

***In Vitro* Marginal Fit of Three All-Ceramic Crown Systems Before and After Cementation**

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Clinical Relevance

The results of this study suggest that the evaluated resin-modified glass ionomer cement and resin cement will increase the marginal discrepancy after cementation of the evaluated ceramics.

SUMMARY

Statement of the Problem: Full-coverage all-ceramic restorations are widely used. The impact of various classifications of luting

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agent on marginal discrepancies is not well understood.

Purpose: The purpose of this study was to evaluate the cervical fit of all ceramic crowns (IPS e.maxPress, Cergogold, and In Ceram) on bovine teeth with two luting agents before and after cementation.

Materials and Methods: Ninety bovine incisors were embedded in resin. The coronal portions of the teeth were prepared to receive full-coverage crowns. Thirty crowns of 7.0 ± 0.5 mm height, 8.0 mm cervical diameter, and 4.2 mm incisal diameter were fabricated for each ceramic system. The crowns were seated on the teeth, and the marginal discrepancy was measured using a measuring microscope. Then, 15 crowns of each ceramic system were luted on the teeth with resin cement (Variolink II) or resin-modified glass ionomer cement (Rely X luting), and the marginal discrepancy was measured. The results were submitted to analysis of variance, t test and Tukey's test ($p < 0.05$).

Results: The three ceramic systems showed cervical fits after cementation statistically

inferior to cervical fits before cementation for the two cements. The IPS e.maxPress showed values for cervical fit statistically superior to Cergogold before cementation. No statistically significant difference was found between IPS e.maxPress and In Ceram and In Ceram and Cergogold. After cementation, no statistically significant difference was found for the three ceramics systems when luted with resin or resin-modified glass ionomer luting agents.

Conclusions: Within the limitations of this study, it can be concluded that both cements studied increase the marginal discrepancy between the crown and the preparation for the three ceramic systems evaluated.

INTRODUCTION

Dental ceramics have increasingly become the best choice for achieving natural looking restorations and are appropriate materials to mimic destroyed or missing dental structures.^{1,2} These materials have desirable characteristics such as chemical stability, biocompatibility, high compressive strength, and a coefficient of thermal expansion similar to that of tooth structure.³⁻⁵ Moreover, recent progress in material technology and processing of ceramic restorations has expanded their indication for use due to more reliable results.⁶ Because of the fact that ceramics are indirect restorations and have to be cemented, there will be always be a space between the restoration and preparation. If this space is large, more luting material is exposed to the oral environment. Bacterial plaque can accumulate in this area and can result in gingival inflammation, caries, and pulp lesions, resulting in restoration failure.^{7,8} In addition, a large gap can create stress concentrations, which could reduce the final strength of the restoration.⁹

Different types of cement have been used, and there have been controversial opinions about which kind would be more appropriate.^{6,7} When considering all-ceramic restorations, it has been reported that fracture strength can be improved by using resin cement. It has been argued that this kind of cement should be the preference when cementing all-ceramic restorations.^{10,11} The development of resin-modified glass ionomer cement was intended to improve some physical properties that were present in the conventional glass ionomer cements with better esthetics, working time, and adhesion.^{12,13} Furthermore, it has been shown that resin-modified glass ionomer cement does not decrease the final strength of all ceramic crowns.¹⁴

Marginal discrepancies have been evaluated extensively; however, relatively small sample sizes and low numbers of measurements per specimen have limited statistical analysis.¹⁵ As few as four measurements per specimen have been reported, even though Groten et al¹⁶ stated that at least 50 measurements are required to achieve relevant information. A variety of methodologies have reported marginal discrepancies between 19 and 160 μm .¹⁴⁻²⁴ It has also been shown that discrepancies between the master die and inner surface of a crown will increase the gap. Steel dies or resin dies have been employed to measure the marginal accuracy of indirect restorations.²⁵⁻²⁷ Although the use of these materials results in more accurate standardization of the abutment preparation, they do not supply the specific character of dental hard tissues.²⁸⁻³² In the present study, bovine teeth were used because they are histologically and morphologically similar to human dentin and are easier to obtain.³³

The difference in marginal gap created using resin cement and resin-modified glass ionomer cement with different ceramic systems has not been thoroughly reported. The aim of this study was to evaluate the cervical fit of all-ceramic crowns (IPS e.maxPress, Cergogold, and In Ceram) on bovine teeth with two cements before and after cementation. The null hypotheses were 1) the type of cement does not affect the marginal adaptation of the three different ceramic systems and 2) there is no difference before and after cementation with respect to the marginal adaptation of the three different ceramic systems.

