Load-fatigue performance of gold crowns luted with resin cements

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Statement of problem. Resin cements have gained popularity over the past few years because of their improved physical properties. There is a need to test these cements under fatigue loading, as there is growing recognition that fatigue testing is more clinically relevant than traditional monotonic static tests.

Purpose. This study investigated the load-fatigue performance of complete gold crowns cemented with 4 types of resin cement.

Material and methods. Four resin cements (C & B Opaque [CBO], Calibra Esthetic [CE], RelyX Unicem [RU], and Panavia F [PF]) and a control, zinc phosphate cement (HY-Bond [HBZPC]) were tested. Fifty human maxillary premolars were prepared to an occluso-cervical dimension of 4 mm and a convergence angle of 20 degrees. Complete gold crowns were cast (Strator 3) and cemented with 1 of the 5 cements (n=10). A fatigue load of 73.5 N was applied at an angle of 135 degrees to the long axis of each tooth-crown specimen. Preliminary failure was defined as the propagation of a crack in or around the crown luting cement layer. The number of cycles to preliminary failure and the cement failure location were determined. Significant differences in cycles to preliminary failure were assessed by the nonparametric Kruskal-Wallis test, with follow-up Mann-Whitney tests (α=.05).

Results. Group CE had the highest rank of cycles to preliminary failure, while HBZPC had the lowest cycles to preliminary failure. Group CE had a significantly higher failure cycle count compared to PF (P=.016), RU (P=.001), and HBZPC (P<.001), but was not significantly different from CBO (P=.112). There was no significant difference in the failure cycle count between RU and HBZPC (P=.070).

Conclusion. Not all tested resin cements had a superior fatigue life when compared with zinc phosphate cement. Of the 4 resin cement groups, Groups CE, CBO, and PF were significantly superior to HBZPC.
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CLINICAL IMPLICATIONS

This in-vitro study suggests that the use of certain resin cements increases the fatigue life of gold crowns. Clinically, the use of these cements may improve crown longevity, especially in situations in which prepared teeth have minimal retention and resistance forms.

Zinc phosphate cement is one of the most frequently used cements in dentistry and is the gold standard against which all cements are compared. In a marginal leakage study of extracted teeth with cast crowns at least 20 years old, Kydd et al[1] concluded that zinc phosphate cement is an effective luting agent. In recent years, resin cements have gained popularity because of their improved physical properties and ability to bond to enamel, dentin, composite, and porcelain.[2] Resin cements are recommended when the preparation lacks optimal retention and resistance forms.[2] Static tensile loading tests, using standardized castings from stylized crown preparations, have demonstrated the superiority of these cements.[3-9] These studies compared different luting agents, namely zinc phosphate, zinc polycarboxylate, glass ionomer, resin-modified glass ionomer, and resin cements. Authors have reported resin cements to have significantly greater retention than other cements.[3-9] On the other hand, a recent study by Ernst et al[10] on the retentive strengths of cast gold crowns cemented with a glass ionomer, a compomer, and a resin cement showed that the resin cement had the lowest retentive strength. However, the authors did not use a dentin adhesive system with the resin cement.

Dental restorations are subject to repetitive dynamic loading during mastication and parafunction, and this

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loading is simulated in vitro by fatigue loading studies.[11] Fatigue is defined as the breaking or fracturing of a material caused by repeated cyclic or applied loads below the yield limit.[12] This failure is characterized by crack initiation or nucleation, crack propagation, and finally, catastrophic failure.[11,13-15]

Two types of fatigue test loading approaches have been described in the dental literature: unidirectional and rotational fatigue testing.[11] In the unidirectional approach, cyclic fatigue is performed for asymmetrical dental restorations, such as fixed partial denture connectors,[16] post-and-core restorations,[17-20] and dentin bonding systems.[21] For rotational fatigue testing, symmetrical specimens may be tested at a faster rate, and the test specimens are subjected to a sinusoidal variably applied stress.[11] This methodology of fatigue testing has been used to test the fatigue life of dental solder joints, laser-welded dental joints, crowns with varying tooth preparations luted with various cements, porcelain repair systems, and various implant and abutment systems.[22-25]

