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Effect of Finishing and Polishing on the Surface Roughness and Gloss of Feldspathic Ceramic for Chairside CAD/CAM Systems

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Clinical Relevance

Comparison among two furnace-based and five manual systems for finishing and polishing feldspathic ceramic for chairside CAD/CAM systems resulted in clinical recommendations for selection of the most appropriate system able to produce enamel-like surface.

SUMMARY

Objectives: To evaluate surface roughness and gloss of feldspathic ceramic blocks for chairside CAD/CAM systems before and after finishing and polishing.

Methods: VITA Mark II ceramic blocks for the CEREC CAD/CAM system were cut perpendicularly in order to obtain a total of 70 specimens (14 × 18 × 3 mm). The flat surface was roughened using a grinder/polisher with dry 120-grit silicone-carbide paper. Surface roughness and gloss were measured using a digital profilometer (Ra) and a glossmeter (GU), respectively. Specimens were randomly divided into seven groups (n=10) based on the finishing/polishing system as follows: 1) Identoflex NGPorcelain Polisher (INP), 2) Identoflex Diamond Ceramic Polisher (IDP), 3) Hiluster Polishing System (HPS), 4) OptraFine (OF), 5) Identoflex Lucent (IL), 6) VITA Akzent Glaze Spray (AGS), and 7) VITA Shading Paste and Liquid (SPL). Surface analysis was repeated after the finishing/polishing treatment, and the obtained data were compared to the baseline in order to evaluate the ΔRa and ΔGU. Results were statistically analyzed. The surface morphology was observed by scanning electron microscopy.

Results: The mean surface roughness of polished systems increased in the order (statistical groups designated) SPLa < ILa < OFab < IDPbc < AGSbc < INPbc < HPSc and mean

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gloss decreased in the order AGSa > SPLa > OFab > ILabc > HPSbcd > INPcd > IDPd.

Conclusions: The smoothest surface of CAD/CAM feldspathic ceramic blocks was achieved using the furnace-based glaze systems VITA Akzent Glaze Spray and VITA Shading Paste and Liquid and manual systems Identoflex Lucent and OptraFine.

INTRODUCTION

The demands for enhanced esthetics of dental restorations have resulted in an increased use of all-ceramic materials.[1] Metal-free restorations were introduced in the 1960s and evolved over the intervening decades. The same is true for the introduction and development of CAD/CAM technology over the past 25 years.[2] These systems have become less expensive, more user friendly, and more precise, thus improving the clinical performance of all-ceramic restorations.[3] Several CAD/CAM systems are currently available on the market. Among them, some consider the CEREC system (Sirona, Bernsheim, Germany) the reference system for the "chairside" procedure, in which the prosthetic restoration is produced entirely by the dentist in the office during a single appointment.[4] In accordance with clinicians' demands, other CAD/CAM systems for chairside procedures have been recently introduced, including Planmeca Planscan/Planmill (Planmeca Oy, Helsinki, Finland), KaVo ARCTICA (KaVo Dental GmbH, Biberach, Germany), and Carestream CS solutions (Carestream Dental, Atlanta, GA). CAD/CAM materials allow combining the advantages of metal-free restorations, such as biocompatibility, durability, and esthetics,[5] with the advantages of computer-aided technology, including the reduction of clinical steps, shorter fabrication time, and lower cost.[4] While specific procedures, such as crystallization, glass infiltration, or sintering, are needed for some ceramic materials, feldspathic ceramic (with or without leucite) does not require additional laboratory processing after milling and is fully compatible with chairside procedures. However, milling feldspathic blocks does not produce ready-to-cement restorations. The milling process produces rough surfaces that require finishing and polishing of the clinically exposed surface. Achieving a smooth ceramic surface is important for several reasons, including esthetics, patient comfort, and biological aspects.[6,7] Staining and plaque accumulation are more pronounced on rough surfaces,[8] thus increasing the likelihood for gingivitis or tooth decay. In addition, rough ceramic restorations are abrasive and can cause greater wear of antagonist teeth.[9] Roughness can also affect the strength of brittle ceramics, thereby causing cracking, chipping, and fracture.[10] Traditionally, finishing and polishing are performed by furnace glazing for feldspathic ceramics fused to metal. When it comes to chairside fabricated restorations, manual finishing and polishing with in-office instruments is a desirable option due to its speed and ease of use. Some studies have reported that manual finishing and polishing systems provided smooth surfaces of layered feldspathic porcelain fused to metal.[11] Less information is available for CAD/CAM blocks. One manufacturer claimed that, due to the industrial sintering process, the CAD/CAM blocks showed a less porous structure of the feldspathic ceramic than for those ceramics that underwent laboratory-based sintering.[12] Manufacturers have also claimed this less porous structure to be a primary reason for the more effective manual polishability of feldspathic CAD/CAM blocks.

