. (Retentive value, 30° taper).

GI30A11 = 94 N	cement on preparation	85-95%
GI30A15 = 134 N	cement on preparation	70-80%
GI30A05 = 50 N	cement on preparation	55-65%
GI30A06 = 84 N	cement on preparation	65-75%
GI30A07 = 118 N	cement on preparation	65-75%

MEAN = 96 N S.D. = 32 S.E. = 14

Table 7.16 COMPOSITE. (Retentive value, 30° taper).

CO30A11 = 160 N	cement on preparation	0-10%
CO30A15 = 134 N	cement on preparation	0-10%
CO30A23 = 102 N	cement on preparation	5-15%
CO30A24 = 186 N	cement on preparation	50-60%
CO30A28 = 124 N	cement on preparation	0-10%

MEAN = 141 N S.D. = 33 S.E. = 15

Table 7.17 ORIGINAL DATA FROM JORGENSEN'S PAPER[1].

Taper	M	SE	SD	A	M/A
^{0}	kg	--	--	mm^2	g/mm^2
5	15.62	1.57	1.95	192	81.3
10	7.62	1.20	3.87	184	41.4
15	6.22	0.96	2.89	176	35.3
20	4.31	0.97	3.08	168	25.7
25	2.76	0.61	1.92	160	17.3
35	2.60	0.73	2.30	144	18.1
45	1.53	0.40	1.25	112	13.7

Note. The SE for 5^0 is the value quoted[1], but calculations show it to be incorrect

Table 7.18 ORIGINAL DATA FROM THE PAPER OF KAUFMAN ET AL[2].

height mm	Taper ^{0}	stress psi
	20	245
	15	561
4	10	892
	5	1288
	1	1951
	20	398
	15	606
7	10	835
	5	1152
	1	1901
	15	708
10	10	903
	5	1181
	1	2002

Table 7.19

DIMENSIONS OF DENTINE CONES OF 7º TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
151	3.94	6.9	5.00
152	3.81	7.0	5.04
153	3.79	7.2	5.00
154	MISSING		
155	4.02	7.0	5.05
156	3.74	7.3	5.06
157	3.93	7.1	5.02
158	3.82	7.0	5.00
259	4.01	7.0	5.03
260	3.76	6.9	5.07
Max	4.02	7.3	5.07
Min	3.74	6.9	5.00
Mean	3.87	7.0	5.03
SD	0.11	0.13	0.03

Table 7.20 ZINC PHOSPHATE (Retentive value of crowns where the whole of the die was coated with die-spacer).

ZP07A01 = 100 N	cement on preparation	25-35%
ZP07A08 = 82 N	cement on preparation	0-10%
ZP07A10 = 100 N	cement on preparation	0-10%
ZP07A25 = 164 N	cement on preparation	0-10%
ZP07A27 = 96 N	cement on preparation	0-10%

MEAN = 108 N S.D. = 32 S.E. = 14

Table 7.21 ZINC PHOSPHATE (Retentive value of crowns which were vented with a No 2 round bur).

ZP07A02 = 72 N	cement on preparation	0-10%
ZP07A06 = 154 N	cement on preparation	15-25%
ZP07A13 = 96 N	cement on preparation	10-20%
ZP07A14 = 119 N	cement on preparation	5-15%
ZP07A19 = 156 N	cement on preparation	0-10%

MEAN = 119 N S.D. = 37 S.E. = 16

Table 8.1

DIMENSIONS OF DENTINE CONES OF 23° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
260	2.45	23.1	5.03
261	2.41	23.0	5.01
262	2.45	22.8	5.03
263	2.39	23.1	5.02
264	2.42	23.0	5.07
265	2.41	23.0	5.00
266	2.45	22.9	5.06
267	2.45	23.1	5.06
268	2.43	23.1	5.02
269	2.40	23.2	5.01
270	2.42	23.1	5.02
271	2.41	23.0	5.02
Max	2.45	23.1	5.07
Min	2.39	22.8	5.00
Mean	2.42	23.0	5.03
SD	0.02	0.1	0.02

Table 8.2

DIMENSIONS OF DENTINE CONES OF 23° TAPER.

dentine cone no.	occlusal diameter mm	taper degrees	height mm
272	2.43	23.0	5.09
273	2.38	23.1	5.01
274	2.44	23.0	5.02
275	2.38	23.1	5.02
276	2.43	23.1	5.08
277	2.22	23.0	5.08
278	2.37	23.0	5.01
279	2.40	23.0	5.08
280	2.35	23.0	5.03
281	2.43	23.1	4.99
Max	2.44	23.1	5.09
Min	2.22	23.0	4.99
Mean	2.38	23.0	5.04
SD	0.07	0.1	0.04

Table 8.3 ZINC PHOSPHATE FIRST CEMENTATION.

(Retentive value).

ZP23A12 = 88 N	cement on preparation	0-10%
ZP23A17 = 104 N	cement on preparation	20-30%
ZP23A25 = 64 N	cement on preparation	0-10%
ZP23A26 = 72 N	cement on preparation	0-10%
ZP23A27 = 80 N	cement on preparation	0-10%
ZP23A29 = 86 N	cement on preparation	0-10%
ZP23A30 = 62 N	cement on preparation	0-10%

MEAN = 79 N S.D. = 15 S.E. = 6

Table 8.4 ZINC PHOSPHATE RECEMENTATION 1.

(Retentive value).

R1ZPA12 = 92 N	cement on preparation	0-10%
R1ZPA17 = 118 N	cement on preparation	0-10%
R1ZPA25 = 64 N	cement on preparation	0-10%
R1ZPA26 = 80 N	cement on preparation	0-10%
R1ZPA27 = 40 N	cement on preparation	0-10%
R1ZPA29 = 124 N	cement on preparation	0-10%
R1ZPA30 = 82 N	cement on preparation	0-10%

MEAN = 86 N S.D. = 29 S.E. = 11

Table 8.5 ZINC PHOSPHATE RECEMENTATION 2.

(Retentive value).

R2ZPA12 = 128 N	cement on preparation	5-15%
R2ZPA17 = 142 N	cement on preparation	0-10%
R2ZPA25 = 106 N	cement on preparation	0-10%
R2ZPA26 = 120 N	cement on preparation	0-10%
R2ZPA27 = 104 N	cement on preparation	0-10%
R2ZPA29 = 182 N	cement on preparation	0-10%
R2ZPA30 = 110 N	cement on preparation	0-10%

MEAN = 127 N S.D. = 28 S.E. = 10

Table 8.6 ZINC PHOSPHATE RECEMENTATION 3.

(Retentive value).

R3ZPA12 = 122 N	cement on preparation	0-10%
R3ZPA17 = 132 N	cement on preparation	20-30%
R3ZPA25 = 100 N	cement on preparation	0-10%
R3ZPA26 = 64 N	cement on preparation	0-10%
R3ZPA27 = 76 N	cement on preparation	40-50%
R3ZPA29 = 100 N	cement on preparation	0-10%
R3ZPA30 = 80 N	cement on preparation	0-10%

MEAN = 96 N S.D. = 25 S.E. = 9

Table 8.7 ZINC PHOSPHATE RECEMENTATION 4.

