Surface Evaluation of Polishing Techniques for New Resilient CAD/CAM Restorative Materials

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ABSTRACT

Purpose: The purpose of this study was to measure the surface roughness of milled chairside computer-assisted design/computer assisted machining (CAD/CAM) restorations using several contouring/polishing systems as to their effectiveness for creating a clinically acceptable surface.

Materials and Methods: One hundred onlays were milled from monolithic CAD/CAM blocks with an MCXL milling chamber (Sirona Dental) as follows: 30 resin nano-ceramic (Lava Ultimate, 3M ESPE), 30 hybrid ceramic (Enamic, Vita) and 40 leucite-reinforced ceramic (EmpressCAD, Ivoclar). A single group of EmpressCAD onlays was glazed-fired in a porcelain oven (Programat CS2, Ivoclar). Finishing and polishing systems consisted of either an abrasive-polish technique or a brush-polish technique. Roughness values were measured using a three-dimensional measuring laser microscope (OLS4000 LEXT by Olympus).

Results: There was a significant difference in the baseline surface roughness of the CAD/CAM materials ($p \leq 0.05$), with the resin nano-ceramic (Lava Ultimate) being smoother than the hybrid ceramic (Enamic), and both being smoother than the leucite-reinforced ceramic (EmpressCAD). All polishing techniques resulted in a smoother surface compared with the baseline surface for the leucite-reinforced ceramic ($p \leq 0.05$), with both techniques resulting in a significantly smoother surface than glazing in a porcelain oven ($p \leq 0.05$). Both polishing techniques resulted in a smoother surface compared with the baseline surface for both the nano-ceramic and hybrid ceramic materials ($p \leq 0.05$).

Conclusions: It is possible to create an equally smooth surface for chairside CAD/CAM resilient materials compared with milled ceramics using several finishing and polishing techniques. In general, the polished ceramic surfaces were smoother than the glazed ceramic surfaces.

CLINICAL SIGNIFICANCE

The results of the study indicate that it is possible to create an equally smooth surface for chairside CAD/CAM resilient materials compared with milled ceramics using several finishing and polishing techniques. In addition, both polishing techniques resulted in smoother ceramic surfaces when compared to glazed ceramic surfaces. The polished surface of the ceramic material was smoother than the glazed ceramic surface.

(J Esthet Restor Dent ••:••–••, 2015)

INTRODUCTION

Chairside computer-assisted design/computer assisted machining (CAD/CAM) systems have enjoyed a significant evolution in capability, efficiency, and material options since the CEREC system was first marketed in 1985.[1,2] Recently, several newer systems have been introduced, including Planmeca

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Planscan/Planmill (D4D Technologies, Richardson, TX, USA), Carestream CS solutions (Carestream Dental, Atlanta, GA, USA), and Fast Scan (Glidewell, Newport Beach, CA, USA), confirming the increased interest in the chairside digital workflow.

Ceramic restorations are commonly fabricated in a dental laboratory where the final glazed surface of the restoration is created with an oven firing process. This results in a smooth and biocompatible surface to the restoration. Chairside CAD/CAM systems can fabricate ceramic restorations in a single appointment requiring the doctor to design and mill the restoration in the dental office. However, the milling process does not create a smooth surface ready for cementation. The ceramic material must be contoured and finished post-milling to make it ready for delivery. There are two types of ceramic materials available for chairside CAD/CAM restorations that can be hand-finished and polished or glaze-fired in a porcelain oven. Vita Mark II (Vita, Yorba Linda, CA, USA) and Sirona Blocs (Vita) are fine-grained feldspathic porcelain, and EmpressCAD (Ivoclar Vivadent, Schaan, Liechtenstein) is a leucite-reinforced glass ceramic. Although these ceramic materials may be glazed by oven firing, many chairside ceramic CAD/CAM restorations are alternatively hand-finished and polished prior to delivery.

Instruments and techniques advocated for contouring and polishing must create a smooth surface to maximize the flexural strength of the restoration,[3–6] minimize the risk of chipping or fracture,[7] minimize abrasive wear of opposing teeth and restorations,[8–10] and maximize biocompatibility by limiting adherence of bacteria to the surface of the restorations.[11,12] Finishing and polishing procedures also enhance the esthetic appearance of the milled CAD/CAM restorations by resulting in a glossy surface that has similar reflection and refraction characteristics as natural teeth. A number of laboratory studies have reported that the use of diamond impregnated rubber polishers and diamond polishing pastes results in the smoothest polished ceramic surfaces.[13–15]

The dental literature contains a number of in vitro studies documenting the effectiveness of polishing devices and techniques for adjusting and repolishing laboratory fabricated ceramic restorations. Alternatively, chairside CAD/CAM restorations can be completed in a single dental appointment in a dental office without the use of a porcelain oven. This requires considerable time and effort devoted to hand-finishing and polishing the entire restoration prior to delivery. Two new chairside CAD/CAM materials have been introduced that are described as more resilient than conventional ceramics to resist chipping and fracture while offering ease in contouring and polishing without the use of a porcelain oven. Lava Ultimate (3M ESPE, St Paul, MN, USA) is described as a resin nano-ceramic material containing a combination of aggregated 20 nm silica and 4 to 11 nm zirconia clusters in a resin matrix.[16] Enamic (Vita) is described as a hybrid ceramic containing feldspathic porcelain 86% by weight and an interpenetrating polymer network 14% by weight.[17]

There is little documentation as to the effectiveness of various instruments, materials, or processes for the total hand-finishing procedure on newer chairside CAD/CAM materials. The purpose of this study was to document the surface roughness of milled chairside CAD/CAM restorations of various materials using several contouring/polishing systems and processes as to their effectiveness of creating a clinically acceptable smooth surface.