As manufacturers consider glaze firing not mandatory but rather as an alternative to manual finishing and polishing, it was considered appropriate to compare the efficacy of different manual finishing and polishing systems and two furnace-based glaze systems on the surface roughness and gloss of feldspathic CAD/CAM ceramic. The null hypothesis was that there was no statistically significant difference in average roughness (Ra) and gloss (GU) among the tested finishing and polishing systems.

METHODS AND MATERIALS

Twenty-five VITA Mark II ceramic blocks for the CEREC CAD/CAM system (VITA Zahnfabrik, Bad Säckingen, Germany) were used. The blocks were cut perpendicularly using a low-speed diamond saw (IsoMet Low Speed Saw, Buehler, Lake Bluff, IL) to obtain $14 \times 18 \times 3$ mm specimens. A total of 70 specimens were prepared. The surface roughness (Ra, the arithmetic average of the profile ordinates within the measured section – average height)[13] of 10 crowns produced using the MC-XL InLab milling unit (Sirona, Bernsheim, Germany) and VITA Mark II CAD/CAM blocks (VITA Zahnfabrik) was measured using a digital profilometer (Mitutoyo SJ-201P, Mitutoyo Corp, Kanagawa, Japan), while a Gloss Meter (Novo-Curve, Rhopoint Instruments, UK) was used for gloss measurements (GU, gloss units). The baseline Ra and GU values, corresponding to the ceramic surface after milling, were 1.08 ± 0.18 μm and 2.37 ± 0.86 GU, respectively. In order

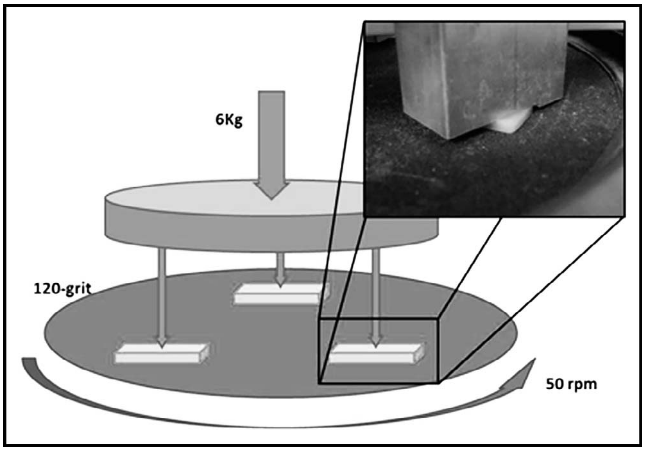

Figure 1. *Roughening scheme and specimen holder.*

to produce the baseline roughness and gloss, specimens were processed with a grinder/polisher (EXTEC Labpol 8, Extec, Enfield, CT) with an equal force distribution during the roughening procedure (Figure 1) using a 120-grit silicon-carbide paper (South Bay Technology, San Clemente, CA) and a 6 kg weight applied on a custom-made support for five seconds at 50 rpm. A new silicone-carbide paper was used for each roughening cycle.

After roughening, the specimens were ultrasonically cleaned in distilled water for 10 minutes before performing the measurements.

The roughness evaluation settings for the profilometer were set with a cutoff value of 0.8 mm, a stylus speed of 0.5 mm/s, and a tracking length of 5.0 mm.[14] Specimens were marked with numbers, and the baseline Ra (Ra^{bl}) was recorded for each specimen. The overall mean specimen Ra was 1.04 ± 0.25 μm. Gloss assessment was performed at a 60-degree angle following the ISO 2813 specifications for ceramic materials.[15] An opaque silicon mold was placed over the specimens while performing the measurements to eliminate the influence of ambient light and to standardize the reading area of the sample. The baseline gloss (GU^{bl}) was recorded for every specimen; the sample mean baseline gloss was 2.2 ± 0.6 GU.

