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Surface Evaluation of Resilient CAD/CAM Ceramics after Contouring and Polishing

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Abstract:

Objective: This *in-vitro* study measured the differences in surface roughness for CAD/CAM resilient ceramic and CAD/CAM composite materials.

Materials & Methods: The materials included Lava Ultimate (3M), Cerasmart (GC America), Vita Enamic (Vita Zahnfabrik), and Brilliant Crios (Coltene). One calibrated operator polished each material with 3 polishing sytems: spiral polishers (Diacomp FeatherLite/Brasseler), rubbercup polishers (Enhance/DentsplyCaulk), and brush-paste (Diashine/VH Technologies). Surface roughness was assessed using a confocal laser microscope (Lext OLS4000/Olympus).

Results: A two-way ANOVA revealed statistically significant differences in mean surface roughness values (Sa) among materials and polishers. Tukey multiple comparisons showed that mean Sa values for Lava Ultimate, Enamic, Cerasmart and Brilliant Crios polished with brush-paste as well as Lava Ultimate and Cerasmart values polished with spiral polishers were not significantly different from each other.

Conclusions: The finished surfaces were significantly smoother than milled surfaces for all materials. The brush-paste polishing technique created the lowest surface roughness values for all CAD/CAM materials and values were comparable to what was achieved by spiral polishers for Lava Ultimate and Cerasmart. Rubber polishers did not provide a clinically smooth surface for CAD/CAM resilient ceramic/composite materials.

Clinical Significance: The results of the study indicate that polishing creates smooth surfaces for CAD/CAM resilient ceramic and CAD/CAM composite restorations.

MeSH Keywords:	CAD/CAM	Hybrid ceramics
	Resilient ceramics	Polishing
Other Keywords:	Resin composite CAD/CAM	Chair-side CAD/CAM

INTRODUCTION:

Over the past three decades, the dental community has witnessed the increasing popularity of Computer Assisted Design/Computer Assisted Manufacturing (CAD/CAM) applications for same-day esthetic restorations. The increase in demand for high-quality esthetic restorations has sustained the search for fabrication techniques that are more efficient and produce outcomes that meet the expectations of the patients.[1] It is possible to complete an esthetic ceramic restoration within a single appointment and this has been made possible by the availability of novel dental materials, the advancements in computer technology as well as more capable digital equipment. This improves efficiency by removing the need for a second appointment strictly to deliver the restoration saving both the clinician and patient time.

The materials used to make the CAD/CAM restorations must have physical and mechanical properties that allow for rapid milling, are resistant to machining damage, easily finished before placement, and, finally, must be functionally stable.[2] In dentistry, restorative materials used to make dental crowns using CAD/CAM systems can be placed into five categories. These are high-strength ceramics, glass ceramics, resilient ceramics, zirconia, and composite materials. Table 1 provides a list of chairside CAD/CAM materials available on the market.[3]

The term resilient ceramic has been used to describe CAD/CAM materials that attempt to mimic the esthetic potential of ceramic materials but without the brittleness of ceramics. They have a resin-based component as well as ceramic fillers. In addition to an improved brittleness index, resin-based materials are also easier to handle during both machining and delivery processes. Resilient ceramics may be further described as nanoceramics (Lava Ultimate and Cerasmart), polymer-infiltrated ceramic network materials (PICN; Vita Enamic). A major advantage of these novel materials is that, when compared to glass ceramics, they have a greater flexural strength and lower modulus of elasticity.[4] Though they wear at a greater rate than ceramic materials, they tend to cause less wear to the opposing dentition, an important attribute if the opposing dentition is unrestored.[5] Furthermore, the risk of fracture and chipping (better machinability) is considerably less for these novel materials reportedly because their Young moduli, a mechanical property concerned with quantifying the stiffness of solid material, are almost equivalent to that of dentin.[6-8]

