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Evaluation of Various Polishing Systems for Lithium Disilicate Glass-Ceramics

Keywords

Surface Roughness
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ABSTRACT

Objective: The aim of this study was to investigate the surface roughness of lithium disilicates (LS2s) polished using various polishing systems. Materials and Methods: Two types of LS2 (A, Amber Mill and E, IPS e.max CAD) were polished using LS2-specific polishing systems (L-Edenta, L-Jota), a zirconia-specific polishing system (Z-Jota), and a conventional ceramic polishing system (P-Shofu) (n = 8 per group). The compositions of different polishing systems were analyzed using EDS. Surface roughness was measured using confocal laser scanning microscopy and analyzed using EDS and SEM. ANOVA and Tukey's tests were used for the statistical analyses (p = 0.05). Results: The polishing systems were mainly composed of C, O, and Si. The L-Jota group exhibited rougher surfaces than the other groups. Amber Mill exhibited higher surface roughness than IPS e.max CAD (p<0.001). Among the polishing systems, the L-Jota group presented the highest roughness value (p<0.001). The surface roughness of the AL-Jota group was higher than that of the other groups. Conclusions: A sufficiently smooth surface can be achieved without a LS2-specific polishing system. Further, the same polishing system can have different effects depending on the type of LS2.

INTRODUCTION

Lithium disilicate (LS2) is a widely used glass-ceramic material owing to its favorable aesthetic and mechanical properties among dental ceramics.[1] Approximately 50% of all dentists choose LS2 for anterior restoration.[2] The translucency of LS2 exceeds that of zirconia by 30%.[3] Various colors can be created by adding staining pigments or glassy matrices. Further, the translucency can be adjusted based on the size and distribution of the crystals in the glass matrix.[4]

Monolithic LS2 (IPS e.max CAD) can be used for monolithic all-ceramic inlays, onlays, crowns, and 3-unit fixed partial dentures. It can be applied to the molar region as well as the anterior region.[5] Pieger *et al.*[1] reported that the 10-year survival rate of a single LS2 crown was approximately 97%. Sulaiman *et al.*[6] reported that LS2 single restorations had a 4-year failure rate of approximately 1%, whereas that of fixed partial dentures was 5%. Another type of LS2 that differs from IPS e.max CAD in terms of its spindle-like structure, Amber Mill, offers the same range of applications as IPS e.max CAD, while also exhibiting higher flexural strength.[7]

According to a previous *in vitro* study, well-polished LS2 exhibits good biocompatibility owing to low plaque accumulation.[8] Moreover, in an *in vivo* study of the inflammatory markers in the gingival crevicular fluid, no inflammatory reaction was observed on LS2 restoration, similar to the case of zirconia, which features excellent biocompatibility.[9]

To realize ceramic restorations with biocompatibility, aesthetics, and favorable mechanical properties, a well-polished surface must be formed.[10,11] Developments in computer-aided design and computer-aided manufacturing technology have enabled more elaborate restorations. However, occlusal adjustments are occasionally required during restoration placement. As a result, the restoration surface becomes rough and requires polishing.[12] Ceramic surfaces that are not sufficiently polished facilitate bacterial adhesion, which hinders oral hygiene[13] and results in the wear of the antagonist.[14–16] Surface cracks and flaws due to insufficient polishing affect the flexural strength of the ceramic[17] and reduce restoration strength.[18] The polishing method and quality also have significant impacts on color stability by altering the surface texture and roughness.[12,13,19–21] Bollen *et al.*[22] recommended that the surface roughness of a polished ceramic surface should be less than 0.2 µm (Ra).

The zirconia-specific polishing system is effective in achieving uniform and smooth zirconia surfaces. In a study comparing the surface roughness achieved using three zirconia-specific polishing systems, all polishing systems afforded smoother surfaces than the conventional ceramic polishing system.[23] Even for the zirconia-specific polishing system, differences were observed according to the type of polishing system.[24] Furthermore, polishing efficiency varies depending on the type of ceramic.[25–27]

Recent studies on LS2 polishing have mainly focused on comparing types of ceramics in terms of their glazing and mechanical polishing states.[28–33] When comparing glazed LS2 with glazed feldspathic porcelain, the polishing effect on the surface can be masked due to the glazing. Thus far, very few studies have compared the polishing effects for LS2 alone; the differences in polishing effects with respect to the different microstructures of LS2 have also not been evaluated. Hence, this study aimed to compare the surface roughness of two types of LS2s polished using various ceramic polishing systems. To this end, polishing systems specifically designed for LS2, zirconia, and conventional ceramic were selected and compared. The null hypothesis was that there is no difference in surface roughness between the two types of LS2s when the same polishing system is used. The second null hypothesis was that there is no difference in surface roughness among the polishing systems when they are used for the same LS2.

MATERIALS AND METHODS

Four dental ceramic polishing systems were used: two types of LS2-specific polishing systems, a zirconia-specific polishing system, and a conventional ceramic polishing system *(Table 1)*. The polishing process consisted of 3 steps (prepolishing, polishing, and superpolishing), and each polishing instrument was disk-shaped *(Figure 1)*. Two types of LS2s were cut with a high-speed

Table 1. Materials used in this study.

Material	Group	Brand	Manufacturer	Mfg. Part No.	Recommended rpm (max)
Lithium disilicate	A	Amber Mill	HASS Corp	C14/A2	
Lithium disilicate	E	IPS e.max CAD	Ivoclar Vivadent AG	C14/A2	
High-speed bur	H	DIA-BURS	MANI INC	TR-25F	300,000
Lithium disilicate-specific polishing system	L-Edenta	StarTec	Edenta AG	ST1020HP	15,000
				ST1030HP	
				ST1040HP	
	L-Jota	LS Gloss	Jota AG	LS9877M	7,000–10,000 (opt)
				LS9878M	15,000
				LS9878F	15,000
Zirconia-specific polishing system	Z-Jota	ZIR Gloss	Jota AG	ZIR9867M	8,000 (opt)
				ZIR9868M	15,000
				ZIR9868F	15,000
Conventional ceramic polishing system	P-Shofu	Ceramiste	Shofu INC	Standard	20,000
				Ultra	
				Ultrall	

saw (Accutom-50) to produce square-shaped specimens (15 × 15 × 1.4 mm^3). According to a statistical power analysis performed using G*Power 3.1, the appropriate number of specimens was eight per group (effect size = 0.65, α error = 0.05, power = 0.80).