A number of studies have used unidirectional load fatigue to test compromised endodontically treated teeth.[17-20,26] Libman and Nicholls[17] tested teeth with crowns and cast post-and-cores fabricated with a ferrule height varying from 0.5 to 2.0 mm in 0.5-mm increments. The authors referred to fatigue life as a ''preliminary failure'' condition as opposed to complete fracture of the specimen. This preliminary failure was defined as the point at which failure of cement occurred and was verified with a water test. The test was done by placing a drop of water at the crown-tooth interface of the failed specimen and applying intermittent pressure on the crown, while stabilizing the brass specimen holder. Water was seen pumping in and out of the crack at the crown-tooth interface. Cement fracture will result clinically in microleakage between the crown and the tooth, ingress of bacteria, and consequent bacterial disease, loss of retention, fractured posts, or complete dislodgement of the crown and foundation restoration.[27-30] Junge et al[19] compared the load fatigue performance of complete cast crowns on compromised teeth cemented with zinc phosphate, a hybrid glass-ionomer cement, and a resin cement. The resin cement specimens had a significantly higher number of load cycles to preliminary failure. These results were found to be consistent with the tensile strengths of the cements.

Other investigators have used load fatigue to test dental cements.[23-25,31] Wiskott et al[23-25] used rotational fatigue loading to investigate the relationship between an abutment and crown, testing different parameters such as height, taper, and cements. The authors concluded that crowns luted with resin cement were more resistant to dynamic lateral loading than glass-ionomer or zinc phosphate cements. Mitchell and Orr[31] used fatigue loading to compare 1-piece post-and-core crowns on bovine teeth cemented with conventional versus resin-modified glass-ionomer luting cements. Using cumulative survival analysis, the authors concluded that there was no significant difference among the cement groups. The purpose of this study was to evaluate the load-fatigue performance of 4 resin cements used to cement cast restorations to human premolars. Zinc phosphate cement was used as a control.

MATERIAL AND METHODS

Human maxillary first and second premolars, extracted for orthodontic reasons, were used in this study. The criteria for selection were absence of cracks or fractures, no evidence of caries or restorations, and no previous endodontic treatment. From the time of extraction, the teeth were kept hydrated in room-temperature physiologic saline solution (Sodium chloride 0.9% w/v; Baxter Healthcare Pty Ltd, Deerfield, Ill).

The bucco-palatal dimensions of the teeth were measured using an electronic vernier caliper with an accuracy of ±0.02 mm and repeatability of ±0.01 mm (Absolute Digimatic Caliper; Mitutoyo Corp, Kanagawa, Japan). Three measurements were made at the greatest bucco-palatal width of the specimen, and the average was determined. The teeth were then ranked according to decreasing dimension. The ranked teeth were divided into 5 groups as follows: the first tooth was assigned to group A, the second to group B, the third to group C, the fourth to group D, the fifth to group E, the sixth to group E, the seventh to group D, the eighth to group C, the ninth to group B, the tenth to group A, and the eleventh to group A. This procedure was repeated until each group had 10 teeth. Each group was then assigned to 1 of the 5 cements. A 1-way analysis of variance showed no significant difference among the bucco-palatal widths of the 5 groups.

Brass cylinders were machined to retain the specimens during testing (Fig. 1). The cemento-enamel junction (CEJ) of each specimen was outlined with a permanent marker. Then a mark was made 4 mm occlusal to the CEJ at the midpoint of the buccal and palatal surfaces. These 2 marks were connected with a circumferential line that determined the tooth preparation height (Fig. 1). A second circumferential line was drawn 3 mm below the CEJ to designate bone level (Fig. 1). Acrylic resin (GC Pattern Resin; GC Corp, Tokyo, Japan) was used to retain the tooth inside the brass cylinder (Fig. 1). The brass cylinder was filled with acrylic resin and the tooth placed into the acrylic resin in the brass cylinder. The circumferential line designating the bone level was positioned flush with the top of the brass cylinder. Prior to embedment, 2 notches were made on the specimen root slightly below the bone level line to enhance tooth retention within the acrylic resin.

