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Performance of Different Polishing Techniques for Direct CAD/CAM Ceramic Restorations

S Flury • A Lussi • B Zimmerli

Clinical Relevance

VITA Mark II and IPS Empress CAD specimens polished with Sof-Lex discs exhibit smoother surfaces than glazed specimens. The investigated ceramic polishing systems are universally applicable and show increased durability, but they do not result in smoother surfaces than Sof-Lex treatment. Furthermore, certain steps of some polishing methods do not contribute to improved smoothness and could be omitted.

SUMMARY

This *in vitro* study evaluated the performance of three ceramic and two commonly used polishing methods on two CAD/CAM ceramics. Surface roughness and quality were compared. A glazed group (GLGR) of each ceramic material served as reference. One-hundred and twenty specimens of VITABLOCS Mark II (VITA) and 120 specimens of IPS Empress CAD (IPS) were roughened in a standardized manner. Twenty VITA and 20 IPS specimens were glazed (VITA Akzent Glaze/Empress Universal Glaze). Five polishing methods were investigated (n=20/group): 1) EVE Diacera W11DC-Set (EVE), 2) JOTA 9812-Set (JOTA), 3) OptraFine-System (OFI), 4) Sof-Lex 2382 discs (SOF) and 5) Brownie/Greenie/Occlubrush (BGO). Polishing quality was measured with a surface roughness meter (Ra and Rz values). The significance level was set at α=0.05. Kruskal Wallis tests and pair-wise Wilcoxon rank sum tests with Bonferroni-Holm adjustment were used. Qualitative surface evaluation of representative specimens was done with SEM. On VITA ceramics, SOF produced lower Ra (p<0.00001) but higher Rz values than GLGR (p=0.003); EVE, JOTA, OFI and BGO yielded significantly higher Ra and Rz values than GLGR. On IPS ceramics, SOF and JOTA exhibited lower Ra values than GLGR (p<0.0001). Equivalent Ra but significantly higher Rz values occurred between GLGR and EVE, OFI or BGO. VITA and IPS exhibited the smoothest surfaces when polished with SOF. Nevertheless, ceramic polishing systems are still of interest to clini-

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DOI: 10.2341/09-373-L

cians using CAD/CAM, as these methods are universally applicable and showed an increased durability compared to the investigated silicon polishers.

INTRODUCTION

Achieving a smooth surface for ceramic restorations is important not only for the patient's comfort, but also for esthetic and biological reasons. Rough restoration surfaces facilitate discoloration and encourage plaque accumulation responsible for gingivitis or secondary caries.[1-2] Furthermore, surface roughness can negatively influence ceramic strength.[3] Finally, rough ceramic restorations lead to abrasion and increased wear rates of antagonists.[4-5]

Consequently, dental technicians frequently glaze indirect ceramic restorations. However, chairside CAD/CAM (computer-aided designed/computer-aided manufactured) restorations need to be polished by the dentist. Moreover, polishing ceramic surfaces can be necessary after the removal of excessive luting cement or following occlusal adjustments.[6-7]

The quality of ceramic polishing methods is a controversial topic in the literature. Depending on the study, the smoothest surfaces have been obtained by using polishers with diamond abrasive particles or diamond polishing pastes.[8-10] Sof-Lex discs have also been described as an efficient polishing method for dental ceramics:[11-12] Depending on the ceramic material used and the profilometrical measuring parameters, Ra values ranging from 0.2 µm to 0.7 µm have been achieved.[13-15]

Furthermore, there are studies indicating that polished surfaces are qualitatively inferior to glazed ones, while other authors describe polished and glazed surfaces as being equivalent in surface roughness.[10,13,16-20]

In summary, results concerning polishing systems and their performance are inconsistent, because of different measuring parameters and different combinations of polishing method and ceramic material. Especially for dental practitioners who use chairside CAD/CAM-technologies, such as CEREC, it would be of great interest to find an efficient method to finish and polish dental ceramic restorations.

Therefore, the current *in vitro* study evaluated the effects of three ceramic and two commonly used polishing methods on two different CAD/CAM ceramics for CEREC and compared both surface roughness and surface quality. A glazed group of each ceramic material served as comparison and reference group.

METHODS AND MATERIALS

Baseline Surface Roughness and Profilometric Measurement

A total of 240 ceramic specimens was produced. One-hundred and twenty specimens were made of VITABLOCS Mark II for CEREC (size I 8; Vita Zahnfabrik, Bad Säckingen, Germany) and 120 specimens were made of IPS Empress CAD for CEREC (size I 8; Ivoclar Vivadent AG, Schaan, Liechtenstein). To obtain this, 60 blocks of each ceramic material were cut in half and the metal stubs were removed (Isomet Low Speed Saw, Isomet, Lake Bluff, IL, USA). Specifications for the two ceramics are listed in Table 1. Each cut surface of the halved specimens was then roughened to obtain standard baseline surfaces. A grinding machine (Struers Tegra Pol 15/Tegra Pol 1, Struers/AP, Ballerup, Denmark) and papers (Struers Silicon Carbide paper [SicC] grit #120, diameter 200 mm, Struers/AP) were used under water cooling at a speed of 200 rpm for 20 seconds with a pressure of 10 N. Three specimens could be roughened simultaneously using mountings made of a silicone index (Optosil Putty, Heraeus Kulzer, Hanau, Germany) to affix the specimens to the machine. The SicC-grinding paper was changed after each group of three specimens was roughened. The ceramic specimens were then sonicated (Telsonic TUC-150, Telesonic, Bronschhofen, Switzerland) for three minutes in distilled water and air-dried. All of the specimens were profilometrically tested with the surface roughness tester (Mahr Perthometer S2, Mahr GmbH, Göttingen, Germany): in order to survey/monitor the homogeneity of the baseline roughness, the average surface roughness (Ra) and arithmetic mean height of the surface profile (Rz) were measured. Three measurements were determined over a transverse length of Lt=5.600 mm with a

Table 1: *Ceramic Materials Used (Manufacturer Information)*

VITABLOCS Mark II (Vita, Bad Säckingen, Germany)	**Lot #: 16390 Shade: 2M3C**
Type	Feldspar ceramic
Average particle size	4 µm
SiO_2	56-64% by weight
Al_2O_3	20-23% by weight
Na_2O	6-9% by weight
K_2O	6-8% by weight
IPS Empress CAD (Ivoclar Vivadent AG, Schaan, Liechtenstein)	**Lot #: M06107 Shade: A3**
Type	Leucite glass ceramic
Average particle size	1-5 µm
SiO_2	60-65% by weight
Al_2O_3	16-20% by weight
Na_2O	3.5-6.5% by weight
K_2O	10-14% by weight

cutoff value of 0.8 mm and a stylus speed of 0.5 mm/seconds. The specimen was turned 45° for each new measurement. Thus, three Ra and Rz values (at position 0°/45°/90°) were achieved for every specimen (mean Ra=0.98 μm [0.77-1.28 μm], mean Rz=6.61 μm [5.6-8.1 μm]). During the experimental period, the surface roughness tester was controlled with a calibration device (Mahr GmbH) on each day prior to measuring. The specimens were then randomly distributed into the different test groups.