As dentists increasing incorporate chairside CAD/CAM technology into their practices, it is important to appreciate that the entire fabrication and finishing process must be completed in the dental office. Chairside CAD/CAM systems require a subtractive milling process using diamond burs to manufacture the restorations. The milling process results in a relatively rough restoration surface that must be finished before restoration delivery.[9] Failure to properly finish the surface may promote the retention of a microbial film and, if the improperly finished material is situated close to the gingival area, inflammation of the periodontal tissue may occur, an adverse oral health outcome that impacts negatively on the quality of life of the patient.[10,11] Restorations should have smooth surfaces to minimize abrasive wear of the opposing dentition, inhibit discoloration, and, if the abrasive surface is located on the occlusal surface, it may result in wear of the opposing dentition.[12-15]

The hypothesis is there will be a statistically significant difference in surface roughness among various resin-ceramic hybrid CAD/CAM materials after chairside milling and polishing with different polishing systems. A number of studies have evaluated the ability of different techniques and materials to produce restorations with the desired surface roughness. An increase in surface roughness above $R_a = 0.2$ μm can substantially increase plaque accumulation with increase caries and periodontal inflammation.[10] Generally, it has been shown that hand polishing creates a smoother surface compared to oven glazing and is a better approach than reglazing a glazed surface requiring adjustment.[16-20] One recent study concluded that surfaces of manually polished CAD/CAM ceramics are smoother compared to glazed feldspathic ceramics.[21] This may be related to the filler particles that in addition to contributing better physical and mechanical properties to the material and protecting the organic matrix against the force applied to the restoration, they directly influence surface properties such as smoothness and surface gloss.[22, 23,24] Smoother polishing outcomes are therefore realized on resin-based dental materials when an abrasive tool removed the resin matrix and cut the relatively harder filler particles.[25] There are few studies discussing the effect of milling and post-milling procedures on CAD/CAM materials.[18,26,27] This *in-vitro* study is to measure the surface roughness of resin-based CAD/CAM resilient ceramics using several alternate polishing materials and techniques.

MATERIALS & METHODS:

Three resilient CAD/CAM ceramics and one CAD/CAM composite material were used in the study (Table 2). To standardize the samples, a novel technique reported by Fasbinder et.al was utilized.[7] A mandibular molar ivorine tooth was prepared for a full coverage ceramic onlay on a typodont with flat preparation without proximal boxes. The oval-shaped samples measured 14 x 12 mm in diameter with a thickness of 4mm. The preparation was imaged and designed using a CEREC OmniCam with 4.5 software (Dentsply Sirona) using Biogeneric mode (Figure 1). The intaglio surface of the restoration provided a flat, milled surface replicating the surface of milled restorations. The flat surface was used for the test surface. One hundred forty-four onlays were milled from monolithic CAD/CAM blocks using an MCXL milling unit (Dentsply Sirona) at standard speed for chair-side CAD/CAM restorations. Sample size calculation yielded a total of 36 samples (12 per group, n=144) for a difference in means of 0.5 with an expected standard deviation of ± 0.05. Significance level was set at 5% and statistical power at 80%. Previous studies of surface roughness have detected significant differences using similar sample size.

Immediately after milling, baseline measurements were made for 12 samples from each group. This was followed by contouring the surface of all samples using an electric straight hand-piece mounted contour wheel (Brasseler product #5021292U0) with a speed of 10,000 RPM for 40 seconds using moderate pressure. The samples were then divided into 3 groups based on the surface treatment (Table 3). All the samples were polished using the polishing instruments and instructions recommended by the respective manufacturers (Table 3). The polishing of all samples was done by the same calibrated operator using a low-speed contrangle hand-piece (Brasseler product #A2504754) and a straight electric handpiece (Brasseler product #5021292U0). The same electric motor and straight handpiece were used to control the rotation speed for each step and each contouring and polishing step in the sequence was performed for 40 seconds.