Following tooth placement in the brass cylinder, occlusal reduction to the 4-mm mark or preparation

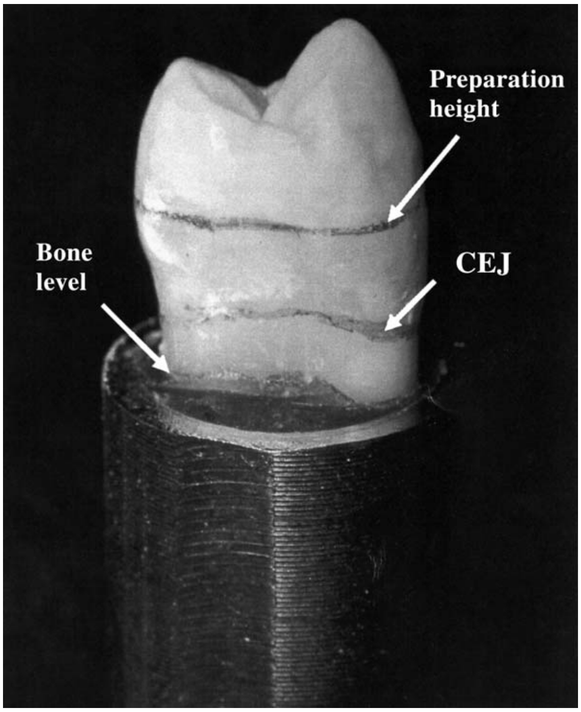

Fig. 1. Specimen in brass holder with circumferential lines.

height was performed using a high-speed handpiece (KaVo BellaTorque Mini; KaVo, Lake Zurich, Ill) and a fissure bur (016C; NTI Diamond Instruments, NTI Kahla-GmbH, Thuringia, Germany). Each tooth was prepared to a bucco-palatal convergence angle of 20 degrees, using a tooth preparation guide. This guide consisted of a dental surveyor and an attached clamp, which not only held the handpiece to the movable vertical arm of the surveyor, but also allowed this handpiece to rotate about a horizontal axis. This rotation was measured by a protractor attached to the surveyor. The bur used had a 6-degree included angle. Thus, to form a 20-degree convergence angle for the preparation, the handpiece had to be rotated through an angle of 7 degrees. After preparation of the occlusal surface, the specimens were placed on the surveyor platform and the buccal and palatal axial walls were prepared. The mesial and distal walls were then prepared freehand using the same bur, keeping the bur parallel to the long axis of the tooth specimen. The direction of loading on the specimens was in a buccal-palatal direction; therefore the taper of the proximal surfaces was not critical. Lastly, the preparations were finished using a fissure bur (016F, NTI Diamond Instruments; NTI-Kahla GmbH).

Custom trays were fabricated from acrylic resin (Shofu Tray Resin II; Shofu, Kyoto, Japan). Impressions of each specimen were made using a dual-phase technique with light- and heavy-body vinyl polysiloxane (Aquasil; Dentsply DeTrey, Konstanz, Germany). Type IV stone (Silky Rock; Whip Mix Corp, Louisville, Ky)

