The effects of surface roughness and surface area on the retention of crowns luted with zinc phosphate cement

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Abstract

The retention of cast gold crowns luted with zinc phosphate cement to smooth and rough surfaced extracted teeth was examined. No significant difference in retention was observed between smooth and rough surfaced teeth. A significant linear association existed between the surface area of the teeth tested and the retentive force but, statistically, area could not be used as a useful predictor for crown retention.

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Introduction

The retention of a crown to a prepared tooth provided by zinc phosphate cement has been considered in theory[1,2] to be by micromechanical interlocking of the cement into the surface roughness of both casting and tooth. A theory by Smyd[1] proposed that the retention was proportional to the cross-sectional area of a projection and the number of projections on the axial surfaces.

The retentive properties of zinc phosphate cement have been investigated in a multitude of ways including model evaluation,[3,4] mechanical failure testing of various cemented devices including testplates,[5-9] inlays,[10-12] machined cones/caps[13-16] or sleeves,[17-19] machined metal cones or cylinders/cast crowns,[20-24] castings of conventional tooth preparations/cast crowns,[25,26] machined tooth cones/open cast crowns,[27] machined tooth cones/cast crowns,[28-32] clinical tooth preparations/prefabricated crowns,[33,34] and clinical tooth preparations/cast crowns.[35-39] However, none of these evaluated the effects of tooth surface roughness and surface area on the retentive strength of zinc phosphate cement using conventional clinical and laboratory steps, though, some studies have shown that as surface area of the 'tooth'[21,25,40] and surface roughness of the 'tooth'[2,10,13,27] and 'casting'[17,26] increased so too did the retention of these zinc phosphate cemented devices.

In the literature there are misgivings concerning the clinical significance of the micromechanical interlocking concept[41] and surface area[22,38] on cement retention and adhesiveness.[27,39] The factors that influence the retention of a cemented crown to a tooth have been extensively discussed in the literature[1,2,13,14,17,27,42,43] and where possible in this project have been standardized or measured. This research project also involved simultaneous measurements of cement film thickness, crown tilting, twisting and axial lifting following cementation, and surface analysis of tooth preparations and cast gold surfaces. Details of these results will be reported in future papers.

The aim of this project was to investigate the retentive properties of zinc phosphate cement with respect to surface roughness and surface area using test piece shapes which more realistically represent the clinical situation than do more commonly used circular cross-sections.

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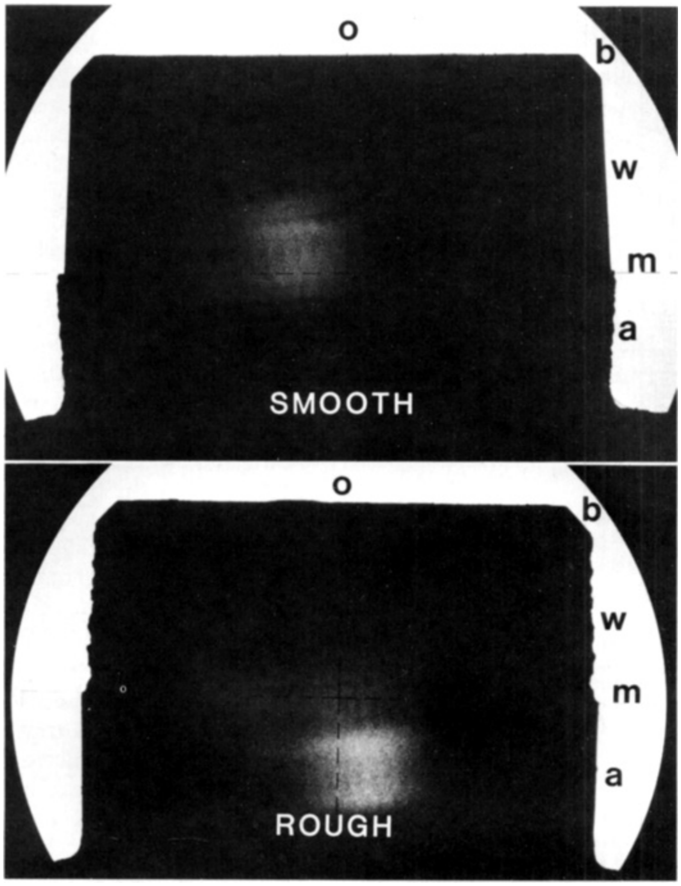


Fig. 1.–Profile projection (×25) of a smooth and a rough surfaced full veneer crown preparation illustrating respective occlusal surface (o), bevel (b), axial walls (w), margin (m), apron (a).

Material and method

Full veneer crown preparations were cut on two groups of twelve molar teeth. One group was finished with a smooth surface and the other with a rough surface using clinical instruments where possible in order to simulate two ends of a possible spectrum found in clinical practice (Fig. 1). The teeth were prepared by removing all the enamel, leaving a dentine core that was oval in cross-section thus enabling the surface area to be measured by computer (Fig. 2).