Scanning electron microscopy (SEM, QUANTAFEG 250) and energy dispersive spectrometry (EDS, Octane Elite EDS) were performed to investigate the shape and compositions of the polishing systems. The specimens were sputter-coated with gold and examined in the high-vacuum mode under SEM. EDS was conducted to analyze the composition of each surface at a magnification of 1,000×. The measurements were conducted at the peripheral and central parts of the cutting plane of the polishing wheel. The peripheral part was the region in direct contact with the specimen, whereas the central part was defined as the region between the center of the wheel and the periphery.

For each LS2, the cut specimens were categorized as the "as-received" group. The remaining specimens were treated with one-way grinding for 10 s, which reproduces the occlusal adjustments. After grinding, the remaining specimens (n = 64) were also categorized into 8 test groups (n = 8 per group, where 4 polishing instruments and 2 types of LS2s were used). Each specimen was fixed to a custom-made fixation device to minimize movement and then polished with a low-speed handpiece (Strong 102 L) (*Figure 2*).[24] Considering that the optimal speed for the first step of the process was 7,000–10,000 rpm for the L-Jota and 8,000 rpm for Z-Jota groups, the speeds of both these

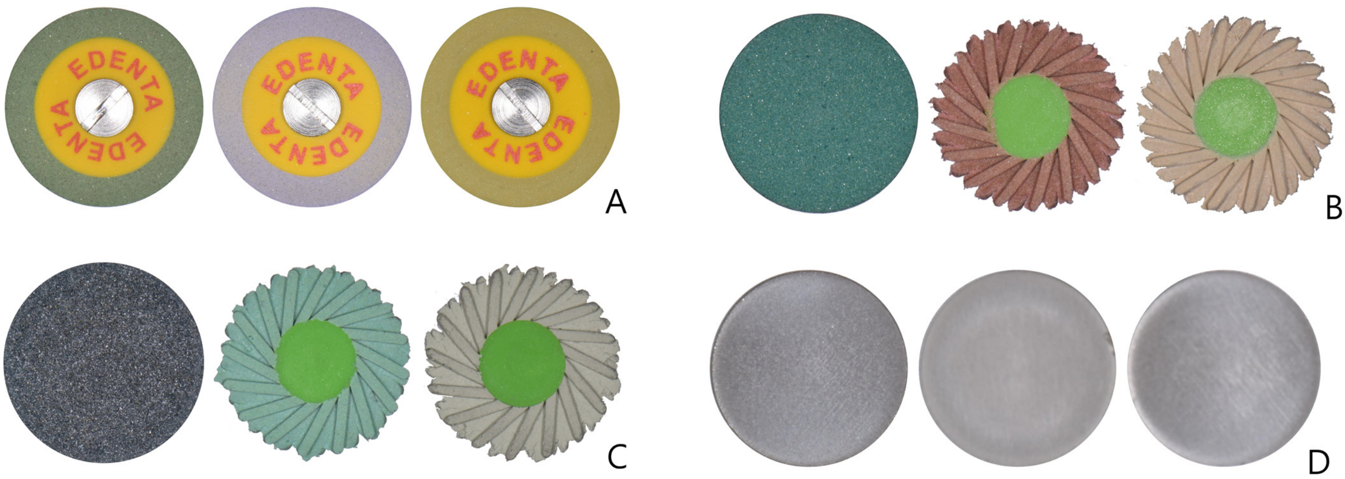

Figure 1: Images of the polishing systems applied sequentially from the left: (A) L-Edenta, (B) L-Jota, (C) Z-Jota, and (D) P-Shofu.