METHODS AND MATERIALS

All materials studied are listed in Table 1.

Ninety bovine mandibular incisors were collected and stored in a 10% formalin solution.¹⁶ Calculus deposits and soft tissue were removed from the selected teeth with a scaler and cleaned with a bristle brush and nonfluoridated flour of pumice (Zircate Prophyl Paste, Dentsply, Milford, DE). Mechanical retention was made in the root of the tooth before embedding with autopolymerizing acrylic resin (Jet, Clássico-Produtos Odontológicos, São Paulo, Brazil) in polyvinyl chloride tubes (Marron, Tigre, Joinville, Brazil). The teeth were placed upright with the long axes parallel to the height of the tube, and the cemento-enamel junctions (CEJ) were placed 3 mm above the resin. The assembled specimens were attached to a lathe (Nardini-ND 250 BE, São Paulo, Brazil) with a grinding device and preparation accomplished under water spray. The

Table 1: *Materials Used in the Study*^a

Material	Manufacturer	Type	Composition
IPS e.maxPress	Ivoclar Vivadent, Schaan, Liechtenstein	Lithium disilicate ceramic	SiO ₂ , Al ₂ O ₃ , La ₂ O ₃ , MgO, ZnO, K ₂ O, Li ₂ O, P ₂ O ₅
e.maxCeram	Ivoclar Vivadent	Feldspatic porcelain	SiO ₂ , K ₂ O, ZnO, ZrO ₂ , Li ₂ O, CaO, Na ₂ O, Al ₂ O ₃
Cergogold	Degussa Dental, Hanau, Germany	Leucite ceramic	SiO ₂ , Al ₂ O ₃ , K ₂ O, Na ₂ O, CaO
DuceraGold	Degussa Dental	Feldspatic porcelain	SiO ₂ , Al ₂ O ₃ , K ₂ O, Na ₂ O, CaO, BaO, SnO ₂ , Li ₂ O, F, Sb ₂ O ₃ , CeO ₂ , B ₂ O ₃ , TiO ₂
InCeram Alumina	Vita Zanafabrik, Seefeld, Germany	Infiltrated Alumina ceramic	Al ₂ O ₃ , La ₂ O ₃ , SiO ₂ , CaO, other oxides
VM7	Vita Zanafabrik	Feldspatic porcelain	SiO ₂ , Al ₂ O ₃ , B ₂ O ₃ , Na ₂ O, K ₂ O, CaO, TiO ₂
Variolink II	Ivoclar Vivadent	Dual-polymerizing resin luting agent	HEMA, dimethacrylate, phosphoric acid acrylate, highly-dispersed silicon dioxide, initiators and stabilizers in an alcohol solution; the brush is coated with initiators
Rely X luting	3M ESPE, Seefeld, Germany	Resin-modified glass ionomer cement	A: fluoroaluminosilicate, potassium persulfate, ascorbic acid, opacifying agent B: 30%-40% copolymer of acrylic and itaconic acids, 25%-35% 2-hydroxyethyl-methacrylate, 25%-35% water

^a Manufacturer information.

final dimensions of the preparations were 7.0 ± 0.5 mm in height, 8.0 mm for the cervical diameter, and 4.2 mm for the incisal diameter, which resulted in a peripheral surface convergence of 8°. This degree of convergence was used since it has been shown that retention increases considerably as the taper decreases.²⁴ A 0.8-mm-deep shoulder finish line with a rounded internal line angle was prepared using a diamond instrument (No. 5850-018; Brasseler USA, Savannah, GA). All sharp angles were rounded, and all cervical margins were located 1.0 ± 0.2 mm above the CEJ (Figure 1). All teeth were measured after the preparation using a precision electronic micrometer (Electronic Micrometer; LS Starrett, Athol, MA) with an accuracy of 0.002 mm.¹⁶

The 90 prepared teeth were divided into three groups (n=30) as follows: In Ceram Alumina, IPS e.maxPress, and Cergogold. An impression was made for each prepared tooth with a polyvinyl

siloxane impression material (Express, 3M ESPE, St Paul, MN) using a custom-made impression tray fabricated with acrylic resin. Then, type IV gypsum (Fuji Rock, GC America, Aslip, IL) was poured to produce dies. The teeth were stored in distilled water at 37°C until the cementation process.