Table 2: *Glazing Procedures*

VITA Mark II Program	**VITA Akzent Fluid (Lot #15581) VITA Glaze Akz 25 (Lot #24690)**
Closing Time	4 minutes
Starting Temperature	403°C
Temperature Rise	80°C/minute
Final Temperature	920°C
Holding Time of Final Temperature	1 minute
Vacuum	no
IPS Empress CAD Program	**Empress Universal Glaze & Stain Liquid (Lot #E47832) Empress Universal Glazing Paste (Lot #L30040)**
Closing Time	6 minutes
Starting Temperature	403°C
Temperature Rise	100°C/minute
Final Temperature	790°C
Holding Time of Final Temperature	2 minutes
Vacuum	yes (start: 420°C—end: 789°C)

Glazing Procedures

Twenty roughened ceramic specimens of VITABLOCS Mark II and 20 roughened specimens of IPS Empress CAD were glazed to serve as a reference; the specimens were sonicated for three minutes in ethanol (Telsonic TPC-25, Telesonic) and air-dried. Two

Table 3: *Finishing/Polishing Instruments Used (Manufacturer Information)*

Instruments	Lot #	Grit/Contents	Manufacturer
Composhape FG 4305L	020812	40 μm (diamond bur)	Intensiv, Grancia, Switzerland
EVE Diacera W11DCmf (medium)	212831	na (diamond particles)	EVE Ernst Vetter GmbH, Pforzheim, Germany
EVE Diacera W11DC (fine)	212830	na (diamond particles)	EVE Ernst Vetter GmbH, Pforzheim, Germany
JOTA 9812G (coarse)	762077	na (diamond particles)	Jota AG Rotary Instruments, Rüthi, Switzerland
JOTA 9812M (medium)	762074	na (diamond particles)	Jota AG Rotary Instruments, Rüthi, Switzerland
JOTA 9812F (fine)	762073	na (diamond particles)	Jota AG Rotary Instruments, Rüthi, Switzerland
OptraFine F (coarse)	ML1756	na (synthetic rubber, diamond granulate, titanium dioxide)	Ivoclar Vivadent AG, Schaan, Liechtenstein
OptraFine P (fine)	JL1603	na (synthetic rubber, diamond granulate, titanium dioxide)	Ivoclar Vivadent AG, Schaan, Liechtenstein
OptraFine HP nylon brush	JL1601	(nylon bristles)	Ivoclar Vivadent AG, Schaan, Liechtenstein
OptraFine HP diamond paste	ML1775	2-4 μm (diamond dust, emulsion of glycerine, sodium lauryl sulphate, propylene glycol)	Ivoclar Vivadent AG, Schaan, Liechtenstein
Sof-Lex 2382C (coarse)	70-2005-2392-9	50-90 μm (aluminum oxide)	3M ESPE, St Paul, MN, USA
Sof-Lex 2382M (medium)	70-2005-2393-7	10-40 μm (aluminum oxide)	3M ESPE, St Paul, MN, USA
Sof-Lex 2382F (fine)	70-2005-2394-5	3-9 μm (aluminum oxide)	3M ESPE, St Paul, MN, USA
Sof-Lex 2382SF (superfine)	70-2005-2395-2	1-7 μm (aluminum oxide)	3M ESPE, St Paul, MN, USA
Brownie Mini Points PN H403	1008196	35-48 μm (silicon carbide)	Shofu, Kyoto, Japan
Greenie Mini Points PN H404	1008200	6 μm (silicon carbide)	Shofu, Kyoto, Japan
Occlubrush Regular Cup 2510	70705527	5 μm (fibers impregnated with silicon carbide)	KerrHawe, Bioggio, Switzerland

na= no further/detailed information from the manufacturer available glaze layers of VITA Akzent Glaze Akz25/Fluid (Vita Zahnfabrik, Table 2) were applied to the VITABLOCS Mark II specimens, and for IPS Empress CAD, two glaze layers of Empress Universal Glazing Paste/Glaze and Stain Liquid (Ivoclar Vivadent AG, Table 2) were applied. The glazing procedures were performed in a Programat P500 oven (Ivoclar Vivadent AG). The two different Programat P500 glazing programs are described in Table 2. All the glazed specimens were sonicated for three minutes in distilled water and air-dried. For each glazed specimen, three measurements (at 0°/45°/90°) of Ra and Rz values were made using the surface roughness tester as described above.

Polishing Methods

For the polishing groups, all the roughened specimens were first finished with a 40 µm grit composhape diamond bur to simulate occlusal adjustment (FG 4305L, Intensiv SA, Grancia, Switzerland). The five polishing methods that were investigated (n=20/method of Mark II; n=20/method of IPS Empress) include the EVE Diacera ceramic polishing set (W11DCmf/W11DC, EVE Ernst Vetter GmbH, Pforzheim, Germany; method 1), the JOTA ceramic polishing kit (9812G/M/F, Jota AG, Rüthi, Switzerland; method 2), the OptraFine ceramic polishing system (OptraFine F/P, OptraFine HP paste/brushes; Ivoclar Vivadent AG; method 3), Sof-Lex 2382 coarse to superfine discs (3M ESPE, St Paul, MN, USA; method 4) and, as method 5, Brownie and Greenie silicon polishers (Shofu, Kyoto, Japan), followed by Occlubrushes (KerrHawe, Bioggio, Switzerland). The different finishing/polishing instruments and the methods are listed in Tables 3 and 4.

For finishing/polishing, the specimens were mounted with a silicone index (Optosil Putty, Heraeus Kulzer) in the lower jaw (region 36/37; universal tooth numbering system: region 18/19) of a mannequin head (KaVo, Biberach, Germany).