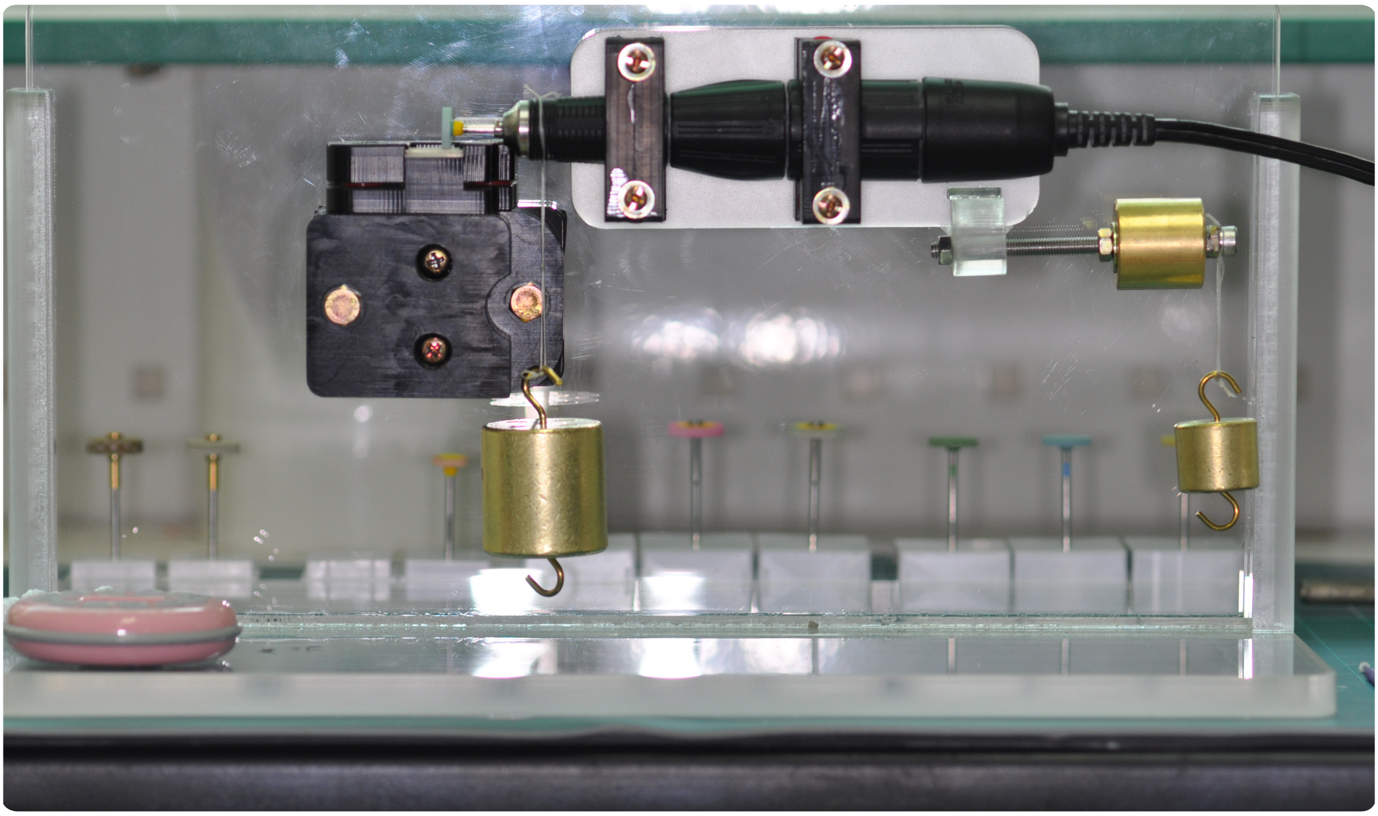

Figure 2: Custom-made fixation device

systems were set to 7,000 rpm in order to unify the experimental conditions. The speed of the remaining polishing systems was set to 10,000 rpm, and polishing was performed in 1-min steps under continuous water cooling. One person performed all the polishing procedures. Each polishing step was used to polish two specimens. Each specimen was cleaned by air spraying for 15 s between the polishing steps to reduce the remnant generated during polishing. Acetone and 70% ethanol were mixed and utilized to wash each specimen using an ultrasonic cleaner (CP1100, CP2600) for 10 min.

The surfaces of the as-received Amber Mill and IPS e.max CAD groups were observed at 10,000× magnification. The specimen surfaces after each polishing step were observed using SEM (400×, 500×, and 1,000× magnification). The remnants after polishing were observed through the SEM images at 200× magnification. The three-dimensional morphology of each surface was observed using confocal laser scanning microscopy (CLSM, Leica DCM8), and the surface roughness (Ra, ISO 4287) of each specimen was measured three times. The mean value of these three measurements was used for subsequent analyses. Thus, the Ra value indicates the average surface roughness based on the mean profile height above (peak) and below (hill) the central line. All the values were determined at a cutoff length of 250 µm. Each scanning covered an area of 1.5 × 1.5 mm^2; to determine the surface values, a Gaussian filter was applied. The elemental compositions of the specimen surfaces were examined using EDS at 1,000× magnification.

All the statistical analyses were performed using IBM SPSS v21.0. To verify whether the two variables, i.e., LS2 type and polishing system, have a significant effect on the surface roughness, two-way analysis of variance (ANOVA) followed by Tukey's HSD test was performed. To verify the significant intergroup differences, *post hoc* Tukey's HSD test after one-way ANOVA was performed.

RESULTS

The surfaces of the polishing systems were examined using SEM *(Figure 3*). The smoothness of the surfaces increased from the first step to the third step. The P-Shofu group exhibited smoother surfaces than the other groups, with the most noticeable differences occurring in the third step.

The elemental compositions were compared by measuring the peripheral and central parts of the polishing instrument with EDS. The main elements of the peripheral and central parts were C and O. This implies that silicon carbide, which is the main composition of conventional ceramic polishing instruments, was detected in large amounts in the polishing systems used in this study. Only in the first step of the P-Shofu systems, O was not one of the main elements of the central part. Although there was a difference in that N was one of the trace elements, the remaining elements in peripheral and central parts were similar *(Table 2*). A comparison of the elemental compositions between the polishing systems revealed a difference in the types of main elements. Those in the P-Shofu group and in the first step of the Z-Jota group included Si as well as C and O. Al was detected in all the polishing systems, except for the P-Shofu group *(Table 2*).

Analyses of the SEM images at 10,000× magnification indicated that the crystal size of Amber Mill was smaller than that of IPS e.max CAD *(Figure 4*). Amber Mill was composed of more homogeneous crystals, whereas IPS e.max CAD exhibited a structure in which large spindles and small crystals were mixed.

After polishing, the specimen surfaces were qualitatively analyzed at 500× magnification *(Figure 5*). The L-Edenta group displayed polished lines at a constant distance. The L-Jota group exhibited defective surfaces as well as rough surfaces. Although the specimens were cleaned using the same method, they exhibited more remnants from the polishing system, as compared to the other polishing methods *(Figure 6*). The Z-Jota group was generally smooth; however, rough areas were observed irregularly. The P-Shofu group exhibited shapes similar to those of the L-Edenta group but more even surfaces. The surfaces resulting from the polishing steps in each group were observed using SEM. After the first step, the L-Jota group was the roughest, whereas the P-Shofu group was the smoothest. In the CLSM analysis, the L-Jota group exhibited a significantly rough surface. When the two types of LS2s were polished with the same polishing system, their surfaces exhibited similar morphologies *(Figure 7*).

When the specimen surfaces after polishing were analyzed using EDS, O and Si were the main elements, and small amounts of Al and K were detected. Trace amounts of Na were observed in the Amber Mill specimens. P, which did not appear in the as-received state, was detected in the specimens after polishing *(Table 3*).

Two-way ANOVA revealed significant differences among the polishing systems with respect to the LS2 types in terms of the surface roughness of the specimen ($p = 0.000$). Amber Mill exhibited higher surface roughness than IPS e.max CAD ($p = 0.000$). The surface roughness of the Amber Mill and IPS e.max CAD specimens did not exhibit significant differences in the as-received group ($p = 0.772$). However, the surface roughness of all test groups was significantly lower than that of the as-received group ($p = 0.000$). Based on a comparison of the polishing systems, L-Jota presented the highest value, followed by L-Edenta and Z-Jota; P-Shofu presented the lowest surface roughness ($p = 0.000$, *Table 4*). There was a significant interaction between the LS2 types and polishing systems ($p = 0.001$). One-way ANOVA results indicated that, among the groups, the AL-Jota group had the highest surface roughness, whereas the AP-Shofu and EP-Shofu groups had the lowest surface roughness *(Table 5*). There was no difference among the polishing systems for IPS e.max CAD.