Preparation

One-hundred-and-ten large human molars were selected from recently extracted teeth, cleaned with pumice and stored in deionized water. Initially, most of the enamel was removed from each tooth using a bullet-shaped diamond‖ in a turbine handpiece. Teeth with pulp exposures, deep carious lesions, cracks, small crowns or roots and irregular coronal circumferences were discarded. The surface of the roots was roughened with this bur and retentive slots placed with a diamond disc. The apparatus used to mount the prepared teeth is shown in Fig. 3. The brass holders (a) were lightly lubricated internally with petroleum jelly and the roots of the teeth were then embedded vertically within the holders using self-curing acrylic resin. Twelve brass holders were employed and designed with a thread system and slot so that each resin block was removable using a screw driver (g). After the acrylic had hardened the petroleum jelly was cleaned from the holder and block with a petroleum solvent and soapy water.

Each brass holder and embedded tooth was placed on a machinist's lathe and the occlusal surface cut with a tungsten carbide cutting tool until smooth,

‖**Horico.** Hopf, Ringleb & Co. GmbH & Cie, Berlin, West Germany.

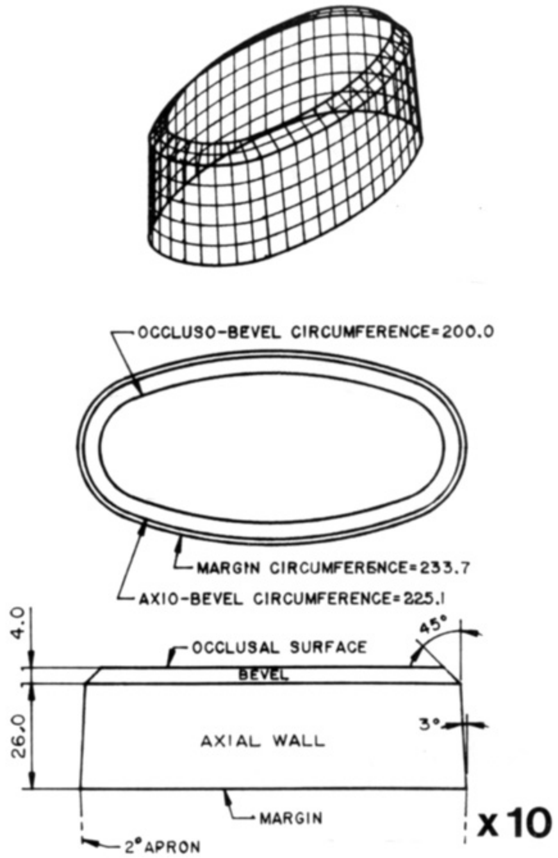


Fig. 2.–Graphic computer trace (×10) of a generalized tooth form illustrating approximate shape and dimensions of representative crown preparation. This model was used to aid surface area calculations of the tooth profile.

flat and free of enamel 'specks'. Twelve of these teeth were then roughened in the lathe against a firmly fixed diamond (extra rough grit) bur.¶

A milling machine** was used to cut a 3 mm high (occluso-marginal) preparation with axial walls of 2° to 3° taper. The axial walls of the tooth above the resin were prepared with a tapered diamond (medium grit) but¶ so that the final preparation was four-walled and the circumference possessed a continuous arcuate outline free of concavities and sharp line angles (Fig. 1, 2). To produce the required smooth and rough surfaced teeth the axial walls were cut with an approximately 2° tapered tungsten carbide¶ and diamond (extra rough grit) bur¶, respectively.

To delineate the margin edge, an apron was cut to the level of the margin, with an approximately 2° negative taper, using an inverted cone diamond¶ (medium grit) and tungsten carbide bur¶ for smooth and rough surfaced teeth, respectively (Fig. 1, 2). The margins were further refined with the tapered burs until a feather margin with an identifiable edge was produced (Fig. 1). The axio-occlusal line angle of all the teeth was bevelled smooth to an approximate vertical height of 0.4 mm and angulation of 45° using a tungsten carbide 'blank' with a 45° point†† (Fig. 1).

The final dimensions and angulations of all surfaces of the prepared teeth were measured using a profile projector‡‡ (×25) (Fig. 1). The mean taper of the axial walls of the teeth varied from 2° 5' to 2° 48' and of the bevel from 41° 41' to 43° 48'. The mean vertical height of the axial walls of the teeth varied from 2.55 mm to 2.73 mm, the bevel from 0.29 mm to 0.43 mm and the total height from 2.93 mm to 3.07 mm.

Crown construction

A polysulphide impression§§ was taken of each tooth using a custom tray and from this a silver-plated die was constructed (Fig. 3). A brass holder was filled with acrylic resin to secure each die. The precise location was achieved with a parallelometer** so that the occlusal surface of the die was parallel to the base of the brass holder (Fig. 3). The die, with lubricant‖‖ applied, was dipped into a bowl of molten wax to form the crown. On cooling it was machined flat with a wax milling bur¶ until the occlusal surface was flat and approximately 2.1 mm in thickness (Fig. 4). The axial walls were shaved to produce a uniform thickness of wax and trimming ceased when the thickness around the margins approached 0.5 mm.