The composhape finishing diamonds were used in a 1:5 high-speed handpiece (GENTLEpower LUX 25 LP, KaVo) at 100,000 rpm under water cooling. All of the polishing instruments were used in a 1:1 handpiece (GENTLEpower LUX 20 LP, KaVo) in accordance with the manufacturers' instructions: For every finishing/polishing step, detailed information about revolutions per minute, water cooling and processing time is listed in Table 4.

The dental unit and associated micromotor were the same during the entire study and the revolutions-per-minute of the micromotor were measured and calibrated before the tests using a rotation speed control counter (testo 470, Testo GmbH, Lenzkirch, Germany). Both handpieces were the same for all specimens. Each polishing instrument was used for polishing one specimen only; composhape diamonds were used for finishing 10 specimens.

The polishing method was randomly selected for every specimen, and one calibrated operator always performed the finishing/polishing steps. Periodic controls with an electronic balance (Voltcraft PS-500X0.1g, Conrad Electronics, Hirschau, Germany) measured an average working force of 3.3 N (2.6-3.5 N).

After every finishing or polishing step, the specimens were sonicated for three minutes in distilled water and air-dried. For every specimen, three measurements (at

Table 4: *Polishing Methods*

Methods	Finishing/Polishing Instruments	Revolutions Per Minute (rpm)	Water Cooling	Time Per Instrument (seconds)	Total Processing Time (seconds)
Method 1 EVE Diacera (n=20/ceramic)	Composhape 40 µm	100,000	+	15	75
	Diacera W11DCmf medium	≤15,000	+	30	
	Diacera W11DC fine	≤15,000	+	30	
Method 2 JOTA 9812 (n=20/ceramic)	Composhape 40 µm	100,000	+	15	105
	JOTA 9812G coarse	≤10,000	+	30	
	JOTA 9812M medium	≤10,000	+	30	
	JOTA 9812F fine	≤10,000	+	30	
Method 3 OptraFine (n=20/ceramic)	Composhape 40 µm	100,000	+	15	105
	OptraFine F coarse	≤15,000	+	30	
	OptraFine P fine	≤15,000	+	30	
	OptraFine HP (brush w/paste)	≤10,000	-	30	
Method 4 Sof-Lex 2382 (n=20/ceramic)	Composhape 40 µm	100,000	+	15	135
	Sof-Lex 2382C coarse	≤15,000	-	30	
	Sof-Lex 2382M medium	≤15,000	-	30	
	Sof-Lex 2382F fine	≤15,000	-	30	
	Sof-Lex 2382SF superfine	≤15,000	-	30	
Method 5 Shofu/Occlubrush (n=20/ceramic)	Composhape 40 µm	100,000	+	15	105
	Shofu Brownie	≤20,000	+	30	
	Shofu Greenie	≤20,000	+	30	
	Occlubrush	≤20,000	+	30	

0°/45°/90°) of the Ra and Rz values were made using the surface roughness tester as described above.

SEM Evaluation

For qualitative scanning electron microscopy (SEM) evaluation, representative specimens (three per group) were mounted on aluminum stubs and gold/palladium sputter-coated (100 seconds, 50 mA) using a sputtering device (Balzers SCD 050, Balzers, Liechtenstein). SEM was performed with a Stereoscan S360 scanning electron microscope at 20 kV (Cambridge Instruments, Cambridge, UK). Equal digital SEM micrographs (100x and 1000x magnification, respectively) were generated for each specimen (Digital Image Processing System, version 2.3.1.0, point electronic, GmbH, Halle, Germany).

Statistical Analysis

Of the three Ra and Rz values per specimen, a mean Ra and Rz value was calculated. Therefore, 20 mean Ra and Rz values per glazed group and 20 mean Ra and Rz values per polishing method for each of the two dental ceramics were used for statistical analyses. The polishing methods were compared using two Kruskal Wallis tests for Ra and Rz values, respectively. For pairwise comparisons of the polishing methods, Wilcoxon rank sum tests with Bonferroni-Holm adjustment for multiple testing were used. The main statistical analysis was performed with R version 2.9.1 (The R Foundation for Statistical Computing, Vienna, Austria; www.r-project.org).

Ra and Rz data from the preliminary tests was statistically analyzed with NCSS/PASS 2005 (NCSS, Kaysville, UT, USA) for sample size determination after the level of significance had been set at α=0.05 for both ceramic materials.

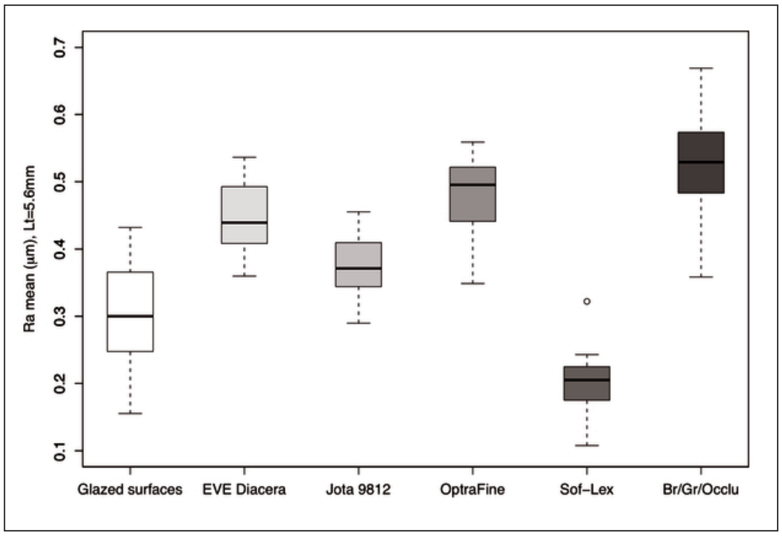

Figure 1. *Boxplots of Ra values of the six groups on VITABLOCS Mark II (n=20/group).*

RESULTS

VITABLOCS Mark II

Ra Values

Ra results for the six groups are shown in Figure 1. Polishing with Sof-Lex discs produced significantly lower Ra values (mean Ra=0.198 µm) than did the glazed group (mean Ra=0.306 µm; p<0.00001); whereas EVE Diacera, JOTA, OptraFine and Brownie/Greenie/Occlubrush yielded significantly higher Ra values (Table 5). No significant differences were determined between Ra values for EVE Diacera and the OptraFine system (p=0.044) or between the OptraFine system and Brownie/Greenie/Occlubrush (p=0.025).

For the five polishing groups, the Ra values after every individual finishing/polishing step of each method are shown in Table 7.