METHODS AND MATERIALS

A ceramic onlay covering all cusps was prepared on a mandibular molar ivorine tooth in a typodont. The preparation was made flat without proximal boxes to produce an onlay with a flat intaglio surface. The preparation was imaged, designed, and milled at standard speed with a CEREC OmniCam (Sirona Dental, Bensheim, Germany) and MCXL milling chamber using 4.0 software. (Figure 1) The intaglio surface was used as the test surface as it provided a flat, milled surface for polishing. One hundred onlays were milled from pre-manufactured mill blocks for chairside CAD/CAM restorations, including 30 resin

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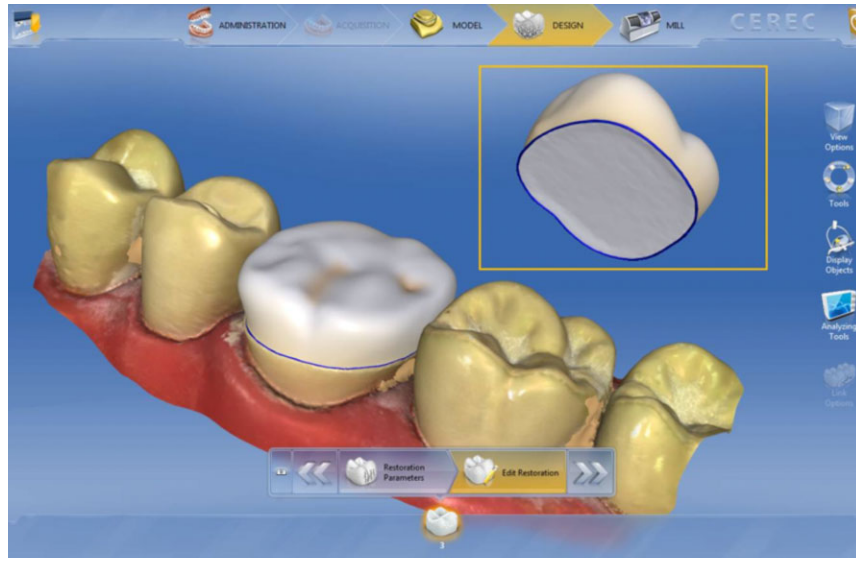

FIGURE 1. Virtual design of the onlay prototype used for sample fabrication. Preparation surface was a plane ensuring a flat internal surface to the onlay for roughness testing.

nano-ceramic mill blocks (Lava Ultimate, 3M ESPE), 30 hybrid ceramic mill blocks (Enamic, Vita), and 40 leucite-reinforced mill blocks (EmpressCAD, Ivoclar Vivadent). Onlays of each material were distributed into groups of 10 by randomly drawing them one at a time from a sealed urn.

Finishing or contouring is a distinctly different process than polishing. Finishing or contouring involves the adjustments required to achieve the final shape of the restoration generally using microfine diamonds and/or coarse rubber abrasives. Polishing involves the process required to achieve the final surface smoothness of the restoration with minimal change to the surface shape. Two types of finishing and polishing techniques were evaluated for each material. One technique consisted on rubber polishing abrasives, followed by a brush/paste specific for the type of material (abrasive-polish technique). The second technique consisted of a series of brushes and polishing pastes specific to the material (brush-polish technique). Prior to any finishing and polishing, 10 samples of each material were measured to establish the baseline roughness of the material as a result of being milled, and a single group of EmpressCAD was glazed-fired in a porcelain oven (Programat CS2, Ivoclar Vivadent) for the positive control comparison. Materials and techniques are listed in Table 1.

Two experienced clinicians were calibrated to carry out the contouring and polishing sequences simulating clinical procedures in accordance with the manufacturer's instructions for rpm and pressure. The same straight handpiece and electric motor was used to control the rpm setting for each step. Each contouring and polishing step in the sequence was performed for 30 seconds. The objective of the contouring and polishing procedures was to achieve a clinically acceptable smooth surface. This was achieved when a glassy surface was created with no grooves or scratches visible to the naked eye. Operators could not be masked as blocks of each material had a distinct look as well as a particular feel during finishing and polishing procedures.