(Retentive value).

R4ZPA12 = 116 N	cement on preparation	15-25%
R4ZPA17 = 152 N	cement on preparation	25-35%
R4ZPA25 = --- N	cement on preparation	?
R4ZPA26 = 96 N	cement on preparation	10-20%
R4ZPA27 = 78 N	cement on preparation	85-95%
R4ZPA29 = 120 N	cement on preparation	5-15%
R4ZPA30 = 112 N	cement on preparation	5-15%

MEAN = 112 N S.D. = 25 S.E. = 10

Table 8.8 ZINC PHOSPHATE RECEMENTATION 5.

(Retentive value).

R5ZPA12 = 136 N	cement on preparation	5-15%
R5ZPA17 = 132 N	cement on preparation	0-10%
R5ZPA25 = 144 N	cement on preparation	0-10%
R5ZPA26 = 94 N	cement on preparation	5-15%
R5ZPA27 = 76 N	cement on preparation	10-20%
R5ZPA29 = 150 N	cement on preparation	0-10%
R5ZPA30 = 80 N	cement on preparation	0-10%

MEAN = 116 N S.D. = 32 S.E. = 12

Table 8.9 ZINC PHOSPHATE RECEMENTATION 6.

(Retentive value).

R6ZPA12 = 126 N	cement on preparation	5-15%
R6ZPA17 = 128 N	cement on preparation	0-10%
R6ZPA25 = 114 N	cement on preparation	5-15%
R6ZPA26 = 88 N	cement on preparation	25-35%
R6ZPA27 = 78 N	cement on preparation	35-45%
R6ZPA29 = 110 N	cement on preparation	10-20%
R6ZPA30 = 74 N	cement on preparation	45-55%

MEAN = 103 N S.D. = 22 S.E. = 9

Table 8.10 POLYCARBOXYLATE FIRST CEMENTATION.

(Retentive value).

PC23A01 = 238 N	cement on preparation	25-35%
PC23A06 = 250 N	cement on preparation	35-45%
PC23A09 = 196 N	cement on preparation	55-65%
PC23A10 = 166 N	cement on preparation	75-85%
PC23A11 = 154 N	cement on preparation	85-95%

MEAN = 201 N S.D. = 43 S.E. = 19

Table 8.11 POLYCARBOXYLATE RECEMENTATION 1.

(Retentive value).

R1PCA01 = 276 N	cement on preparation	40-50%
R1PCA06 = 278 N	cement on preparation	35-45%
R1PCA09 = 242 N	cement on preparation	25-35%
R1PCA10 = 130 N	cement on preparation	5-15%
R1PCA11 = 160 N	cement on preparation	15-25%

MEAN = 217 N S.D. = 68 S.E. = 31

Table 8.12 POLYCARBOXYLATE RECEMENTATION 2.

(Retentive value).

R2PCA01 = 216 N	cement on preparation	5-15%
R2PCY06 = 276 N	dentine fracture	
R2PCA09 = 194 N	cement on preparation	0-10%
R2PCA10 = 254 N	cement on preparation	30-40%
R2PCA11 = 174 N	cement on preparation	20-30%

MEAN = 223 N S.D. = 42 S.E. = 19

Table 8.13 POLYCARBOXYLATE RECEMENTATION 3.

(Retentive value).

R3PCA01 = 254 N	cement on preparation	60-70%
R3PCA09 = 250 N	cement on preparation	80-90%
R3PCA10 = 230 N	cement on preparation	85-95%
R3PCA11 = 196 N	cement on preparation	85-95%

MEAN = 233 N S.D. = 27 S.E. = 13

Table 8.14 POLYCARBOXYLATE RECEMENTATION 4.

(Retentive value).

R4PCA01 = 320 N	cement on preparation	10-20%
R4PCA09 = 308 N	cement on preparation	25-35%
R4PCA10 = 310 N	cement on preparation	25-35%
R4PCA11 = 190 N	cement on preparation	45-55%

MEAN = 282 N S.D. = 62 S.E. = 31

Table 8.15 POLYCARBOXYLATE RECEMENTATION 5.

(Retentive value).

R5PCA01 = 264 N	cement on preparation	35-45%
R5PCA09 = 284 N	cement on preparation	35-45%
R5PCY10 = 318 N	dentine fracture	
R5PCA11 = 222 N	cement on preparation	0-10%

MEAN = 272 N S.D. = 40 S.E. = 20

Table 8.16 POLYCARBOXYLATE RECEMENTATION 6.

(Retentive value).

R6PCA01 = 282 N	cement on preparation	50-60%
R6PCA09 = 286 N	cement on preparation	65-75%
R6PCA11 = 310 N	cement on preparation	90-100%

MEAN = 293 N S.D. = 15 S.E. = 9

Table 8.17 GLASS-IONOMER FIRST CEMENTATION.

(Retentive value).

GI23A02 = 210 N	cement on preparation	65-75%
GI23A03 = 238 N	cement on preparation	65-75%
GI23A06 = 106 N	cement on preparation	65-75%
GI23A10 = 180 N	cement on preparation	75-85%
GI23A13 = 184 N	cement on preparation	90-100%

MEAN = 184 N S.D. = 49 S.E. = 22

Table 8.18 GLASS-IONOMER RECEMENTATION 1.

(Retentive value).

R1GIA02 = 322 N	cement on preparation	45-55%
R1GIY03 = 350 N	dentine fracture	
R1GIA06 = 312 N	cement on preparation	65-75%
R1GIA10 = 302 N	cement on preparation	45-55%
R1GIY13 = 162 N	dentine fracture	

MEAN = 290 N S.D. = 74 S.E. = 33

Table 8.19 GLASS-IONOMER RECEMENTATION 2.

(Retentive value).

R2GIY02 = 142 N	dentine fracture	
R2GIA06 = 298 N	cement on preparation	75-85%
R2GIY10 = 176 N	dentine fracture	

MEAN = 205 N S.D. = 82 S.E. = 47

Table 8.20 GLASS-IONOMER RECEMENTATION 3.

(Retentive value).

R3GIA06 = 230 N	cement on preparation	65-75%

Table 8.21 GLASS-IONOMER RECEMENTATION 4.

(Retentive value).

R4GIA06 = 68 N	cement on preparation	85-95%

Table 8.22 GLASS-IONOMER RECEMENTATION 5.

(Retentive value).

R5GIA06 = 116 N	cement on preparation	55-65%

Table 8.23 GLASS-IONOMER RECEMENTATION 6.

(Retentive value).

R6GIA06 = 182 N	cement on preparation	65-75%

Table 8.24 COMPOSITE FIRST CEMENTATION.

