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Marginal and Internal Discrepancies Related to Margin Design of Ceramic Crowns Fabricated by a CAD/CAM System

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Abstract

Purpose: The aim of this study was to evaluate the marginal discrepancy (MD) and internal discrepancy (ID) of ceramic crowns manufactured by a CAD/CAM system, having different finish lines. The hypotheses tested were that the finish line type would not influence the MD or ID of the crowns, and ID would not change in different regions.
Materials and Methods: Three aluminum master dies (height: 5.5 mm, Ø: 7.5 mm, conicity: 6°) with different finish lines (TC: tilted chamfer; LC: large chamfer; RS: rounded shoulder) were manufactured. Ten impressions were made from each master die using a modified parallelometer. Impressions were poured in type IV dental stone, and 30 ceramic crowns (IPS Empress CAD, Ivoclar) were subsequently milled. The crowns were fixed on their respective metallic die using a metallic fixation device. The distance between the external edges of the crown to the edge of the cervical preparation was performed at 50 points on the respective metallic die (MD analysis). With the replica technique, the ID values of each crown were further evaluated at 12 points equidistant to each other in three regions: radius (R), axial (A), and occlusal (Occl). The measurements were performed using an optical microscope (250×). The data (μm) were analyzed using ANOVA and Tukey's test (5%).
Results: The RS group (28.24 ± 11.42 μm) showed significantly lower MD values ($p = 0.001$) than those of TC (99.92 ± 18.32 μm) and LC (64.71 ± 25.64 μm) groups, both of which also differed statistically from one another. The ID results demonstrated significantly lower values in the LC group (183.01 ± 62.82 μm) ($p = 0.0014$) than those of TC (216.26 ± 83.23 μm) and RS (219.12 ± 87.24 μm) groups. ID results of TC and RS were not significantly different. Additionally, the ID results showed significant differences among the regions ($p = 0.0001$). The null hypotheses were rejected.
Conclusion: The RS finish line produced MD values significantly lower than tilted and large chamfer, but large chamfer presented the lowest internal discrepancy values. Independent of the finish line type, internal discrepancy was the lowest in the axial region followed by radius and occlusal regions.

With the objective of improving laboratory procedures and clinical performance of ceramic restorations, several ceramic systems based on computer science have been developed. Computer-aided design/computer-aided manufacturing (CAD/CAM) has been used in dentistry since its development by Duret in France in the 1970s (System Duret CAD/CAM).[1]

Among the available CAD/CAM systems, the CEREC (*CER*amic *REC*onstruction) system is commonly used, as it was the first to be commercially available. This system uses

Table 1 Brands, manufacturers, and batch numbers of materials used

Material	Brand	Manufacturer	Batch number
Ceramic block	IPS Empress CAD	Ivoclar Vivadent, Schaan, Liechtenstein	#J00337
Addition silicone impression	Elite H-D Putty Soft Normal Setting	Zhermack S.p.A., Rovigo, Italy	#40987
	Elite H-D Light Body Normal Setting	Zhermack S.p.A., Rovigo, Italy	#35024
Dental stone type IV	CAM-base	Dentona AG, Dortmund, Germany	#10300206
Surface tension reduction agent	Surfacer	Polidental Ind. Ltd, Cotia, Brazil	Not available

prefabricated high-quality ceramic blocks, resulting in biocompatible, esthetic, and durable restorations.[2,3] The CEREC system was developed by Dr. Werner Mörmann and by an electrical engineer, Dr. Marco Brandestini, in 1980. The first inlay ceramic restoration (Vita Mark I, Vita Zahnfabrik, Bad Sackingen, Germany) was luted on September 19, 1985, using the CEREC 1 system (Siemens, Bensheim, Germany). Today, the CEREC 3 system is available for chairside and CEREC inLab for laboratory use.[4] One major problem still of concern with all computerized systems is the marginal fit of the indirect restorations.[5] The clinical success of restorations depends on multiple factors, and according to some studies, marginal and internal discrepancy between the ceramic restoration and the prepared tooth is of importance.[6-8] Excessive marginal gaps may affect periodontal tissues, increase dental plaque retention,[9,10] favor the development of recurrent caries or pulp lesions,[11-14] and lead to bone resorption.[10] In addition, excessive internal discrepancies can reduce the fracture strength of full-ceramic restorations, as these areas induce different load concentrations.[15,16]

Thus, the aim of this study was to evaluate the influence of different finish lines on the marginal and internal discrepancies of ceramic crowns made using the CEREC inLab CAD/CAM system. The hypotheses tested were that the marginal and internal discrepancies of the crowns would be similar, independent of the finish line, and that the internal discrepancy would be similar in different regions.