Table 5: *Ra/Rz Values/VITABLOCS Mark II:* p*-values of Pairwise Wilcoxon Rank Sum Tests*

Ra Values	Glazed	Eve Diacera	JOTA 9812	OptraFine	Sof-Lex	Br/Gr/Occlu
Glazed	-	3.286E-7*	0.0049*	1.407E-9*	8.064E-6*	2.017E-9*
Eve Diacera	-	-	0.00019*	0.0439	1.451E-11*	0.00047*
JOTA 9812	-	-	-	2.202E-6*	1.016E-10*	1.341E-7*
OptraFine	-	-	-	-	1.451E-11*	0.0245
Sof-Lex	-	-	-	-	-	1.451E-11*
Rz Values	**Glazed**	**Eve Diacera**	**JOTA 9812**	**OptraFine**	**Sof-Lex**	**Br/Gr/Occlu**
Glazed	-	1.451E-11*	3.946E-9*	2.317E-8*	0.0026*	1.451E-11*
Eve Diacera	-	-	2.757E-10*	4.353E-10*	1.451E-11*	0.0032*
JOTA 9812	-	-	-	0.2853	7.37E-9*	6.529E-10*
OptraFine	-	-	-	-	3.452E-6*	6.529E-10*
Sof-Lex	-	-	-	-	-	1.451E-11*

*(p-values marked with * show significant differences after Bonferroni-Holm adjustment)*

Table 6: *Ra/Rz Values/IPS Empress CAD:* p-*values of Pairwise Wilcoxon Rank Sum Tests*

Ra Values	Glazed	Eve Diacera	JOTA 9812	OptraFine	Sof-Lex	Br/Gr/Occlu
Glazed	-	0.4407	6.004E-5*	0.2286	6.786E-8*	0.0132
Eve Diacera	-	-	0.00036*	0.0315	6.77E-8*	0.00036*
JOTA 9812	-	-	-	3.963E-6*	6.786E-8*	3.028E-8*
OptraFine	-	-	-	-	6.729E-8*	0.1016
Sof-Lex	-	-	-	-	-	6.786E-8*
Rz Values	**Glazed**	**Eve Diacera**	**JOTA 9812**	**OptraFine**	**Sof-Lex**	**Br/Gr/Occlu**
Glazed	-	8.341E-8*	0.0531	0.01056*	0.0002*	6.53E-10*
Eve Diacera	-	-	1.469E-6*	1.099E-5*	6.786E-8*	0.011
JOTA 9812	-	-	-	0.2615	1.653E-7*	1.326E-7*
OptraFine	-	-	-	-	1.225E-7*	7.901E-7*
Sof-Lex	-	-	-	-	-	6.786E-8*

*(p-values marked with * show significant differences after Bonferroni-Holm adjustment)*

Table 7: *Development of Ra Values (µm) After Finishing/Polishing Steps of a Method on VITABLOCS Mark II*

Method	40 µm Diamond Bur (lq) median (uq) (min - max)	Polishing Step 1 (lq) median (uq) (min - max)	Polishing Step 2 (lq) med (uq) (min - max)	Polishing Step 3 (lq) median (uq) (min - max)	Polishing Step 4 (lq) median (uq) (min - max)
Eve Diacera	(1.14) 1.2 (1.26) (1.03 - 1.37)	(0.57) 0.61 (0.63) (0.57 - 0.79)	(0.41) 0.44 (0.49) (0.36 - 0.54)		
JOTA 9812	(1.11) 1.18 (1.23) (1.07 - 1.48)	(1.05) 1.13 (1.19) (0.96 - 1.43)	(0.43) 0.47 (0.5) (0.37 - 061)	(0.35) 0.37 (0.41) (0.29 - 0.46)	
OptraFine	(1.17) 1.23 (1.29) (1.05 - 1.46)	(0.68) 0.73 (0.78) (0.61 - 0.82)	(0.59) 0.62 (0.66) (0.53 - 0.74)	(0.44) 0.5 (0.52) (0.35 - 0.56)	
Sof-Lex	(1.13) 1.19 (1.33) (1.06 - 1.45)	(0.43) 0.48 (0.57) (0.24 - 0.67)	(0.12) 0.13 (0.15) (0.1 - 0.23)	(0.14) 0.17 (0.21) (0.11 - 0.28)	(0.18) 0.21 (0.22) (0.11 - 0.32)
Br/Gr/Occlu	(1.18) 1.23 (1.28) (1.06 - 1.41)	(0.48) 0.54 (0.58) (0.42 - 0.66)	(0.45) 0.5 (0.57) (0.36 - 0.63)	(0.49) 0.53 (0.57) (0.36 - 0.67)	

lq = lower quartile; med = median; uq = upper quartile; min = minimum; max = maximum

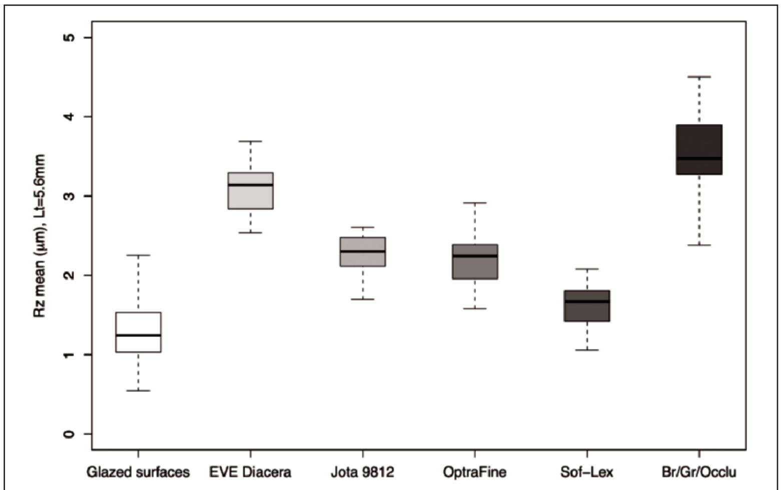

Figure 2. *Boxplots of Rz values of the six groups on VITABLOCS Mark II (n=20/group).*

Rz Values

Rz results for the six groups are shown in Figure 2. The glazed specimens exhibited significantly lower Rz values (mean Rz=1.282 µm) than the five other groups (Table 5). No statistically significant differences were determined between the Rz values of JOTA and the OptraFine system (p=0.285). The Rz values produced with the Brownie/Greenie/Occlubrush method (mean Rz=3.54 µm) were significantly higher than those of any other group.

For the five polishing groups, the Rz values after every individual finishing/polishing step of each method are shown in Table 8.