(Retentive value).

CO23Y14 = 232 N	dentine fracture	
CO23A15 = 260 N	cement on preparation	0-10%
CO23A16 = 294 N	cement on preparation	25-35%
CO23A20 = 286 N	cement on preparation	0-10%
CO23Y28 = 386 N	dentine fracture	

MEAN = 292 N S.D. = 58 S.E. = 26

Table 8.25 COMPOSITE RECEMENTATION 1.

(Retentive value).

R1COA15 = 268 N	cement on preparation	0-10%
R1COA16 = 436 N	cement on preparation	15-25%
R1COY20 = 366 N	dentine fracture	

MEAN = 357 N S.D. = 84 S.E. = 49

Table 8.26 COMPOSITE RECEMENTATION 2.

(Retentive value).

R2COA15 = 276 N	cement on preparation	0-10%
R2COA16 = 174 N	cement on preparation	0-10%

MEAN = 225 N S.D. = 72 S.E. = 51

Table 8.27 COMPOSITE RECEMENTATION 3.

(Retentive value).

R3COA15 = 196 N	cement on preparation	0-10%
R3COA16 = 394 N	cement on preparation	15-25%

MEAN = 295 N S.D. = 140 S.E. = 99

Table 8.28 COMPOSITE RECEMENTATION 4.

(Retentive value).

R4COA15 = 168 N	cement on preparation	0-10%
R4COA16 = 356 N	cement on preparation	85-95%

MEAN = 262 N S.D. = 133 S.E. = 94

Table 8.29 COMPOSITE RECEMENTATION 5.

(Retentive value).

R5COA15 = 102 N	cement on preparation	0-10%
R5COA16 = 154 N	cement on preparation	5-15%

MEAN = 128 N S.D. = 37 S.E. = 26

Table 8.30 COMPOSITE RECEMENTATION 6.

(Retentive value).

R6COA15 = 98 N	cement on preparation	0-10%
R6COA16 = 264 N	cement on preparation	0-10%

MEAN = 181 N S.D. = 117 S.E. = 8

APPENDIX 3.

Publications Arising.

The retention of gold crowns on human dentine preparations — a comparison of eight cements

By **S M BLACK** BDS; and **G CHARLTON** BDS MDS FDSRCS; Department of Conservative Dentistry, University of Edinburgh, Old Surgeons' Hall, Edinburgh

Experiments were carried out to compare the retentive properties of eight dental luting cements, using gold crowns cemented onto human dentine. The order of retention of the cements was: 1 Composite (Panavia-Ex, J & S Davis); 2 Glass-ionomer (AquaCem, DeTrey); Glass-ionomer (Ketac-Bond, Cottrell); and Polycarboxylate (Bondalcap, Vivadent); 3 Polycarboxylate (Poly F Plus, DeTrey); Zinc phosphate (DeTrey); and Zinc phosphate (Phosphacap, Vivadent); and 4 Zinc oxide/eugenol, alumina, EBA (Opotow, Teledyne Getz).

Introduction

Jorgensen and Holst[1] used crown preparations of metal, and metal crowns, to test four cementing materials and showed a correlation between compressive strength and retention. Lorey and Myers[2] found that this correlation was not true for three-quarter crowns. Williams, Swartz, and Phillips[3], reported a direct correlation between the retention of orthodontic bands and the compressive strengths of an EBA reinforced zinc oxide/eugenol cement and a zinc phosphate cement.

The poor agreement between the reported results led Richter, Mitchem, and Brown[4], to question the validity of extrapolating the retention of a dental cement from its compressive strength. They tested four cements, zinc phosphate (Flecks), hydrophosphate (Calmix), polycarboxylate (Duralon), and alumina reinforced ZOE/EBA (Opotow), and showed that there was no linear relationship between retention and either compressive, tensile or shear strengths. Richter *et al* used human dentine preparations and cast crowns but each specimen was cemented twice with four different cements.

In this investigation gold crowns were cemented to crown preparations of human dentine (some cements adhere to dentine) and each specimen was used once only, because McComb[5] has shown that recementation affects the retention of cement lutes.

Methods and materials

Eight cements were used as shown in **Table 1.**

The crown preparations were made on extracted human teeth. Before preparation the teeth were kept in water at room temperature, and after preparation they were stored at 37°C and 100 per cent humidity. **Fig 1** shows the dimensions of the specimens, which were mounted in chromium plated tubes using acrylic resin (Howmedica). The tooth enamel was removed using a diamond bur, with water coolant, in a dental handpiece. The crown preparation was done on a lathe using a tungsten-carbide tool with water coolant and a special tungsten-carbide lathe tool was kept for fine finishing.

A groove was cut 5mm from the occlusal end of the preparation in order to give a clear margin to the core. The accuracy of the fit of the gold crown could be examined against the sharp margin, and the groove also ensured a well defined area of cementation for each preparation. The dimensions of the dentine cores were measured on a

Table 1. The cements used in the comparison

Luting cements
1 Zinc oxide/eugenol, alumina, EBA (Opotow, Teledyne Getz)
2 Zinc phosphate (Phosphacap encapsulated, Vivadent)
3 Zinc phosphate (DeTrey)
4 Polycarboxylate (Poly F Plus, DeTrey)
5 Polycarboxylate (Bondalcap encapsulated, Vivadent)
6 Glass-ionomer (Ketac-Bond, Cottrell)
7 Glass-ionomer (AquaCem, DeTrey)
8 Composite (Panavia-Ex, J & S Davis

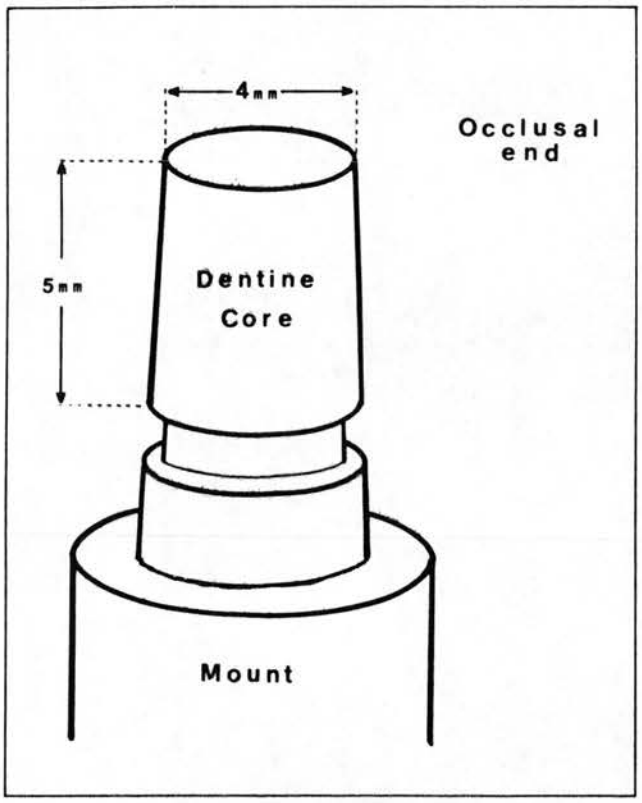

FIG 1 Dimensions of human dentine preparations. The cores were truncated cones of 7° taper.

