Crowns Cemented on Crown Preparations Lacking Geometric Resistance Form. Part II: Effect of Cement

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Purpose: **This study evaluated the effect of different cements on resistance to dislodgment of crowns cemented on preparations lacking geometric resistance form.**

Materials and Methods: **A preparation that offered no geometric resistance form, with 20° total occlusal convergence (TOC), 0.9 mm wide shoulder finish line, and a 2.5 mm axial wall height was created on an ivorine tooth using a milling machine. Ten metal test specimen die replicas and 10 standardized metal crowns with recipient sites for the application of external forces through a universal testing machine were fabricated. The crowns were cemented on the dies under 5 and 10 kg external loads, the marginal openings measured, loaded to dislodgment, and cleaned of cement. The process was repeated using zinc oxide and eugenol (ZOE), zinc phosphate (ZPh), resin modified glass ionomer (RMGI), and composite resin (CR) cements.**

Results: **Marginal openings under 5 kg cementation loads were 74.63 (±15.04) for ZOE, 75.98 (±18.20) μm for ZPh, 98.58 (±22.62) μm for RMGI, and 105.82 (±20.07) μm for CR cements respectively; under 10 kg cementation loads they were 57.62 (±15.86) μm, 59.55 (±15.41) μm, 95.00 (±19.52) μm, 101.30 (±12.52) μm respectively. Oblique dislodgment forces, measured with a Universal testing machine, were 40.18 (± 6.76) N for ZOE, 215.65 (±45.79) N for ZPh, 165.43 (±19.53) N for RMGI, and 181.54 (±30.75) N for CR respectively when crowns were cemented under 5 kg loads. The corresponding values for 10 kg loads were 38.62 (±4.19), 274.86 (±54.22), 139.70 (±21.71), and 160.40 (±21.21) respectively. Only zinc phosphate cement produced statistically enhanced resistance when crowns were cemented under 10 kg force (p value = 0.035).**

Conclusions: **Under the conditions of the present study only crowns cemented with zinc phosphate displayed increased resistance to dislodgment on preparations lacking resistance form.**

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INDEX WORDS: resistance form, occlusal convergence, cementation

RESISTANCE FORM is defined as "the features of a tooth preparation that enhance the stability of a restoration and resist dislodgment along an axis other than the path of placement."[1] Several factors can affect the resistance of a crown to forces applied on an axis other than the path of placement. A variety of crown preparation modifications have been proposed as ways to provide enhanced resistance to a crown.

Reisbick and Shillingburg[2] reported that placement of interproximal grooves and boxes increased the resistance form of the tooth preparation. Woolsey and Matich[3] reported that placement of grooves in an interproximal location can offer more increased resistance than placement in a buccal or lingual location. Potts et al,[4] Kishimoto et al,[5] and Owen[6] further emphasized the effect of the placement of grooves on the resistance form of a tooth preparation. Total occlusal convergence (TOC),[7,8] occluso-cervical dimension of the preparation,[9] and diameter of the crown preparation[9] have been reported as important factors that determine resistance form; a linear relation has been documented between these parameters and the

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preparation resistance form. On the other hand, Parker[10] and Zuckerman[11] reported through a mathematical analysis that resistance form has an "all or nothing" nature; in other words, a crown preparation has, or totally lacks, resistance form.

Zuckerman[11] described a boundary circle concept that has the dimension of the base of the crown preparation (the dimension between any point along the margin and a corresponding point 180° around the circumference) as its diameter. The boundary circle is related to the preparation by orienting it in a plane in space perpendicular to the occlusal surface of the preparation and contacting the preparation tangent at the 2 points along the crown preparation margin that define its diameter. If the opposing axial walls of the crown preparation "lie" within the circle, then it has no resistance form. If the opposing axial walls of the crown preparation are outside the circle, the crown preparation has resistance.

The controversy of whether the resistance form is linear or has an "all or nothing" nature still remains. Clinical studies[10,12-16] have shown that TOC of typical preparations is not consistent and deviates from the definition of "ideal" resistance form. Molar preparations frequently possess the most excessive total occlusal convergence.[10,15,16]

Zuckerman and Parker's mathematical models utilized the hypothesis that intimate and uniform contact exists between the crown and the preparation. Several studies have shown that space needed for cement and casting technology limitations prohibit such intimate and uniform contact.[17-22] There will always be a space between a crown and a preparation; when the crown is cemented, this space will be occupied by cement. Based on this observation, several authors[7,9,22] have indicated that this cement film is the determining factor for the resistance of a crown.