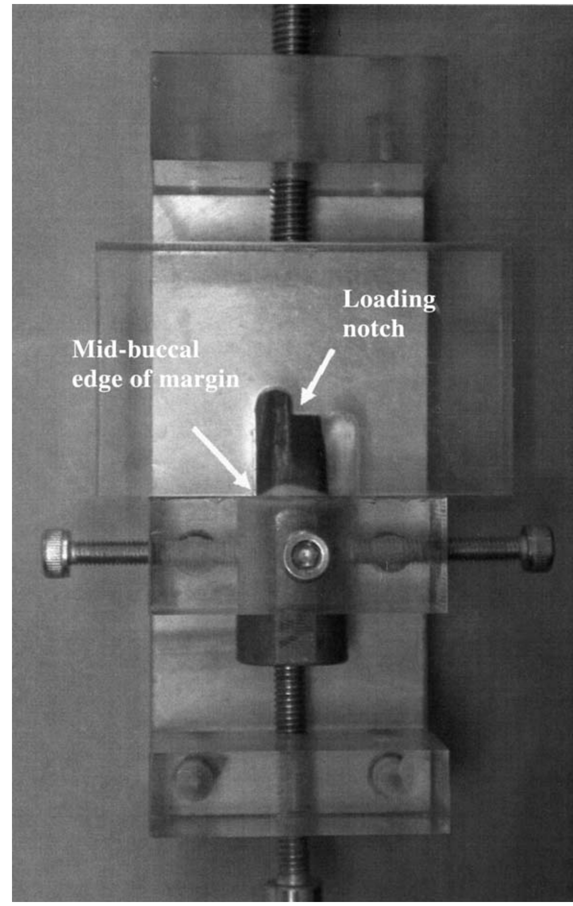

Fig. 2. Waxing jig with waxed crown in position.

was poured into the impressions and allowed to set for 24 hours. Two coats of die spacer (Trufit Die Spacer; George Taub Products and Fusion Co, Inc, Jersey City, NJ) and 1 coat of die hardener (Stone Die and Plaster Hardener Resin; George Taub Products and Fusion Co, Inc) were applied to each die. Crown copings were waxed (Crowax; Renfert, Hilzingen, Germany) on these working dies and then transferred to the corresponding test specimens. These were then positioned in a custom waxing device, which allowed a standardized notch to be waxed on the crown pattern, located 8 mm above the buccal finish line (Fig. 2). The fatigue load was applied at this notch.[17] After waxing, each pattern was transferred back to its working die, and the crown contours were completed. Crown margins were refined under ×20 magnification (SZ-FLR; Olympus, Japan).

All of the wax patterns were invested within 30 minutes of margin refinement in a gypsum-based investment material (Novocast; Whip Mix Corp). A Type III gold alloy containing 40% Ag, 20% Au, and 20% Pd by weight (Strator 3; Cendres & Métaux SA Dental, Biel- Bienne, Switzerland) was used to cast the crowns. After divesting, the crowns were inspected under ×20 magnification for fit. Once correct fit had been

Table I. Components of dental cements and dentin adhesive systems tested

Company	Cement	Dentin adhesive system
Bisco, Schaumburg, Ill	C & B Opaque (CBO)	All Bond 2
	All Etch (10% H_3PO_4)	Primer A
	Pre-bond resin	Primer B
	Base	
	Catalyst	
Dentsply Caulk, Milford, Del	Calibra Esthetic resin cement (CE)	Prime and Bond NT
	Base	Dual-polymerized adhesive
	Catalyst	Autopolymerized activator
3M ESPE, St. Paul, Minn	RelyX Unicem (RU) Aplicap	Nil
Kuraray, Okayama, Japan	Panavia F (PF)	ED Primer
	Alloy primer	Primer A
	Paste A	Primer B
	Paste B	
Shofu, Kyoto, Japan	HY-Bond ZPC (HBZPC)	Nil
	Zinc oxide powder	
	Phosphoric acid liquid	

ascertained, the internal surfaces of the crowns were airborne-particle abraded with 50-μm aluminum oxide under .29 MPa.

The crowns were cemented with one of the cement/bonding agent combinations shown in Table I. All teeth were pumiced prior to cementation, and all cements were mixed according to manufacturers' directions. During cementation, 1 polymerization light (Polylux II; Kavo) was used for all crown specimens. The polymerization light had a mean intensity of 540 mW/cm^2 and was placed as close as possible to a specimen. Each crown was held in place for the duration of the manufacturer recommended setting time under finger pressure. Following are the 5 cementing procedures.

