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RESEARCH AND EDUCATION

Effect of grinding and polishing on the roughness and fracture resistance of cemented CAD-CAM monolithic materials submitted to mechanical aging

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ABSTRACT

Statement of problem. The effect of clinical adjustments on the strength of cemented computer-aided design and computer-aided manufacturing (CAD-CAM) monolithic materials under aging challenge is unclear.

Purpose. The purpose of this in vitro study was to assess the surface roughness and fracture resistance (with or without mechanical aging) of cemented CAD-CAM monolithic materials submitted to grinding and polishing procedures.

Material and methods. Disks of Lava Ultimate, Vita Enamic, crystallized Vita Suprinity, and IPS e.max CAD were analyzed for roughness after polishing by using silicon carbide papers (Lava Ultimate and Vita Enamic) or glazing (IPS e.max CAD and Vita Suprinity) (control), after grinding by using 30-μm grit diamond rotary instruments, and after grinding and polishing by using a polishing kit. For fracture resistance, a simplified trilayer model consisting of a restorative disk, an epoxy resin disk, and a steel ring was used. The bonded trilayer disks received the same treatments described for the roughness analysis. Half of the specimens underwent mechanical aging for 1×10^6 cycles. All specimens were loaded until failure. The Weibull modulus was calculated.

Results. The IPS e.max CAD and Vita Suprinity showed the highest roughness after grinding and the lowest at baseline. For the Lava Ultimate and Vita Enamic, polishing provided lower roughness than at baseline. Grinding, followed or not by polishing, and mechanical aging did not adversely affect the fracture resistance or the reliability of the materials.

Conclusions. Polishing did not recover the initial surface roughness of the glass-ceramic materials. Fracture resistance was not affected by grinding, followed or not by polishing, even after mechanical aging. (J Prosthet Dent 2019;121:866.e1-e8)

Research to improve the esthetic properties of monolithic materials proceeds in parallel with the development of their physical and mechanical properties in an attempt to replicate those of the natural teeth.[1-3] Monolithic materials indicated for indirect restorations are available for computer-aided design and computer-aided manufacturing (CAD-CAM) technology, including yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramic, lithium disilicate, zirconia-reinforced lithium silicate, polymer-infiltrated ceramic, and nanofilled composite resin.[4-7]

Ideally, indirect restorations should not require any adjustment at the delivery appointment. However, this is not always possible because the removal of premature contacts or adjustment of the proximal contact areas may be needed.[8-11] Clinical adjustments may have undesirable consequences such as rougher surfaces,[9,12-15] which may facilitate biofilm formation,[16,17] increase antagonist wear,[18-20] or affect the restoration color.[21-26] In addition, surface roughness induces stress concentrations, compromising porcelain strength.[27-31] Clinical

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Clinical Implications

Grinding glass-ceramic restorations should be avoided because the smoothness given by the glaze can be compromised, even after polishing.

adjustments made by using diamond rotary instruments may also be detrimental to the strength of lithium disilicate glass-ceramics[32,33] and Y-TZP ceramics.[34-36] In addition to the adjustment configuration (diamond rotary instrument grit size, handpiece speed, wet or dry conditions), the damage tolerance of indirect restorative materials submitted to grinding depends also on their mechanical properties,[32,37] which are determined by the composition and microstructure.[38,39] Because polymer-containing materials exhibit lower elastic modulus than lithium disilicate,[40-42] they absorb stress better by elastic deformation, minimizing the flaws or defects that grow in brittle materials.[32,43,44]

When ceramic restorations have been adjusted before cementation, they can be glazed. However, once cemented, polishing is recommended to reduce the roughness of the ground surfaces and minimize the adverse effects on the strength of the ceramic or metal-ceramic fixed dental prostheses,[8] glass-ceramics,[32,43,45-47] and Y-TZP ceramics.[35] To the best of the authors' knowledge, no studies have investigated the effect of clinical adjustments and polishing on cemented specimens submitted to aging. The purpose of this in vitro study was to assess the surface roughness and fracture resistance (with or without mechanical aging) of cemented CAD-CAM monolithic materials submitted to grinding and polishing procedures. The null hypothesis was that the surface treatments would not affect the surface roughness and fracture resistance (even with aging) of the evaluated materials.

MATERIAL AND METHODS

The evaluated materials are listed in Table 1. The CAD-CAM blocks were transformed into cylinders (diameter 10 mm), which were sliced into sixty-eight 1.8-mm disks and thirty 1.5-mm disks by using a precision saw (Isomet 1000; Buehler). The disks were polished (400-, 600-, 1200-grit silicon carbide papers) (3M) under irrigation in a polisher (Metaserv 2000; Buehler). Vita Suprinity and IPS e.max CAD disks were glazed (VITA AKZENT Plus GLAZE SPRAY; VITA Zahnfabrik) and crystallized (Programat P310; Ivoclar Vivadent AG).