Qualitative SEM Evaluation

Glazed VITABLOCS surfaces presented a regular surface morphology with small and quite superficial inhomogeneities across the entire specimen (Figure 3). EVE, JOTA and Sof-Lex (Figure 4) exhibited clear irregularities with striations

Table 8: *Development of Rz Values (µm) After Finishing/Polishing Steps of a Method on VITABLOCS Mark II*

Method	40 µm Diamond Bur (lq) median (uq) (min - max)	Polishing Step 1 (lq) median (uq) (min - max)	Polishing Step 2 (lq) med (uq) (min - max)	Polishing Step 3 (lq) median (uq) (min - max)	Polishing Step 4 (lq) median (uq) (min - max)
Eve Diacera	(7.55) 7.77 (8.28) (6.61 - 9.06)	(4.05) 4.18 (4.43) (3.76 - 5.06)	(2.85) 3.14 (3.27) (2.54 - 3.69)		
JOTA 9812	(7.53) 7.74 (8.22) (7.15 - 9.45)	(6.82) 7.21 (7.62) (6.27 - 8.91)	(2.92) 3.00 (3.15) (2.62 - 3.65)	(2.12) 2.3 (2.47) (1.7 - 2.61)	
OptraFine	(7.78) 8.06 (8.22) (6.69 - 8.92)	(4.28) 4.68 (4.92) (3.98 - 5.73)	(3.56) 3.74 (3.88) (3.15 - 4.43)	(1.97) 2.25 (2.38) (1.58 - 2.91)	
Sof-Lex	(7.45) 7.86 (8.59) (7.16 - 9.17)	(3.33) 3.66 (4.09) (1.75 - 5.01)	(0.95) 1.02 (1.16) (0.81 - 1.62)	(1.22) 1.39 (1.7) (0.92 - 2.22)	(1.44) 1.67 (1.8) (1.06 - 2.08)
Br/Gr/Occlu	(7.52) 7.95 (8.1) (7.2 - 8.97)	(3.37) 3.63 (3.8) (2.55 - 4.45)	(3.08) 3.32 (3.61) (2.35 - 4.3)	(3.3) 3.48 (3.89) (2.38 - 4.5)	

lq = lower quartile; med = median; uq = upper quartile; min = minimum; max = maximum

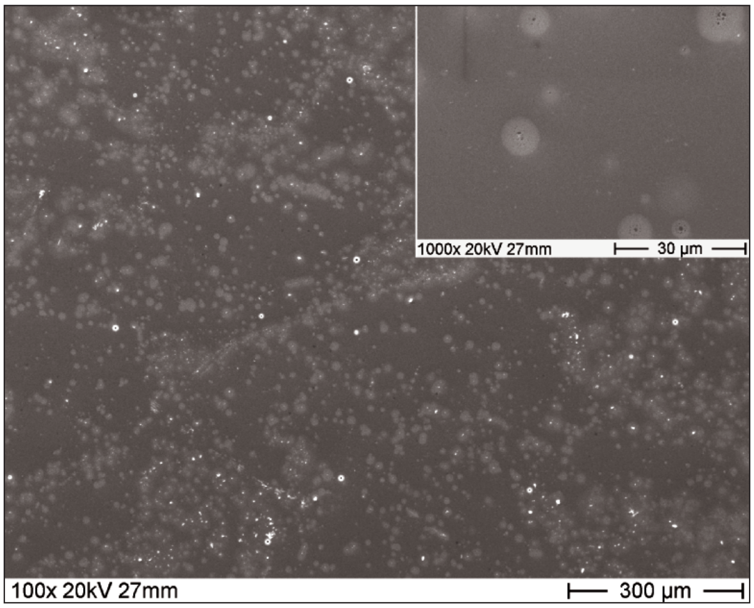

Figure 3. *Glazed VITABLOCS Mark II surface.*

and split-off regions. Inhomogeneities appeared smaller for specimens treated with OptraFine, but scratches could be seen, instead. Figure 5 of the Brownie/Greenie/Occlubrush method showed chipping and scratches, which involved a deeper part of the ceramic.

IPS Empress CAD

Ra Values

The Ra results for the six groups are shown in Figure 6. The Sof-Lex method yielded significantly lower Ra values (mean Ra=0.154 µm) than the other five groups (Table 6). The Ra values of JOTA (mean Ra=0.342 µm) were significantly lower than the Ra values of the glazed group (mean Ra=0.433 µm; p<0.0001). There were no statistically significant differences between the Ra values of the glazed specimens and EVE Diacera (p=0.441), OptraFine (p=0.229) or Brownie/Greenie/Occlubrush (p=0.013). Moreover, no significant differences were determined between the Ra values of EVE Diacera and the OptraFine system (p=0.031) or between the OptraFine system and Brownie/Greenie/Occlubrush (p=0.102).

For the five polishing groups, the Ra values after every individual finishing/polishing step of each method is shown in Table 9.

Rz Values

The Rz results for the six groups are shown in Figure 7. The Rz values produced with Sof-Lex discs (mean Rz=1.195 µm) were significantly lower than the Rz values of the glazed group (mean Rz=1.774 µm; p=0.0002). No significant differences were found between the Rz values of the glazed specimens and JOTA (p=0.053). However, the Rz values for EVE Diacera, OptraFine and Brownie/Greenie/Occlubrush were significantly higher than the Rz values of the glazed group (Table 6). The Rz values of EVE Diacera and Brownie/Greenie/Occlubrush exhibited no statistically significant differences (p=0.011). Finally, there were no significant differences between JOTA and the OptraFine system (p=0.262).

For the five polishing groups, the Rz values after every individual finishing/polishing step of each method are shown in Table 10.