The dies were coated with one layer of die spacer (Spacelaquer Ducera Lay, Degussa Huls, Hanau, Germany) to approximately 1 mm above the finish line. For IPS e.maxPress and Cergogold, the dies were isolated with lubricating oil (Die Lube, Denta-urum J.P. Winkelstroeter KG, Pforzheim, Germany) and 0.7-mm-thick wax patterns were prepared over the master dies using a wax-dipping unit (Hotty, Renfert, Hilzingen, Germany). Following the preparation of the wax patterns, each pattern was sprued and invested in an investing ring. A two-stage burnout sequence was used: temperature increased 5°C/minute to 250°C and held for 30

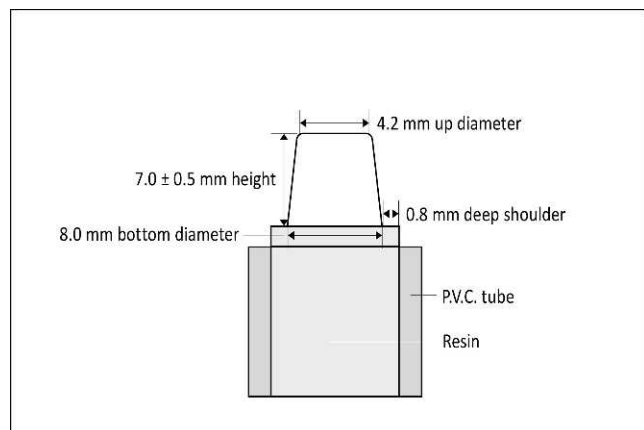


Figure 1. Schematic diagram of full-coverage preparation.

minutes before increasing the temperature at 5°C/minute to 850°C and holding for 1 hour. After the preheating stage, the investment cylinders were immediately transferred to the pressing furnace (EP500, Ivoclar AG, Schaan, Liechtenstein). The pressing temperatures for Empress 2 core and Cergogold core ceramics were 920°C and 850°C, respectively. Following the pressing procedure, the investment cylinders were removed from the pressing furnace and cooled for 2 hours in a ventilated room. The cooled specimens were divested by grit blasting with 80- μ m glass beads (Williams glass beads, Ivoclar North America, Amherst, NY). Before etching, the sprues were cut away, and excess sprue segments were removed by grinding from the specimen surfaces using water as a coolant. The core specimens were placed in one plastic bottle containing 20 mL of 1% hydrofluoric acid solution (Invex Liquid, Ivoclar AG), and these bottles were placed in an ultrasonic bath. After etching, the specimens were cleaned under running tap water for 10 seconds and then dried thoroughly. These procedures were performed by a certified dental technician.

For the In Ceram alumina, three layers of die spacer (Vita Zanzfabrik, Seefeld, Germany) were applied on the stone die surface to approximately 1 mm above the finish line. Impressions were made using a polyvinyl siloxane impression material (Express, 3M ESPE) with a plastic ring. These impressions were poured with In Ceram special plaster using a liquid-to-powder ratio of 0.23 mL/g to make refractory models. In Ceram powder slip was prepared according to the manufacturer's instructions and was applied to the models. A sculpturing device was used to ensure a uniform core thickness.¹⁹ The stabilizer was applied, and the coping

was fired on the plaster dies and infiltrated with glass. Excess glass was removed with a diamond bur. These procedures were conducted in an authorized laboratory by a certified technician. The final dimension of IPS e.maxPress and Cergogold copings were 0.7 mm and 0.5 mm for In Ceram.