Wiskott et al[23] demonstrated in a computer study that the axis of rotation in resistance is not at the crown margin, and resistance to lateral dislodgment is a function of the distribution of compressive force vectors acting on the cement interface. Wiskott et al[9] reported that the limiting taper theory by Parker[10] developed as a mathematical model may not be supported in a laboratory study. Wiskott et al[9] found a direct linear relationship between the height of the axial wall and the degree of resistance of crown preparations. Crowns with more axial wall height had enhanced resistance form. Similarly, Weed and Baez[7] found an inverse linear relation between the TOC of a crown preparation and the corresponding resistance. Crowns with more TOC had reduced resistance form. Wiskott et al[22] reported that the compressive strength of the cement is the parameter that determines the amount of resistance of a specific preparation design.

The purpose of this study was to evaluate the effect of different cements on crown resistance when crowns are cemented on crown preparations lacking geometric resistance form.

Materials and Methods

An Ivorine tooth (Columbia, Long Island, NY) was utilized to fabricate a master preparation die. The tooth was placed in a plastic base,[4] and prepared on a milling machine (AF 30, Type 1369, Switzerland) with a 10° tapered acrylic resin bur (Cone cutter bur H356S-060, Brasseler, Savannah, GA) resulting in a 20° TOC. A 0.9 mm wide shoulder was prepared at the finish line.

After preparation, the bucco-lingual dimension between the most apical areas of the buccal and lingual walls at the mesio-distal midpoint of the preparation was measured with a caliper (Darby Dental Supply Inc., Rockville, NY). This dimension is such that axial walls lie within the radius of the boundary circle; thus the preparation design did not offer geometric resistance form[11] (Fig 1). The occlusal surface of the preparation was reduced so that the axial walls were included within the boundary circle. The preparation of the occlusal surface was performed by using a 0° (nontapered) acrylic resin finishing bur (Parallel cutter carbide milling bur H364E-023, Brasseler, Savannah, GA) and by placing the Ivorine tooth at a 90° angle to the long axis of the

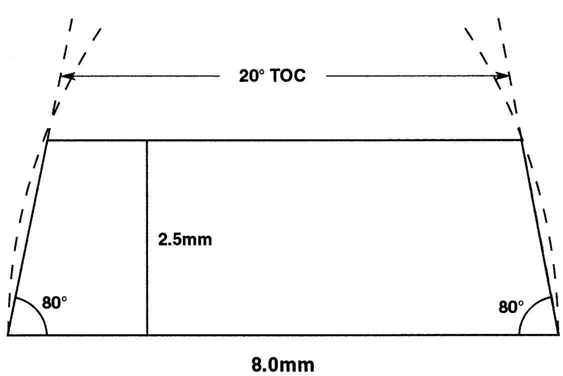

Figure 1. A 2.5 mm axial wall height was prepared so the crown preparation lacked geometric resistance form.

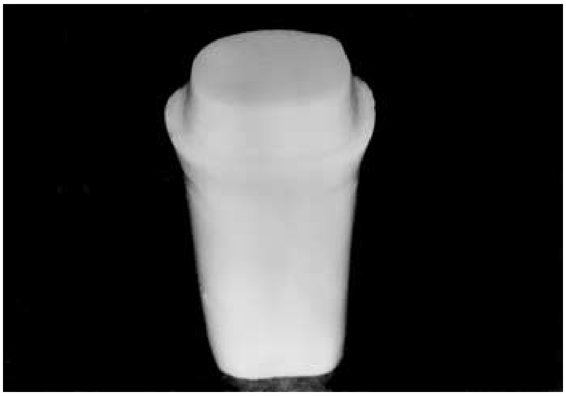

Figure 2. The Ivorine tooth has been prepared with no geometric resistance form.

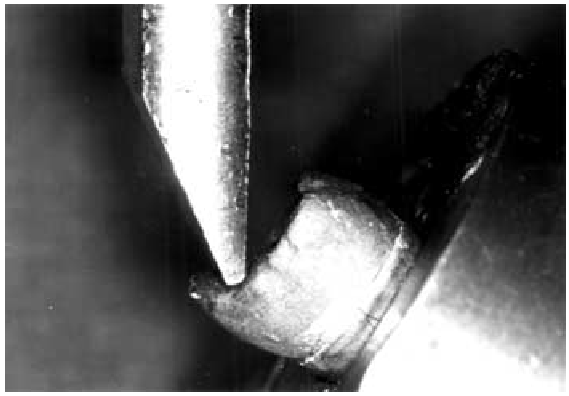

Figure 3. External force was applied at 45° angle through a Universal testing machine.

bur. The final axial wall height was 2.5 mm. The junction of the axial and occlusal walls was beveled (Fig 2).