Materials and methods

The brand, manufacturers, and batch numbers of the materials used for this experiment are presented in Table 1.

Preparation of metallic dies

From an aluminum aeronautic bar (15 mm diameter; 69 mm length) (AMS 4050F, SAE Aerospace International Group, São Paulo, Brazil), three master dies with equal dimensions were milled. The crown configuration was 5.5 mm high with a 7.5 mm diameter at the base and an occlusal convergence of 6°. The large chamfer (LC) and tilted chamfer (TC) groups presented finish lines with radius of 1.2 mm. The rounded shoulder (RS) group had a horizontal base (0.6 mm) and a radius of 0.4 mm (Fig 1).

A spiral was made on the base of the master dies to fit the movable vertical stem of the parallelometer during impression making. To standardize the marginal discrepancy (MD) measurements, approximately 1.5 mm below the finish line, 25 laser marks (0.5 mm thick) were made, each being 0.5 mm apart.

Imaging and CEREC crown production

Using a modified parallelometer (Bio-Art, São Carlos, São Paulo, Brazil), ten impressions were made for each master die using the double impression technique (Elite H-D Putty

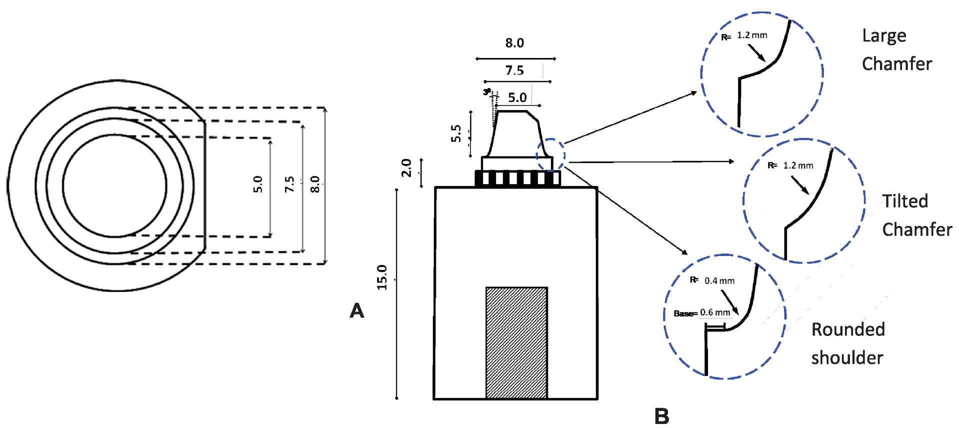

Figure 1 Schematic drawing of the master dies, showing the dimensions (mm) and finish lines: (A) occlusal view, (B) lateral view.

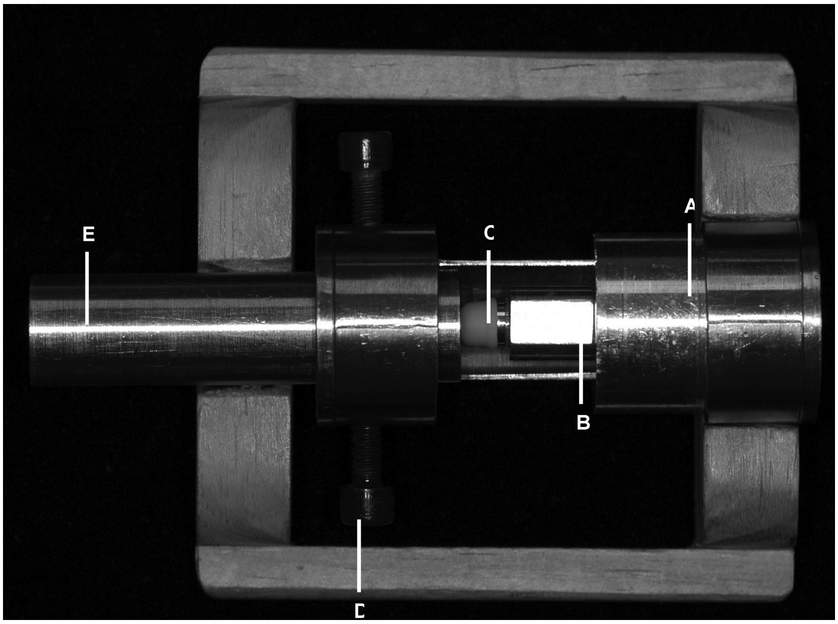

Figure 2 Device used for fixation of the crowns to the metallic die supported on a wooden base: (A) cylindrical metallic base, (B) metallic die, (C) ceramic crown, (D) side screws for piston fixation, (E) piston.