Spruing, investing and casting in Type III gold¶¶ was performed in the usual manner. Each casting was cleaned in an ultrasonic cleaner using a solvent* for removing investment. A stereomicroscope using a magnification of ×40 was used to identify microbubbles present inside the casting and these were removed with round steel burs. The axial walls of the casting and margins were contoured and polished with sandpaper and cuttle discs until

¶**Komet.** Gebr. Brasseler GmbH & Co., Lemgo, West Germany.
****Bachmann.** Cendres & Metaux SA, Biel-Bienne, Switzerland.

††**Baker-Curson.** Dentsply, York, USA.
‡‡Hilger Watts Ltd, London, England.
§§**Permlastic.** Kerr Mfg Co., Romulus, Michigan, USA.
‖‖**Microfilm.** Kerr Mfg Co, Romulus, Michigan, USA.
¶¶**Ceramigold.** Whip-mix Corp, Louisville, Kentucky, USA.
*Denson. L&R Mfg Co, New Jersey, USA.

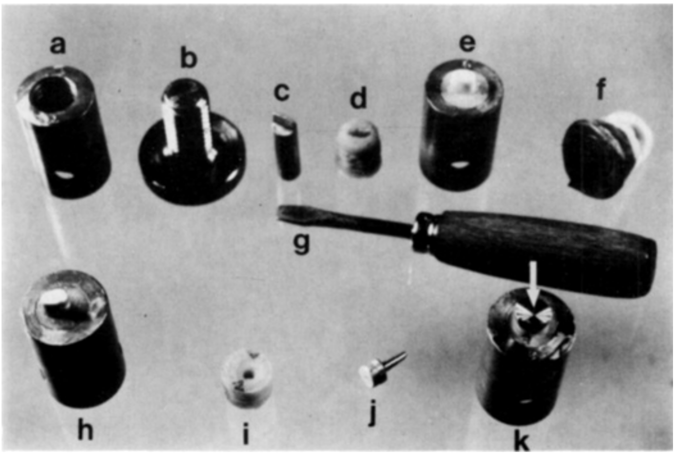


Fig. 3.–Components and devices used in preparation of the tooth and construction of the crown. (a) Brass holder with screw thread; (b) screw used to apply petroleum jelly into the threads of the brass holder; (c) brass device used to form a slot in the acrylic resin block to fit screwdriver; (d) slot in an acrylic resin block; (e) prepared tooth embedded in the acrylic resin block; (f) custom tray and impression of tooth preparation; (g) screwdriver; (h) silver-plated die embedded in acrylic resin block; (i) acrylic resin block with dowel hole; (j) dowel and silver-plated die; (k) crown complete with centre of area of tooth transferred and indented (arrow) onto the occlusal surface of the crown.

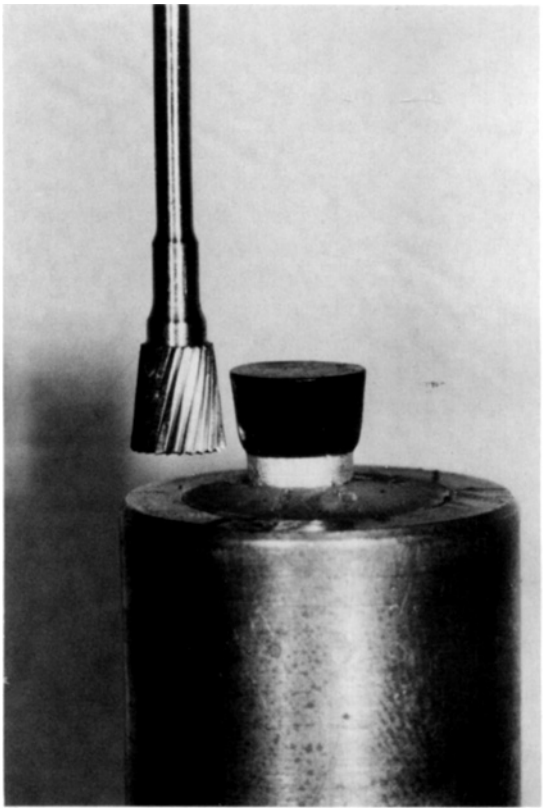


Fig. 4.–Wax pattern for the crown illustrating the wax milling bur used to produce an approximately uniform thickness of wax at the axial walls and a relatively flat occlusal table.

uniform thicknesses were produced. The occlusal surface of the crown was flattened using the milling machine and machinist's lathe until the occlusal table was approximately 2.0 mm thick.

As retentive testing was to be performed through the centre of area of the tooth, it was necessary to identify this point and then transpose it to the external aspect of the crown prior to cementation. To identify the centre of area of the tooth a tracing was made of the occlusal surface using the profile projector (×25). A graphic computer† located the centre of the tracing. By placing this tracing back on the profile projector it was possible to mark a point on the occlusal surface of the die that coincided with the centre of the tracing. The final step involved drilling a locating hole 0.7 mm deep and wide into the occlusal surface of the crown which coincided with the mark on the die (Fig. 3). This was performed with a jig-boring machine,‡ its microscope attachment and a 0.7 mm diameter twist drill.

Surface roughness measurements

A surface roughness testing instrument§ was used to measure the arithmetical average roughness

†Computervision Corp, Bedford, Massachusetts, USA.
‡Hauser SA, Bienne, Switzerland.
§**Surtonic 3.** Rank Taylor-Hobson Ltd, Leicester, England.