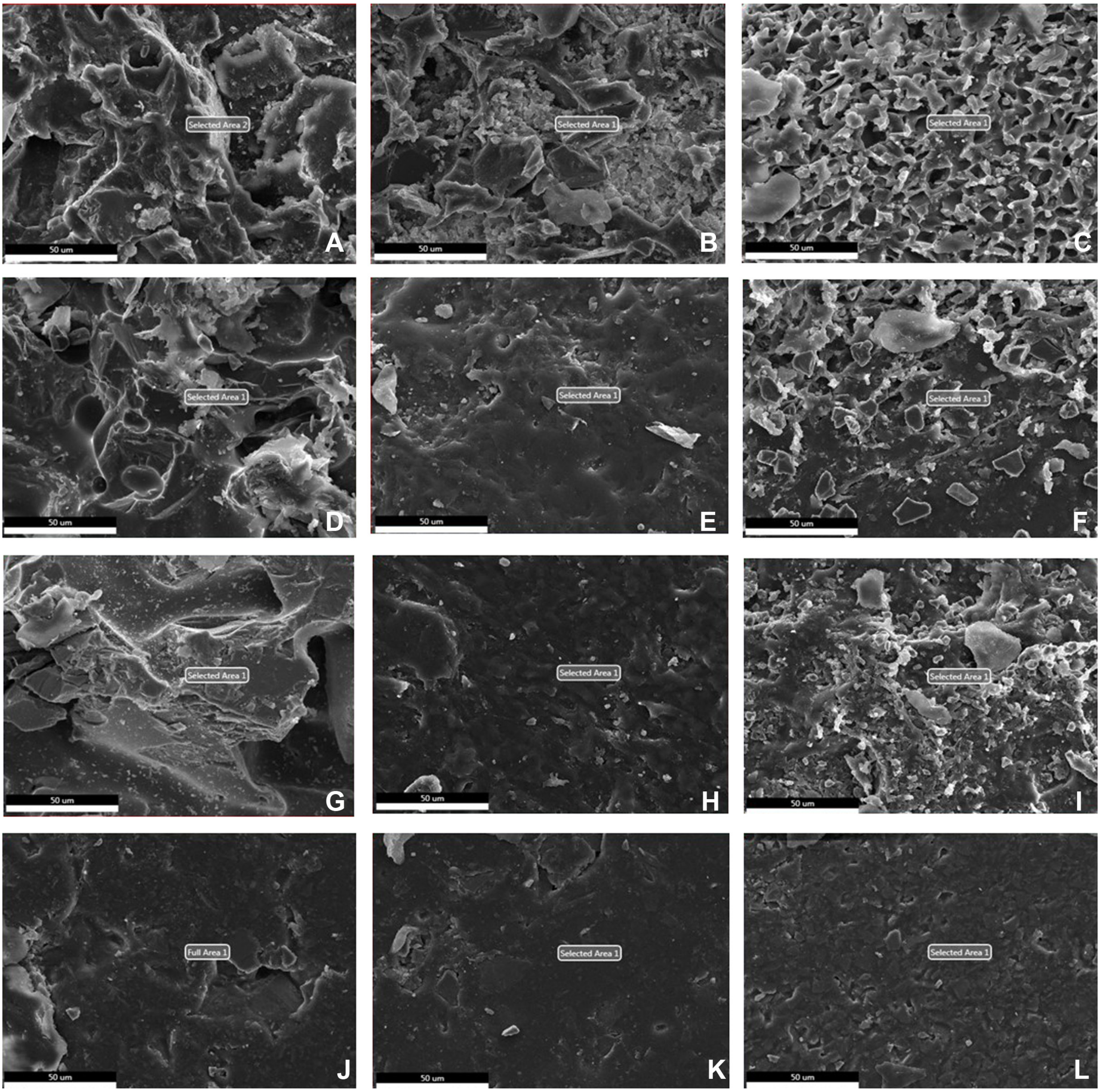

Figure 3: SEM images of the polishing systems at each step (original magnification: 1,000×): (A) L-Edenta 1, (B) L-Edenta 2, (C) L-Edenta 3, (D) L-Jota 1, (E) L-Jota 2, (F) L-Jota 3, (G) Z-Jota 1, (H) Z-Jota 2, (I) Z-Jota 3, (J) P-Shofu 1, (K) P-Shofu 2, and (L) P-Shofu 3

DISCUSSION

There was a significant difference between the two types of LS2. Hence, the first null hypothesis was rejected. Furthermore, the surface roughness differed depending on the polishing system; thus, the second null hypothesis was also rejected. Even for the same LS2 type, the surface roughness differed depending on the polishing system. Amber Mill showed a difference in surface roughness depending on the polishing system, whereas IPS e.max CAD showed no difference. In addition, Amber Mill exhibited higher surface roughness than IPS e.max CAD. This can be attributed to the differences in mechanical properties, LS2 crystal sizes, or fabrication methods. The IPS e.max CAD blocks were milled in the lithium metasilicate state for machinability and heat treated at 840 °C for 7 min in order to achieve crystal phase formation for crystalline LS2 in a glassy matrix.[7] By contrast, the Amber Mill blocks were milled in the nano LS2 state and heat treated at 840 °C for 15 min to induce the growth of spindle-like LS2 crystals. The flexural strength of Amber Mill is 529.5 MPa, which is higher than that of IPS e.max CAD (381 MPa).[7] In addition, SEM analyses showed that Amber Mill had a smaller crystal size than IPS e.max CAD (*Figure 4*). Thus, the crystal density of Amber Mill was high, and the hard crystal content was higher than the glassy matrix content, which resulted in

Table 2. Elemental compositions of polishing systems.