Qualitative SEM Evaluation

The glazed IPS specimens presented a regular surface morphology. However, inhomogeneities in the glaze layer seemed to be smaller than for glazed VITABLOCS surfaces. The surfaces of EVE (Figure 8) and the Sof-Lex specimens exhibited extensive irregularities and split-off regions. There was no apparent

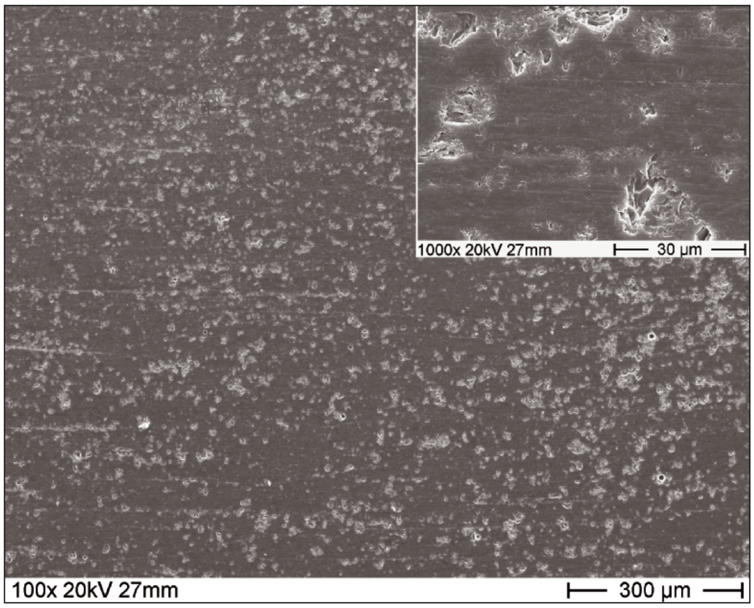

Figure 4. *Sof-Lex on VITABLOCS Mark II.*

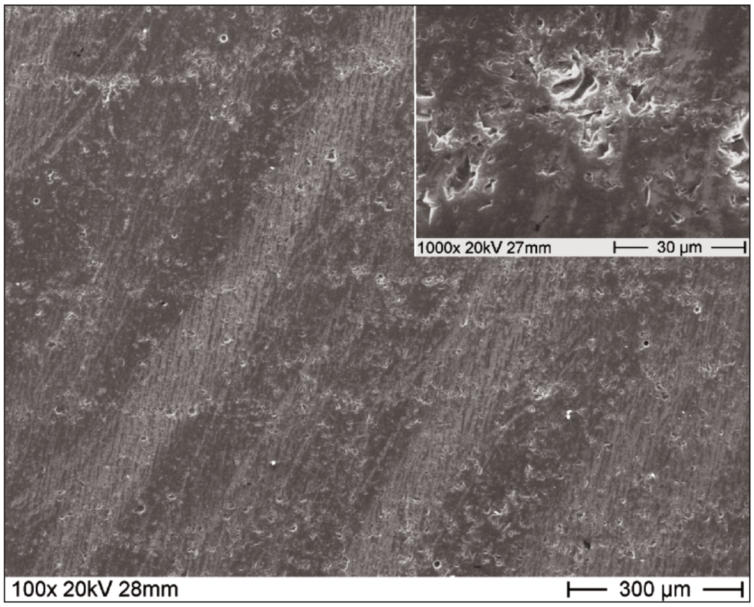

Figure 5. *Brownie/Greenie/Occlubrush on VITABLOCS Mark II.*

chipping and only slight scratches on the OptraFine surface (Figure 9). Brownie/Greenie/Occlubrush showed a striation combined with detrimental areas, instead of scratches, as on the VITABLOCS.

DISCUSSION

The current study determined that the different polishing methods had marked effects on the surface roughness and quality of dental ceramics.

Glazed feldspar ceramic (VITABLOCS Mark II) and leucite glass ceramic specimens (IPS Empress CAD) for CEREC served as reference groups. The SEM micrographs for qualitative characterization demonstrated that the surface of the glazed specimens was homogeneous (Figure 3). Surprisingly, the range of Ra and Rz values in the glazed groups was rather broad (Figures 1 and 2, Figures 6 and 7), although the standardized glazing procedure was performed twice on all specimens.

Several studies have found glazed ceramic surfaces to be superior to polished ones.[17-18] In the current study, however, on IPS Empress CAD, the JOTA method exhibited significantly lower Ra values compared to the glazed specimens, and Sof-Lex discs exhibited significantly lower Ra and Rz values compared to the glazed specimens. This was also the case for the Ra values of Sof-Lex on VITABLOCS Mark II (Table 5).

Compared to the other four polishing methods, Sof-Lex discs produced the smoothest surfaces. On VITABLOCS Mark II, a mean Ra value of 0.2 µm and a mean Rz value of 1.6 µm were obtained. On IPS Empress CAD, Sof-Lex discs produced a mean Ra value of 0.15 µm and a mean Rz value of 1.2 µm. These results are in accordance with those of Martínez-Gomis and others, who analyzed ceramic surfaces profilometrically over a transverse length of 4.8 mm. After polishing with Sof-Lex, a mean Ra value of 0.2 µm and a mean Rz value of 1.1 µm was obtained.[11] Furthermore, Sof-Lex discs were found to be superior to the other polishing methods studied. Good polishing performance for Sof-Lex has been reported in other studies, as well.[9,12-13]

Measurements of the Ra and Rz values after each individual polishing step in a given method demonstrated that the smoothest surface was achieved after the Sof-Lex medium treatment (Tables 7 to 10); fine or superfine discs did not further decrease the Ra or Rz values. Aluminum oxide particles of 3 µm-9 µm (Sof-Lex fine) and 1 µm-7 µm grit size (Sof-Lex superfine) were obviously not able to additionally smooth the hard ceramic materials. After 30 seconds of use, no abrasive particles appeared to be left on the fine and superfine discs. Deprived of abrasive particles, the discs seemed to damage the ceramic surface; after treatment with the fine and superfine Sof-Lex discs, areas with slight scratches appeared on the ceramic specimens. Furthermore, plastic smear marks from the discs were observed on the specimen surfaces.

Comparing the EVE and OptraFine methods, there were no significant differences between the Ra values of EVE (mean Ra=0.4-0.44 µm) and the OptraFine methods (mean Ra=0.45-0.48 µm) for both ceramics (Tables 5 and 6). The Ra values of EVE polishers were also profilometrically investigated by Tholt de Vasconcellos and others, who obtained a mean Ra value of approximately 0.35 µm-0.4 µm, however, under different measuring

Table 9: *Development of Ra Values (µm) After Finishing/Polishing Steps of a Method on IPS Empress CAD*