The specimens were then randomly divided into seven groups (n=10), as seven different procedures for finishing and polishing were tested. Materials and procedures are reported in Table 1. Manual finishing and polishing procedures were performed by the same operator. The operator was calibrated using a precision scale before and during the procedure, considering that a 40 g force was considered light pressure. The operator calibration was repeated every 10 specimens.[16] Specimens were processed for 30 seconds for each single step. The "small point" polishing point was selected for systems with various tip shapes.

For groups 1 (Identoflex NG-Porcelain Polisher [INP]), 2 (Identoflex Diamond Ceramic Polisher [IDP]), and 3 (HiLuster Polishing System [HPS]), rubber diamond points were used in a low-speed angled hand piece (Kavo INTRAmatic 20CN, Kavo Dental) at 5000 rpm following the manufacturers' instructions. Wet and dry use was implemented as indicated by the manufacturers. The dry condition was chosen because it was considered easier and no

Table 1: *Finishing/Polishing Systems Evaluated*

Groups	Finishing and Polishing System (Code)	Manufacturer	Type	Passages	Batch
1	Identoflex NG-Porcelain Polisher (INP)	KerrHawe SA, Bioggio, Switzerland	Office	Prepolisher—green Gloss—gray High gloss—pink	3186071 3175840 31171192
2	Identoflex Diamond Ceramic Polisher (IDP)	KerrHawe SA	Office	Two-zone technology minipoint—green	3164499
3	HiLuster Polishing System (HPS)	KerrHawe SA	Office	Gloss polishers—pink Diamond polishers—light blue	3066755
4	Optra-Fine (OF)	Ivoclar Vivadent, Schaan, Liechtenstein	Office	Finisher F—light blue Polisher P—dark blue High gloss—diamond paste	PL 1781 PL 1782
5	Identoflex Lucent (IL)	KerrHawe SA	Lab	PVE—green PGR—gray high PVI—pink	124LU
6	VITA Akzent Glaze Spray (AGS)	VITA Zahnfabrik, Bad Säckingen, Germany	Lab	Ceramic spray	21790
7	VITA Shading Paste and Liquid (SPL)	VITA Zahnfabrik	Lab	Shading paste glaze Shading paste liquid	19520 21110