For the roughness (Fig. 1), eight 1.8-mm disks from each material were analyzed after polishing (Lava Ultimate and Vita Enamic) or glazing (IPS e.max CAD and Vita Suprinity) (control groups). Using a custom matrix with a circular central hole (10 mm diameter and 1.5 mm thickness), the same disks were ground 0.3 mm by using 30-μm grit diamond rotary instruments (#3101FF; KG Sorensen) in a high-speed handpiece (KaVo Dental Corp) under constant irrigation, and a second measurement was recorded. Then, the ground disks were polished by using a polishing kit (Ceramiste Polishers; SHOFU Dental GmbH) in a slow-speed motor (BELTEC MICROMOTOR LB100) for 30 seconds in one direction and 30 seconds in the opposite direction under constant irrigation. A 2- to 4-μm diamond paste (Diamond Excel; FGM Produtos Odontológicos) was applied with a felt disk in the same way as described for polishing, and a third measurement was made. Grinding and polishing were performed by a single operator (F.S.L.) in a custom-made device (USICAP). The surface roughness (Rq) was measured by using a 3D laser confocal microscope (LEXT OLS 4100; Olympus) at ×5 magnification. Three equidistant parallel measurements were made on each specimen, and the mean value was calculated (μm). The baseline, ground, and ground and polished surfaces were examined by using a scanning electron microscope (SEM) (Leica Cambridge Stereoscan 440) at ×3000 magnification.

Sixty 1.8-mm disks and 30 1.5-mm disks from each material were prepared for the fracture resistance test. A simplified trilayer model[48] consisting of a restorative disk, G10 epoxy resin disk (diameter 10 mm and 2.0 mm thickness) to simulate the dentin, and a steel ring (6.5 mm inner diameter, 10 mm outer diameter, and 1.5 mm thickness) to replicate the pulp chamber was used. The restorative disk was cemented to the epoxy resin disk, which in turn was cemented to the steel ring. For this, the Lava Ultimate, Vita Enamic, and the steel ring were airborne-particle abraded with Al_2O_3; the IPS e.max CAD and Vita Suprinity were etched with 9.5% hydrofluoric acid (PorcelEtch; Cosmedent); and the epoxy resin disks were etched with 40% phosphoric acid (K-Etchant Gel; Kuraray). The restorative disks were treated with mixed CLEARFIL SE Bond; Primer and Clearfil Porcelain Bond Activator (Kuraray), and the epoxy resin disks and steel rings were treated and cemented to each other with Clearfil SE Bond; Primer. The restorative disks were cemented to the epoxy resin disks by using the resin cement Panavia F 2.0 (Kuraray). A 10-N load was applied

Table 1. Materials used

Materials (Manufacturer)	Composition	Type of Block
IPS e.max CAD (Ivoclar Vivadent AG)	Lithium disilicate	HT A2/C14
Vita Suprinity (Vita Zahnfabrik)	Glass-ceramic reinforced with zirconium dioxide	A2-HT LS-14
Vita Enamic (Vita Zahnfabrik)	Hybrid Ceramic with resin polymers	2M2 – HT – EM-14
Lava Ultimate (3M ESPE)	Nanoceramic resin	A1-LT/14L

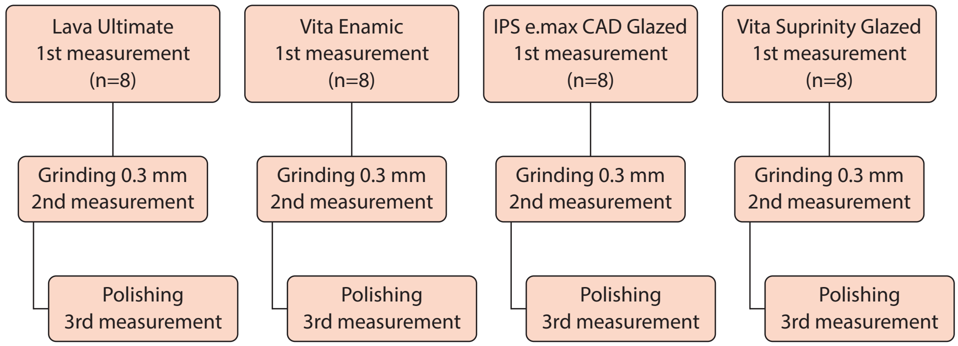

Figure 1. Roughness analysis scheme.

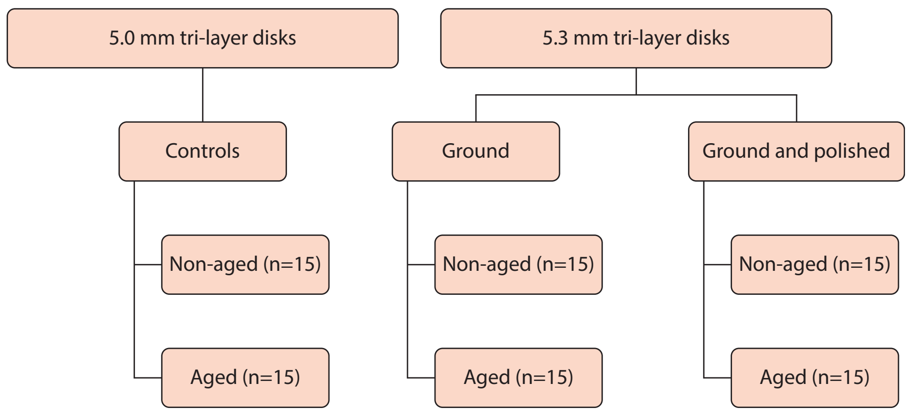

Figure 2. Fracture resistance: groups analyzed for each material.

on the specimen, and the 3 opposing sides were each light polymerized for 60 seconds.