Immediately prior to surface measurement, the onlays were cleaned of any oils or debris with soap and water, followed by an ultrasonic bath in distilled water for 10 minutes and dried. The surface analysis of each specimen was completed in a masked fashion using a three-dimensional (3D) measuring laser microscope (OLS4000 LEXT by Olympus, Center Valley, PA, USA). The 3D measuring laser microscope provides simultaneous acquisition of brightness, height, and color information in the same visual field, as well as high-resolution observation with high-accuracy, non-contact measurement. Two primary measurement

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TABLE 1. Test group descriptions

Material	Instruments and technique
1. Lava Ultimate	Baseline > surface as onlay is removed from the MCXL mill
2. Lava Ultimate	VH Technology instruments (brush–polish technique)—4 steps BH-105A wheel at 10,000 rpm Diashine Fine Soft Pink polish/soft bristle brush (SHP) at 10,000 rpm Diashine Superfine Soft Grey polish/soft bristle brush at 10,000 rpm Chamois center soft bristle brush (dry) at 15,000 rpm
3. Lava Ultimate	Meisinger Polishing Kit (abrasive–polish technique)—5 steps Coarse wheel (#9511U) at 10,000 rpm Medium red point (#9507P) at 10,000 rpm Fine green point (#9507H) at 10,000 rpm Diamond polishing paste (5μm grit) with soft bristle brush at 10,000 rpm Cotton buff wheel (dry) at 10,000 rpm
4. Enamic	Baseline > surface as onlay is removed form the MCXL mill
5. Enamic	VH Technology instruments (brush–polish technique)—4 steps BH-100B wheel at 10,000 rpm Diashine Fine Soft Pink polish/medium bristle brush at 8,000 rpm Diashine Superfine Soft Grey polish/medium bristle brush at 12,000 rpm Chamois center soft bristle brush (dry) at 15,000 rpm
6. Enamic	Vita Enamic Polishing kit (abrasive–polish technique)—2 steps Pink Enamic polisher at 10,000 rpm Grey Enamic polisher at 10,000 rpm
7. EmpressCAD	Baseline > surface as onlay is removed form the MCXL mill
8. EmpressCAD	Surface glazed fired in a porcelain oven (per manufacturer's instructions) 6-minute closing oven cycle; 100°C/minute temp increase rate; 790°C firing temp; hold time of 1 minute
9. EmpressCAD	VH Technology instruments (brush–polish technique)—4 steps BH-213A wheel at 8,000 rpm Diashine Fine Yellow polish/stiff bristle brush at 10,000 rpm Diashine Fine Soft Pink polish/soft bristle brush at 10,000 rpm Chamois center soft bristle brush (dry) at 15,000 rpm
10. EmpressCAD	Brasseler Dialite kit (abrasive–polish technique)—5 steps Ceramipro white universal coarse wheel (10P white wheel) Dialite Blue coarse rubber point at 10,000 rpm Dialite Pink medium rubber point at 10,000 rpm Dialite Gray fine rubber point at 10,000 rpm Dialite diamond polishing paste (#5015241U0) with soft Robinson bristle brush at 10,000 rpm

parameters were evaluated. Sa is a 3D parameter expanded from the roughness (2D) parameter Ra. It expresses the average of the absolute values of Z (x,y) in the measured area. It is equivalent to the arithmetic mean of the measured region on the 3D display diagram when valleys have been changed to peaks by conversion to absolute values. Sq is a 3D parameter expanded from the roughness (2D) parameter Rq. It expresses the root mean square of Z (x,y) in the measured area. It is equivalent to the average mean square of the measured region on the 3D display diagram when valleys have been changed to high peaks by squaring. All measurements were made using a 20× objective, under laser light. The field of recording on the center of the sample was measured at 625 μm × 625 μm. To compensate for the small visual field range (which is a function of higher magnification imaging), advanced image stitching was utilized. The computer combined four adjacent measured areas into a single arithmetic mean to create a wider field view of

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1.2 mm × 1.2 mm. Visual images of the surfaces were also recorded for qualitative assessment of the surface roughness.

RESULTS

The collected surface data were subjected to a one-way analysis of variance for each material and contouring/polishing technique in order to analyze the differences among materials as well as the differences among the various contouring/polishing group means. A Tukey's Test multiple comparison test was applied at 0.05 significance level to determine statistically significant differences between polishing sequences and materials. The means and standard deviations for surface roughness at baseline and after finishing and polishing, as well as the statistical significance, are presented in Tables 2 and 3. Statistically significant differences were found between CAD/CAM materials and contouring/polishing sequences ($p \le 0.05$).

There was a statistically significant difference in the baseline surface roughness of the CAD/CAM materials when they were removed from the MCXL milling chamber ($p \le 0.05$) (Table 2). Lava Ultimate onlays were significantly smoother than both of the other two materials, and Enamic onlays were significantly smoother than EmpressCAD onlays ($p \le 0.05$).

All polishing techniques resulted in a smoother surface compared with the baseline surface for the leucite-reinforced ceramic ($p \le 0.05$). (Table 3) There

TABLE 2. Baseline surface roughness means (Sa and Sq), standard deviations and statistical significance among groups

Material	Polishing technique	Sa; ± SD (μm)	Sig.*	Sq; ± SD (μm)
Lava Ultimate	Baseline	0.39; ± 0.079	a	0.56; ± 0.097
Enamic	Baseline	0.62; ± 0.055	b	0.81; ± 0.070
EmpressCAD	Baseline	0.80; ± 0.098	c	1.07; ± 0.110

*Values with different letters were significantly different from each other ($p < 0.05$).