For group CBO specimens, the dentin was etched using All-Etch for 15 seconds, rinsed thoroughly, and then air dried gently. Care was taken not to desiccate the tooth specimen, as recommended by the manufacturer. Primers A and B were mixed, and 5 consecutive coats were placed on the dentin, air dried for 5 to 6 seconds, and then light polymerized for 20 seconds. Finally, a thin layer of Pre-bond Resin was applied and air thinned. The internal surface of the crown was airborne-particle abraded, rinsed and dried, and 2 coats of Primer B were applied and air dried. Equal amounts

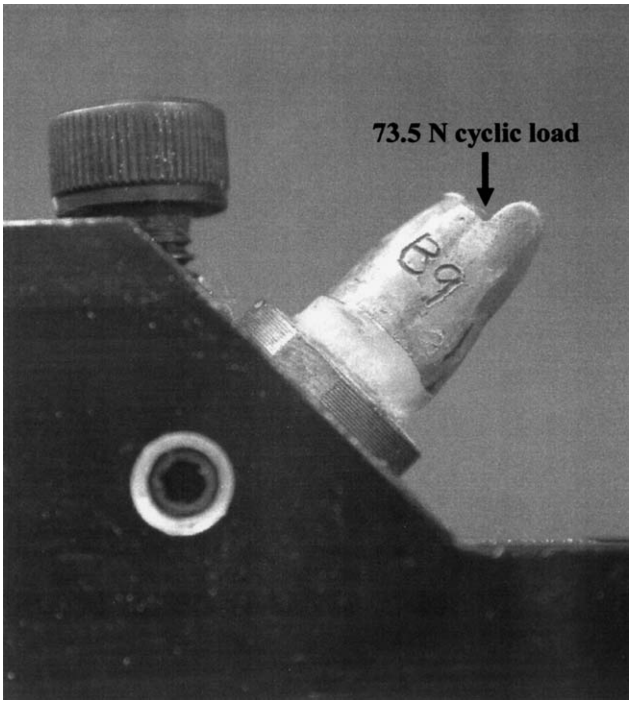

Fig. 3. Specimen in positioning jig.

of base and catalyst were mixed into a uniform paste (10-15 seconds), placed inside the crown, and the crown was seated on the specimen with finger pressure. Excess cement was removed immediately from the margins.

For group CE specimens, tooth etching was not required. Two drops each of Prime and Bond NT dual-polymerized adhesive and autopolymerized activator were mixed, applied to the tooth surface for 20 seconds, air dried for 5 seconds, and then light polymerized for 10 seconds. A single coat of the same mixture was applied to the internal surface of the crown and air dried for 5 seconds. Equal amounts of base and regular-viscosity catalyst (Calibra) were mixed until uniform, and then a thin layer was applied to the intaglio surface of the crown. The crown was slowly seated, and the marginal area was given a 10-second light prepolymerization. After removal of excess cement, all marginal areas were light polymerized for 20 seconds.

Group RU specimens were sprayed with water and air dried, taking care to avoid desiccation. The resin cement (RelyX Aplicap) was mixed in a mixing unit (Promix; Dentsply Caulk, Milford, Del) for 15 seconds. Using the Aplicap applier, the crown was filled with cement and placed on the tooth. Excess cement was removed with an explorer after a 2-second light polymerization. Then all 4 tooth surfaces were light polymerized for 20 seconds each.

Tooth etching was not required for group PF specimens. One drop each of ED Primers A and B were mixed and applied to the entire tooth surface for 60 seconds.