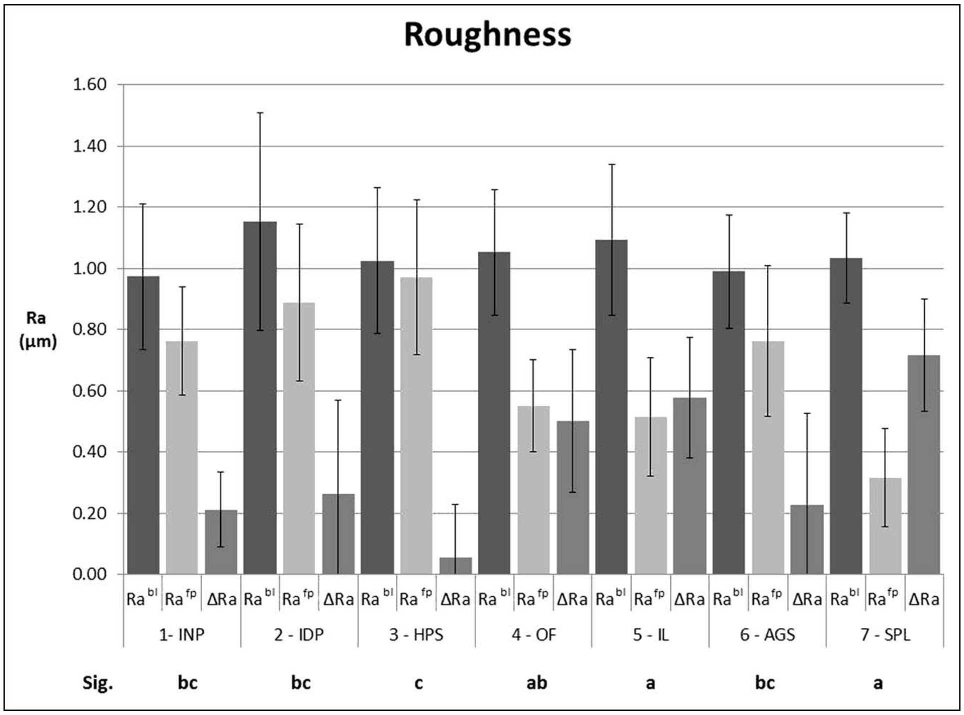

Figure 2. *Bar chart of roughness result.*

risk of tissue overheating is associated with finishing and polishing of a chairside-produced restoration as the procedure is performed extraorally. For group 4 (Optra-Fine [OF]), the rubber diamond points of the first two steps were used at 15,000 rpm and under water cooling in the same low-speed angled hand piece as for groups 1, 2, and 3. The third step, high-gloss polishing with diamond paste, was performed with the same hand piece at 10,000 rpm under wet conditions (paste wetted but no water cooling). For group 5 (Identoflex Lucent [IL]), as the rubber diamond points of the system are marketed only in the "long" mandrel mount, they were used in a straight hand piece (Kavo INTRAmatic 10CH, Kavo Dental) at 15,000 rpm in dry conditions. The procedures for the two furnace-based systems, groups 6 (VITA Akzent Glaze Spray [AGS]) and 7 (VITA Shading Paste and Liquid [SPL]), were performed following the manufacturers' instructions. The firing was performed in the VITA Vacumat 6000M furnace (VITA Zahnfabrik) for both systems.

On completion of the finishing and polishing steps for all seven groups, roughness and gloss measurements were repeated (Ra^{fp} and GU^{fp}), and the obtained values were compared to the baseline. The ΔRa (µm) and the ΔGU were then calculated for each specimen ($\Delta Ra = Ra^{bl} - Ra^{fp}$) ($\Delta GU = GU^{bl} - GU^{fp}$). For roughness, since pooled data for all finishing systems passed the normality test ($p>0.05$), the results were analyzed using one-way analysis of variance (ANOVA) followed by Tukey *t*-tests ($\alpha=0.05$) to determine the level of significance between groups. As pooled data for gloss from all the finishing systems did not pass the normality test ($p>0.05$), the gloss results were analyzed using the Kruskal-Wallis one-way ANOVA on ranks followed by Dunn *t*-tests ($\alpha=0.05$) to determine the level of significance between groups.

Two finished and polished specimens per group were randomly selected, and two extra baseline specimens were processed for observation by scanning electron microscopy (SEM) (JSM-6060LV, JEOL, Tokyo, Japan) at 100× and 1000× magnification to visualize the surface morphology.

RESULTS

Surface Roughness

Means and standard deviations for surface roughness at baseline and after finishing and polishing, difference in roughness, and statistical significance are presented in Figure 2. Significant differences were found between the finishing systems in their ability to reduce after-milling surface roughness of feldspathic ceramic CAD/CAM blocks ($p\leq0.001$). The lowest final Ra value (highest smoothness) was achieved by SPL, but no significant differences were

Table 2: *Means and Standard Deviations (SD) for Surface Roughness and Gloss at Baseline ($Ra^{bl} - GU^{bl}$) and After Finishing and Polishing ($Ra^{fp} - GU^{fp}$), Differences (Δ>Ra – ΔGU), and Statistical Significance (Different Letters Indicate Statistically Different Groups)*

	1: INP			2: IDP			3: HPS			4: OF			5: IL			6: AGS			7: SPL		
	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa	Ra^{bl}	Ra^{fp}	ΔRa
Mean	0.97	0.76	0.21	1.15	0.89	0.27	1.03	0.97	0.06	1.05	0.55	0.50	1.09	0.52	0.58	0.99	0.76	0.23	1.03	0.32	0.72
SD	0.24	0.18	0.12	0.35	0.26	0.30	0.24	0.25	0.17	0.21	0.15	0.23	0.25	0.19	0.20	0.19	0.25	0.30	0.15	0.16	0.18
Significance		BC			BC			C			AB			A			BC			A	
	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU	GU^{bl}	Gu^{fp}	ΔGU
Mean	2.5	7.0	4.5	1.8	4.9	3.0	2.0	14.6	12.6	2.2	38.7	36.4	2.4	27.9	25.5	2.2	60.7	58.5	2.5	54.7	52.1
SD	0.9	1.3	1.2	0.3	0.6	0.5	0.5	3.9	3.5	0.4	8.8	8.7	0.6	7.6	7.5	0.3	13.6	13.7	0.4	17.4	17.6
Significance		CD			D			BCD			AB			ABC			A			A	