The veneer porcelains (e.max Ceram, Ivoclar for IPS e.maxPress core; VM7, Vita Zahnfabrik for In Ceram core and Duceragold, Degussa Dental for Cergogold core) were applied to the core materials, which had been placed in a split brass mold to make a complete crown shape with a stratification porcelain thickness measuring 0.1 mm for IPS e.maxPress and Cergogold and 0.3 mm for In Ceram specimens in the cervical region and increasing in thickness in accordance with the taper angle. Following veneer porcelain sintering, the final dimensions of the crowns were 0.8 mm in the cervical region, 1.0 mm in the mid-facial region, and 1.5 mm in the incisal region.¹⁶

Measurements of Marginal Adaptation Before Cementation

Tooth surfaces were cleaned with a bristle brush and nonfluoridated flour of pumice (Zircate Prophyl, Dentsply). Each crown was placed onto its preparation under a constant controlled pressure of 9 kgf for 1 minute using a pneumatic pressure machine (developed in the Dental Materials Laboratory of the University of Campinas School of Dentistry, Piracicaba, Brazil). A metallic device was designed to maintain the assembled tooth/restoration at a reproducible position and allow measurement on a measuring optical microscope (Nikon measurescope UM2, Nikon Co, Tokyo, Japan) at original magnification 50 $\times$. The accuracy of the microscope was ± 0.5 μ m. The marginal discrepancy was evaluated by measuring the gap between the edge of the crown and prepared tooth margin. Sixteen diametrically placed marks were created on the root tooth surface 2 mm below the prepared margin using a round diamond bur (#1011, KGSorensen, São Paulo, Brazil). The distance of the gap was measured at each demarcated area with four different measurements. These measurements were taken from the prepared margin to the edge of the crown (Figures 2 and 3).

Application of Cement

Variolink II (Ivoclar-Vivadent, Schaan, Liechtenstein). Tooth surfaces were cleaned with a bristle brush and nonfluoridated flour of pumice (Zircate Prophyl, Dentsply). The dentin was treated for 15

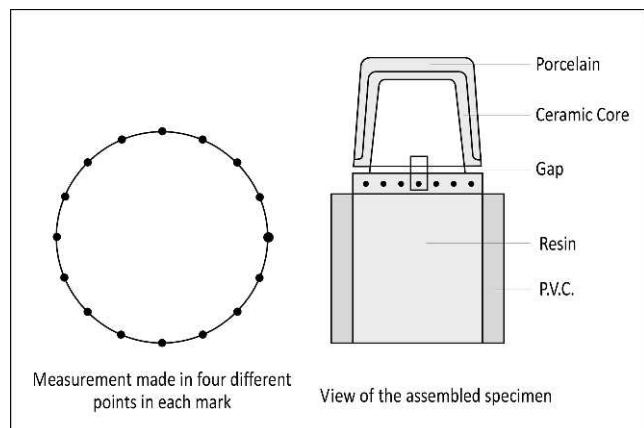


Figure 2. Points of measurement and view of the assembled specimen.

seconds with 35% phosphoric acid and rinsed for 10 seconds under running tap water. Excess water was removed with a cotton pellet, leaving a moist surface. Two consecutive coats of adhesive were then applied using a saturated microbrush tip. The ceramic surface was etched with 10% hydrofluoric acid (Ácido hidrofluorídrico, Dentsply Brazil, Petropolis, RJ, Brazil) for 1 minute (Cergogold and In Ceram) or for 20 seconds (IPS e.maxPress), followed by rinsing for 1 minute. Samples were then ultrasonically cleaned with distilled water for 10 minutes and dried with oil-free air. The silane agent Monobond S (Ivoclar-Vivadent) was applied, and the surface was dried after 1 minute using compressed air. The resin cement was mixed and applied to the internal ceramic crown surface. A load of 454 gf was applied while the excess cement was removed. The cement was light-cured (XL3000, 3MEspe) for 40 seconds on each side (labial, lingual, medial, and distal) of the crown, resulting in 160 seconds of light polymerization for each crown with 500 mW/cm² light intensity. Ten minutes after the start of the mix, specimens were immersed in distilled water at 37°C and stored until testing.

Rely X luting (3M ESPE). The procedures were the same as for the aforementioned resin cement, but the dentin was simply cleaned and did not receive any adhesive application. The specimens were stored in distilled water for 24 hours before making the measurements.