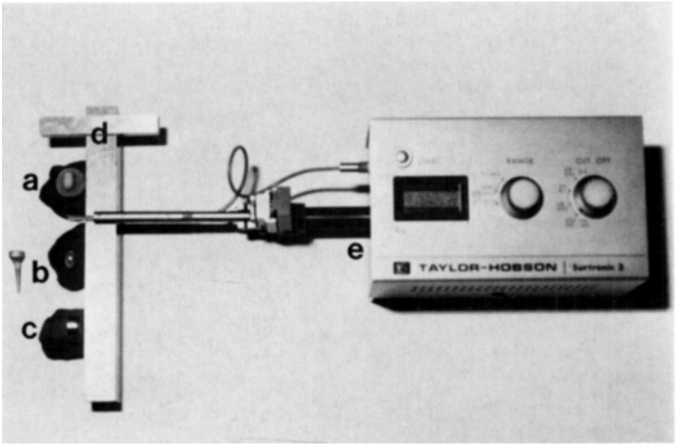


Fig. 5.–Devices used for testing surface roughness. (a) Tooth and acrylic resin block embedded in **Plasticine**; (b) the resin replica of the occlusal surface of the crown embedded in **Plasticine** and stabilized with a brass dowel; (c) gold crown embedded in **Plasticine**; (d) levelling blocks; (e) electronic surface roughness testing instrument.

values (R_a) of the occlusal and axial surfaces of the prepared teeth and crowns in accordance with standard methods[44] (Fig. 5). The nose of the stylus was small enough to fit inside the crown and allow measurement of the axial surfaces. However, to measure the occlusal surface a surface roughness replica was made with resin‖ (Fig. 5). Before mixing the resin a separating medium was applied to the axial surface of the crown and before set a dowel pin was placed in the resin, both procedures ensured easy removal of the replica from the crown.

All measurements were recorded in hundredths of a micrometre and only those that were usually high and associated with casting pits were rejected. Ten measurements were made of the occlusal surface and five measurements of the four axial surfaces for each tooth and crown. Every measurement was checked three times and averaged before recording.

Calculations of surface area of tooth profiles

A graphic computer was used to aid in the calculation of surface area for the tooth profiles. A three dimensional model ($\times 10$) of a generalized tooth form was created with the computer (Fig. 2). The model was constructed from segments of truncated cones, such that the axial walls and bevel slopes would be constant around the tooth profiles. The computer calculated the surface areas of the generalized tooth forms and from this it was possible to develop equations.

To determine the surface area of the occlusal surface required running a sensor probe around the occluso-bevel circumference of a tooth tracing ($\times 25$) utilizing the computer to make the calculation.

To calculate the surface area of the bevel required the use of the following equation:

$$\text{Surface area of bevel} = \left\{\frac{C_1 + C_2}{2}\right\} h_1 \cdot r_x$$

where:

C_1 = Occluso-bevel circumference calculated by computer from tracing.

C_2 = Axio-bevel circumference calculated by computer from tracing.

h_1 = Mean vertical height of bevel measured by profile projector.

r_x = Relevant ratio for angle x measured by profile projector.

The computer calculated that for a mean bevel angle of 45° the ratio necessary to calculate the surface area in this equation was 1.414.

To calculate the surface area of the axial walls for a given height required the following equation:

$$\text{Surface area of axial walls} = c_2 \cdot h_2 \cdot r_x$$

where:

c_2 = Axio-bevel circumference.

h_2 = Mean vertical height of axial walls measured by profile projector.

r_x = Relevant ratio for angle x measured by profile projector.

‖**Technovit.** Kulzer Co, Hamburg, West Germany.

The computer calculated that for a fixed vertical height and angles 2° and 3° the ratios necessary to calculate surface area for this equation were 1.014 and 1.020, respectively. It was possible to calculate that if r_x was ignored, then the percentage error would be 1.4 and 2.0 for teeth with 2° and 3° walls, respectively. As a new computerized ratio was required for different height walls all calculations were simplified by the following equation and this range of error accepted:

Surface area of axial walls $= c_2 \cdot h_2$.

Cross-sectional shape calculations

A tracing (×25) of the occlusal surface of each tooth illustrated the cross-sectional shape. To represent this shape in mathematical terms the longest axis and the widest axis (at right angles to the long axis) were measured and a ratio calculated. This was called the cross-sectional shape ratio.

Cementation

Before mixing the cement the teeth were gently cleaned with a slow revolving rubber cup filled with a fine pumice[6] and water. The crowns were ultrasonically cleaned with a permanent cement solvent.* Each crown and tooth was secured in its respective brass holder, and the assembly centred in the compression device and a static load of 15 kilograms applied (Fig. 6). On removal of this load the dial gauge was adjusted to zero the assembly in the vertical axis. The gold crown was removed and dipped in alcohol and then the crown and tooth dried for 10 seconds using an air syringe.