Abbreviations: INP, Identoflex NG-Porcelain Polisher; IDP, Identoflex Diamond Ceramic Polisher; HPS, HiLuster Polishing System; OP, Optra-Fine; IL, Identoflex Lucent; AGS, Vita Akzent Glaze Spray; SPL, Vita Shading Paste and Liquid.

found among the SPL, OF, and IL groups ($p<0.05$). HPS showed the lowest polishing ability, but no statistically significant differences were found among the HPS, IDP, AGS, and INP groups (Table 2).

Gloss

There were no statistically significant differences between the laboratory systems SPL, IL, or AGS and an in-office water-based system, such as OF (Table 2). The lowest ΔGU value was obtained with IDP, and no statistical differences were found with the HPS and INP groups; the ΔGU ranged from 3.0 for IDP to 12.6 for HPS (Figure 3).

SEM Observations

The tested finishing procedures influenced the surface morphology compared to baseline. Figure 4 shows the SEM images of the specimen baseline surfaces and of the tested groups; grooves and surface irregularities were present (Figure 4a). For the manual finishing and polishing systems, the presence of surface defects showed a direct correlation with the final surface roughness and gloss reported in Table 2. The surface treated with HPS exhibited diffuse irregularities and the absence of smooth areas. Conversely, the ceramic surface treated with IL showed an almost complete reduction of grooves present in baseline specimens and