TABLE 3. Surface roughness means (Sa and Sq) and standard deviations for all tested groups and statistical significance among groups

Material	Group	Polishing technique	Sa; ± SD (μm)	Sig.*	Sq; ± SD (μm)
Lava Ultimate	1	Baseline	0.39; ± 0.079	a	0.56; ± 0.097
	2	Brush–polish (VH Technology)	0.03; ± 0.003	b	0.04; ± 0.007
	3	Abrasive–polish (Meisinger)	0.03; ± 0.004	b	0.06; ± 0.028
Enamic	4	Baseline	0.62; ± 0.055	c	0.81; ± 0.070
	5	Brush–polish (VH Technology)	0.04; ± 0.003	d	0.06; ± 0.018
	6	Abrasive–polish (Vita)	0.05; ± 0.010	d	0.08; ± 0.033
EmpressCAD	7	Baseline	0.80; ± 0.098	e	1.07; ± 0.110
	8	Brush–polish (VH Technology)	0.03; ± 0.006	f	0.06; ± 0.020
	9	Abrasive–polish (Brasseler)	0.03; ± 0.010	f	0.05; ± 0.021
	10	Glazed	0.07; ± 0.011	g	0.15; ± 0.031

*Values with different letters were significantly different from each other ($p < 0.05$).

was no statistically significant difference in surface roughness between the VH Technology (Seattle, WA, USA) and Brasseler (Savannah, GA, USA) polishing techniques, with both techniques resulting in a significantly smoother surface than glazing in a porcelain oven ($p \leq 0.05$).

Both polishing techniques resulted in a smoother surface compared with the baseline surface for the hybrid ceramic Enamic ($p \leq 0.05$) (Table 3). There was no significant difference in surface roughness between the brush-polish technique (VH Technology) and the abrasive-polish technique (Vita) ($p \leq 0.05$).

Both polishing techniques resulted in a smoother surface compared with the baseline surface for the nano-ceramic Lava Ultimate ($p \leq 0.05$) (Table 3). There was no significant difference in surface roughness between the brush-polish technique (VH Technology) and abrasive-polish technique (Meisinger, Neuss, Germany) ($p \leq 0.05$).

Both 2D and 3D images were recorded with the laser microscope of the measured surface areas of representative specimens (Figures 2–9). One advantage of the laser microscope is that although the 2D image shows the relative surface smoothness of the measured areas, the 3D image reveals the tendency of the finishing and polishing sequences to create a smooth but undulating surface over the area that was measured.

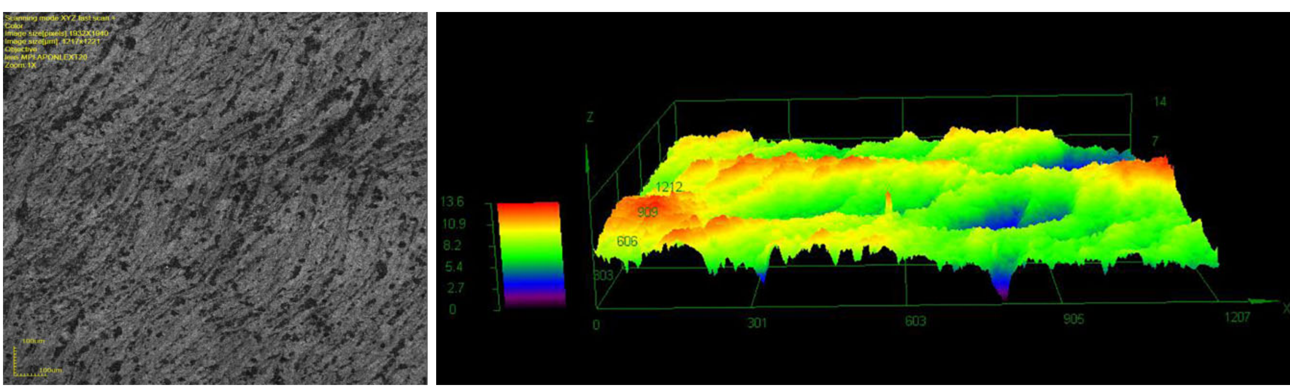

FIGURE 2. Group 1—Lava Ultimate (3M ESPE) baseline, no surface polishing. Surface as milled by the diamonds in the MCXL milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–14 µm.