Nikon Profile Projector V-12 (Nippon Kogaku) and the results are shown in **Table 2.**

The dentine cores were duplicated using an elastomeric impression material and stone dies. Four layers of die spacer (Adapt-rite) equivalent of 25 μm were applied to the die leaving 1 mm uncoated above the finishing groove. Crowns were waxed on the dies and a 3 mm diameter plastic sprue was attached to the occlusal surface of the crown. This sprue was aligned with the long axis of the dentine core so that it could be used to pull the crown from the core.

The crowns were cast in Matticast N gold. After casting, devesting and finishing, the fitting surfaces of the crowns were cleaned with propan-2-ol. The accuracy of fit was checked by ensuring that each crown margin finished exactly level with the groove at the base of the dentine core.

The encapsulated cements were mixed in a Silamat (S3) and the other cements were mixed on a slab to the manufacturers' specifications. The dentine cores were dried with a jet of air and the crowns were cemented using a jig designed to ensure that the cementation loads were axial. An initial cementation load of 6 kg was applied for 30 seconds followed by a maintenance load of 3 kg until the cement had set.

These values are derived from experiments where ten operators simulated cementing a crown 50 times, and they are the subject of a separate paper not yet published. The force used was comparable with the 5 kg static load advised by Jorgensen[6]. Surplus cement was removed from the junction of the gold crown and the edge of the dentine groove, and the specimens were returned to storage at 37°C and 100 per cent humidity for 24 hours.

The crowns were pulled off the dentine cores using an RDP Howden Universal Servo-hydraulic testing machine (UM5/2) with a range of 0 to 500 N over 60 seconds. The output from the test machine was passed via a load amplifier to a computer. The data was stored and statistical analysis and graph generation carried out at a later stage.

Each sample was examined to ascertain whether the cement, dentine, or both, had fractured when the crown was removed from the dentine preparation.

Table 2 Dimensions of dentine preparations for gold crowns

	Mean of 11 samples	Standard deviation
Occlusal diameter (mm)	3.99	0.07
Height (mm)	5.07	0.03
Taper (degrees)	7.06	0.16

Results

The glass ionomer cements failed at the cement/metal interface leaving the cement mostly on the dentine. Polycarboxylate no 5 was variable, with cement both in the crown and on the dentine after fracturing. All the other cements failed at the cement/dentine interface leaving the cement in the crown. The results of the retention tests are shown in **Table 3** and **Fig 2.**

The dentine core (crown preparation) was completely fractured off at the level of the groove leaving the preparation in the crown on six specimens (one Poly F Plus, two Ketac-Bond and three Panavia-Ex).

Using a Wilcoxon rank sum test with a significance level of $p = 0.05$ there was no significant difference between the two zinc phosphate cements. There was also no statistical difference between the two glass ionomer cements, but the two polycarboxylate cements differed from each other.

The zinc oxide/eugenol EBA cement was significantly less retentive than the other cements. The zinc phosphate cements showed no significant difference from polycarboxylate no 4, but were significantly less retentive than polycarboxylate

Table 3 Retention of gold crowns cemented on human dentine cores

Cement	No	Retention mean (n)	Standard deviation	Standard error
1 Zoe/ERA	5	55	33	15
2 Zinc phosphate	5	113	29	13
3 Zinc phosphate	5	125	7	3
4 Polycarboxylate	5	113	35	15
5 Polycarboxylate	5	170	21	9
6 Glass ionomer	5	170	35	16
7 Glass ionomer	5	229	75	34
8 Composite	5	252	50	22

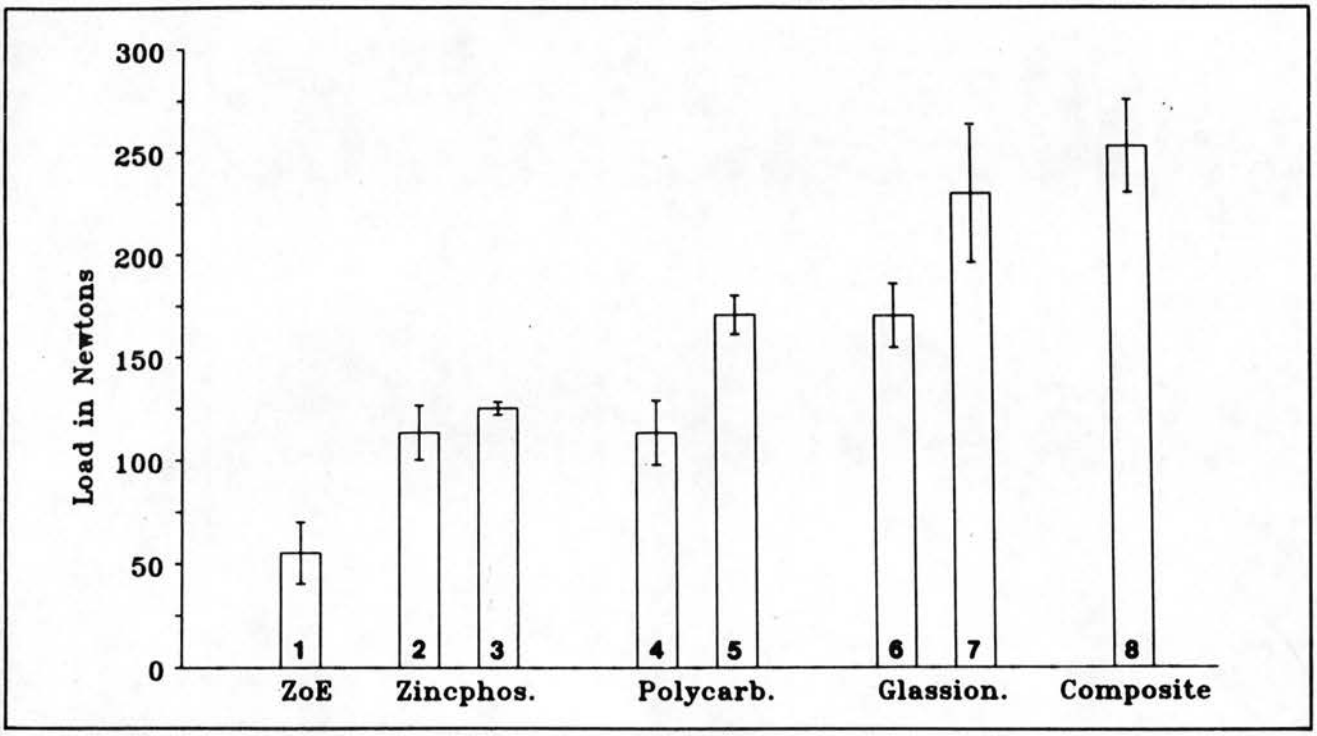

FIG 2 Retention of gold crowns cemented on human dentine cores using eight different cements. The bars each represent the mean of 5 results and the standard error is indicated.

no 5, the glass ionomers and the composite cement.