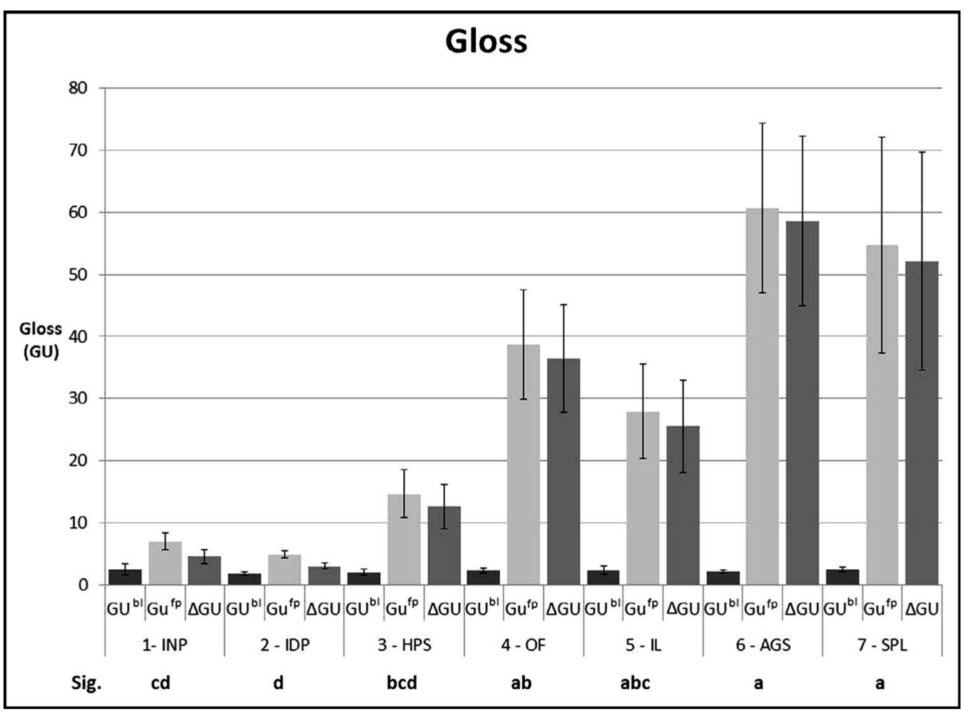

Figure 3. *Bar chart of gloss results.*

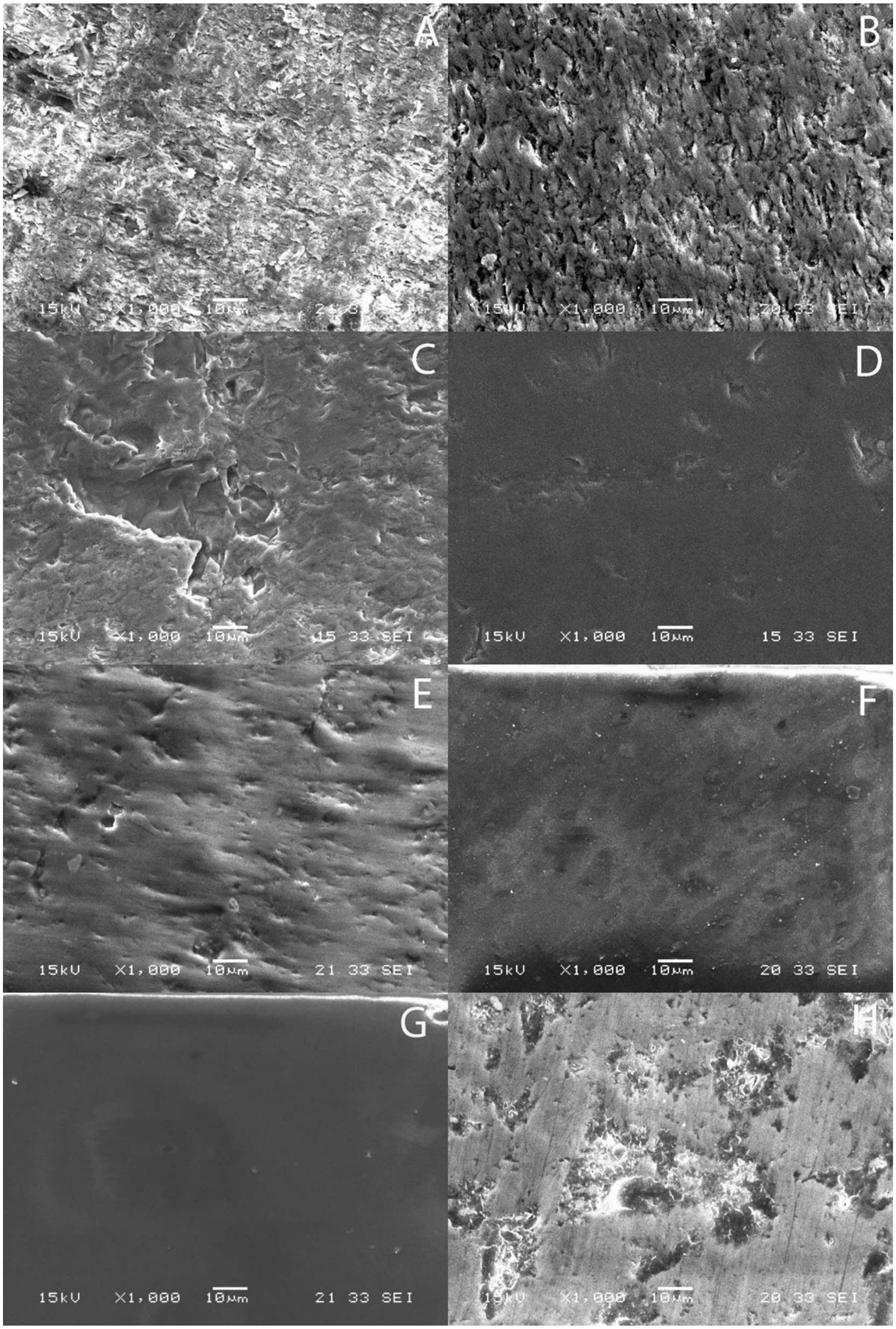

Figure 4. *(A-H): Scanning electron micrograph at 1000× of the different porcelain surfaces analyzed. (A): Baseline specimen. (B): Identoflex NG-Porcelain Polisher (INP). (C): Identoflex Diamond Ceramic Polisher (IDP). (D): HiLuster Polishing System (HPS). (E): Optra-Fine (OP). (F): Identoflex Lucent (IL). (G): Vita Akzent Glaze Spray (AGS). (H): Vita Shading Paste and Liquid (SPL).*

large areas of smooth surfaces. The most regular and smoothest surface was recorded for the two furnace-based glaze systems: SPL and AGS. The SEM images of these two groups showed an absence of grooves and defects. In contrast to the other groups, a poor correlation was found between the SEM appearance and roughness for AGS.