Zinc phosphate cement¶ was mixed in accordance with the American Dental Association specification No. 8 on a glass slab held at 23 ± 2 °C, using 1.0 g of powder and 1.46 mL of liquid. The cement was applied to the crown and the tooth with an artist's ox hair brush and excess removed by brushing until only a thin translucent film remained. The crown was located on the tooth and initially seated by hand with a light force. The brass holder with luted crown was centred in the compression device and a static load of 3 kilograms applied for 10 minutes. After removing the load, the dial gauge was read to determine by what amount the crown had lifted vertically off the tooth due to the cementation procedure. Excess cement was removed from the tooth and crown and the assembly was placed in a water bath held at 38 °C.

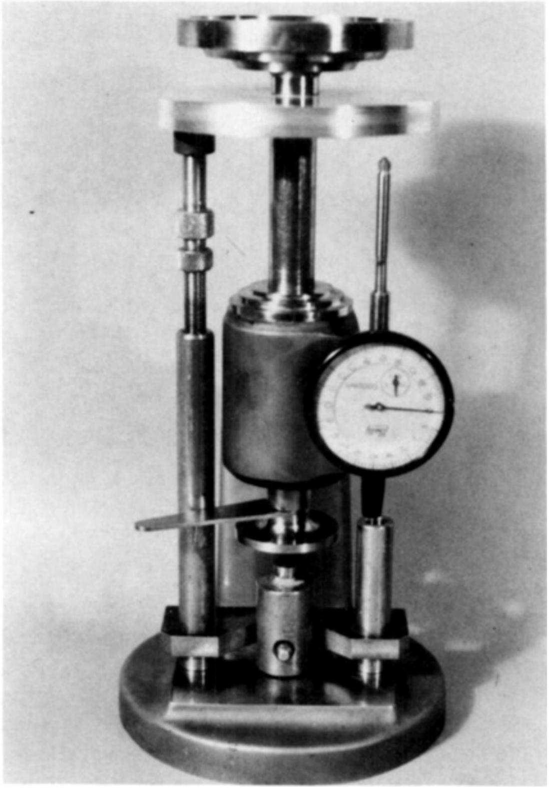


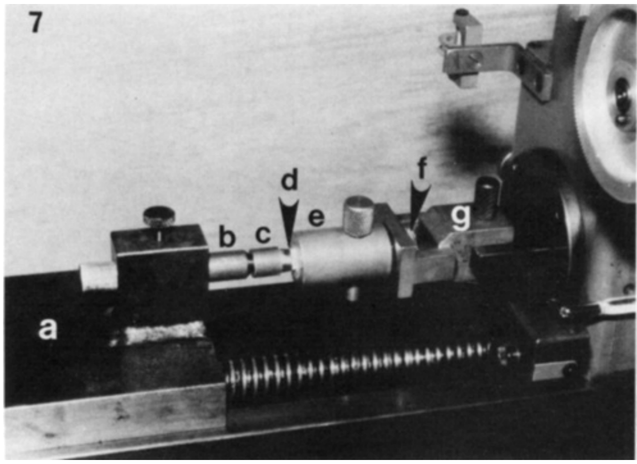
Fig. 6.—Compression device used for cementation and customized to centre the brass holder and accurately measure, with the aid of the dial gauge, vertical changes in crown height due to the cement film.

Gluing the pulling attachment to the crown

The pulling attachment was a brass cylinder 12 mm long and 12 mm wide (Fig. 7). At one end of the cylinder was a 6 mm hole with a screw thread while the other end was flat. The flat end of the pulling attachment could only be glued to the crown after the centre of area of the tooth was aligned to the centre of pull of the tensile testing machine** using a centring device (Fig. 7). This device, with either a 14° or 45° interchangeable steel cone point, when placed on the rails of the tensile testing machine coincided with the centre of pull (Fig. 7).

The brass holder with cemented crown was linked to the tensile testing machine and within this linkage apparatus was an adjustable hand screw allowing fine movements of the brass holder to be made (Fig. 7). To align the locating hole present on the occlusal surface of the crown to the centring device required moving the brass holder until it coincided with the 14° cone point before tightening the nut on the screw.

¶Harvard Richter & Hoffman Harvard Dental Co, Berlin, West Germany.
**Alfred J. Amsler Co, Schaffhouse, Switzerland.



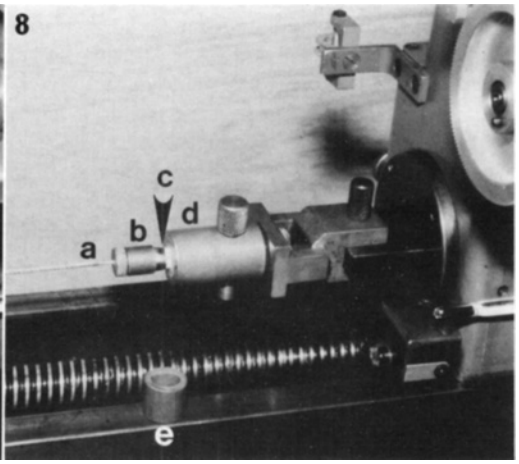


Fig. 7.—Centring device (a) mounted on the rails of the tensile testing machine illustrating the 45° cone point (b) used to locate the pulling attachment (c) and to glue it to the cemented crown/tooth (d). The brass holder (e) with cemented crown/tooth was previously centred in the tensile testing machine with the aid of a 14° cone point and hand adjusting screw (f) which is part of the linkage apparatus (g).