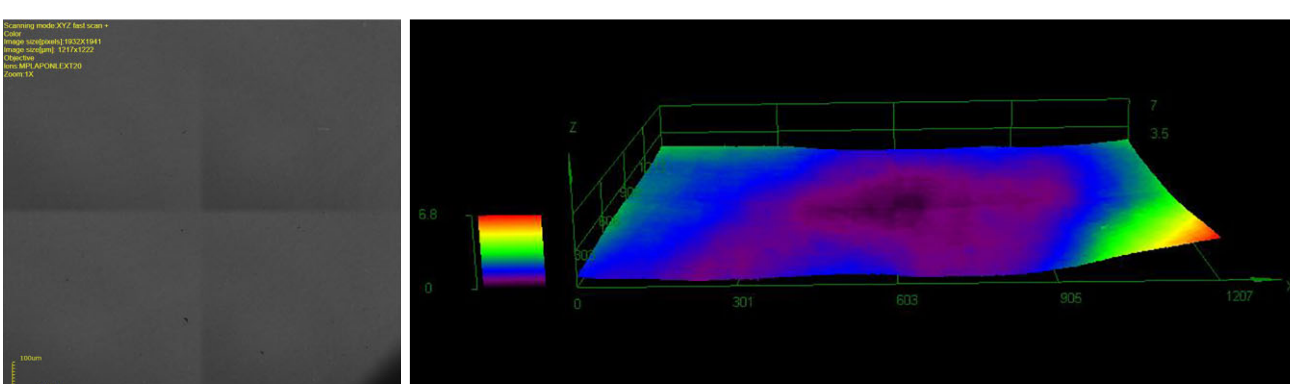

FIGURE 3. Group 2—Lava Ultimate (3M ESPE) VH Technology polishing technique. Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–7 µm.

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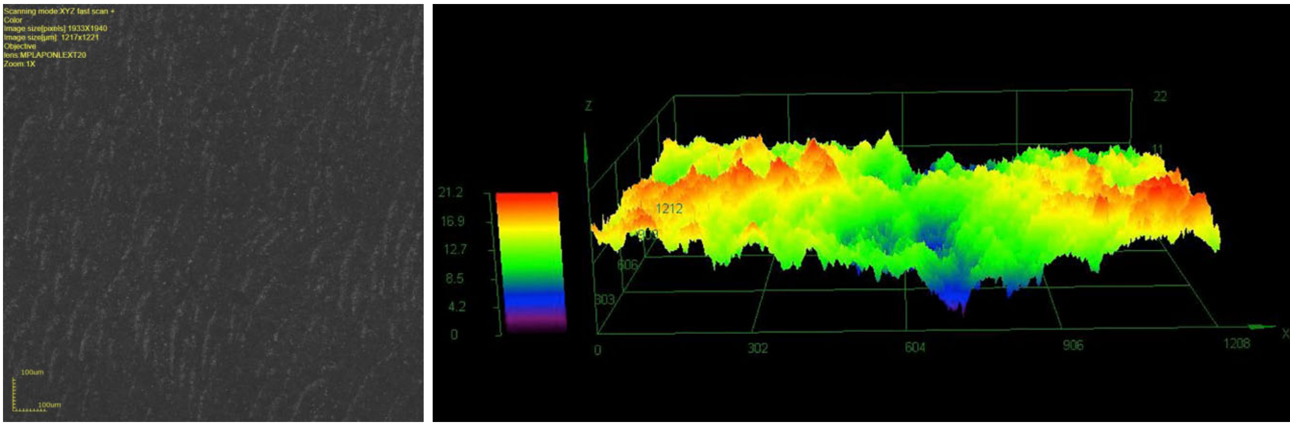

FIGURE 4. Group 4—Enamic (Vita) baseline, no surface polishing. Surface as milled by the diamonds in the MCXL milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–21 µm.

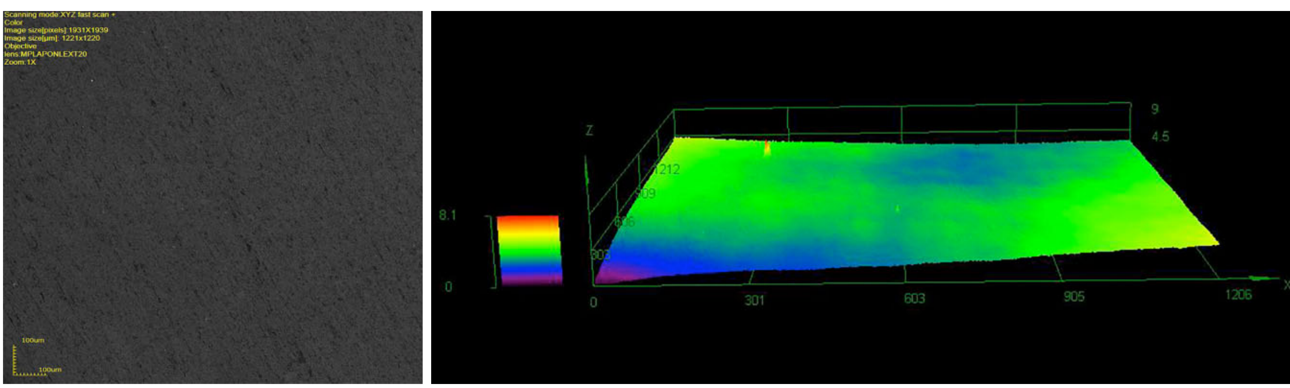

FIGURE 5. Group 5—Enamic (Vita) VH Technology polishing technique. Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–8 µm.