		Central part		Peripheral part	
Group	**Stage**	**Main**	**Trace**	**Main**	**Trace**
L-Edenta	1	C, O	Al, Si, Ti, Cr	C, O	Al, Si, Ti, N
	2	C, O	Al, Si, Ti	C, O	Al, Si, Ti, N
	3	C, O		C, O	Si
L-Jota	1	C, O	Al, Si, Cr, Na, Mg	C, O	Al, Si, Cr, N, Mg
	2	C, O	Si, F, NbL	C, O	Si, N
	3	C, O	Si, F	C, O	Si, N
Z-Jota	1	C, O, Si	Al, K	C, O, Si	Al, K
	2	C, O	Si, N	C, O	Si
	3	C, O	Si, N	C, O	Si, N
P-Shofu	1	C, Si, Cl	O, Na, Mg, MoL, Fe	C, O, Si, Cl	N, Na, Mg, MoL, Fe
	2	C, O, Si, Cl	Mg, MoL	C, O, Si, Cl	Ha, Mg, MoL
	3	C, Si	O, Mg, Cl	C, Si	O, Mg, MoL, Cl

L: Lithium disilicate, Z: Zirconia, P: Conventional ceramic

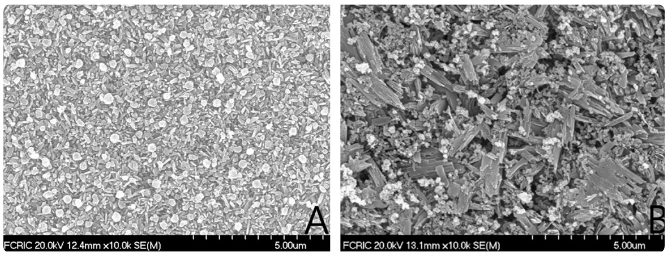

Figure 4: SEM images of as-received groups (original magnification: 10,000×): (A) As-received Amber Mill group, and (B) As-received IPS e.max CAD group

high wear resistance and a rough surface. Mormann *et al.*[16] also reported high wear resistances in ceramics with high surface hardnesses. This high wear resistance of Amber Mill could have contributed toward reducing the polishing effect.

According to the two-way ANOVA, the P-Shofu group exhibited significantly lower surface roughness than the other groups. The SEM analysis also revealed that the P-Shofu group had the smoothest surfaces. Rubber-based abrasives are composed of silicon carbide, aluminum dioxide, silicon dioxide, and zirconium oxide.[27] The compositions of the polishing systems used in this study were analyzed via EDS. C and O accounted for 90% of the content for the L-Edenta and L-Jota groups, which are LS2-specific; 45% for the Z-Jota group; and 60% for the P-Shofu group. It can be assumed that the silicon carbide particles are the main components, as C and O had the highest proportions in all the polishing systems. Aluminum oxide was indicated by the detection of Al in the LS2 and zirconia-specific polishing systems, except for the P-Shofu group. Silicon carbide was present in all the polishing systems. However, high Si contents were detected in the P-Shofu and Z-Jota groups, which had relatively high polishing efficiencies. In summary, a high polishing efficiency corresponded to the Si content being higher than the C and O contents. It is presumed that these composition differences influenced the surface roughness. In addition, the P-Shofu group had smoother surfaces and smaller grain sizes than the other groups. This difference was most noticeable in the third step. Wright *et al.*[34] reported that the grain size of the polishing system has considerable effects on the surface morphologies of ceramic materials. Silva *et al.*[25] reported results similar to those of this study and stated that the polishing of LS2 with a conventional ceramic polishing system reduces the surface roughness.

According to the qualitative evaluation, analyses of the SEM and CLSM images showed that the L-Jota group was rougher than the other test groups. Steiner *et al.*[33] compared the surface roughness by polishing LS2 with zirconia- and LS2-specific polishing systems as well as a conventional ceramic polishing system. The LS2-specific polishing system produced higher surface roughness than the conventional ceramic polishing system, similar to the results of this study. These findings could be attributed to the differences between the compositions of the polishing systems. In addition, the Jota polishing systems exhibited morphological differences as compared to the other polishing systems (*Figure 1*). The L-Jota and Z-Jota polishing instruments exhibited circular shapes with abrasives edges on both sides. Furthermore, the experiment was performed using a one-way polishing motion, which is expected to be unsuitable for the L-Jota and Z-Jota polishing methods. Hence, a polishing method suitable for the shape of the polishing instrument is necessary. The L-Jota and Z-Jota groups had identical shapes; as such, the difference in surface roughness is attributed to the difference in the components of the polishing instrument, as mentioned above. All the specimens were air-sprayed and cleaned after each polishing step. The highest amounts of remnants were observed in the L-Jota specimens (*Figure 6*). This could be attributed to the excessive remnant between the 2 edges contacting each specimen. Dental polishing systems act in a two-body wear mode; however, remnants are generated when polishing is performed and can be interposed on the specimen surface, leading to a three-body mode.[27] The remnant generated during polishing was presumed to be one of the factors causing wear in the L-Jota specimens. According to the SEM images obtained after polishing each test group stepwise, the L-Jota group was rougher than the other test