Fig. 8.—Part of the tensile testing machine for the retention test, including the steel cable with soldered screw attachment (a), the pulling attachment (b), the cemented crown/tooth (c), and brass holder (d).

Finally, the pulling attachment was glued to the crown with cyanoacrylate,†† using the 45° cone point in the centring device to locate the cylinder to the previously centred tooth (Fig. 7). This gluing procedure was performed approximately 24 hours after cementation.

Retention testing

Seventy-two hours after cementation, the crown/tooth/brass holder/pulling attachment assembly was removed from the water bath, centred in the tensile testing machine and attached with a cable for testing (Fig. 8). Using a constant crosshead speed of 2.1 mm/min, a tensile load was applied and testing performed at 38 ± 2 °C.

To conserve the tooth, one test only was performed as the next procedure involved cleaning the cement off the tooth ultrasonically in deionized water, recementing the cleaned* crown at the previous vertical lift height, sectioning, lapping and measuring the cement film thickness under a microscope. These results are yet to be reported.‡‡

Results

The data were statistically analysed using Student's *t*-test and where relevant the correlation coefficient.

The means and standard deviations of the force required to remove the crowns from the smooth and rough surfaced teeth are presented in Table 1. There was no significant difference between the mean force required for the two groups of teeth. The means and standard deviations of the occlusal, bevel, axial and total areas of the smooth and rough surfaced teeth are also presented in Table 1. There was no significant difference between the mean areas of the two groups of teeth.

The retentive strength of a cemented crown/tooth combination can be expressed as a ratio between the force required to remove the crown per unit area of the tooth.[10,28] The retentive strengths with respect to the total, occlusal, bevel and axial areas of the two groups are presented in Table 1. There was no significant difference between the mean retentive strengths of the two groups of teeth with respect to any of the surface areas. As a normal distribution was not found and classical statistics did not take account of the high and low stress 'tails' of the distribution, a Weibull[45] analysis was performed (Fig. 9).

The relationship between force and total surface area of the 24 teeth was tested using a correlation coefficient (Table 2). An r value of 0.56 was statistically significant at the level $p < 0.05$. However, as approximately 31 per cent of the variation in force can be accounted for by the variation in area, it is unlikely to be a very useful predictor of force required to remove a crown, given the general trend of increasing force with increasing area.

††**Loctite.** Loctite Corp, Hertfordshire, England.
‡‡Darveniza M, Meek J. PhD research project. Unpublished data.

Table 1. Means and standard deviations of the force (N) and force per unit area (N/mm²) required to axially remove gold crowns cemented to smooth and rough surfaced teeth in relation to the occlusal, bevel, axial and total areas

Sample	Force N	Occlusal Area force/area		Bevel Area force/area		Axial Area force/area		Total Area force/area	
		mm^2	N/mm^2	mm^2	N/mm^2	mm^2	N/mm^2	mm^2	N/mm^2
12 smooth teeth									
Mean	206.7	32.4	6.1	10.9	18.8	61.2	3.3	104.5	1.9
SD	149.3	7.4	4.0	1.6	13.8	7.3	2.2	16.0	1.3
12 rough teeth									
Mean	235.1	31.5	7.4	11.2	21.5	59.8	3.9	102.5	2.3
SD	140.8	5.0	4.1	2.0	13.3	4.5	2.2	10.7	1.3

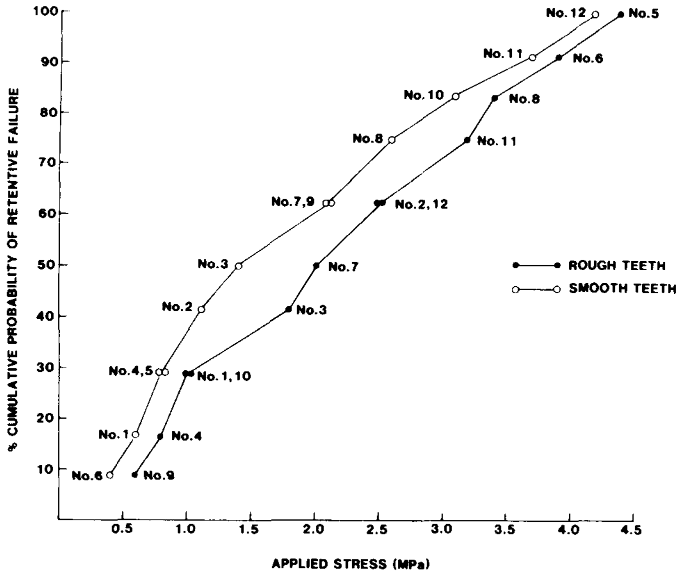


Fig. 9.—Graph derived from a Weibull[46] analysis comparing the applied stress against probability of cement fracture for gold crowns luted to smooth and rough surfaced teeth. The level of probability for cement fracture is higher in the smooth surfaced group. However, there was no significant difference between the applied stress for the two groups.