Soft Normal Setting/Light Body Normal Setting). The parallelometer allowed standardization of the insertion and removal of the master dies during the impression procedures. Using an acetate sheet prepared under vacuum for each master die, a standardized relief thickness (1.4 mm) of light body silicone was made.

To allow a more accurate flow on the stone die, a surface tension reducing agent (Surfacer) was applied on each impression 24 hours after pouring the impressions. A special dental stone (CAM-base®) was mixed under vacuum and carefully poured into each silicon impression under vibration.

For fabrication of the crowns, the CEREC inLab system (Sirona Dental Systems, Bensheim, Germany) was used. The stone dies were removed from the impressions, trimmed, and positioned in a metallic device placed on an inEOS optical scanner base (Model no: D3446, Sirona Dental Systems). Using the strip light projection,[3] the scanning and design procedures for all 30 stone dies were done with the assistance of the CEREC 3D program (version 2.9, Sirona Dental Systems). The ceramic crowns were designed as frameworks at an approximately 1.0 mm thickness.

Each image was sent to the computer, and 30 crowns were milled from IPS Empress CAD LT C2/C14 blocks. A new set of cylindrical milling burs (1.6 mm diameter, 1.2 mm/step bur) was used for each group. Based on the results of a pilot study, the luting space was set to 20 μm.

Crown fit adjustment

The internal adjustment of the crowns was controlled on the master dies using red lipstick. With a brush, the metallic dies were painted along the preparation area, and the respective crowns were inserted. The internal marked areas were removed manually with cylindrical burs. This sequence was repeated until several points of the crown margins were in contact with the preparation edge, observed using a stereomicroscope (Stemi 2000-C, Carl Zeiss, Gottingen, Germany) at 20× magnification.

Marginal discrepancy measurement

Each metallic die was fixed on a metallic cylindrical base that allowed 360° of rotation of the metallic die around its axis. The metallic die/crown assembly was positioned in a metallic device that allowed the application of a constant load on the crown during the whole process of analysis (Fig 2).

The marginal fit was analyzed between the crown and preparation margins under a 3D optical microscope at a precision of 1 μm (Roi, RAM Optical Instrumentation, Irvine, CA) at 250× magnification. This measurement was defined by Holmes et al[17] as the vertical marginal discrepancy (MD). Fifty measurements were made along the crown margins based on the 25 laser-marked reference points. One operator carried out all measurements, and MD values below 1 μm were considered 0 μm.

Internal discrepancy measurement

Internal discrepancy (ID) of the crowns was measured using a replica technique.[18-20] Each crown was filled out with light-body silicone (Elite H-D Light Body Normal Setting, #35024), inserted on the respective master die under a constant load (750 g) for 10 minutes, using a modified parallelometer. After the light-body silicone was set, the crown was removed. Since it was not possible to remove the light-body silicone from the interior parts of the crown without distorting it, a heavy body silicone was used to stabilize the light body silicone. Using a razor blade (no: 15c), the replicas were carefully cut into four equal segments.

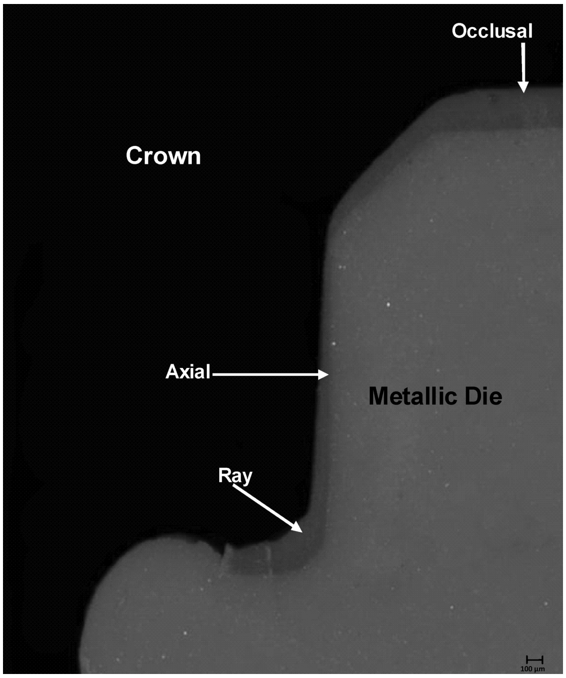

Figure 3 Light-body silicone replica from the internal surface of the crown after sectioning, showing the radius axial, and occlusal regions.