DISCUSSION

The tested finishing and polishing systems exhibited different abilities to smooth the surfaces of Vita Mark II feldspathic ceramic blocks. Therefore, both null hypotheses were rejected.

Roughness and gloss are two important factors for evaluating the surface properties of dental materials after finishing and polishing. Despite a strong correlation between the two parameters,[17-21] they represent two different surface properties. Roughness is a dimensional evaluation of the surface topography that could be described by several linear (Ra, Rq, Rz) or three-dimensional (Sa, Sq, Sz) parameters,[22] while gloss is an optical phenomena that is defined as the property of a surface that involves specular reflection and is responsible for a lustrous or mirror-like appearance.[23]

Even if other systems for the evaluation of surface properties are available, the use of profilometer and Ra measurements is the most common combination for evaluating surface roughness in dentistry. Roughness is a high-frequency, short-wavelength component of a measured surface and refers to the fine irregularity of surfaces, measured in micrometers.[24] The Ra (μm) is the mean value of the distances of the roughness profile to the intermediate height along the measured length.

In order to provide minimal bacterial retention, the average values of surface roughness (Ra) should be lower than 0.2 μm.[25] Ceramics have exhibited the least bacterial and glucan adhesion when compared to other restorative materials.[26] None of the systems tested in the present study were able to achieve an Ra < 0.2 μm. However, it should be noted that Ra values of intact human enamel are generally between 0.45 and 0.65 μm.[27-29] In the present study, SPL, IL, and OF, yielded Ra values similar to those reported for enamel; therefore, they were considered adequate to smooth ceramic surfaces to a clinically adequate level. Conversely, the systems that did not achieve results within this range cannot be considered adequate in terms of clinically acceptable smoothness.

The factors that have been reported to affect gloss include refractive index of the material, angle of incident light, and surface topography.[30] In the present study, the refractive index of the material can be considered constant due to the presence of a single fine ceramic substrate, and the angle of incident light was set to 60 degrees, as indicated by ISO 2813 for specimens of medium gloss.[15] Therefore, the surface topography was considered the main factor influencing the ceramic gloss. In contrast to roughness, a clinically accepted threshold for gloss in terms of GU has not yet been established. Nevertheless, some data are available for enamel surface gloss. When the visual luster of different composites were compared to and approximated natural enamel, the gloss of the latter ranged from 40 to 47 GU.[31] In a more recent study, a value of 53 GU was reported for polished enamel.[32] In the same study, a value of 52 GU was reported for Vita Mark II, comparable to the results in the present study after glazing with SPL.

Although the glazing systems achieved the highest mean ΔGU, there was no statistically significant difference when compared to the intraoral wet system of OF and the laboratory system based on dry rubber tips: IL. This could be explained by the positive influence of the water-cooling operating mode for the OF system and with the peripheral higher speed of the laboratory tips mounted on a straight hand piece when compared to the smaller tips of the other dry intraoral systems tested in the present study. As far as gloss is concerned, only a few systems were able to finish and polish the milled surfaces to the referenced values for enamel (40-47 GU).