Measurements of Marginal Adaptation After Cementation

The marginal discrepancy was measured as described for marginal adaptation measurement before

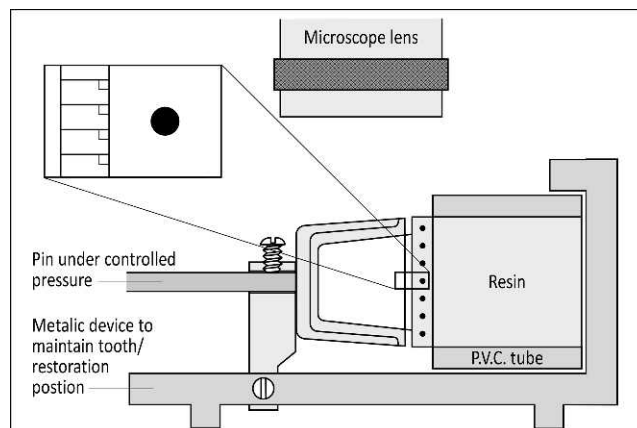


Figure 3. Assembled specimen under the microscope.

cementation (Figures 2 and 3). However, the pressure was not applied because the crowns were already cemented. ANOVA one-way, post hoc Tukey and t test were applied (Table 2). The marginal adaptations were determined, and since two different cements were used and the readings were before and after cementation, the data were statistically analyzed using two-way analysis of variance (ANOVA), with the independent variables being the cement and the time of evaluation (before and after cementation) (Tables 3, 4 and 5). Means and standard deviations were calculated for each material and each condition. Individual comparisons between the materials and conditions were made using a Tukey Honestly Significant Difference test to determine significant differences. All statistical testing was performed with $\alpha=0.05$.

RESULTS

The one-way ANOVA (Table 2) revealed significant differences in the marginal discrepancy values ($p<0.001$). Tables 3, 4, and 5 show the mean marginal discrepancies and standard deviations. Table 3 displays the values of the three ceramic systems before and after cementation with resin-modified glass ionomer cement. It can be seen that before cementation, IPS e.maxPress resulted in a discrepancy significantly higher than Cergogold, and both did not differ from In Ceram ($p<0.05$). The same situation was observed after cementation ($p<0.05$). When comparing the discrepancies within each ceramic before and after cementation, the results after cementation were statistically significantly higher than before cementation ($p<0.05$).

Table 2: *Statistical Analysis*^a

Causes of Variation	Applied Test	Mean	SD	F	p
Ceramic before	ANOVA one-way			13.0445	0.0000631
In Ceram		81.43 B	17.27		
e.maxPress		95.65 A	19.54		
Cergogold		71.51 B	18.31		
Ceramic after	ANOVA one-way			9.4975	0.0003803
In Ceram		122.92 A	17.27		
e.maxPress		137.97 A	40.69		
Cergogold		101.95 B	26.43		
Before and after	t-test paired				<0.0001
Before		82.87	20.74		
After		121.0	35.09		
Cement	t-test not paired				0.8405
Glass ionomer		121.7	33.66		
Resin cement		120.2	36.84		

^a Means followed by the same letter indicate no statistical difference.

Table 4 shows the mean values of discrepancies of the three ceramic systems before and after cementation with resin cement. It can be observed that before cementation, IPS e.maxPress resulted in a discrepancy significantly higher than Cergogold, and both IPS e.maxPress and Cergogold did not differ from In Ceram ($p < 0.05$). The same situation was observed after cementation ($p < 0.05$). When comparing the discrepancies within each ceramic before and after cementation, the results after cementation showed a statistically significant increase ($p < 0.05$). Table 5 compares the mean values of discrepancies between the two cements for the three ceramic systems. It shows that there was no statistically significant difference between the cements for the ceramics evaluated.

DISCUSSION

The null hypotheses that the type of cement does not affect the marginal adaptation of the three different ceramic systems and that the time of evaluation (before and after cementation) does not affect the marginal adaptation of the three different ceramic systems were rejected by the results. The marginal discrepancy of the three ceramic systems evaluated was affected by the cement and by the time of evaluation (Tables 3 and 4). These results seem to correlate well with *in vitro* studies assessing the discrepancies of ceramic restorations.^{19,20} Many studies evaluating the marginal discrepancy of all-ceramic crowns have been published;^{15,17,19–21} however, no study was found comparing resin-modified glass ionomer cement and resin cement before and after cementation for different ceramic restoration systems. It is well known that

Table 3: Marginal Discrepancies of the Three Ceramic Systems Before and After Cementation With Resin-Modified Glass Ionomer Cement (Means and Standard Deviations [SD] in μm^a)