From four sections obtained in each replica, two sections (2 and 4; 1 and 3) were used to measure the internal fit, where three regions were measured on each section: R = radius, A = axial, Occl = occlusal, yielding 12 internal measurements for each crown (Fig 3). Using a 3D optical microscope (Roi) at 250× magnification at a precision of 1 μm, the light-body silicone thickness was measured for all replicas, representing the distance between the internal surface of the crown and external surface of the preparation.[17]

Statistical analysis

All marginal and internal discrepancy data (μm) were analyzed using one- and two-way ANOVA and Tukey′s multiple comparison test (5%) (SPSS 11.0 software for Windows, SPSS Inc., Chicago, IL). Pearson′s correlation coefficient was also determined between marginal and internal discrepancies.

Results

Marginal discrepancy

The results of one-way ANOVA for the experimental conditions are presented in Table 2. Significant effect of the finish line type was observed ($p = 0.001$) as MD varied among the groups.

According to Tukey's test, the RS group presented significantly lower MD values ($p < 0.05$), followed by LC and TC, with all groups being statistically different from one another (Table 3, Fig 4). In all groups, MD values showed high variation within the same sample ranging from 0 to 283 μm, 0 to 208 μm, and 0 to 122 μm for the TC, LC, and RS groups, respectively (Fig 5).

Table 2 Results of 1-way ANOVA for the vertical marginal discrepancy values

Effect	DF	SS	MS	F	*P*
Finish line	2	25,693.0	12,846.5	34.3	0.001
Residue	27	10,106.9	374.3		
Total	29	35,799.9			

Table 3 Mean (standard deviations) vertical marginal discrepancy values (μm). The same superscripts indicate no significant differences (Tukey's test, $\alpha = 0.05$)

Experimental groups	Mean (SD)
Tilted chamfer (TC)	99.92 (18.32)^{a}
Large chamfer (LC)	64.71 (25.64)^{b}
Rounded shoulder (RS)	28.24 (11.42)^{c}

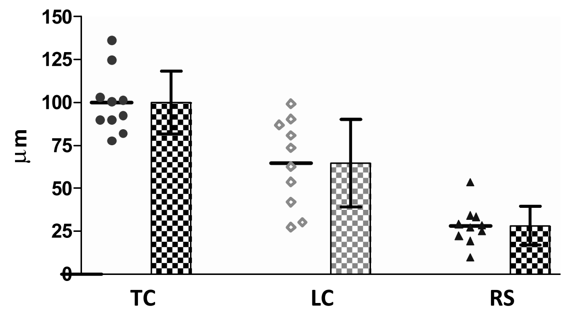

Figure 4 Means and standard deviations of the marginal discrepancy values with respect to the finish line types; TC: tilted chamfer; LC: large chamfer; RS: rounded shoulder.

Internal discrepancy

The results of one-way ANOVA for the experimental conditions are presented in Table 4. Significant effects for the finish line type and region were observed. Interactions between the finish line types and the regions were statistically significant (Tukey's test). The absence of the interaction effect indicates that for the ID measurements, there is a relationship between the regions and the finish lines analyzed. Thus, for the TC and RS groups, ID measurements between the axial and occlusal regions were similar (Fig 6).

The axial region of the RS group presented lower, but not statistically significant, ID values than those of LC and TC groups in the same region (Tukey's test) (Table 5); however, these values were statistically lower than those of other regions (radius and occlusal) in all groups ($p < 0.05$). When the mean ID values were compared to the factor finish line types (Tukey′s test), the LC group (183.01 μm) differed statistically ($p < 0.05$) compared to the TC (216.26 μm) and RS (219.12 μm) groups. TC and RS were not statistically significantly different from each other. When the variable region was compared among groups (Tukey′s test), the axial region showed significantly less discrepancy (117.69 μm) ($p < 0.05$) compared to the radius (218.31 μm) and occlusal (282.39 μm) regions. The radius and occlusal regions differed statistically

Table 4 Results of 2-way ANOVA and the interaction terms for internal discrepancies depending on the finish line types and regions (*significant at $p < 0.05$)

Effect	DF	SS	MS	F	*P*
Finish line	2	24,170	12,085	8.45	0.0014*
Residue I	27	38,623	1,430		
Region	2	413,572	166.09		0.0001*
Interaction	4	16,599	4,150	3.33	0.0164
Residue II	54	67,230	1,245		
Total	89	560,193			

from each other ($p < 0.05$). A weak or negative correlation was found between the MD and ID in all experimental groups: TC (r = 0.302), LC (r = −0.149) and RS (r = −0.559) (Pearson's correlation coefficient).