The trilayer disks were allocated according to Figure 2. The surface procedures for the control, ground, and ground and polished conditions have been previously described. Half of the specimens were stored in distilled water at 37 °C, and the other half was aged in a universal cycling machine (Biocycle; Biopdi) for 1×10^6 cycles at a frequency of 2 Hz with a 100-N load in distilled water at 37 °C. All the specimens were loaded in a mechanical testing machine (EMIC DL2000; EMIC Equipment and Systems Testing Ltd) at a crosshead speed of 1 mm/min with a hemispherical steel indenter (Ø=4.9 mm) centered on the top surface. The load (N) at failure of each specimen was recorded as the fracture resistance.

Strength reliability was assessed by using the following formula: P=1−exp ([−σ/σ0]^{m}), where P is the probability of failure, σ is the biaxial flexural strength, σ0 is the characteristic strength at the fracture probability of 63.21%, and m is the Weibull modulus. For the roughness analysis, data were log-transformed to meet the assumptions of parametric analysis (Shapiro-Wilk and Levene, P>.05) and submitted to a mixed repeated-measures ANOVA, followed by the Tukey HSD pos hoc test. The fracture resistance data were analyzed by 3-way ANOVA and the Tukey HSD post hoc test (α=.05).

Table 2. Roughness: mixed repeated-measures ANOVA

Source	SS	df Num	SQ Error	df Den	F	*P*
Intercept	215.204	1	1.3454	28	4478.887	<.001
Material	18.484	3	1.3454	28	128.234	<.001
Treatment	20.993	2	2.5833	56	227.542	<.001
Material×treatment	21.435	6	2.5833	56	77.442	<.001

Table 3. Roughness results in log mean (Rq) ±standard error

Material	Control	Ground	Polished
IPS e.max CAD	−3.242 ±0.077 bC	−969 ±0.076 bcA	−1.575 ±0.077 bB
Vita Suprinity	−3.025 ±0.077 bC	−1.213 ±0.076 cA	−1.584 ±0.077 bB
Lava Ultimate	−1.013 ±0.077 aB	−0.612 ±0.076 aA	−1.699 ±0.077 bC
Vita Enamic	−0.934 ±0.077 aA	−0.844 ±0.076 abA	−1.257 ±0.077 aB

Multiple comparisons of log averages (Rq) of materials and treatments. Different lowercase letters in columns indicate statistical differences (P<.05). Uppercase letters indicate statistical differences between treatments.

Statistical software (IBM SPSS Statistics, v22.0; IBM Corp) was used for the analysis.

RESULTS

Statistics on the roughness data (Table 2) indicated significance for the main effects and interaction. Table 3 shows the roughness results. Of the control groups, no significant difference was found between the IPS e.max CAD and Vita Suprinity or between the Lava Ultimate