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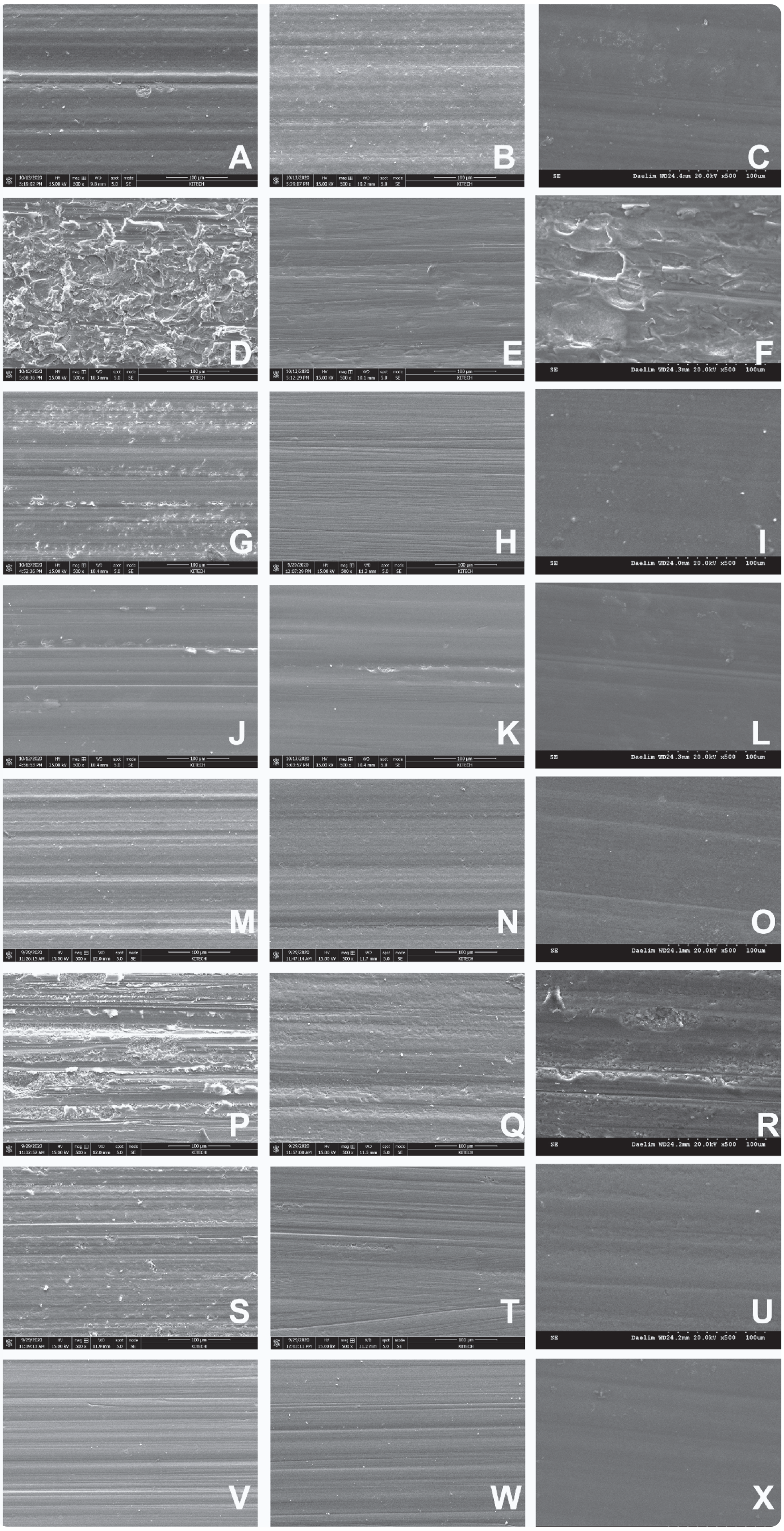

Figure 5: SEM images of the surfaces of lithium disilicate specimens after each polishing step (original magnification: 500×): (A) AL-Edenta 1, (B) AL-Edenta 2, (C) AL-Edenta 3, (D) AL-Jota 1, (E) AL-Jota 2, (F) AL-Jota 3, (G) AZ-Jota 1, (H) AZ-Jota 2, (I) AZ-Jota 3, (J) AP-Shofu 1, (K) AP-Shofu 2, (L) AP-Shofu 3, (M) EL-Edenta 1, (N) EL-Edenta 2, (O) EL-Edenta 3, (P) EL-Jota 1, (Q) EL-Jota 2, (R) EL-Jota 3, (S) EZ-Jota 1, (T) EZ-Jota 2, (U) EZ-Jota 3, (V) EP-Shofu 1, (W) EP-Shofu 2, and (X) EP-Shofu 3