Ceramic Type	Before Cementation			After Cementation		
	No. of Spec	Mean	SD	No. of Spec	Mean	SD
IPS e.maxPress	15	83.13 ^a A	25.04	15	137.82 ^a B	44.44
In Ceram	15	77.04 ^{ab} A	18.32	15	122.67 ^{ab} B	18.88
Cergogold	15	66.20 ^b A	20.19	15	104.64 ^b B	25.28

^a Means followed by the same superscript letters within each column and capital letters within the row indicate no statistical difference at the 95% confidence level ($p > 0.05$).

resin cement is the most popular luting agent when using all-ceramic restorations³⁴; however, resin-modified glass ionomer cement has been used to cement all-ceramic restorations, and some authors argue that this cement has advantages.^{13,14} Even though controversy exists regarding a clinically acceptable marginal adaptation, the study by McLean and von Fraunhofer¹⁸ proposed that a restoration would be successful if marginal gaps of less than 120 μm could be obtained. Before cementation, the marginal discrepancy of the all-ceramic systems evaluated in the current study was within this clinically acceptable standard, and it is in agreement with other studies^{19–21} that found marginal discrepancies deemed clinically acceptable. Nevertheless, the current results do not agree with Grey et al²⁶ that found discrepancies larger than 120 μm for conventional In Ceram crowns. After cementation, Cergogold and In Ceram showed acceptable discrepancy values for both cements evaluated, but IPS e.maxPress resulted in a discrepancy larger than recommended (Tables 3, 4, and 5). Some studies

have evaluated the marginal discrepancies without taking the cementation process into consideration.^{35–37} Evaluating discrepancies without luting them is not reflective of clinical reality because the cement and the cementation process play a relevant role in the final discrepancy achieved. In the current study, although a space was created to allow the cement to flow into the space between the tooth and internal ceramic surface, the results for the all-ceramic and cement combinations increased the discrepancy after cementation. The convergence angle could influence the final marginal discrepancy acquired since an angle with a higher divergence would permit easier displacement of the cement. In the current study, the 8° taper angle might not have allowed the same flow of the cements as a clinical preparation would, because clinical angles range between 12° and 20°, and increased taper could affect the crown retention.^{23,24} However, the current results are in agreement with previous studies that found an increase in the marginal discrepancy after cementation using approximately the same taper-

Table 4: Marginal Discrepancies of the Three Ceramic Systems Before and After Cementation With Resin Cement (Means and Standard Deviations [SD] in μm^a)

Ceramic Type	Before Cementation			After Cementation		
	No. of Spec	Mean	SD	No. of Spec	Mean	SD
IPS e.maxPress	15	101.50 ^b A	21.20	15	138.10 ^b B	38.13
In Ceram	15	85.83 ^a A	15.22	15	123.20 ^a B	34.55
Cergogold	15	76.82 ^a A	15.06	15	99.26 ^a B	28.16

^a Means followed by the same superscript lowercase letters within each column and uppercase letters within the row indicate no statistical difference at the 95% confidence level ($p > 0.05$).

Table 5: Marginal Discrepancies of the Three Ceramic Systems After Cementation With Resin Cement and Resin-Modified Glass Ionomer Cement (Means and Standard Deviations [SD] in μm) ^a						
Ceramic Type	RMGI			Resin Cement		
	No. of Spec	Mean	SD	No. of Spec	Mean	SD
IPS e.maxPress	15	123.20 A	38.13	15	137.80 A	44.44
In Ceram	15	138.10 A	34.55	15	122.70 A	18.88
Cergogold	15	99.26 A	28.16	15	104.60 A	25.28
^a Means followed by the same capital letters within each row indicate no statistical difference at the 95% confidence level ($p>0.05$).						

ing.^{19,20} Further study should be pursued to delineate the optimum convergence angle for adhesively retained all-ceramic restorations. Despite the fact that ceramic restorations have been used extensively, the cementation procedure is one of the most critical parts of the overall process. In the present study, the conditions were well controlled. Even though clinically, the practitioner cares about the final fit of the restoration, it is not possible to control all of the steps as in an experimental study. Since an increase in marginal discrepancy was seen in a well-controlled environment, it would seem important for the clinician to pay close attention to environmental factors that might interfere with the cement line thickness.

CONCLUSION

Within the limitations of this study, it can be concluded that the cementation increases the marginal gap between the crown and the preparation for the three ceramic systems evaluated regardless of the type of cement evaluated.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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