The means and standard deviations of the arithmetic average roughness values (R_a) for smooth and rough surfaced teeth and their respective crowns are presented (Table 3). There was a statistically significant difference ($p < 0.01$) in mean roughness between the smooth and rough surfaced teeth at the axial and occlusal surfaces. However, there was no significant difference in mean roughness of the internal surfaces of the crowns constructed from the dies of smooth and rough surfaced teeth at the axial and occlusal surfaces.

The means and standard deviations of the retentive strength and ratio of longest/widest axes for smooth and rough surfaced teeth are presented in Table 4. There was no significant difference between the mean retentive strength for the two groups of teeth for their mean cross-sectional dimensions. The relationships between retentive strength and the cross-sectional dimensions of the teeth was tested using the correlation coefficient. The r values for the smooth, rough and the 24 teeth were −0.24, 0.09, and −0.02, respectively. No correlation between the retentive strength and the cross-sectional dimensions was evident from these values.

Table 2. Force (N) required to axially remove gold crowns cemented to smooth and rough surfaced teeth with respect to their total area (mm^2) with means and standard deviations

Tooth number	Smooth teeth Force N	Smooth teeth Area mm^2	Rough teeth Force N	Rough teeth Area mm^2
1	60	108	95	97
2	80	74	295	117
3	133	94	203	111
4	74	98	78	94
5	78	100	460	105
6	38	91	475	121
7	242	117	188	91
8	302	117	310	90
9	260	123	70	114
10	398	128	93	98
11	340	90	310	97
12	475	114	244	95
$\bar{x}$	206.7	104.5	235.1	102.5
SD	149.3	16.0	140.8	10.7
r		0.56*		

$\bar{x}$ = mean.
SD = standard deviation.
r = correlation coefficient.
* = significant at $p<0.05$ for smooth and rough teeth together.

whether the tooth surface be smooth or rough, under pressure phosphoric acid in the cement may etch through the grinding debris,[2,50] including smear layers,[50] to the tooth and into some dentine tubules[51] or into enamel[52] to form a firm attachment or bond. This could partly explain why the different surface roughness of the dentine did not demonstrably affect the retention of the crowns.

Øilo and Jørgensen[13] showed that with an increase of surface roughness from 5 to 50 μm in dentine there was a corresponding improvement in retention by a factor of 3. However, it is likely that there comes a point in the 'smoothness' of dentine where the mechanical locks formed are too small to substantially improve retention. A weak and 'slippery'[2,13] lock may occur because of the combined effect of a smaller cross-sectional area[1] of cement projection along with a more delicate dentine projection, which is elastic in nature. In this study, the mean axial surface roughnesses evaluated were 0.39 and 6.12 μm for the smooth and rough teeth, respectively. It is possible that these figures may be below a point where demonstrable changes[30] in retention are likely because of inadequate mechanical interlocking. As well, Eick et al.[51] found

Table 3. Means and standard deviations of the arithmetic average roughness values (R_a), in μm, for smooth and rough surfaced teeth and their respective crowns

R_a	Teeth Axial surfaces $\bar{x}$	Teeth Axial surfaces SD	Teeth Occlusal surface $\bar{x}$	Teeth Occlusal surface SD	Crowns Axial surfaces $\bar{x}$	Crowns Axial surfaces SD	Crowns Occlusal surface $\bar{x}$	Crowns Occlusal surface SD
12 smooth teeth and crowns	0.39	0.04	1.06	0.31	2.05	0.54	1.89	0.36
	**		**					
12 rough teeth and crowns	6.12	0.58	3.65	0.60	2.51	0.58	2.09	0.34

$\bar{x}$ = mean.
SD = standard deviation.
** = significant at $p<0.01$.

Discussion

The effect of surface roughness of the tooth preparation on the retention of crowns must be considered in perspective with other influencing factors, particularly the phenomena of adhesion[10,46,47] and cement film thickness.[1,15,16,18,19]

It can be hypothesized that to achieve maximum retention of a crown cemented to a tooth should involve equal attachment of the cement to the tooth and casting so that when tested fracture occurs within the cement layer. This type of bond failure did not occur in this study. However, it was noticed in many instances that the cement fractured at the casting/cement interface‡‡ as in other studies,[48,49] and remained firmly attached to the tooth irrespective of surface finish. It is suggested that, that rough surfaces were not ideal for adhesion as the topography of the dentine affected the wetting process and small air pockets in the cement concentrated in the surface grooving. Brängström and Nyborg[53] found bacteria lived in the debris layer and under the zinc phosphate cement further illustrating the potential for unpredictable bonding to rough or smooth dentine surfaces.

The weak bond at the casting/cement interface[9] may relate to the magnitude of the surface roughness and surface contaminants present inside a casting. Worley, Hamm, and von Fraunhofer[39] showed that placing a circumferential groove in a crown resulted in a significant improvement in retention with no bond failure at the casting/cement interface. Jørgensen[17] observed that increasing the surface roughness inside a brass cap also improved

Table 4. Means and standard deviations of the retentive strength (N/mm^2) required to axially remove gold crowns cemented to smooth and rough-surfaced teeth in relation to the ratio of the longest and widest axes in their cross-sectional shape (mm/mm)