Method	**40 µm Diamond Bur** (lq) median (uq) (min - max)	**Polishing Step 1** (lq) median (uq) (min - max)	**Polishing Step 2** (lq) med (uq) (min - max)	**Polishing Step 3** (lq) median (uq) (min - max)	**Polishing Step 4** (lq) median (uq) (min - max)
Eve Diacera	(1.15) 1.18 (1.23) (1.01 - 1.39)	(0.55) 0.57 (0.61) (0.49 - 0.68)	(0.38) 0.40 (0.42) (0.31 - 0.52)		
JOTA 9812	(1.05) 1.26 (1.37) (0.94 - 1.45)	(0.97) 1.03 (1.11) (0.82 - 1.26)	(0.39) 0.42 (0.45) (0.36 - 0.5)	(0.32) 0.33 (0.35) (0.27 - 0.53)	
OptraFine	(1.11) 1.19 (1.34) (0.97 - 1.48)	(0.61) 0.67 (0.69) (0.58 - 0.8)	(0.53) 0.57 (0.61) (0.48 - 0.64)	(0.41) 0.44 (0.49) (0.36 - 0.61)	
Sof-Lex	(1.16) 1.23 (1.3) (0.99 - 1.4)	(0.33) 0.42 (0.49) (0.25 - 0.71)	(0.11) 0.12 (0.13) (0.09 - 0.16)	(0.13) 0.14 (0.15) (0.11 - 0.26)	(0.13) 0.15 (0.16) (0.1 - 0.24)
Br/Gr/Occlu	(1.09) 1.23 (1.32) (0.96 - 1.47)	(0.48) 0.51 (0.54) (0.38 - 0.64)	(0.44) 0.48 (0.51) (0.38 - 0.57)	(0.45) 0.48 (0.52) (0.39 - 0.61)	

lq = lower quartile; med = median; uq = upper quartile; min = minimum; max = maximum

Table 10: *Development of Rz Values (µm) After Finishing/Polishing Steps of a Method on IPS Empress CAD*

Method	**40 µm Diamond Bur** (lq) median (uq) (min - max)	**Polishing Step 1** (lq) median (uq) (min - max)	**Polishing Step 2** (lq) med (uq) (min - max)	**Polishing Step 3** (lq) median (uq) (min - max)	**Polishing Step 4** (lq) median (uq) (min - max)
Eve Diacera	(7.49) 7.91 (8.29) (6.38 - 9.21)	(3.8) 4.02 (4.25) (3.49 - 4.69)	(2.49) 2.73 (2.91) (1.98 - 3.68)		
JOTA 9812	(7.08) 8.34 (8.64) (5.72 - 9.43)	(6.43) 6.77 (7.11) (5.52 - 8.17)	(2.66) 2.80 (2.84) (2.4 - 3.15)	(1.82) 1.95 (2.15) (1.51 - 2.64)	
OptraFine	(7.21) 8.14 (8.76) (6.66 - 9.33)	(4.1) 4.34 (4.66) (3.98 - 5.18)	(3.31) 3.63 (3.78) (3.07 - 4.2)	(1.91) 2.12 (2.19) (1.65 - 3.1)	
Sof-Lex	(7.71) 8.21 (8.5) (6.53 - 9.23)	(2.35) 3.23 (3.87) (1.95 - 5.14)	(0.71) 0.75 (0.8) (0.64 - 1.31)	(0.86) 1.07 (1.26) (0.63 - 1.82)	(0.92) 1.25 (1.4) (0.76 - 1.77)
Br/Gr/Occlu	(7.5) 7.97 (8.58) (6.83 - 9.44)	(3.09) 3.24 (3.56) (2.47 - 4.37)	(2.81) 3.00 (3.26) (2.1 - 3.74)	(2.82) 2.98 (3.37) (2.22 - 3.98)	

lq = lower quartile; med = median; uq = upper quartile; min = minimum; max = maximum

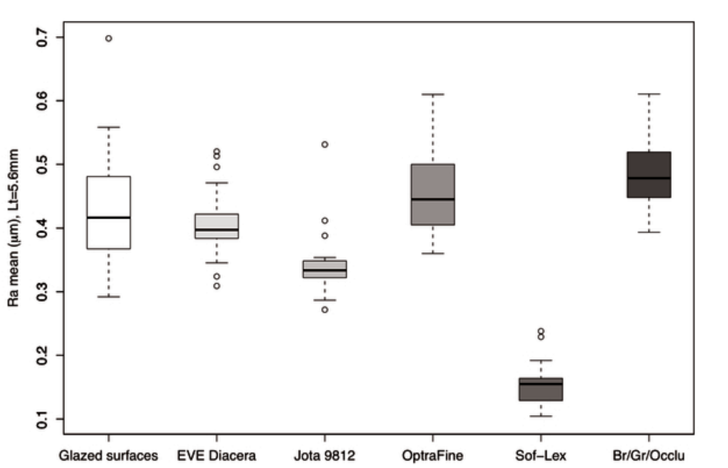

Figure 6. *Boxplots of Ra values of the six groups on IPS Empress CAD (n=20/group).*

conditions.[20] The EVE method consists of only two rubber points (EVE W11DCmf and W11DC), whereas the two rubber points of OptraFine (OptraFine Finisher and Polisher) were followed by a final diamond polishing paste (HP brush/paste). While there was no significant difference in Ra between the EVE and OptraFine system, the Rz values were significantly lower with OptraFine than with EVE (Tables 5 and 6). As summarized by Martínez-Gomis and others, diamond polishing pastes might round the profile shape and lower the height of maximum roughness peaks, which would reduce the arithmetic mean height of the surface profile (Rz) but may not influence the average surface roughness (Ra values).[11]

With regard to the SEM micrographs of OptraFine and EVE, one could assume that the average roughness of a surface polished with the EVE method is probably poorer (Figures 8 and 9). However, there

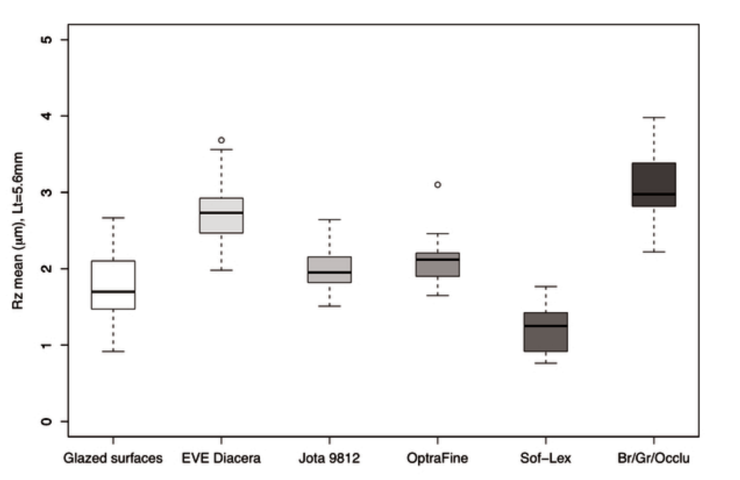

Figure 7. *Boxplots of Rz values of the six groups on IPS Empress CAD (n=20/group).*