One impression was made of the finished preparation with high viscosity polyvinylsiloxane (PVS) impression material (Aquasil HV, Dentsply International Inc., York, PA) in a custom impression tray fabricated from photopolymerized acrylic resin (Triad, Dentsply International Inc., York, PA).

The impression was used to fabricate 10 wax patterns ("Pro-Art," Williams, Amherst, NY) of the tooth preparation. Two sprue formers (Tri-wax, Williams, Amherst, NY) were placed at the lateral aspect of the patterns. Two wax patterns were placed on each crucible former and invested with phosphate-bonded investment (Fastfire, WhipMix, Louisville, KY). A 20:4 ratio of special liquid/distilled water was used.

Base metal alloy ("Will-Ceram Litecast—B," Williams, Amherst, NY) was used to cast 10 metal dies; each numbered 1–10 (to identify the die).

Die lubricant ("Keen Lube," Belle de St. Claire, Chatsworth, CA) was applied to the surface of 1 metal die. A wax pattern of the final crown ("Pro-Art," Williams) was then made on this die. Soft wax ("Cervical wax," Williams, Amherst, NY) was used to perfect the margin area of the wax patterns. A recipient site for the tip of the universal testing machine was carved at the axial–occlusal area of the buccal side of the pattern (Fig 3). A polyvinylsiloxane material ("Aquasil HV," Dentsply International Inc.) in a custom tray was used to make an impression of the final wax pattern. This impression was used to standardize crown fabrication. Ten crowns were fabricated, one on each preparation die, by using the same casting investment, special liquid/distilled water ratio, and casting alloy as described for the fabrication of the metal dies.

The marginal opening was evaluated and measured for each crown. A notch was made with a sharp razor at the mid-buccal, mid-mesial, mid-lingual, and mid-distal area of each metal die and at the region of the margin of each metal crown. For each die/crown pair, 4 marginal measurements were made and averaged. The average provided the marginal opening for each crown. All measurements were made by 1 investigator (PP) and under 100× microscope (Leica Inc., Buffalo, NY).

The 10 crowns were cemented onto the corresponding metal dies with 4 different cements: zinc oxide and eugenol cement (Temp-Bond, Kerr Co., Romulus, MI) (ZOE), zinc phosphate cement, (Mizzy Inc., Cherry Hill, NJ) (ZPh), resin modified glass ionomer (Vitremer, 3M, St. Paul, MN) (RMGI), and composite resin cement (Variolink, Ivoclar Vivadent Inc., Amherst, NY). A 5 kg load was applied for 2 minutes to the crown, as per Morey,[20] while the cement set. The metallic dies with the cemented crowns were placed in a humidifier (Model VWR 1520, Sheldon Manufacturing Inc., Cornelius, OR). The cement set for 24 hours at 37°C under 100% humidity (water placed in humidifier according to manufacturer's recommendations) to simulate intraoral conditions. The average marginal opening was recorded for each of the 10 crowns. The cemented crowns were loaded with an external force applied at 45° angulation[4] in a lingual-to-buccal direction using a universal testing machine (Instron Corp., Quincy, MA). The force was applied at the lingual inclined plane of the recipient site aligned with the buccal cusp (Fig 3) until crowns were dislodged from the dies. The force required for crown dislodgment was recorded for each cement. Following dislodgment from the 5 kg cementation load the cement was removed manually from the dies and the crowns with a sharp explorer.

The crowns were again cemented with the same cements (ZOE, ZPh, RMGI, CR) but 10 kg of external load was applied during cementation. The average marginal opening was again recorded for each of the 10 crowns. Similar dislodgment procedures and measurements followed the second cementation (with 10 kg external force).

Table 1. Marginal Opening Measurements

Crown No.	Initial	5 kg Cementation ZOE	5 kg Cementation ZPh	5 kg Cementation RMGI	5 kg Cementation CR	10 kg Cementation ZOE	10 kg Cementation ZPh	10 kg Cementation RMGI	10 kg Cementation CR
1	51.5	85.50	87.50	125.25	108.75	72.25	62.25	115.75	112.50
2	30.25	60.50	62.25	100.00	125.50	50.00	47.75	95.75	105.75
3	55.25	75.75	68.00	97.25	105.50	59.75	62.50	105.25	92.50
4	20.00	50.25	42.50	54.00	65.70	30.00	32.50	58.00	75.25
5	49.50	80.00	85.25	91.00	95.25	62.25	67.50	97.25	105.25
6	34.50	88.25	92.50	116.75	105.25	52.25	68.50	97.25	97.75
7	70.50	94.00	102.50	124.00	125.50	85.00	87.25	112.25	112.50
8	27.25	52.75	58.00	70.00	82.25	38.75	42.50	62.75	90.00
9	50.50	78.25	75.75	10.375	118.75	65.00	64.00	97.75	105.75
10	40.25	81.00	85.50	103.75	125.75	61.50	57.75	108.00	115.75
Mean	42.95	74.63	75.98	98.58	105.82	57.67	59.55	95.00	101.30
SD	15.26	15.04	18.20	22.62	20.07	15.86	15.41	19.52	12.52