DISCUSSION

The surface smoothness of a material has been described in the dental literature using a number of parameters, generally from a surface profilometer. The most common measurement is Ra, the arithmetical average value of all absolute distances of the linear roughness profile.[18] An innovative surface measurement technique was used in this study. The 3D measuring laser microscope (OLS4000 LEXT by Olympus) expands on the more commonly used 2D profilometer measurements. A considerably larger surface area can be measured using the 3D measuring laser microscope, providing a more representative surface roughness measurement rather than combining multiple linear profilometer readings. The 3D measuring microscope also provides simultaneous high-resolution images of the surfaces that are measured, so recorded images are those of the actual measured surfaces.

Prior to the finishing and polishing procedures, it was necessary to create a baseline rough surface that would be comparable among all materials tested, as analyzed by 3D laser microscopy. However, establishment of the baseline roughness required considerable trial and error. The desired baseline surface was the surface roughness after a restoration had been milled in the MCXL milling chamber. The milling chamber has two 64-micron grit diamonds driven by two separate milling motors. The 12s step bur mills the intaglio surface of the restoration, and the 12s pointed cylinder diamond mills the external surface of the restoration. Several

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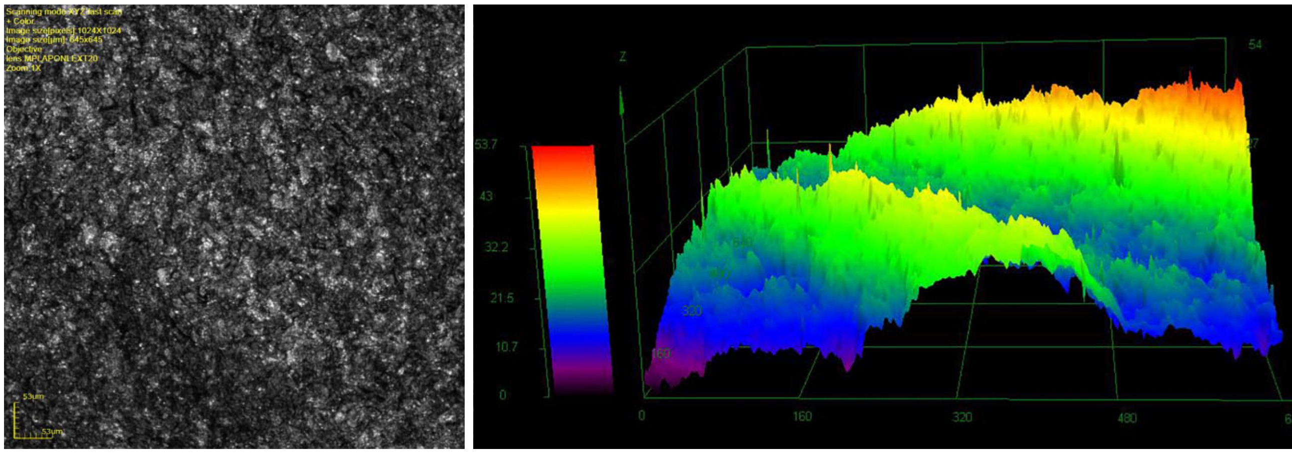

FIGURE 6. Group 7—EmpressCAD (Ivoclar Vivadent) baseline, no surface polishing. Surface as milled by the diamonds in the MCXL milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–55 μm.