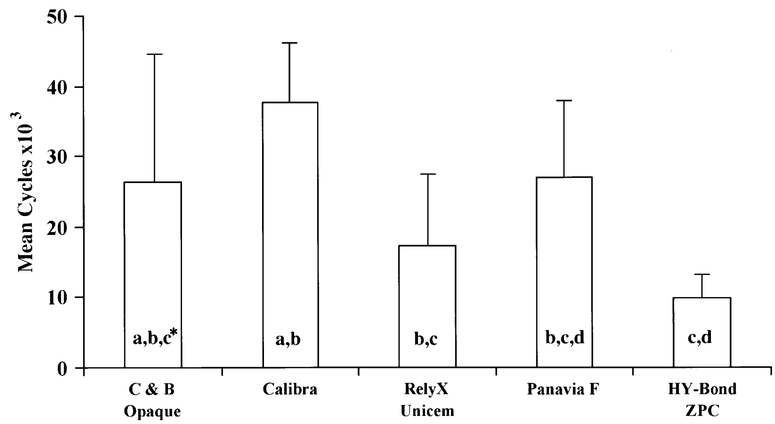

Fig. 4. Mean cycles to preliminary failure, by test groups. *Asterisk,* Cement groups with same lowercase letter denote no significant differences ($P<.05$).

Excess primer was removed with a gentle stream of air. The crown was airborne-particle abraded, and a thin coat of alloy primer was applied to the internal surface. Equal amounts of Panavia F base and catalyst pastes were mixed for 20 seconds. Then a thin layer of this mixture was applied inside the crown, and the crown was placed on the tooth. Excess cement was removed with an explorer. All 4 surfaces were then light polymerized for 20 seconds each.

Group HBZPC specimens were pumiced, rinsed, and air dried. A spoonful of powder and 4 drops of liquid were placed on a room temperature glass slab. The powder was divided into 3 parts and then mixed with the liquid using a metal spatula for 1.5 minutes. A thin layer was then placed inside the crown, and the crown was placed on the tooth. Excess cement was removed with an explorer.

Twenty-four hours after crown cementation, a strain gauge (model EA-05-050AH-120 LE; Measurements Group, Inc, Raleigh, NC) was placed on the palatal surface of the crown-tooth interface. Prior to bonding, the area was lightly buffed with finishing discs (Sof-Lex; 3M ESPE, St. Paul, Minn) and wiped with 95% alcohol. The bonding surface of the strain gauge was also cleansed with alcohol. Bonding was achieved with an adhesive (DP-460 Epoxy Adhesive; 3M ESPE), ensuring that the strain gauge grid was centered over the crown-tooth interface. The strain gauge cement was allowed to set for a minimum of 24 hours before fatigue testing. Following the set of the adhesive, tray adhesive (Caulk Tray Adhesive; Dentsply Caulk) was then painted over the strain gauge to ensure water exclusion.

The fatigue loading machine used was similar to the design used in several studies at the University of Washington, and has been described previously.[17-21] To closely approximate in vivo loading conditions, each specimen was subjected to a fatigue load of 73.5 N on the loading notch at a frequency of 75 cycles per minute. Mean masticatory forces have been reported by Anderson[32,33] to be in the range of 70.6 to 146.1 N. Thus, the applied 73.5-N load lies within the range of these values. The frequency of the loading device conforms to the masticatory rate of 60 to 120 strokes per minute reported by Graf.[34] The load was applied at an angle of 135 degrees to the long axis of the tooth, and a positioning jig was used to hold each specimen in this orientation (Fig. 3). The location of load application, on the triangular ridge of the buccal cusp at a 135-degree angle, was selected to simulate the occlusal scheme of group function. All specimens were immersed in a room-temperature water bath during fatigue loading. The testing protocol used required that 1 specimen from each of the 5 cement groups be fabricated and then tested first. This procedure was repeated until all specimens had been tested, which avoided preparation and testing bias.