Most of the tested manual systems are clinical systems for repolishing feldspathic ceramic surfaces after adjustment, which should be done using fine (red stripe, 40 microns) or extra-fine (yellow stripe, 20 microns) burs. The CEREC milling burs are reported to have a 64-micron grain size, so the initial roughness of the CEREC is higher than the roughness produced by finishing burs indicated for occlusal adjustment. Therefore, the time suggested by the manufacturers of the finishing systems is based on surfaces ground with fine-grained burs and could be insufficient for surfaces milled with the more coarse CEREC milling unit burs in obtaining a clinically acceptable gloss and surface roughness. Vita Mark II feldspathic ceramic has been used in chairside CAD/CAM procedures for more than 20 years and has been evaluated in several studies. In a study on roughness of Vita Mark II ceramic blocks polished using 3M Sof-Lex discs, the reported mean roughness value (Ra=0.46 μm)[33] was comparable to the best results obtained in the present study. The 3M Sof-Lex system was not tested in the present study, as it cannot be considered a "stand-alone" system for posterior areas. The disc shape does not allow to completely finish/polish posterior restorations, and this system is generally combined with other finishing/polishing components.[34] Another study reported a mean Ra value of 0.6-1.0 μm for Vita Mark II, depending on the finishing system.[35] This is generally in agreement with the present study, although the finishing/polishing systems tested were different. In a study that evaluated the efficacy of diamond pastes combined with other polishing systems, a mean Ra value of 0.4 μm was reported for glazed Vita Mark II,[36] which is similar to the findings of the present study. Other studies also reported that final polishing with a diamond paste did not improve the surface smoothness of ceramic restorations.[37,38] In the present study, OF (the only system that includes a diamond paste) provided satisfactory results, which were in the highest statistical rank with the furnace-based SPL and IL systems. Similar results were reported for the Optra-Fine system and Glazed surface on Vita Mark II ceramic blocks in a study that tested different finishing and polishing systems on two different substrates.[39] Those authors concluded that the same polishing system can yield different Ra values depending on the substrate treated. The good results obtained with OF might also be explained due to its wet use. Another study reported that the best results in finishing and polishing ceramic surfaces were obtained using a fine diamond instrument in a wet condition, with authors indicating that polishing in a dry condition has to be associated with a low rotation speed of the instrument for the best results.[40] One interpretation of these results was that ceramic particles were removed from the surface during the polishing procedure and became part of the abrasive system, thereby enabling lower Ra values. Systems such as IL, intended to be used in dry conditions, resulted in a smooth surface with statistically similar Ra values when compared to a glazed surface.

The SEM analysis highlighted the surface morphology without providing evidence that wet systems produce more homogeneous surfaces when compared to dry systems. A similar surface morphology was observed in the dry system, IL, and in the wet system, OF. The working condition factor (wet/dry) was not analyzed in the current study, and subsequent studies should be performed in order to clarify the influence of these factors for finishing and polishing systems. When INP was compared with other polishing systems, it exhibited a statistically lower ability to smooth a ceramic surface when compared to the glazing system SPL.[41] No data were available on the finishing/polishing effects of AGS, IL, HPS, and IDP, recently introduced as "single-step" ceramic polishing systems. In the present study, the factor "number of steps" could not be directly associated with roughness. INP (three-step system), HPS (two-step system), and IDP (single-step system) did not show statistically significant differences in their mean ΔRa values. It has been noted that the use of a sequence of different polishing discs or tips to achieve the desired smoothness resulted in an increase of polishing time for multistep systems.[1]

One of the advantages of using a CAD/CAM system in association with a chairside material is to produce and cement a ceramic restoration in a single appointment.[42] Time needed for every step of fabrication of chairside restorations is of importance. A report on surface finishing of a dental ceramic at clinically acceptable times (180, 120, 60, and 30 seconds) at every step of multistep polishing systems showed that the use of polishing systems for 60 seconds for each step enabled satisfactory results and reasonable timing.[43] Based on the findings of the present study, where better results were achieved by two manual systems and one furnace-based system, a question arose on clinically preferable timing. One study reported that a glazing procedure would save 20% of operator time when compared with manual polishing.[44] This needs to be considered, even if the time savings is related only to the operator time (and not to patients' time). Indeed, if the restoration is subjected to furnace glazing, the procedure would require a considerable delay of cementation or, more likely, a second appointment. This could save operator time but cannot be considered an effective chairside procedure. Based on the present findings, the polishing/finishing ability of furnace-based and selected manual systems was comparable.

CONCLUSION

Within the limitations of the study, the furnace-based glazing system SPL and the manual, dry, three-step system IL exhibited the best results in terms of roughness even if the difference with the manual, wet, two-step-plus-diamond-paste OF system was not statistically significant. When considering gloss, the two furnace-based systems, AGS and SPL, achieved the best results, even though the differences with the two manual systems, OF and IL, were not statistically significant. Only two manual and one furnace-based system enabled clinically acceptable smoothness and gloss on an after-milled CEREC surface.

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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