Discussion

In the present study, MD values varied significantly depending on the finish line type, and ID values were significantly influenced by the finish line type and region. Therefore, the hypotheses that the marginal and internal discrepancies of the crowns would be similar, independent of the finish line, and that

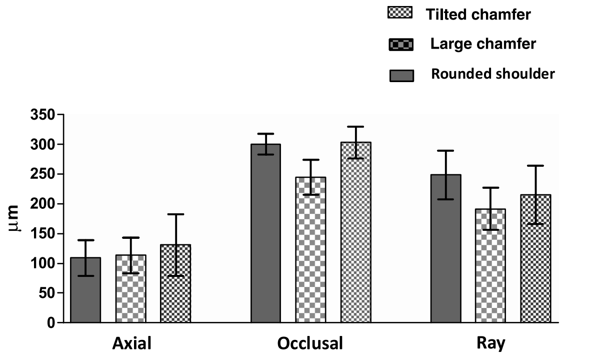

Figure 6 Means and standard deviations of the internal discrepancy values with respect to the finish line types and regions.

the internal discrepancy would be similar in different regions were rejected.

In this study, similar to some other studies,[21-26] metallic master dies were used for the analysis of MD and ID of the crowns. It has been previously stated that since metallic dies are obtained by milling processes, they allow for more uniform measurements along any preparation[21,23] compared to natural teeth[27] or acrylic resin dies.[28] The nonuniform nature of the preparations in the natural teeth and acrylic resins incorporate other variables during discrepancy measurements. For this reason,

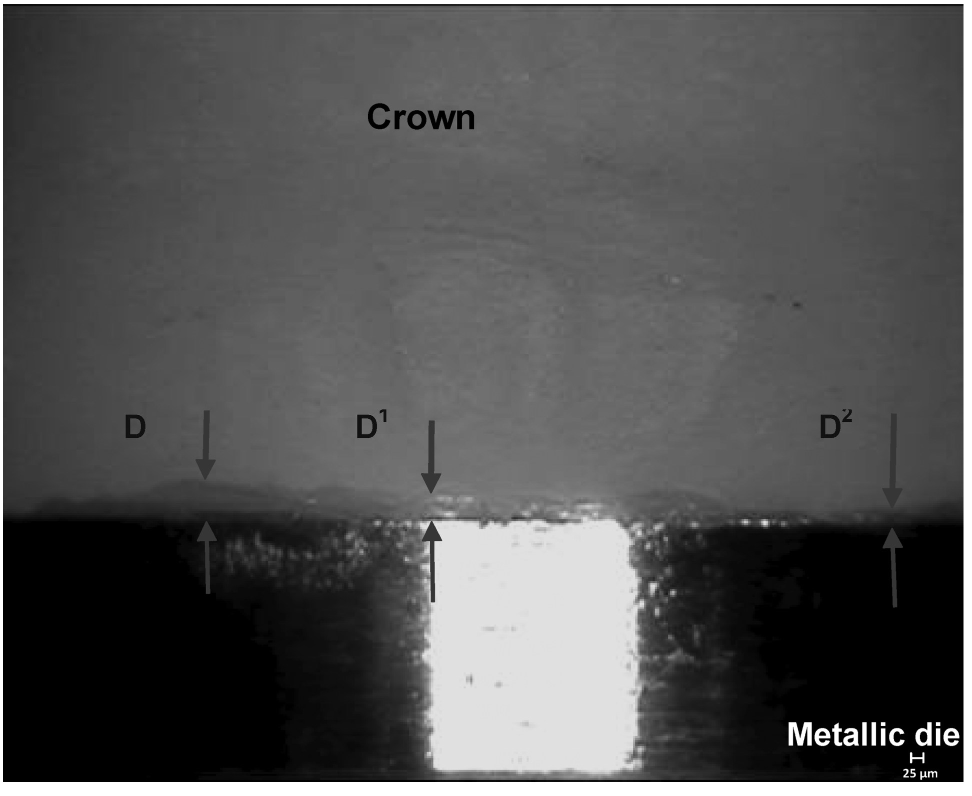

Figure 5 Representative optical microscope image (250x) of the marginal interface from the RS group between metallic die and crown, where D > D1 > D2.