Polycarboxylate no 5 was significantly more retentive than the phosphate cements and polycarboxylate cement no 4; was not significantly different from the glass ionomer cements; and it was less retentive than the composite cement.

The composite cement proved to be the most retentive cement of the eight used in these experiments.

Discussion

If a more homogeneous material had been used for the crown preparations (rather than human dentine) this would have simplified the production of the specimens and given more consistent results. However, the fact that some dental cements adhere to dentine mitigates against using any material other than human dentine if the results are to have good clinical relevance.

Recently published work comparing the retentive capacity of a zinc phosphate, a polycarboxylate and three glass ionomer cements, gave similar results[7].

In selecting a cement for clinical use, other properties must also be considered, such as marginal leakage[8], viscosity[9], solubility and toxicity[10], and ease of use[11]. Indeed, the retention of a crown may be affected over a long period in the mouth, depending on these other important properties.

Conclusions

The EBA reinforced zinc oxide/eugenol cement was less retentive than the other cements tested. There was no significant difference between the zinc phosphate cements and one polycarboxylate cement. The glass ionomer cements and the other polycarboxylate cement showed superior retention to all but the composite cement which was the most retentive of the eight materials tested.

Acknowledgements

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Survival of crowns and bridges related to luting cements

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Abstract

The longevity of 782 items of crown and bridgework was investigated in a retrospective study. The effect of different cement lutes was assessed for periods varying from 70 to 89 months using a survival analysis technique.

The analysis of all types of restoration showed slightly better survival figures for restorations cemented with polycarboxylate but were not statistically significant when compared with those cemented with glass-ionomer. However, those cemented with polycarboxylate were significantly more successful than zinc phosphate. The restorations cemented with glass-ionomer showed no statistically significant improvement in survival rate compared with those cemented with zinc phosphate.

Restorations cemented with zinc/oxide eugenol reinforced EBA cement had the lowest survival rate of the four cement types.

Analysis of the survival of crowns alone showed the same ranking of the cements compared with all restorations. Comparison of bridges, ranked those cemented with glass-ionomer above those cemented with polycarboxylate, but not statistically different. Posts cemented with phosphate were ranked first and lasted significantly longer than those cemented with glass-ionomer.

Introduction

In 1970 Schwartz et al (1) showed that crowns and bridges fail (in order of frequency) because of caries, cement failure, defective margins, excessive wear, periodontal disease, mobility, lost veneer, poor aesthetics, periapical involvement, broken solder joint, broken pontic, and other reasons. In this study there was no specific record of any crown or bridge failing as a result of trauma, periodontal problems, or bridge fracture.

It is accepted that the cement lute is not the only factor involved in the retention of crowns or bridges; surface roughness (2,3); taper (4); film thickness (5); and the size and shape of the tooth preparation (6) are also important. However, in this retrospective clinical investigation it was not possible to assess the influence of these other variables, and therefore the assumption had to be that the causes of failure (other than failure of the cement lute) were randomly distributed. It was considered that the disadvantage of this assumption was offset to some extent, by the large number of cases.

Method

The records of crown and bridge patients treated at Edinburgh Dental Hospital from 25/3/83 to 20/2/85 were scrutinized. All the patients included in this study had regular follow-up from 6 months up to almost 7 years. Those patients who did not attend for a dental examination during the last 6 months of the investigation were sent a questionnaire, which was as simple as possible (Fig. 1), together with a stamped addressed envelope.

During the last 6 months of the study:

430 (51.5%) Restorations were examined
169 (21.6%) Restorations were reported by questionnaire
210 (26.9%) Restorations were lost from the study at this stage.

Fig 1.

Our records show that you had a crown fitted onto your tooth or teeth (described in lay terms)

ON ___/___/___(date)

I would be most grateful if you could answer the following questions.

1. Is the crown all right as far as you know

Yes/No

2. If the crown failed when did it fail. Please give month and year if possible.

..... Month .....Year

3. If you would like a dental inspection please delete as appropriate.

I would/would not like to have a dental inspection

(This questionnaire had "bridge" substituted for "crown" where appropriate.)

FIG 1 The questionnaire sent to patients who had crowns and/or bridges cemented at Edinburgh Dental Hospital 1980-88.

This investigation followed a total of 132 bridges, 534 crowns, 116 post crowns; cemented with polycarboxylate, glass-ionomer, zinc phosphate, or zinc oxide/eugenol reinforced EBA cements over an 8 year period, with patients entering and leaving the study at different times. The periods of study for each of the cements were:

1. Polycarboxylates .....84 months
2. Glass-ionomers.....70 months
3. Zinc phosphates.....84 months
4. Zinc oxide/eugenol, EBA .....89 months

The data was stored in a database on a mainframe computer and was examined using a survival analysis technique (7), to allow for the loss of patients from the study and for those entering at different times. The use of survival analysis and life tables in dental studies have been demonstrated by Elderton (8) and Walls (9).

Results

The results are listed in Tables 1 to 4. and shown graphically in Figs 2 to 5.

The ranking of the cements when all restorations were compared was polycarboxylate, glass-ionomer, zinc phosphate, and zinc/oxide eugenol reinforced EBA cement.

A pairwise comparison of survival of all the restorations using the lee-desu statistic to generate 'p' values, showed that restorations cemented with zinc/oxide eugenol reinforced EBA cements had significantly shorter survival rates than all other cements. ($p > 0.05$). There was no signifi-

FIG 2 Estimated percent survival for all restorations at 1, 2 and 5 years.