Table II. Nonparametric Kruskal-Wallis test for mean ranks ($P<.001$) (n=10)

Cement	Mean rank
CBO	28.00
CE	40.00
RU	19.40
PF	30.80
HBZPC	9.30

Specimen failure was defined as the point at which preliminary failure or a propagation of a crack in or around the luting cement layer occurred.[17,26] This was monitored by the strain gauge on the specimen. The gauge was connected as 1 arm of a Wheatstone Bridge circuit. Voltage output from this circuit was proportional to the movement of the crown margin in relation to the tooth as measured by the gauge. Visual evidence of failure was recorded with a pen chart

Table III. Mann-Whitney tests for significant differences between cement pairs

Statistical comparison	P
CBO – CE	.112
CBO – RU	.174
CBO – PF	.406
CBO – HBZPC	.003*
CE – RU	.001*
CE – PF	.016*
CE – HBZPC	.001*
RU – PF	.059
RU – HBZPC	.070
PF – HBZPC	.001*

*Statistically significant difference (P<.05).

recorder (Model LR 4110E; Yokogawa Electric Corp, Tokyo, Japan). Initially, the amplitude was small and regular, indicating that the movement of the cast crown during loading was elastic. However, as the crack in the cement layer enlarged, the movement increased. Finally, the movement of the crown margin reached a magnitude beyond the range of the strain gauge. This point was deemed as preliminary failure.

Following preliminary failure, each crown was sectioned bucco-palatally with a tungsten carbide bur (FG171; Jet Carbide burs; Kerr, Orange, Calif). One half of each crown was removed, and inspected under ×10 magnification by 2 independent examiners. Results of the 2 evaluators were compared, and any specimens for which evaluations differed were re-examined until agreement was reached. Three cement failure locations were defined: (1) the tooth-cement interface, where at least 75% of the cement remained on the crown, (2) the crown-cement interface, where at least 75% of the cement remained on the axial walls of the tooth, and (3) mixed, where neither tooth nor crown had a clear preponderance of retained cement.[35] The cement failure location for each specimen was recorded.

The dependent variable recorded was the number of load cycles required to induce preliminary failure. This variable was subjected to the nonparametric Kruskal-Wallis test to detect overall significance, with follow-up Mann-Whitney tests to identify which pairs of groups demonstrated a significant difference (α=.05). The data were analyzed using statistical software (SPSS 13.0; SPSS Inc, Chicago, Ill).

RESULTS

Figure 4 shows the mean values and SDs of cycle counts to preliminary failure for all 5 cements. Table II shows the mean ranks of the 5 cements with the Kruskal-Wallis test (P<.001). Group CE had the highest rank of cycles to preliminary failure, whereas Group HBZPC had the lowest rank of cycles to preliminary failure. Mann-Whitney tests were performed to identify which pairs of cement groups demonstrated a significant difference. Results for Mann-Whitney tests are found in Table III. Group CE had a significantly higher number of cycles to preliminary failure compared to PF (P=.016), RU (P=.001), and HBZPC (P<.001), but was not significantly different from CBO (P=.112). Group HBZPC had significantly lower cycles to preliminary failure compared to CE (P<.001), PF (P<.001), and CBO (P=.003), but was not significantly different from RU (P=.070).

Table IV. Cement failure location for all test groups

Cement failure location	Tooth-cement interface	Crown-cement interface	Mixed
C & B Opaque	8	2	-
Calibra	9	1	-
RelyX Unicem	3	5	2
Panavia F	8	-	2
HY-Bond ZPC	2	4	4

The failure locations are given in Table IV. For groups CBO, CE, and PF, most of the failures were seen at the tooth-cement interface. For group RU, 5 failures were seen at the crown-cement interface, 3 at the tooth-cement interface, and 2 were mixed. Group HBZPC also showed a variety of failures, with 4 at the crown-cement interface, 2 at the tooth-cement interface, and 4 mixed failures.

DISCUSSION

The effect of impact loading was tested and found to be 5%. This signifies that the actual load acting on the specimen may be 5% higher than 73.5 N. This is in agreement with other studies done at the University of Washington (JI Nicholls, PhD, written communication, September 2005). In this study, the load indenter fall distance was kept constant for all specimens. This was controlled by the eccentric cam pushing up the load bar. The speed of the load pulses was also constant for all specimens. The 5% load increase can therefore be applied to all specimens; thus, the failure cycle data for all specimens can be compared directly in the statistical analysis.