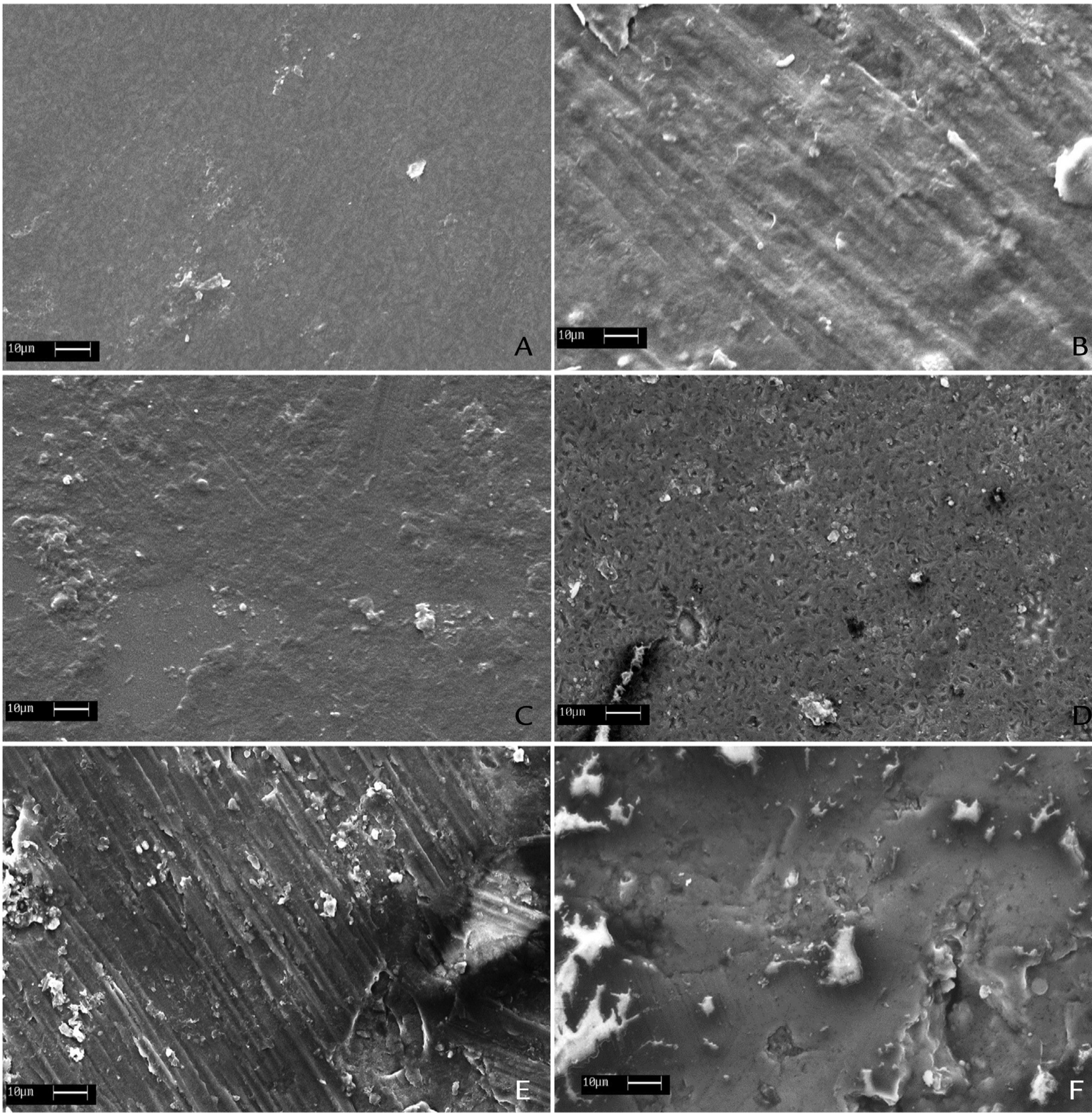

Figure 3. Scanning electron microscope images (original magnification ×3000) of control, ground, and polished groups. A-C, IPS e.max CAD; D-F, Vita Suprinity; G-I, Vita Enamic; J-L, Lava Ultimate.

and Vita Enamic, which were rougher than the glass-ceramic materials. These results are corroborated by the SEM images (Fig. 3). After grinding, this behavior was maintained, except for the Vita Enamic, whose roughness was similar to that of the IPS e.max CAD. After polishing, the Vita Enamic showed the highest roughness, whereas the other materials were not statistically different. The IPS e.max CAD and Vita Suprinity exhibited lower roughness at baseline, and this behavior is also observed in the SEM images, which show that polishing was not able to recover the IPS e.max CAD and Vita Suprinity baseline smoothness. In contrast, for the Vita Enamic and Lava Ultimate, polishing provided the lowest roughness.

Statistical analysis of the fracture resistance data (Table 4) showed that the 3 factors and their interactions were significant. Table 5 shows the fracture resistance results. The surface treatment did not influence the fracture resistance of the materials, except when the IPS e.max CAD was submitted to cyclic fatigue. Aging did not reduce the fracture resistance of the materials. The IPS e.max