Statistical Analysis

Using a Kruskal–Wallis ranks test at a significance level $\alpha = 0.05$, the values obtained from the universal testing machine were compared between the 4 cements at the 5 kg cementation force and 10 kg cementation force. Similarly, and by using the same statistical method, the marginal opening was compared between the 4 types of cements at the 5 kg and 10 kg cementation forces.

A nonparametric test procedure, the Mann–Whitney ranks test, was applied, and the marginal opening recorded for each cement was compared between the 5 and 10 kg cementation force.

Results

The marginal opening of each crown was recorded for each group (Table 1). The dislodgment loads of the crowns were recorded (Table 2).

The Kruskal–Wallis ranks test revealed that the crowns cemented with RMGI and CR cement under 5 kg pressure had a significantly bigger marginal opening than those cemented with ZPh cement (Table 3). Similar results were obtained using the same statistical method for crowns cemented under 10 kg pressure; those cemented with ZPh cement had a smaller marginal opening than those luted with RMGI and CR cements (Table 4).

The data for dislodgment loads obtained from the universal testing machine were evaluated between the different types of cements by using the Kruskal–Wallis ranks test. When cemented under 5 kg pressure, crowns cemented with ZPh cement required significantly more force to dislodge them than those cemented with RMGI. Crowns cemented with ZPh cement required greater, but not statistically significant, forces to cause dislodgment compared to CR. No significant differ-

Table 2. Universal Testing Machine Measurements

Crown No.	5 kg Cementation ZOE	5 kg Cementation ZPh	5 kg Cementation RMGI	5 kg Cementation CR	10 kg Cementation ZOE	10 kg Cementation ZPh	10 kg Cementation RMGI	10 kg Cementation CR
1	35.24	235.49	157.08	155.64	43.82	278.65	127.74	189.17
2	44.86	150.52	165.36	207.64	43.70	285.70	168.41	190.40
3	33.14	223.80	161.81	187.83	40.51	212.54	149.67	157.23
4	39.44	246.76	184.97	198.33	30.66	218.49	165.40	176.05
5	45.77	293.66	182.56	235.26	36.84	239.66	163.56	140.39
6	46.55	229.84	189.13	182.04	35.13	381.58	143.36	166.84
7	35.01	169.92	176.77	180.40	32.12	234.44	114.42	129.94
8	51.63	156.11	159.46	156.63	39.99	275.04	110.32	135.06
9	39.18	201.79	122.64	187.48	44.80	275.97	119.60	154.38
10	31.03	248.57	154.52	124.13	38.64	345.59	134.47	164.50
Mean	40.18	215.65	165.43	181.54	38.62	274.86	139.70	160.40
SD	6.76	45.79	19.53	30.75	4.19	54.22	21.71	21.21

Table 3. Kruskal–Wallis Ranks Test for Marginal Opening at 5 kg Cementation

Pairs Compared	*Comparison*	*P Value*
ZOE vs ZPh	N/S	0.820 (N/S)
ZOE vs RMGI	RMGI > ZOE	0.010 (SS)
ZOE vs CR	CR > ZOE	0.002 (SS)
ZPh vs RMGI	RMGI > ZPh	0.019 (SS)
ZPh vs CR	CR > ZPh	0.005 (SS)
RMGI vs CR	N/S	0.256 (N/S)

SS = Statistically significant; N/S = Statistically not significant.

Table 5. Kruskal–Wallis Ranks Test for Universal Testing Machine at 5 kg Cementation

Pairs Compared	*Comparison*	*P Value*
ZOE vs ZPh	ZPh > ZOE	0.0001 (S/S)
ZOE vs RMGI	RMGI > ZOE	0.0001 (SS)
ZOE vs CR	CR > ZOE	0.0001 (SS)
ZPh vs RMGI	ZPh > RMGI	0.029 (SS)
ZPh vs CR	N/S	0.096 (N/S)
RMGI vs CR	N/S	0.199 (N/S)

ence was shown between RMGI and CR cements (Table 5). Crowns cemented under 10 kg pressure with ZPh cement had significantly higher resistance than both RMGI and CR cements; no significant difference was seen between CR and RMGI cements (Table 6). Zinc oxide eugenol cement offered significantly inferior resistance compared to all other cements.