Tooth number	Smooth teeth Force/total area N/mm^2	Smooth teeth Longest axis/widest axis mm/mm	Rough teeth Force/total area N/mm^2	Rough teeth Longest axis/widest axis mm/mm
1	0.6	1.5	1.0	1.4
2	1.1	1.3	2.5	1.2
3	1.4	1.5	1.8	1.4
4	0.8	1.2	0.8	1.6
5	0.8	1.1	4.4	1.1
6	0.4	1.0	3.9	1.5
7	2.1	1.2	2.0	1.1
8	2.6	1.1	3.4	1.4
9	2.1	1.0	0.6	1.1
10	3.1	1.2	1.0	1.1
11	3.7	1.2	3.2	1.6
12	4.2	1.1	2.5	1.1
$\bar{x}$	1.9	1.2	2.3	1.3
SD	1.3	0.2	1.3	0.2

$\bar{x}$ = mean.
SD = standard deviation.

retention. In this study, the mean surface roughness of the casting was approximately 2 μm and this may have been too small to allow strong mechanical cement locks to form as bond failure at the casting/cement interface was common.‡‡ Otani and Goto[19] also questioned the effectiveness of a mechanical lock when insufficient unreacted powder grains fail to fill a small valley and it is filled instead by the weaker matrix phase of the cement.

Surface contaminants inside a casting can come from the debris layer present on a tooth surface. On seating a casting, before cementation, internal interferences will score the surface of the dentine and thus leave an inorganic and organic debris layer inside the casting.[50] As well, pickling a casting has been shown to produce a surface film detrimental to adhesion.[49] In this project a surface analysis of ultrasonically cleaned cast gold alloy revealed a surface rich in carbon compounds.‡‡ The combined effect of the dentine debris, carbon compounds and air bubbles associated with surface roughness creates a barrier for poor surface wetting and 'adhesion' of the cement. The variation of cement thickness in this study‡‡ and others[9,39,54] was not found to significantly affect retentive strength. However, some researchers have found that film thickness can have a moderate[16,23] influence while Otani and Goto[19] conclude that a 15 μm film is optimal. In this project, the thickness of the cement film significantly increased for the rough surfaced teeth and did not influence retention. The cement films beneath cast crowns are not uniform because of the inaccuracy associated with crown construction. In view of these differing film thicknesses, the presence of slits[7,37,42] within a film and the unfavourable presence of Hopeite crystals[55] on the surface of a cement film, it is difficult to unequivocally separate the effect surface roughness of a tooth has on crown retention. However, Yamamoto[15] found that to maximize retention on stainless steel dies the surface of the 'tooth' had to be roughened to 15 μm while the film thickness was lowered to 30 μm.

The results showed that as the surface area of a tooth preparation increased so too did the retention. However, it was also found that this relationship was not sufficiently precise to be used as a predictor of retention. If area is not a reliable indicator for crown retention, as other studies[22,38] have shown, then it may be strongly influenced by different degrees of surface adhesion. The results also showed that, if one assumed failure to be solely due to a region, namely the occlusal, bevel or axial surfaces, the retentive strength at these sectional areas was not significantly different between smooth and rough surfaced teeth. Although it is unlikely that one region can be solely responsible for cement failure if that situation did exist the retentive strength values and the conclusions remain unchanged.

The results demonstrated that the surface roughness of the internal surfaces of the crowns were similar although prepared from smooth and rough surfaced teeth. This can be explained by understanding the cumulative effects of the many steps involved in crown construction. The major steps that can alter the surface topography of a tooth are details lost or gained during impression taking, die construction, application and retention of separating medium on the die surface, poor adaptation of the wax over retained separating film, smearing of the wax over surface roughness peaks when removing the wax pattern and its surface deterioration during casting.

Different cross-sectional shapes of the smooth and rough surfaced teeth did not significantly influence retentive strength between the groups. Although it has been reported that the rate[22] of curvature of a crown preparation may influence retention, it would appear that if a pulling test is performed through the centre of area that retentive values should not be significantly modified.

Testing the bond strength of 'adhesive' materials to dentine is notorious for producing results with wide variations.[56] This was the case in this study and the Weibull graph helped to give a meaningful separation of these values. A trend towards increasing retention for the rough surfaced teeth was noted on the graph considering the limited number of test specimens.

In summary, from the literature it appears that the micromechanical interlocking concept of retention is realistic and practical. However, it must be applied along with other adhesive principles[46] when determining retention. In view of the presence of surface contaminants on castings and teeth, the surface roughness of veneer tooth preparations and gold crowns found in contemporary clinical and laboratory practice would appear to be too smooth to significantly affect crown retention.

Conclusions

1. Crown retention was not significantly different between smooth and rough surfaced teeth luted with zinc phosphate cement.

2. Crown retention was not significantly different between smooth and rough surfaced teeth in relation to total area and to an assumed sectional failure at the occlusal, bevel and axial areas.

3. There was a significant positive linear relationship between the surface area of the teeth tested and the retentive force required to remove the zinc phosphate cemented crowns, but this statistical relationship could not be used as a useful predictor for crown retention.

4. There was no significant difference in the surface roughness of crowns constructed from smooth and rough surfaced teeth at the axial and occlusal surfaces.

5. There was no significant linear correlation between the retentive strength of the luted crowns and the cross-sectional shape ratio of the smooth and rough surfaced teeth.

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