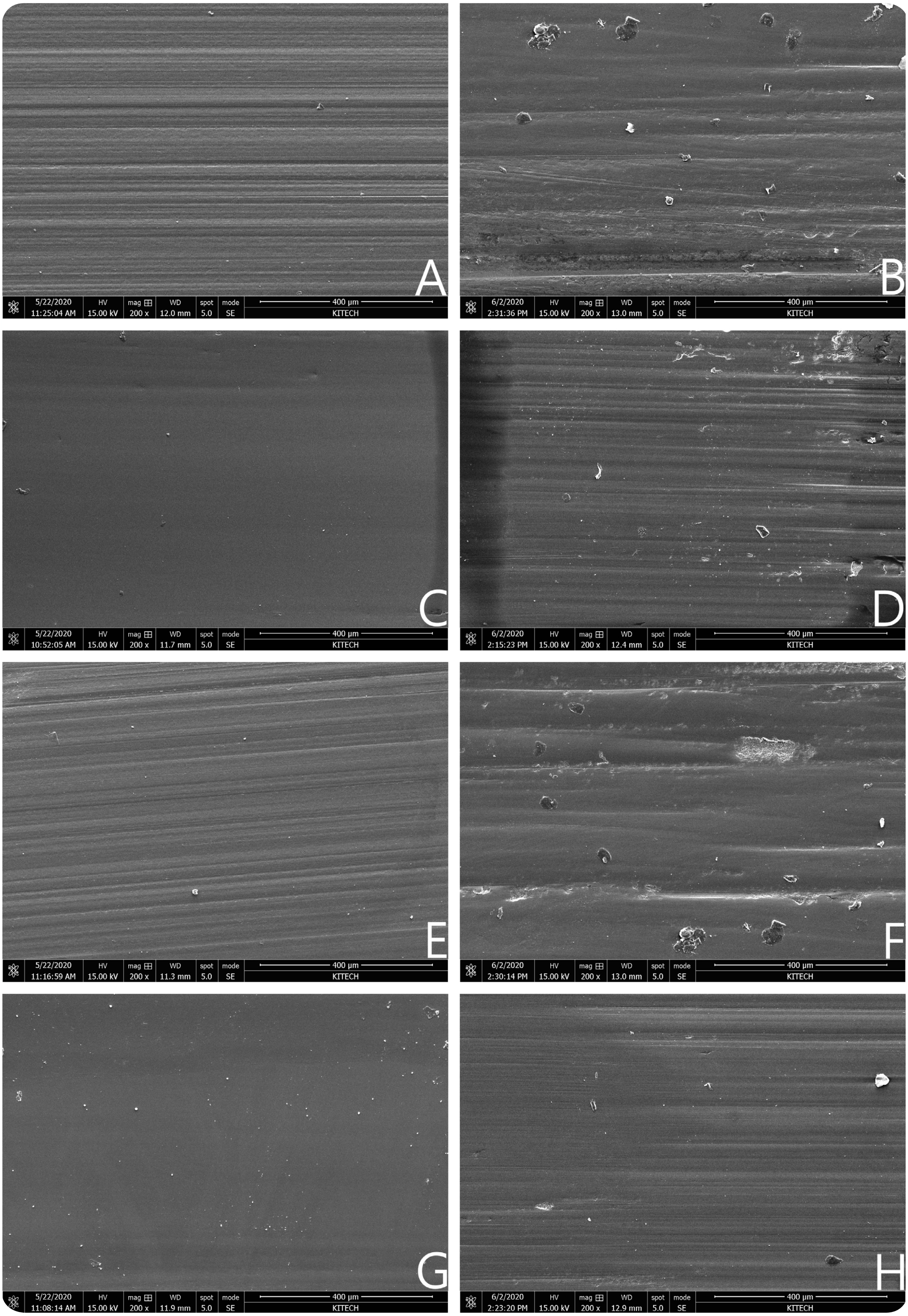

Figure 6: SEM images of the surfaces of the lithium disilicate specimens (original magnification: 200×): (A) AL-Edenta, (B) AL-Jota, (C) AZ-Jota, (D) AP-Shofu, (E) EL-Edenta, (F) EL-Jota, (G) EZ-Jota, and (H) EP-Shofu

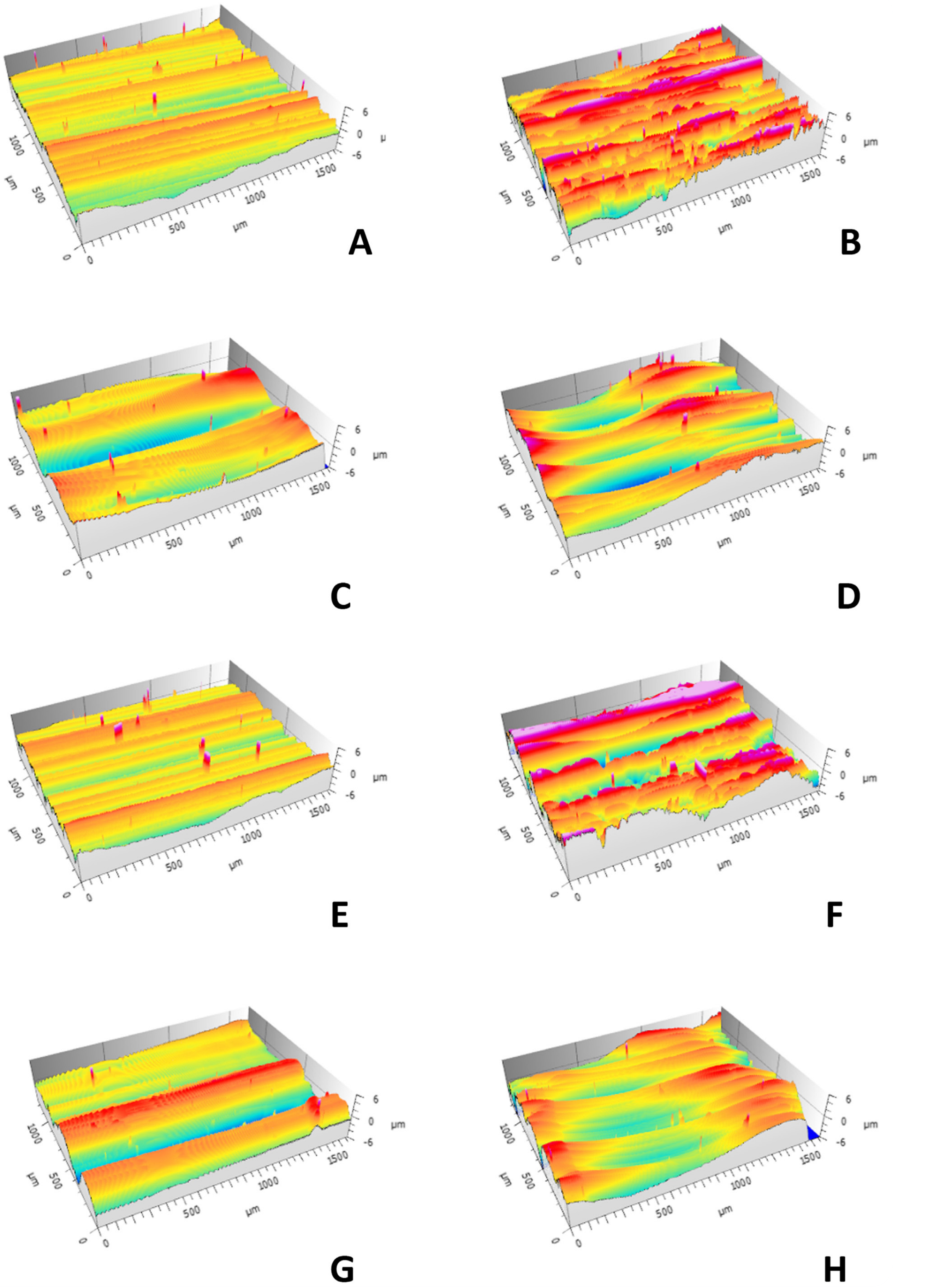

Figure 7: Confocal microscopy images of the surfaces of the lithium disilicate specimens: (A) AL-Edenta, (B) AL-Jota, (C) AZ-Jota, (D) AP-Shofu, (E) EL-Edenta, (F) EL-Jota, (G) EZ-Jota, and (H) EP-Shofu

Table 3. Elements remaining on LS2 surface.