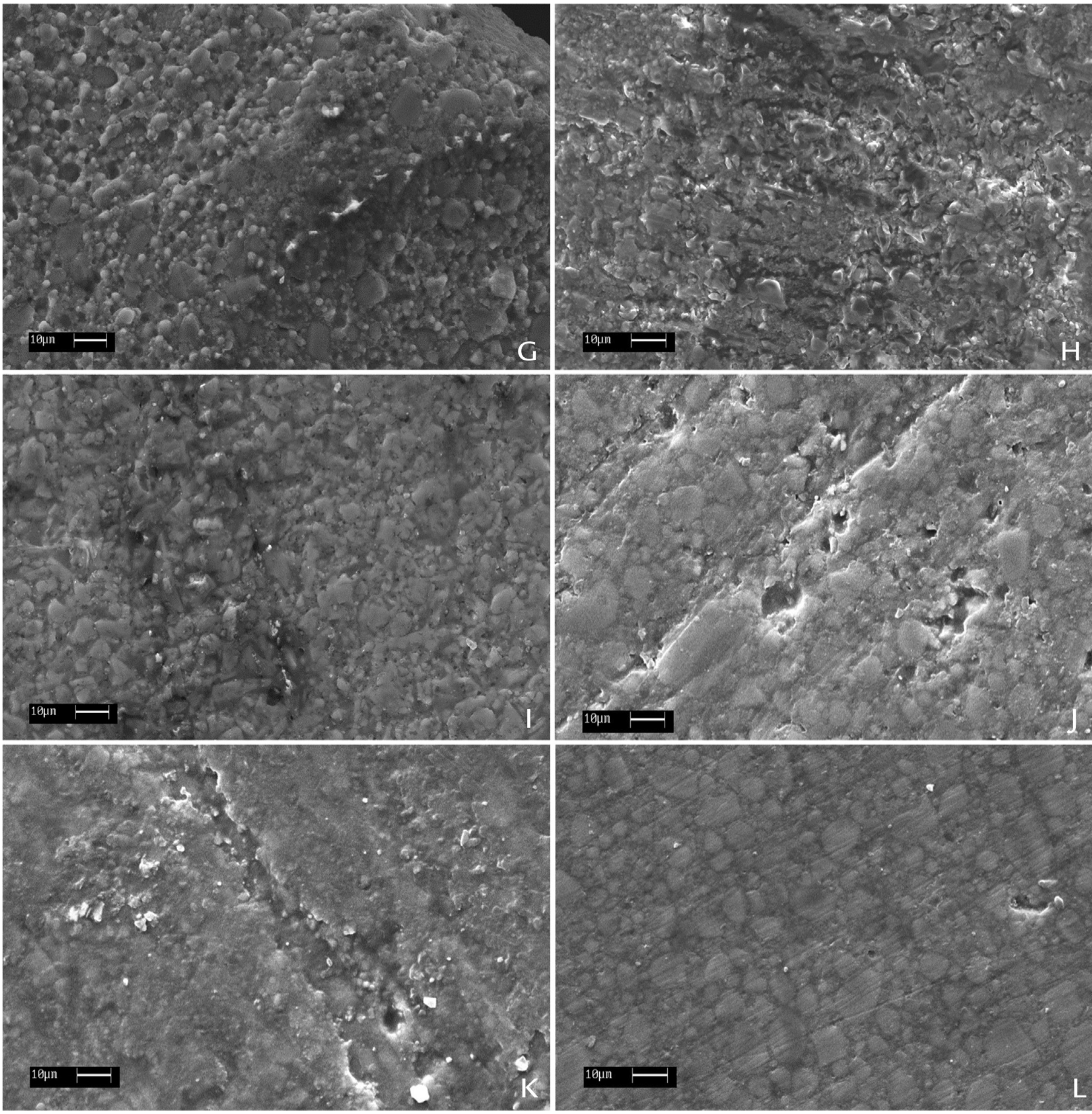

Figure 3. (*continued*).

CAD/control, Vita Suprinity/control, Vita Suprinity/ground, and Vita Suprinity/polished aged groups showed a significant increase in fracture resistance compared with their respective nonaged groups. The results of the Weibull modulus (Table 6) show that reliability was not influenced by the material, surface treatment, or aging.

DISCUSSION

One of the purposes of the present study was to investigate whether occlusal adjustment and polishing protocol modified the initial roughness of CAD-CAM monolithic materials. In view of the obtained results, the first null hypothesis was rejected. In this study, differences in roughness among the materials were observed, which was expected considering that distinct materials were evaluated. Of the control groups, the similarity between the IPS e.max CAD and Vita Suprinity was probably because the same glaze was applied on their surfaces. However, even after the grinding and polishing procedures, this similarity was maintained (except for the comparison between the polished groups

Table 4. Fracture resistance: 3-way ANOVA

Source	SS	df	MS	F	*P*
Corrected model	7972417.464	23	346626.846	12.892	<.001
Intercept	563728169.669	1	563728169.669	20966.519	<.001
Material	2195372.097	3	731790.699	27.217	<.001
Treatment	1603381.739	2	801690.869	29.817	<.001
Aging	1147967.336	1	1147967.336	42.696	<.001
Material×treatment	379869.661	6	63311.610	2.355	.031
Material×aging	1295300.119	3	431766.706	16.059	<.001
Treatment×aging	558413.706	2	279206.853	10.384	<.001
Material×treatment ×aging	792112.806	6	132018.801	4.910	<.001
Error	9034053.867	336	26887.065		
Total	580734641.000	360			
Corrected total	17006471.331	359			

Table 5. Compression test results in N ±standard deviation and statistical comparisons

IPS e.max CAD/control/aged	1670 ±115	A
Vita Suprinity/control/aged	1481 ±225	AB
IPS e.max CAD/ground/nonaged	1455 ±127	ABC
Vita Suprinity/ground/aged	1405 ±232	BCD
IPS e.max CAD/ground/aged	1396 ±178	BCD
Vita Enamic/control/aged	1316 ±186	BCDE
IPS e.max CAD/control/nonaged	1286 ±112	BCDEF
Vita Enamic/ground/nonaged	1284 ±150	BCDEF
Vita Suprinity/polished/aged	1276 ±252	BCDEF
IPS e.max CAD/polished/nonaged	1264 ±110	BCDEFG
Lava Ultimate/control/aged	1263 ±191	BCDEFG
Vita Enamic/control/nonaged	1260 ±149	CDEFG
Vita Enamic/polished/aged	1254 ±191	CDEFG
Lava Ultimate/ground/nonaged	1198 ±186	DEFG
IPS e.max CAD/polished/aged	1187 ±172	DEFGH
Vita Suprinity/control/nonaged	1166 ±114	EFGH
Lava Ultimate/control/nonaged	1164 ±110	EFGH
Vita Enamic/polished/nonaged	1160 ±197	EFGH
Vita Enamic/ground/aged	1154 ±227	EFGH
Lava Ultimate/polished/aged	1145 ±112	EFGH
Lava Ultimate/ground/aged	1145 ±138	EFGH
Vita Suprinity/ground/nonaged	1077 ±81	FGH
Lava Ultimate/polished/nonaged	1053 ±86	GH
Vita Suprinity/polished/nonaged	972 ±103	H

Different letters indicate statistically different means ($P<.05$).