The ranking of the current results are in agreement with Junge et al.[19] In that study, Scotchbond resin cement had the highest number of load cycles to preliminary failure. The actual number of cycles differed from this study because Junge used a 1.5-kg load on compromised central incisors. The results are also in agreement with other static tensile loading studies.[3-9] In this study, RelyX Unicem was not significantly different from HY-Bond ZPC. This was unexpected, as RelyX Unicem is a resin cement. A possible reason for the lower fatigue cycle count may be the higher viscosity of this cement, possibly leading to an increased film thickness, and/or possible air incorporation during trituration.

The cementation protocol for HY-Bond ZPC was the simplest of the 5 cements. For the resin cements, RelyX Unicem was the least technique sensitive because it was provided in unidose capsules (aplicaps) with no dentin pretreatment required. During cementation, it was observed that RelyX was more viscous, and greater resistance was encountered in seating the crowns. Calibra and Panavia F cements each required separate primer applications. C & B Opaque required not only dentin etching, but also a primer application prior to final cementation. Dispensing equal amounts of base and catalyst pastes was easier with Panavia F than with C & B Opaque and Calibra cements. This is because of the reference marks on the Panavia F base and catalyst syringes.

The rate at which fatigue failure occurs is a function of discontinuities in the cement layer.[19] These discontinuities include bubbles or lack of wetting of the dentin and/or crown surfaces. Discontinuities located at the palatal crown margin would result in a lower number of cycles to preliminary failure than those at the mesial, distal, or buccal margins. Since the location of the discontinuity cannot be controlled, some variation in cycles to failure must be expected.[19]

Despite the fact that HY-Bond ZPC had the lowest cycle count to preliminary failure, this material appeared also to have the lowest variation for the cycle count. The standard deviation for this product was at least one third of the values for the resin cements tested.

Finger pressure was used during the cementation of crowns onto the tooth specimens. This may have resulted in an uneven amount of force during seating; however, this technique was preferred, as it simulates clinical methodology more accurately.

It is important to note that even with the low values HY-Bond ZPC showed in this study, zinc phosphate cement has a long and successful clinical track record.[1] However, resin cements have been widely used only for the last decade, and there are limited clinical studies to support their use. In future research, it would be beneficial to incorporate thermal cycling along with dynamic loading. In vivo studies on clinical longevity of restorations cemented with resin cements are also lacking. The clinical superiority of polymer-based cements remains to be seen.

In the restoration of teeth, a dentist is faced with the clinical question of which crown cement to use to enhance clinical longevity. Generally, adhesive cements offer the advantage of increased mechanical properties as well as a bond to both tooth structure and pretreated metal alloys. Use of a resin cement for these situations may improve the prognosis of a restoration, provided a resin cement with a high fatigue-failure cycle count for both the tooth and cast crown interface is used.

CONCLUSIONS

Within the limitations of this in vitro study, where load fatigue was used to fail 4 resin cements and 1 zinc phosphate cement, Calibra had the greatest number of cycles to preliminary failure. Calibra specimens survived roughly 3 times the number of cycles needed to fail the HY-Bond ZPC specimens. RelyX Unicem had significantly fewer cycles to failure than Calibra, and was not significantly different from HY-Bond ZPC. Not all of the tested resin cements can be classified as providing a superior outcome when compared with zinc phosphate.

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Correction

The American Board of Prosthodontics report, published in the November 2005 issue of the Journal, contained errors within the list of Diplomates, pages 474-86. The following names and addresses were omitted from the list of diplomates:

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In the list of **Wisconsin** diplomates, the name **ConrardyAbdulaziz M. Albaker** should have appeared as **Abdulaziz M. Albaker**.