Group	Amber Mill		IPS e.max CAD	
	Main elements	Trace elements	Main elements	Trace elements
As-received	O, Si	Na, Al, K	O, Si	Al, K
L-Edenta	O, Si	Na, Al, K, P	O, Si	Al, K, P
L-Jota	O, Si	Na, Al, K, P	O, Si	Al, K, P
Z-Jota	O, Si	Na, Al, K, P	O, Si O, Si	Al, K, P
P-Shofu	O, Si	Na, Al, K, P	O, Si	Al, K, P

L: Lithium disilicate, Z: Zirconia, P: Conventional ceramic

Table 4. Two-way ANOVA results for polishing systems on lithium disilicate.

Source	Type III Sum of Squares	df	Mean Square	F	P
Lithium disilicates	.034	1	.034	21.929	.000
Polishing systems	.109	3	.036	23.367	.000
Interaction	.028	3	.009	5.967	.001
Error	.087	56	.002		
Total	.258	63			

Table 5. Mean (±standard deviation) and one-way ANOVA results for surface roughness (μm).

Lithium disilicate	L-Edenta	L-Jota	Z-Jota	P-Shofu
Amber Mill (A)	.210 (±.029)^{b}	.303 (±.093)^{a}	.201 (±.020)^{b}	.131 (±.022)^{c}
IPS e.max CAD (E)	.170 (±.017)^{b,c}	.188 (±.034)^{b,c}	.177 (±.020)^{b,c}	.126 (±.016)^{c}

Values in the same column followed by the same letter are not significantly different (P>0.05).
L: Lithium disilicate, Z: Zirconia, P: Conventional ceramic

groups after the first step. The specimen surfaces became smoother toward the third step; however, the difference in roughness in the first step remained unchanged. Thus, the high surface roughness of the L-Jota group was considered to have been produced in the first step.

In this study, polishing systems specific for LS2, zirconia, and conventional ceramic were selected to compare the polishing effects of ceramic polishing instruments. To minimize the errors that could occur during polishing, a customized fixation device was used.[24] Recent studies on polishing efficiencies have compared the glazing and mechanical polishing of LS2.[28-33] There are several disadvantages in the clinical application of glazing. The durability of the glaze layer in the oral cavity remains uncertain,[10] and it can fall out over time, leading to high surface roughness.[31] On glazing the restoration after occlusal adjustment, the strength of the restoration may be negatively affected.[11] Therefore, specimens without glazing treatment were used in this study. In the as-received group without polishing, no difference in the surface roughness of the two types of LS2s was observed. By contrast, the surface roughness of all the polished groups was significantly lower than that of the grinding surface, thus confirming that polishing after adjustment is essential. All the polishing systems exhibited clinically acceptable surface roughness. The threshold for microbial adhesion is a roughness of 0.2 μm,[22] whereas the threshold beyond which the patient can feel the roughness of the oral restoration is a roughness of 0.5 µm.[12] The AL-Jota group had the highest surface roughness (≤ 0.25 µm), whereas the EP-Shofu group exhibited surface roughness ≤ 0.2 µm. Maciel *et al.*[30] reported results similar to those of this study and stated that LS2 polished with a conventional ceramic polishing system exhibited low surface roughness (≤0.2 µm).

Surface roughness may vary depending on the polishing method, pressure, and time. Although the conventional ceramic polishing system was the most efficient in this study, the results may vary depending on the methodology adopted. Previous studies on surface roughness mainly employed contact-type stylus profilometers,[11,15,23,28–30] which are highly accurate as they measure the surface roughness without any interference through direct contact with the surface.[35] However, in this study, the central part of the polished LS2 was concave and not flat; hence, a contact-type stylus profilometer could not be used for the measurements. Therefore, the surface morphology was observed using noncontact CLSM. To reduce the error introduced by the shape of the polishing system, only disk-shaped polishing systems were used. However, very few disk-shaped polishing systems are commercially available; hence, the Jota polishing system with a slightly different shape was included.

The states of the polished surfaces were different for the two types of LS2, even when the same polishing method was applied. As the crystal size and density affect the wear resistance of LS2, it is necessary to increase the polishing time, particularly in the first step of polishing where the polishing efficiency is low. Unlike the polishing efficiency for zirconia,[24] that for LS2 is higher when a conventional ceramic polishing system is used, as compared to that when using an LS2-specific polishing system.

This study has some limitations. EDS was used to analyze the chemical compositions of the surface of the polishing device; however, physical properties such as the hardness of the LS2 or the wear of the polishing systems were not evaluated. According to the manufacturer, the surface shape of the Jota system is effective for polishing irregular occlusal surfaces. However, flat-surfaced specimens were used in this study, and the space between the feather shaped wheel fluctuated. When using a specimen in the form of a restoration with an anatomical shape, the results differ depending on the polishing system. This study failed to reflect the conditions of clinical applications, such as thermal aging and dynamic loading. Therefore, *in vivo* studies may obtain different results. For more accurate results, further studies with additional comparisons should be conducted.

The types of LS2 with different microstructures exhibited different surface roughness for the same polishing systems. The LS2-specific polishing system showed higher surface roughness than the other polishing systems, while a sufficiently smooth surface could be obtained using the conventional ceramic polishing system.

CONCLUSION

Based on the findings of this *in vitro* study, the following conclusions were drawn:

1. All the polishing systems produced clinically acceptable surface roughness.
2. Even if the same polishing system is applied, surface roughness may vary depending on the type of LS2.
3. When polishing LS2, a sufficiently smooth surface can be obtained even when using a conventional ceramic polishing system.

MANUFACTURERS' DETAILS

- IPS e.max CAD, Ivocalr vivadent, Schaan, Liechtenstein
- Amber Mill, HASS Corp, Gangneung, Republic of Korea
- Accutom-50, Struers, Copenhagen, Denmark
- G*Power 3.1, Heinrich-Heine-Universität Düsseldorf, Germany
- QUANTAFEG 250, FEI, Lausanne, Switzerland
- Octane Elite EDS, EDAX Inc, Mahwah, NJ, USA
- Strong 102 L, Saeshin Precision Co, Daegu, Republic of Korea
- CP1100, CP2600, Crest Ultrasonics Corp, Ewing, NJ, USA
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