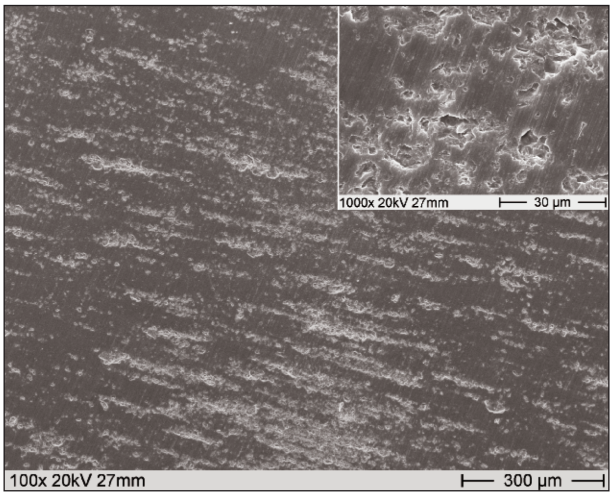

Figure 8. *EVE on IPS Empress CAD.*

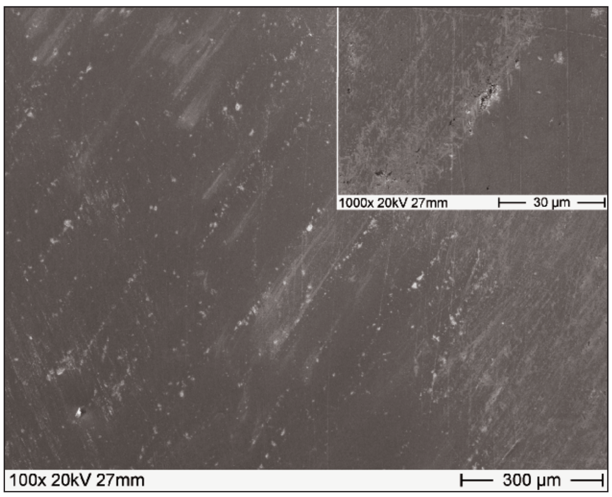

Figure 9. *OptraFine on IPS Empress CAD.*

can be obvious discrepancies between the profilometric roughness parameters and the qualitative appearance of surfaces in SEM micrographs, as demonstrated in the glazed group or, for example, when comparing SEM micrographs of Sof-Lex and OptraFine surfaces (Figures 4 and 9).

Another discrepancy was determined between the SEM micrographs and the Ra, as well as the Rz values of the EVE and JOTA method. Rubber points are features of both methods and, regardless of the type of ceramic material, polishing patterns for the two methods showed similarities with a chipping of the surface. Their polishing capacities were rather different, though. The Ra and Rz values were significantly lower with JOTA (mean Ra=0.34-0.37/mean Rz=1.99-2.27) than with the EVE method (mean Ra=0.4-0.44/mean Rz=2.75-3.08). This result was not unexpected, because there are only two steps in the EVE system, compared to three steps in the JOTA system. However, the first polisher of the JOTA method did not considerably reduce the surface roughness when used after the 40 µm diamond bur (Tables 7 to 10). Therefore, reducing the JOTA method to a two-step polishing system by omitting the JOTA 9812G instrument could be considered.

Method 5 was a three-step polishing procedure comprised of Brownie and Greenie rubber points, which were originally designed for amalgam polishing. As a final step, an Occlubrush was included. All three instruments have silicon carbide abrasive particles of different grit sizes (Table 3). The development of Ra and Rz values was similar to that of the Sof-Lex groups, as shown in Tables 7 through 10. Greenie rubber points and Occlubrushes did not clearly contribute to a smoother surface. Silicon carbide abrasive particles of 6 µm (Greenie Mini Points) and 5 µm (silicon carbide impregnated Occlubrush bristles) were not able to further smooth the ceramic surfaces, quite to the contrary. When analyzing the SEM micrographs, it is obvious that Occlubrushes even scratched the surfaces and, again, there was also a certain chipping of the ceramic. Al-Wahadni and Martin proposed that ceramic particles were removed from the surface during the polishing procedure and, furthermore, the particles even became part of the abrasive system and, hence, rather contributed to an inhomogeneous surface.[4] Therefore, use of a lubricant is strongly recommended. As a clinical consequence, ceramic polishers should only be used with sufficient water cooling. In addition, water spray not only reduces the emission of polishing swarf that could be inhaled, it also decreases frictional heat and thermal differences, which can cause microfissures on the surface, leading to a decrease in structural strength.[21-22]

Regarding the literature, on one hand, a wide variety of combinations of dental ceramics (some for CAD/CAM use, some for dental laboratory fabrication), glazes and polishing instruments have been investigated. On the other hand, the results are not comparable, because of differences in cutoff value or the transverse length of profilometric measurements. Therefore, the baseline and glazed specimens in the current study were measured under alternative conditions; that is, over a shorter transverse length Lt=1.750 mm with a cutoff value of only 0.25 mm and a stylus speed of 0.1 mm/seconds. The Ra values determined over Lt=1.750 mm turned out to be 22%-84% lower than if measured over Lt=5.600 mm, and the Rz values over Lt=1.750 mm were 32%-85% lower than if measured over Lt=5.600 mm.

In conclusion, Sof-Lex discs produced smooth surfaces on ceramics but, due to their rigid and planar form, they are not suitable for polishing all restorations. Ceramic polishing systems with rubber points, rubber cups or nylon brushes are universally applicable and showed good durability during the pretests and the experimental period.

CONCLUSIONS

Within the limitations of the current *in vitro* study, the following conclusions may be drawn:

- Among all polishing methods, Sof-Lex discs produced the smoothest surfaces. Surfaces polished with Sof-Lex were even smoother than glazed ones.
- The roughness of glazed surfaces varied between the two ceramic materials.
- Among the ceramic polishing systems, the JOTA method resulted in the best overall performance.

Conflicts of Interest

The authors declare no conflicts of interest, real or perceived, financial or non-financial.

Acknowledgements

The authors are indebted to Ivoclar Vivadent AG and Vita Zahnfabrik for the ceramic CEREC blocks and to EVE Ernst Vetter GmbH, Jota AG and Ivoclar Vivadent AG for the polishing sets. Furthermore, the authors thank S Hayoz and Prof Dr J Hüsler, Institute of Mathematical Statistics and Actuarial Science, University of Bern, for statistical advice. Finally, the authors thank Dr Anne Peutzfeldt for reviewing the manuscript and for her valuable discussions.

(Received 15 December 2009; accepted 15 March 2010)

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