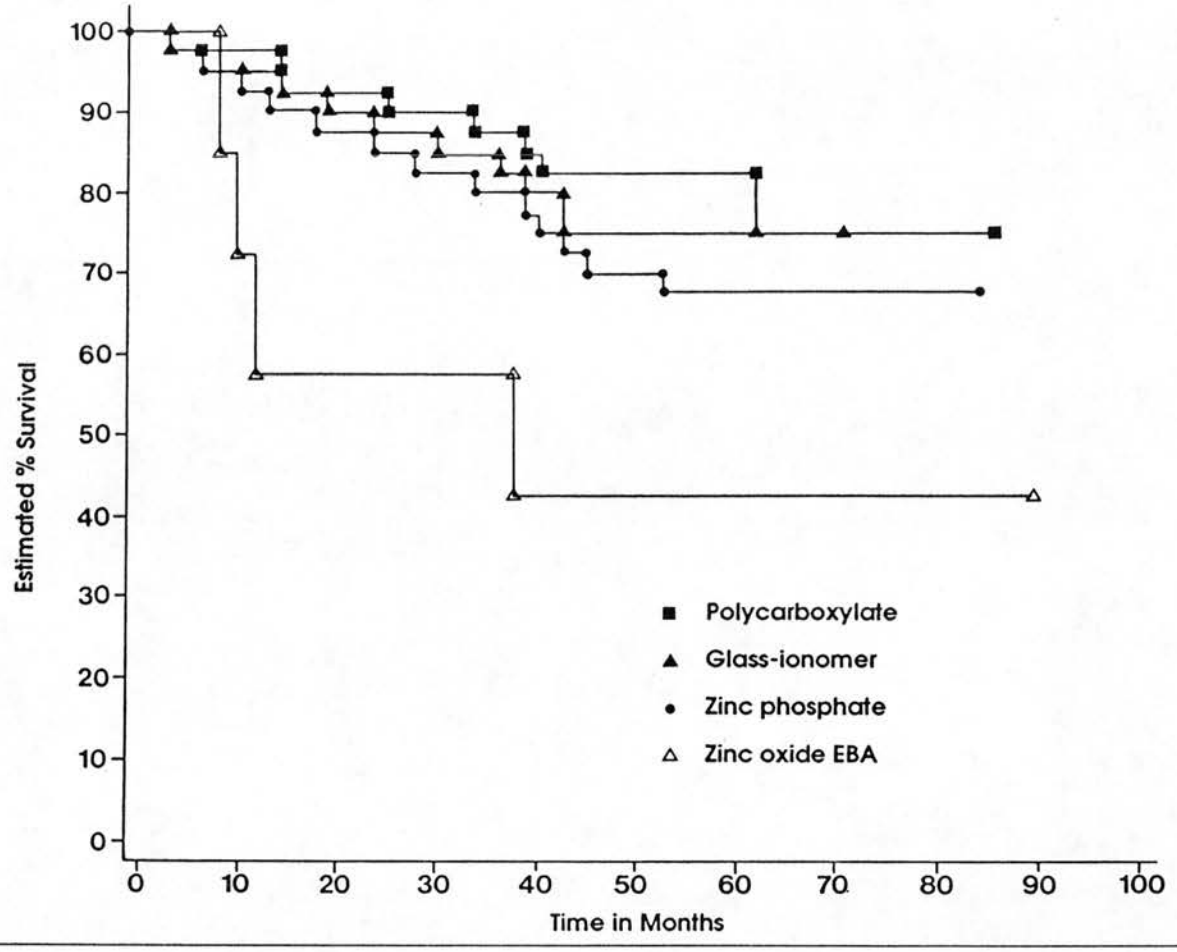
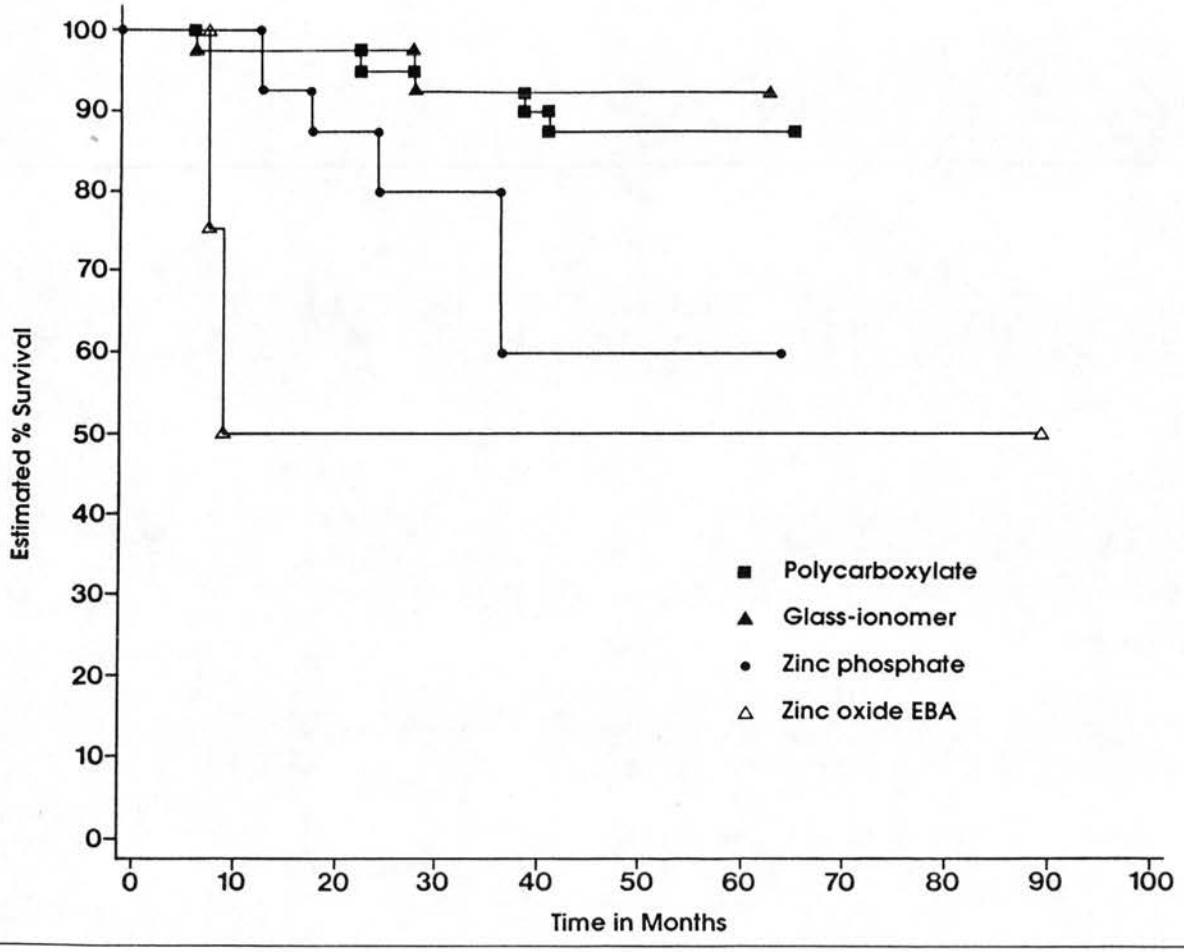


FIG 3 Estimated percent survival for bridges at 1, 2 and 5 years.



cant difference between the survival rates of restorations cemented with zinc phosphate and glass-ionomer cements ($p = 0.5$), or between those with glass-ionomer and polycarboxylate cements ($p = 0.15$). The restorations cemented with polycarboxylates showed a significantly longer survival rate than the zinc phosphate cements ($p = 0.02$).

Pairwise comparisons of crowns alone shows the same ranking as for all restorations but with no significant differences.