Table 6. Weibull modulus and 90% confidence interval

Material/Aging	Control	Ground	Polished
IPS e.max CAD			
Nonaged	12.4 (7.2-17.4)	13.5 (7.8-18.9)	11.9 (6.9-16.6)
Aged	17.1 (9.9-23.9)	8.9 (5.1-12.4)	8.1 (4.7-11.3)
Vita Suprinity			
Nonaged	11.7 (6.8-16.4)	15.2 (8.8-21.3)	11.1 (6.4-15.5)
Aged	7.6 (4.4-10.6)	6.8 (3.9-9.5)	5.8 (3.3-8.1)
Vita Enamic			
Nonaged	9.0 (5.2-12.6)	9.5 (5.5-13.2)	6.1 (3.5-8.5)
Aged	8.5 (4.9-11.9)	5.7 (3.3-8.0)	7.7 (4.4-10.7)
Lava Ultimate			
Nonaged	12.5 (7.2-17.5)	7.3 (4.2-10.2)	14.6 (8.5-20.5)
Aged	7.8 (4.5-11.0)	9.7 (5.6-13.6)	12.0 (6.9-16.8)

Weibull modulus not influenced by material, surface treatment, or aging.

analyzed by the SEM), despite the differences in composition and microstructure between these materials.[40] Strasser et al[12] also reported statistically similar roughness after both glass-ceramics had been ground by using 4-μm or 80-μm diamond rotary instruments. Differently, Vichi et al[45] reported that Vita Suprinity presented significantly lower roughness than IPS e.max CAD after glazing and polishing. This difference can be attributed to the different systems used for each material. Regarding the Lava Ultimate and Vita Enamic, the similarity between the control groups was in good agreement with the SEM images and with the study by Mörmann et al.[9] In contrast, the similarity found between the ground groups was not consistent with that in the study by Strasser et al,[12] in which Vita Enamic was rougher than the Lava Ultimate after being ground by using a coarse-grit diamond rotary instrument (80 μm).

In the present study, even though grinding was carried out by using extrafine diamond rotary instruments, it increased the roughness of the materials, except for the Vita Enamic. The rougher topography caused by grinding is evidenced in the SEM images, mainly for the IPS e.max CAD and Vita Suprinity. This finding was also reported in other studies after the materials had been ground with different grit sizes.[12-15] For both glass-ceramics, polishing after grinding was not able to recover the smoothness given by the glaze that was below the threshold for bacterial adhesion (0.20 μm).[16] This behavior was also reported in previous studies[11,13,46] that investigated lithium disilicate ceramic and is probably related to the high hardness of both materials.[9,41] However, when the polishing was finished with a diamond paste, the roughness of the lithium disilicate was similar to[13] or significantly lower[47] than that of the glazed material, evidencing the importance of this step when clinical adjustments are performed on these materials. For the Lava Ultimate and Vita Enamic, the higher smoothness achieved by polishing after grinding, as previously reported by Fasbinder and Neiva,[10] shows that, even though these materials do not require clinical adjustments, they should be polished.

The second null hypothesis was rejected because the IPS e.max CAD/aged was adversely affected by the surface treatments. Albakry et al[43] also reported that grinding did not influence the strength of a nonaged pressable lithium disilicate, even with the use of a 110-μm diamond disk. In contrast, Curran et al[32] reported that grinding by using an 18-μm diamond disk was still quite detrimental to the IPS e.max CAD, with chip crack formation and a strength loss estimated at 42%. Song et al[44] also observed intergranular and transgranular fractures after diamond rotary instrument penetration into the lithium disilicate ceramic. In the present study, in which the specimens had been cemented before they were ground, grinding affected the fracture resistance of the IPS e.max CAD only in the aged groups. This was consistent with the findings of Mohammadibassir et al,[47] who commented that with cyclic loading and moisture, cracks resulted from the grinding propagate and decreased the strength. However, this significant reduction in the IPS e.max CAD/aged groups was due to the high mean value of the IPS e.max CAD/control/aged group, for which an explanation was not found in the literature. Despite this reduction, the IPS e.max CAD/ground/aged and IPS e.max CAD/polished/aged groups showed no significant difference compared with their respective nonaged groups and with the IPS e.max CAD/control/nonaged group, indicating that grinding followed or not by polishing does not impair the fracture resistance of the IPS e.max CAD.

Besides the Vita Suprinity has not been affected by grinding, it still showed an increase in fracture resistance after cyclic fatigue, regardless of the surface treatment condition. This was unexpected because aging was expected to reduce the fracture resistance, especially of both the glass-ceramics submitted to grinding. Strasser et al[12] reported that water-cooled grinding by using 80-μm diamond rotary instruments caused severe microchipping in both the Vita Suprinity and IPS e.max CAD. However, the crack formation was slight for the former and moderate for the latter. This can be explained by the significantly higher fracture toughness found for Vita Suprinity than that for IPS e.max CAD,[38] indicating that Vita Suprinity presents higher resistance against crack propagation than IPS e.max CAD. Also, Vita Suprinity has significantly higher flexural strength than IPS e.max CAD.[38,39] Elsaka and Elnaghy[38] and Sen and Us[39] attributed this behavior to the presence of the zirconia fillers used to reinforce the glassy matrix of Vita Suprinity. Ramos et al[42] detected zirconium oxide and cerium throughout the entire surface of this material. These findings explain why the fracture resistance of Vita Suprinity was not affected by the surface treatments, even after aging.