By using the Mann-Whitney U Test, the marginal opening was compared for each cement between the 5 and 10 kg cementation force (Table 7). Only ZOE cement demonstrated a statistically significant (p value: 0.035) reduced marginal opening related to the increased force during cementation (10 vs 5 kg). ZPh also had reduced marginal opening at the 10 kg cementation force (59.55 μm at 10 kg vs 85.50 μm at 5 kg); this difference was statistically significant at a higher p value (p value: 0.063).

Discussion

The current study demonstrated that in a laboratory simulation of a clinically compromised situation (increased TOC at 20° and reduced axial wall height at 2.5 mm) the cement that offered statistically significant increased resistance to oblique displacement force on the crown was ZPh cement. In this study 20° TOC was selected because clinical studies have indicated that this represents the average convergence practitioners are able to clinically perform on molar teeth.[15,16]

Several authors have addressed the importance of the cement when crown resistance is evaluated.[8,9,22,24,25] Wiskott et al[23] reported that the compressive strength of the cement is the significant element for crown resistance, while Hegdahl and Silness[25] reported that the cement at the base of the crown receives the functional forces.

Wiskott et al[8,9] demonstrated that CR offers increased resistance to a crown as compared to glass ionomer and ZPh, and that glass ionomer offers increased resistance compared to ZPh cement. These results are opposite of the current study's results.

The current study demonstrated the key factor determining the resistance of a crown to oblique force dislodgment in a laboratory simulation of a clinically compromised situation is the degree to which the crown is seated on the preparation die. This did not apply for the temporary luting cement (ZOE). Even though ZPh cement has reduced compressive strength compared to RMGI and CR cements,[22] because of its reported reduced viscosity,[22] it offers a more complete seating and reduced marginal opening of the crowns. In addition, cementation with ZPh under increased loading pressure (10 vs 5 kg) enhanced the resistance of the crown and reduced the marginal opening, an observation that was not made with RMGI and CR cements.

Table 4. Kruskal–Wallis Ranks Test for Marginal Opening at 10 kg Cementation

Pairs Compared	*Comparison*	*P Value*
ZOE vs ZPh	N/S	0.631 (N/S)
ZOE vs RMGI	RMGI > ZOE	0.001 (SS)
ZOE vs CR	CR > ZOE	0.0001 (SS)
ZPh vs RMGI	RMGI > ZPh	0.002 (SS)
ZPh vs CR	CR > ZPh	0.0001 (SS)
RMGI vs CR	N/S	0.481 (N/S)

Table 6. Kruskal-Wallis Ranks Test for Universal Testing Machine at 10 kg Cementation

Pairs Compared	*Comparison*	*P Value*
ZOE vs ZPh	ZPh > ZOE	0.0001 (S/S)
ZOE vs RMGI	RMGI > ZOE	0.0001 (SS)
ZOE vs CR	CR > ZOE	0.0001 (SS)
ZPh vs RMGI	ZPh > RMGI	0.0001 (SS)
ZPh vs CR	ZPh > CR	0.0001 (SS)
RMGI vs CR	N/S	0.059 (N/S)

Table 7. Mann-Whitney U Test for Marginal Opening Comparisons between 5 and 10 kg Cementation

Cement	*Comparison*	*P Value*
ZOE	5 kg > 10 kg	0.035 (SS)
ZPh	N/S	0.063 (N/S
RMGI	N/S	0.684 (N/S)
CR	N/S	0.436 (N/S)

In the current study, the wax patterns were created directly onto the metal dies. Metal dies were used to avoid fracture or distortion of the die during testing. It has been shown that, when a stone die is used, a superior fit and adaptation of the crown on the tooth is obtained.[26]

The rationale for using base metal alloy in this study was its high compressive strength, which allows it to resist deformation if excessive forces are applied. However, Eden et al[27] have shown that base metal alloy crowns have inferior fit on a metal die. In their study, as in the current study, waxing was performed on metal dies. The use of a base metal alloy may be a limitation of this study.

Conclusions

Within the limitations of this study, zinc phosphate cement offered crowns, cemented on dies representing a clinically compromised tooth preparation, significantly increased resistance to dislodgment under obliquely applied forces.

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