In the analysis of the bridges glass-ionomer is ranked first, polycarboxylate second, zinc phosphate third and zinc/oxide reinforced EBA cement last. with p at the significance level of 0.05 glass-ionomer is significantly more retentive than phosphate cement and the zinc/oxide reinforced EBA cement is less retentive than both the glass-ionomer and polycarboxylate cement. There are no other significant differences.

No post crowns were cemented with zinc/oxide reinforced EBA cement. The ranking for survival of post crowns was zinc phosphate first, polycarboxylate second and glass-ionomer cement third. The survival of phosphate cemented post crowns was significantly better than those cemented with glass-ionomer.

Table 1 Estimated percent survival for all restorations at 1, 2 and 5 years. Standard error in brackets

	Year 1	Year 2	Year 5
Polycarboxylate.....	96.9 (0.9)	91.4 (1.5)	81.7 (2.4)
Glass-ionomer.....	92.7 (2.0)	87.1 (2.7)	74.8 (4.2)
Zinc phosphate	91.9 (2.3)	85.9 (2.9)	68.7 (4.8)
Zinc oxide/ eugenol EBA.....	57.1 (1.9)	57.1 (1.9	42.9 (1.9)

Table 2 Estimated percent survival for bridges at 1, 2 and 5 years. Standard error in brackets

	Year 1	Year 2	Year 5
Polycarboxylate.....	98.5 (1.50)	95.2 (2.7)	87.6 (5.0)
Glass-ionomer.....	96.6 (3.4)	96.6 (3.4)	91.6 (5.8)
Zinc phosphate	100 (0.0)	86.7 (8.8)	60.5 (1.4)
Zinc oxide/ eugenol EBA.....	50.0 (2.5)	50.0 (2.5)	50.0 (2.5)

Table 3 Estimated percent survival for crowns at 1, 2 and 5 years. Standard error in brackets

	Year 1	Year 2	Year 5
Polycarboxylate.....	97.4 (1.6)	92.8 (1.7)	83.8 (2.7)
Glass-ionomer.....	95.7 (1.9)	89.9 (2.9)	77.4 (4.9)
Zinc phosphate	91.9 (2.9)	89.5 (3.3)	73.1 (6.0)
Zinc oxide/ eugenol EBA.....	100 (0.0)	100 (0.0)	50.0 (3.5)

Discussion

Torabinejad (10) observed that retrospective studies can be criticized because the data to be analysed is restricted and all the information about each case is not available. However this type of study is less prone to investigator bias;

FIG 4 Estimated percent survival for crowns at 1, 2 and 5 years.

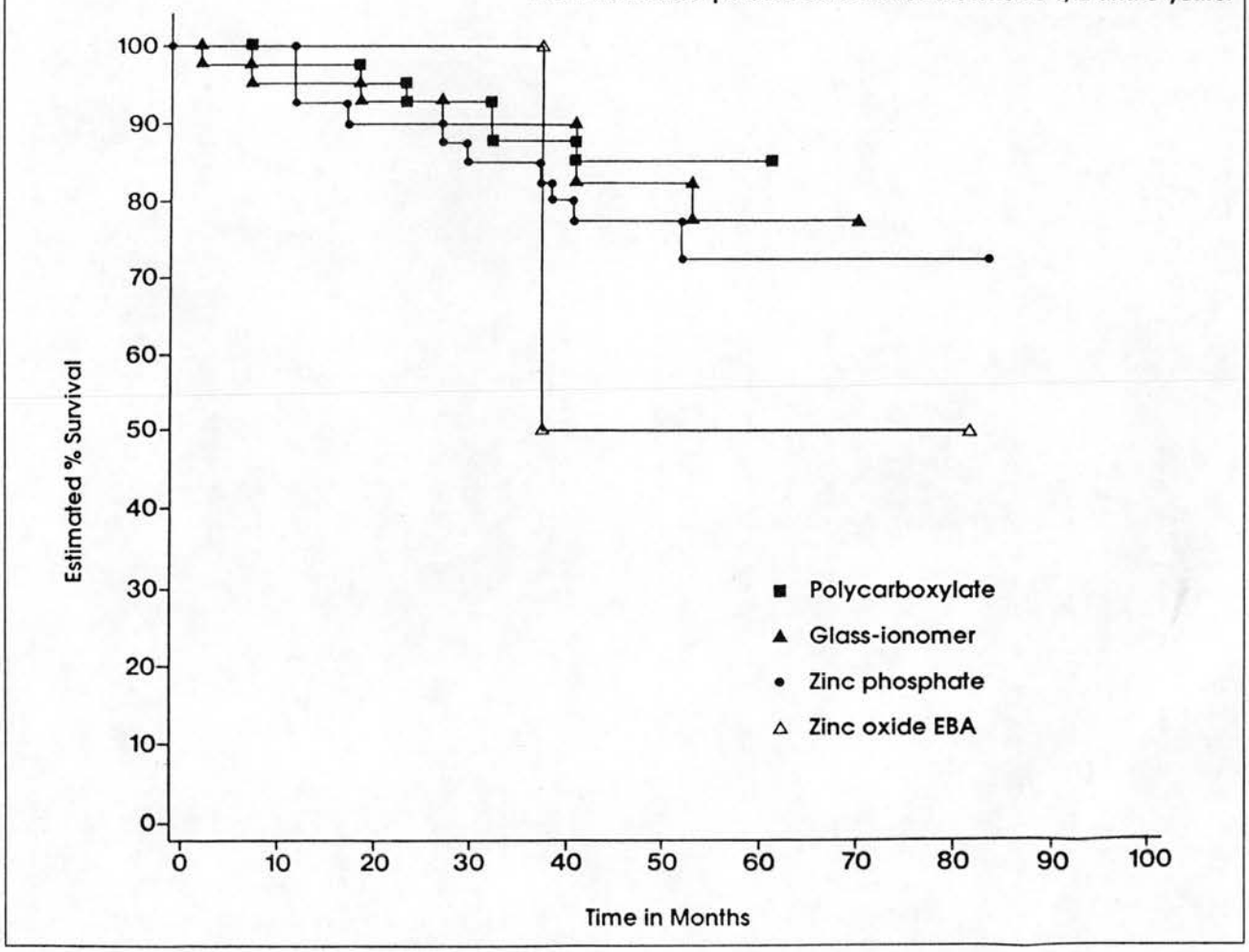
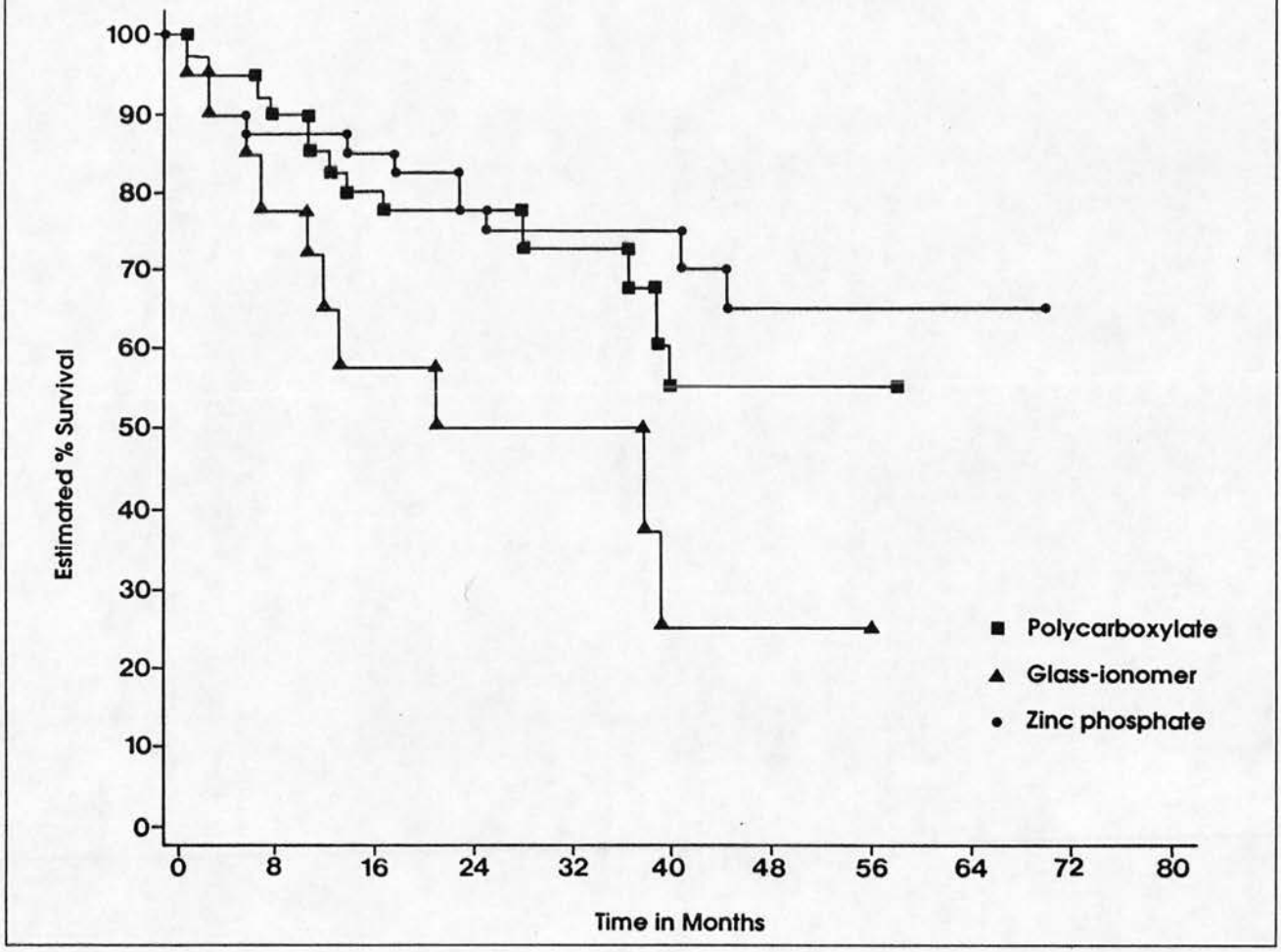