Regarding the maintenance of the fracture resistance of Vita Enamic and Lava Ultimate, Curran et al[32] found that even after grinding and mechanical aging, these materials, due to a combination of lower hardness and lower elastic modulus, have a high resistance to crack initiation and growth, with no estimated potential loss in their strength, even when ground with 75-μm grit size. This is in accordance with 2 other studies that reported little damage from grinding, with only shallow or absent cracks.[12,37]

In the present study, the Weibull modulus was not influenced by the material, surface treatment, or aging. The Weibull modulus represents the scattering of the fracture resistance data, being that a high modulus means that the defects of the material are evenly distributed, having a low risk for the presence of critical flaws. The present results differ from those of a previous study[43] reporting that grinding a heat-pressed lithium disilicate ceramic by using a 110-μm diamond disk reduced its reliability compared with that of the untreated material. According to Albakry et al,[43] grinding introduces defects and flaws distributed over a wide area, resulting in a wider range of strength values. Probably, the disparity of the results can be attributed to the methodological differences between the studies, considering that in the present study, the grit size of the diamond instrument used was much smaller and that the specimens were cemented. Further studies involving coarser diamond rotary instruments and additional aging methods are required for a more comprehensive picture of the behavior of materials when submitted to clinical adjustments. The evaluation of flat specimens can be considered a limitation of the present study because it does not closely reproduce what may happen in the oral cavity.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Grinding increased the roughness of the materials, except for the Vita Enamic. The smoothness of the glazed glass-ceramics was not restored by the polishing kit, whereas the Lava Ultimate and Vita Enamic showed a smoother surface than the baseline.
2. Grinding, followed or not by polishing, did not impair the fracture resistance of the materials.
3. Aging did not reduce the fracture resistance of the materials, not even in the ground groups.
4. The reliability of the materials was not influenced by the material, surface treatment, or aging.

REFERENCES

1. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. Quantitative in vivo wear of human enamel. J Dent Res 1989;68:1752-4.
2. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015;114:587-93.
3. Dirxen C, Blunck U, Preissner S. Clinical performance of a new biomimetic double network material. Open Dent J 2013;7:118-22.
4. Rauch A, Reich S, Dalchau L, Schierz O. Clinical survival of chair-side generated monolithic lithium disilicate crowns: 10-year results. Clin Oral Investig 2018;22:1763-9.
5. Worni A, Katsoulis J, Kolgeci L, Worni M, Mericske-Stern R. Monolithic zirconia reconstructions supported by teeth and implants: 1- to 3-year results of a case series. Quintessence Int 2017;48:459-67.
6. Albero A, Pascual A, Camps I, Grau-Benitez M. Comparative characterization of a novel cad-cam polymer-infiltrated-ceramic-network. J Clin Exp Dent 2015;7:e495-500.
7. Spitznagel FA, Scholz KJ, Strub JR, Vach K, Gierthmuehlen PC. Polymer-infiltrated ceramic CAD/CAM inlays and partial coverage restorations: 3-year results of a prospective clinical study over 5 years. Clin Oral Investig 2018;22:1973-83.