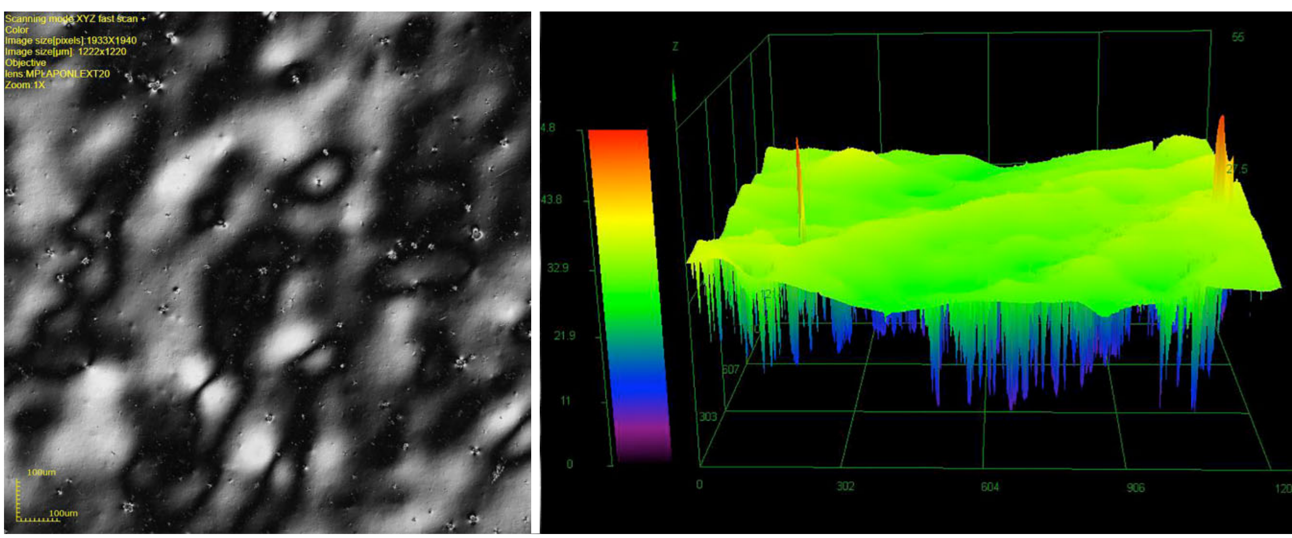

FIGURE 7. Group 8—EmpressCAD (Ivoclar Vivadent) glazed surface. Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–55 μm.

preliminary trials were made to replicate the surface roughness of the milling chamber by using a variety of grits of silicon carbide waterproof paper (Mayer Scientific, Dexter, MI, USA) in a specimen surface grinding and polishing machine (Forcimat, Micro Star 2000 Inc, Concord, Ontario, Canada). Due to differences in time and pressure application, this technique did not consistently replicate the desired roughness. Alternatively, a prototype onlay restoration was created on a typodont, so each sample could be milled by the MCXL milling chamber as would be done clinically.

Even though all samples were subjected to the same CAD/CAM milling instruments and process, there was a significant difference in the surface roughness of the CAD/CAM materials as the samples were removed from the MCXL milling chamber. This was not a surprising result as distinct categories of materials were tested. The materials used in this study have different crystalline structures: Lava Ultimate is a resin nano-ceramic material that combines aggregated zirconia and silica clusters and has no glass particles available for etching, whereas Enamic is a hybrid ceramic material composed of a dual network structure

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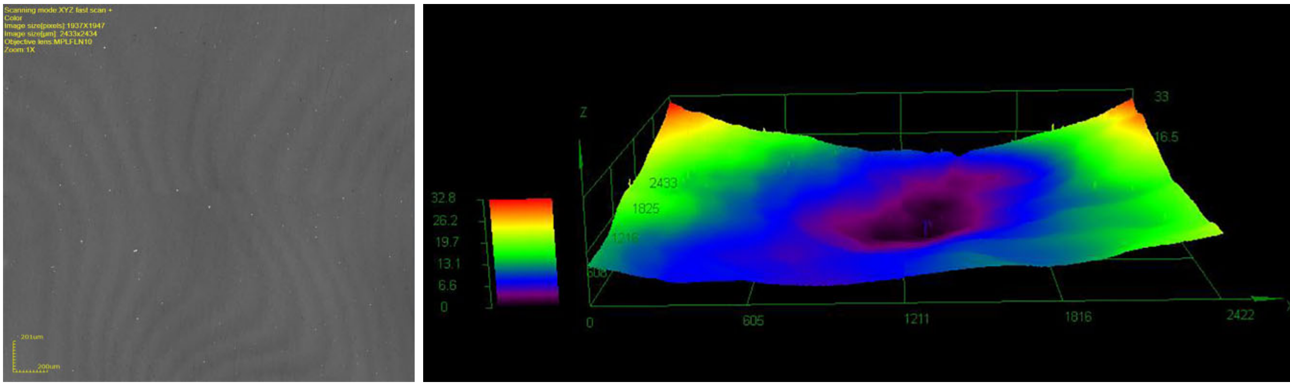

FIGURE 8. Group 9—IPS EmpressCAD (Ivoclar Vivadent) VH Technology polishing technique. Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–33 μm.

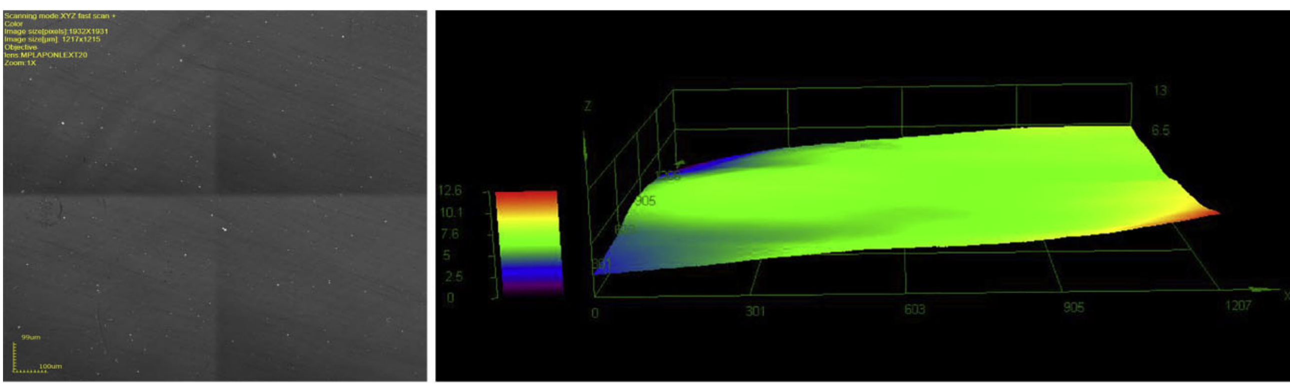

FIGURE 9. Group 10 – IPS EmpressCAD (Ivoclar Vivadent) Brasseler Dialite polishing kit technique. Left image = 2D surface image; Right image = 3D surface roughness laser image.