FIG 5 Estimated percent survival for post crowns at 1, 2 and 4.6 years.



allows for random selection of cases with large sample sizes; and the results are readily extrapolated to the population in general.

In 1977 Silvey and Meyers (11) showed no statistical difference between the survival rates of restorations cemented with zinc oxide eugenol reinforced EBA, polyacrylic acid (polycarboxylate), and zinc phosphate cements. In a later study (12) they compared abutment designs and stated "If only the three-quarter crown is used as a retainer the highest rate of success will be realized when it is cemented with zinc phosphate rather than a reinforced zinc oxide and eugenol or a polyacrylic acid cement". Since that time there have been considerable improvements in the properties of polycarboxylates, and clinical use has also been much improved by the availability of encapsulated types. Some of the restorations reported-on is this study were cemented with capsule mixed polycarboxylates. The work of Silvey and Myers was limited to three years, and their analysis was by chi^2 test, whereas the present study uses the more sensitive survival analysis which, together with the longer period of the study and the life tables, could account for the difference in results.

Table 4 Estimated percent survival for post crowns at 1, 2 and 4.6 years. Standard error in brackets

	Year 1	Year 2	Year 4.6
Polycarboxylate.....	83.2 (5.8)	78.2 (6.4)	53.9 (1.1)
Glass-ionomer.....	65.2 (1.2)	51.0 (1.3)	25.5 (1.4)
Zinc phosphate.....	88.4 (4.9)	77.0 (6.8)	65.7 (4.8)

Glass-ionomer luting cements were not generally available in 1977 when the Silvey and Myers paper was published, and no long-term retrospective studies have been found with which to compare the results reported here. Glass-ionomer luting cements have probably been improved more in recent years than the other 3 cements and seem to offer very good prospects for the future (13).

The number of crowns and bridges cemented with zinc/oxide eugenol reinforced EBA cements was small (a reflection of clinical practice) but this was allowed-for in the anlysis of the data because the statistical method used is capable of coping with samples of varying sizes.

Conclusions

In this retrospective study the following conclusions were evident:

1. Restorations cemented with zinc oxide/eugenol reinforced EBA cements were significantly more liable to clinical failure than those cemented with the other materials investigated when all restorations were considered together.

2. When comparing all restorations together those with cement lutes of polycarboxylate survived significantly longer than those in which zinc phosphates were used.

3. Restorations cemented with glass-ionomer showed no significant difference from those cemented with polycarboxylate cements.

4. When all restorations were considered those cemented with polycarboxylate cement were significantly more likely to survive than restorations cemented with phosphate cements.

When only bridges were considered those cemented with glass-ionomer were significantly better than those cemented with phosphate. However, post crowns cemented with phosphate survived significantly longer than those cemented

with glass-ionomer cements. There is no obvious explanation for this variability of phosphate cements.

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ABSTRACT

Properties of a new polyether urethane dimethacrylate photoinitiated elastomeric impression material. R G Craig and P H Hare. J Prosthet Dent. 1990; 63: 16-20.

The material (Genesis, L D Caulk Division, Dentsply International) contains a polyether urethane dimethacrylate resin with a diketone initiator and an amine accelerator. The polymerisation is photoinitiated by blue light in the wavelength range of 400 to 500 nm. The material is supplied premixed as a light-bodied material in a light-tight plastic syringe and as a heavy-bodied material in a tube. It has excellent physical, mechanical and clinical qualities with noteworthy long working times, short setting times, dimensional stability, accuracy, high tear strength, good wettability, biocompatibility and ease of cold disinfection without loss of quality. Accurate casts can be obtained by means of either a double-impression technique or a double-mix technique and it is compatible with gypsum and silver or copper metallizing baths.

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