8. Pradíes G, Godoy-Ruiz L, Özcan M, Moreno-Hay I, Martínez-Rus F. Analysis of surface roughness, fracture toughness, and Weibull characteristics of different framework-veneer dental ceramic assemblies after grinding, polishing, and glazing. J Prosthodont 2019;28:e216-21.
9. Mörmann WH, Stawarczyk B, Ender A, Sener B, Attin T, Mehl A. Wear characteristics of current aesthetic dental restorative CAD/CAM materials: two-body wear, gloss retention, roughness and Martens hardness. J Mech Behav Biomed Mater 2013;20:113-25.
10. Fasbinder DJ, Neiva GF. Surface evaluation of polishing techniques for new resilient CAD/CAM restorative materials. J Esthet Restor Dent 2016;28:56-66.
11. Amaya-Pajares SP, Ritter AV, Vera Resendiz C, Henson BR, Culp L, Donovan TE. Effect of finishing and polishing on the surface roughness of four ceramic materials after occlusal adjustment. J Esthet Restor Dent 2016;28:382-96.
12. Strasser T, Preis V, Behr M, Rosentritt M. Roughness, surface energy, and superficial damages of CAD/CAM materials after surface treatment. Clin Oral Investig 2018;22:2787-97.
13. Steiner R, Beier US, Heiss-Kisielewsky I, Engelmeier R, Dumfahrt H, Dhima M. Adjusting dental ceramics: an in vitro evaluation of the ability of various ceramic polishing kits to mimic glazed dental ceramic surface. J Prosthet Dent 2015;113:616-22.
14. Güngör MB, Nemli SK, Bal BT, Ünver S, Doğan A. Effect of surface treatments on shear bond strength of resin composite bonded to CAD/CAM resin-ceramic hybrid materials. J Adv Prosthodont 2016;8:259-66.
15. Silva PNFD, Martinelli-Lobo CM, Bottino MA, Melo RM, Valandro LF. Bond strength between a polymer-infiltrated ceramic network and a composite for repair: effect of several ceramic surface treatments. Braz Oral Res 2018;32:e28.
16. Teughels W, Van Assche N, Sliepen I, Quirynen M. Effect of material characteristics and/or surface topography on biofilm development. Clin Oral Implants Res 2006;17(Suppl 2):68-81.
17. Kim KH, Loch C, Waddell JN, Tompkins G, Schwass D. Surface characteristics and biofilm development on selected dental ceramic materials. Int J Dent 2017;2017:7627945.
18. Janyavula S, Lawson N, Cakir D, Beck P, Ramp LC, Burgess JO. The wear of polished and glazed zirconia against enamel. J Prosthet Dent 2013;109:22-9.
19. Ghazal M, Kern M. The influence of antagonistic surface roughness on the wear of human enamel and nanofilled composite resin artificial teeth. J Prosthet Dent 2009;101:342-9.
20. Heintze SD, Cavelleri A, Forjanic M, Zellweger G, Rousson V. Wear of ceramic and antagonist—A systematic evaluation of influencing factors in vitro. Dent Mater 2008;24:433-49.
21. Al-Wahadni A, Martin DM. Glazing and finishing dental porcelain: a literature review. J Can Dent Assoc 1998;64:580-3.
22. Sarac D, Sarac S, Yuzbasıoglu E, Bal S. The effects of porcelain polishing systems on the color and surface texture of feldspathic porcelain. J Prosthet Dent 2006;108:122-8.
23. Al-Wahadni AM, Martin DM. An in vitro investigation into the wear effects of glazed, unglazed and refinished dental porcelain on an opposing material. J Oral Rehabil 1999;26:538-46.
24. Esquivel JF, Chai J, Wozniak WT. Color stability of low-fusing porcelains for titanium. Int J Prosthodont 1995;8:479-85.
25. Yılmaz C, Korkmaz T, Demirkoprulu H, Ergun G, Ozkan Y. Color stability of glazed and polished dental porcelains. J Prosthet Dent 2008;17:20-4.
26. Atay A, Karayazgan B, Ozkan Y, Akyil MS. Effect of colored beverages on the color stability of feldspathic porcelain subjected to various surface treatments. Quintessence Int 2009;40:e41-8.
27. De Jager N, Feilzer AJ, Davidson CL. The influence of surface roughness on porcelain strength. Dent Mater 2000;16:381-8.
28. Fischer H, Schäfer M, Marx R. Effect of surface roughness on flexural strength of veneer ceramics. J Dent Res 2003;82:972-5.
29. Griggs JA, Thompson JY, Anusavice KJ. Effects of flaw size and auto-glaze treatment on porcelain strength. J Dent Res 1996;75:1414-7.
30. Kermanshah H, Shamshirgar F, Ghabraei S, Ameri N. Effect of different flaw sizes and surface treatment on biaxial flexural strength of feldspathic porcelain. Br J Med Med Res 2016;17:1-10.
31. Lohbauer U, Müller FA, Petschelt A. Influence of surface roughness on mechanical strength of resin composite versus glass ceramic materials. Dent Mater 2008;24:250-6.
32. Curran P, Cattani-Lorente M, Wiskott HWA, Durual S, Scherrer SS. Grinding damage assessment for CAD-CAM restorative materials. Dent Mater 2017;33:294-308.
33. Hung CY, Lai YL, Hsieh YL, Chi LY, Lee SY. Effects of simulated clinical grinding and subsequent heat treatment on microcrack healing of a lithium disilicate ceramic. Int J Prosthodont 2008;21:496-8.
34. Pereira GKR, Fraga S, Montagner AF, Soares FZM, Kleverlaan CJ, Valandro LF. The effect of grinding on the mechanical behavior of Y-TZP ceramics: a systematic review and meta-analyses. J Mech Behav Biomed Mater 2016;63:417-42.
35. Aboushelib MN, Wang H. Effect of surface treatment on flexural strength of zirconia bars. J Prosthet Dent 2010;104:98-104.
36. Işeri U, Ozkurt Z, Yalnız A, Kazazoğlu E. Comparison of different grinding procedures on the flexural strength of zirconia. J Prosthet Dent 2012;107:309-15.
37. Coldea A, Fischer J, Swain MV, Thiel N. Damage tolerance of indirect restorative materials (including PICN) after simulated adjustments. Dent Mater 2015;31:684-94.
38. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. Dent Mater 2016;32:908-14.
39. Sen N, Us YO. Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthet Dent 2018;119:593-9.
40. Belli R, Wendler M, de Ligny D, Cicconi MR, Petschelt A, Peterlik H, et al. Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. Dent Mater 2017;33:84-98.
41. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater 2016;32:e275-83.
42. Ramos Nde C, Campos TM, Paz IS, Machado JP, Bottino MA, Cesar PF, et al. Microstructure characterization and SCG of newly engineered dental ceramics. Dent Mater 2016;32:870-8.
43. Albakry M, Guazzato M, Swain MV. Effect of sandblasting, grinding, polishing and glazing on the flexural strength of two pressable all-ceramic dental materials. J Dent 2004;32:91-9.
44. Song XF, Ren HT, Yin L. Machinability of lithium disilicate glass ceramic in in vitro dental diamond bur adjusting process. J Mech Behav Biomed Mater 2016;53:78-92.
45. Vichi A, Fonzar RF, Goracci C, Carrabba M, Ferrari M. Effect of finishing and polishing on roughness and gloss of lithium disilicate and lithium silicate zirconia reinforced glass ceramic for CAD/CAM systems. Oper Dent 2018;43:90-100.
46. Vrochari AD, Petropoulou A, Chronopoulos V, Polydorou O, Massey W, Hellwig E. Evaluation of surface roughness of ceramic and resin composite material used for conservative indirect restorations, after repolishing by intraoral means. J Prosthodont 2017;26:296-301.
47. Mohammadibassir M, Rezvani MB, Golzari H, Moravej Salehi E, Fahimi MA, Kharazi Fard MJ. Effect of two polishing systems on surface roughness, topography, and flexural strength of a monolithic lithium disilicate ceramic. J Prosthodont 2019;28:e172-80.
48. Chen C, Trindade FZ, de Jager N, Kleverlaan CJ, Feilzer AJ. The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater 2014;30:954-62.

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