Table 5 Mean internal discrepancy values (μm) according the three finish lines and regions. The same superscripts indicate no significant differences (Tukey's test, $\alpha = 0.05$)

Experimental conditions		
Finish line	Region	Mean
	Radius	$215.12^{b,c}$
Tilted chamfer (TC)	Axial	130.73^{d}
	Occlusal	302.94^{a}
	Radius	191.45^{c}
Large chamfer (LC)	Axial	113.28^{d}
	Occlusal	244.32^{b}
	Radius	248.35^{b}
Rounded shoulder (RS)	Axial	109.08^{d}
	Occlusal	299.92^{a}

metallic dies were used in this study. As the aim of this study was to analyze the primary precision of the CEREC system, the crowns were not cemented to their respective dies. A cement layer generally covers the evaluation points, interfering with the evaluation process, especially at the crown margins.[29-31]

Similar to the findings of this study, lower MD values were reported with chamfer finish lines compared to round shoulder ones in ceramic systems.[15,32] Several other studies also found that the rounded shoulder finish line produced better marginal fit than the large chamfer.[25,33-35] Using the CEREC inLab system in combination with composite resin blocks (Paradigm MZ100, 3M ESPE, St. Paul, MN), finish lines with 45° preparations (105 ± 34 μm) produced higher MD values than the preparations with a large chamfer (94 ± 27 μm) and rounded shoulder (91 ± 22 μm).[36] Likewise, results obtained in the RS group (28.24 μm) were in line with those reported by Groten et al[23] (25 μm) and Balkaya et al[34] (17 μm). While some authors[19,37,38] observed problems at the cervical regions when cement layers were even lower than 119 μm, others accepted MD values lower than 100 μm as clinically satisfactory.[20,35,39] In that respect, independent of the finish line type, means of MD values of all groups (TC, LC, RS) could be considered clinically acceptable, as they were less than 100 μm.

Although it was not the aim of this study, during optical microscope analysis, small fractures were observed at the crown margins, especially when higher discrepancy values were observed in the TC and LC groups. This could be explained by the ceramic thickness at the thinner marginal areas of the TC and LC groups compared to the RS group that had a flat base in its margin configuration. According to Kokubo et al,[8] production of milled restorations for the chamfer finish line type is complicated, due to the concave and convex areas in the tilted surfaces of this kind of finish line.

ID values of this study presented significantly lower values in the LC group (183.01 μm) than those of TC (216.26 μm) and RS (219.12 μm) groups. Lower values were also reported by Bindl et al[40] in crowns fabricated with the CEREC 2 system (141 ± 21 μm). The studies of Mou et al[41] and Nakamura et al[42] found ID values of 212 ± 45 μm and 146 ± 15 μm for crowns made with CEREC 2 and CEREC 3, respectively. The high ID values observed in this study may be due to the variations in the measurement method, namely the absence of the cement layer. When the ID values were compared depending on the regions, significant differences were found. The occlusal region (282.39 μm) presented higher values than those of other regions (R = 218.31 μm, A = 117.69 μm). Similar results were found by Kokubo et al,[8] who attributed this difference to the scanning process, preparation height, luting space, convergence angle, and the variations between the CAD/CAM systems.

There are controversial opinions for the ideal ID values for ceramic restorations.[41-46] Some studies demonstrated that the adhesive luting of ceramic restorations (Vita Mark II and IPS Empress CAD) made by the CEREC system significantly improves the mechanical properties of these restorations,[40,43-46] since the internal space between the preparation and the crown is filled with resin cement. Previous studies considered ID values between 200 and 300 μm clinically acceptable.[47,48] Thus, the ID results of this study could also be considered clinically acceptable. Clinical survival results[2] confirm this from full ceramic crowns (Vita Mark II) made by the CEREC system; however, to date, limited studies are available identifying a correlation between longevity of ceramic restorations and marginal and/or internal discrepancies. Also, fatigue behavior of crowns with high discrepancies warrants further research.

Conclusions

Within the limitations of this study, the following conclusions may be drawn:

1. The rounded shoulder finish line produced marginal discrepancy values significantly lower than those of the tilted and large chamfer finish lines.
2. The large chamfer finish line presented the lowest internal discrepancy values.
3. Independent of the finish line type, internal discrepancy was lowest in the axial region followed by radius and occlusal regions.

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