(ceramic and polymer) being 86% feldspathic porcelain by weight, and EmpressCAD is a leucite-reinforced glass ceramic. Despite the variation in baseline roughness values between materials, it was possible to achieve equally smooth surfaces for all materials with the tested polishing techniques.

An anecdotal finding of this study was that the use of the first contouring instrument was key to creating a smooth surface for polishing, as it was responsible for removing deeper groves and creating a finer surface texture that could easily be refined with the subsequent polishing steps. It is also noteworthy that all polished surfaces were significantly smoother than the positive control (glazed EmpressCAD samples). Glazed surfaces have traditionally been considered the "gold standard" and accepted as the smoothest surface possible to be achieved with ceramics; however, current literature agrees with the results of this study. A recent study compared surface roughness of CAD/CAM and conventional ceramic disks after polishing or glazing and concluded that manually polished CAD/CAM ceramics were statistically significantly smoother than glazed feldspathic ceramics.[19] In the current study, one explanation for this different result is that the EmpressCAD glazed surfaces were not finished prior to glazing, but instead were done using the "as-milled" surface. The first contouring instrument was critical to creating smooth surfaces and may have also contributed to a smoother glazed surface. This explanation is supported by a study indicating that surface roughness was reduced when specimens were polished prior to overglazing.[20]

Similar results were also reported for diamond polishers versus glazed surface on IPS EmpressCAD and Vita Mark II ceramic blocks in a study that tested different finishing and polishing systems.[21] The authors noted that even though the scanning electron micrograph (SEM) micrographs revealed homogeneous surfaces of glazed specimens, the profilometer readings revealed a much rougher surface than what was observed in polished samples. Lower Ra values were also reported when Soft-Lex disks (traditionally used to polish composite restorations) were used to polish the IPS EmpressCAD and Vita Mark II ceramic disks, despite the fact that SEM micrographs revealed slight scratches and plastic smear marks. The authors alerted to the fact that there can be obvious discrepancies between the profilometric roughness parameters and the qualitative assessment with SEM micrographs. The use of a 3D measuring microscope in this study demonstrated that the finishing/polishing process may cause undulations on the porcelain surface, as most of the finishing/polishing action was concentrated on the center of the sample. These undulations represented a technical artifact; however, they constitute a common finding after countering/polishing of smooth surfaces. The advantage of 3D measuring technology over 2D techniques is that a comprehensive mapping of the surface can be generated; therefore, measurements in areas of deep undulations can be prevented.

Few studies have looked specifically at resilient CAD/CAM restorative materials, as they are relatively new in the market. An in vitro study measured surface roughness of the newer CAD/CAM materials.[22] Lava Ultimate and Enamic specimens were roughened in a standardized manner and then polished with three different polishing systems. Surface roughness and microhardness were measured immediately after polishing and again after 6-month storage with monthly artificial toothbrushing. Their findings suggest that the surface of Enamic tends to be less affected by storage and artificial toothbrushing. It is noteworthy that the average Ra values reported for Lava Ultimate were lower than the values reported for Enamic, and this was consistent with the findings of the current study, even though no statistically significant difference was found between materials.

Although the brush/paste polishing technique (VH Technology) was able to create equally smooth surfaces compared with the abrasive rubber polisher systems for all three tested CAD/CAM materials, the brush/paste systems would seem to have a significant clinical advantage. The use of the abrasive rubber points or wheels would tend to flatten and remove surface anatomy, whereas the brush/paste system would tend to conform to the existing surface anatomy and result in less flattening of the desired surface contours while establishing a smooth surface. This in vitro project should be followed with a clinical study to determine the extent to which the smooth surfaces on flat specimens can be achieved on clinical anatomical surfaces.

CONCLUSIONS

Within the limits of this in vitro study:

The use of various finishing/polishing techniques on a leucite-reinforced ceramic CAD/CAM restorative material produced statistically significantly smoother surfaces when compared with glazed controls ($p < 0.05$).
It is possible to create equally smooth surfaces for the resilient chairside CAD/CAM materials as the chairside CAD/CAM ceramic using several finishing and polishing techniques.
No statistically significant difference was found between brush/paste and abrasive rubber polisher systems with a potential clinical advantage noted to the brush/paste system, as it is less likely to inadvertently flatten the porcelain surface.

DISCLOSURE AND ACKNOWLEDGEMENTS

The authors do not have any financial interest in the companies whose materials are included in this article. Neither of the authors have any conflict of interest related to this manuscript. This study was supported by a research grant from VH Technology.

 DOI 10.1111/jerd.12174 © 2015 Wiley Periodicals, Inc.

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