Prior to surface measurement, all oil or debris was cleaned off the onlays. This was achieved by first cleaning the samples with soap and water followed by a 10 minutes ultrasonic bath in distilled water. All samples were thoroughly dried. Two different surface roughness parameters, Sa and Sq, were assessed using a three-dimensional (3D) laser microscope (OLS4000 LEXT by Olympus, Center Valley, PA, USA). Sa (arithmetic mean height) is a 3D roughness parameter which can be viewed as an expansion of the (2D) parameter Ra. It (Sa) expresses the mean of the non-negative values of Z (x,y) in the measured area. It is comparable to the arithmetic mean of the measured area on the 3D display diagram after valleys have been transformed to peaks by conversion to non-negative values. Sq is a 3D parameter derived from the Rq roughness parameter which is 2D. It represents the root mean square of Z (x,y) in the measured area. This parameter corresponds to the average mean square of the measured area on the 3D display after valleys are transformed to positive values by squaring. All measurements are made at a magnification of 20X under laser light microscope. The field of recording on the center of the sample was measured at 625 μm × 625 μm. It must also be appreciated that higher magnification imaging has small visual field range, and to address this limitation, advanced image stitching was utilized. This technique allowed the computer to combine four adjacent areas measured separately into a single arithmetic mean effectively creating a wider field view measuring 1.2 mm × 1.2 mm. In addition to capturing the arithmetic means, the visual images of the surfaces were also captured for qualitative assessment of surface roughness.

Means and standard deviation for surface roughness were calculated for each group. Data was analyzed using the calculated Pearson’s correlation coefficient for Sq and Sa values to determine if Sq and Sa were highly correlated. A two-way ANOVA (Analysis of variance) revealed a statically significant difference in mean 3D roughness values (Sa) among materials and polishers. Therefore, further analysis (Tukey) was needed to identify where the differences were. All statistical analysis was conducted at a significance level of $P < 0.05$ (<2e-16).

RESULTS:

The means and standard deviation for surface roughness at baseline, and after finishing and polishing, are presented in Table 4. Statistically significant differences in surface roughness were found at baseline between CAD/CAM materials ($P < 0.05$). All four materials presented unique surface patterns after milling. The calculated Pearson's correlation coefficient for Sq and Sa values demonstrate that Sq and Sa are highly correlated, with RA = 0.999 (correlation coefficient) and highly significant p-value (<0.05). There was no statistically significant difference in the Sa and Sq values, therefore they can be used interchangeably, and we elected to use Sa in the study (Table 4).

ANOVA for both Sa and Sq revealed a highly significant p-value ($p = <0.0001$) for the interaction between "ceramic" and "polisher" and a statistically significant difference in mean 3D roughness values (Sa) among materials and polishers. A Tukey's Test multiple comparison test was applied at 0.05 significance level to determine statistically significant differences between polishing sequences and materials. Statistically significant differences were found between CAD/CAM materials and contouring/polishing sequences ($p \leq 0.05$).

The subtractive milling procedure resulted in a significantly increased surface roughness after removal from the MCXL milling chamber for all materials ($p \leq 0.05$). The composite resin block, Brilliant Crios (BC) was significantly smoother at baseline than Lava Ultimate (LU), Enamic (EN), and Cerasmart (CS). All polishing techniques resulted in smoother surfaces compared to baseline surfaces for the resilient ceramics ($p \leq 0.05$) (Table 4). Rubber cup polishers (RC) provided statistically significant difference in surface roughness for LU compared to BC, EN, CS. These values were statistically significantly higher than the other polished surface roughness values in the study, therefore these surfaces were the roughest. Spiral polishers (SP) provided a smooth surface for Cerasmart (CS). There was statistically significant difference between spiral polishers and rubber cup polishers for Lava Ultimate (LU), Enamic (EN) & Brilliant Crios (BC) ($p \leq 0.05$) (Table 4). Despite the lower surface roughness obtained with BP, there was no significant difference between SP and BP for Lava Ultimate and Cerasmart according to Tukey test. There were statistically significant differences between baseline, rubber cup polishers (RC) and spiral polishers (SP) for LU, BC, EN, CS. ($p \leq 0.05$) (Table 4).

A laser microscope (OLS4000 LEXT by Olympus, Center Valley, PA, USA) was used to record both 2D and 3D images as qualitative examples of the surface roughness. One advantage of the laser microscope is that while the 2D image shows the relative surface appearance of the measured areas, the three-dimensional images offer a more accurate surface topography of the samples that are measured. At baseline, all samples appear extremely rough with low gloss. (Figures #2 - 5) After surface treatment, all surfaces improve but samples polished with rubber cup and spiral polishers appear smooth to naked eye but rough microscopically. (Figures #6 – 9) A smooth, homogenous surface finish with high gloss are seen with samples polished with both the spiral polishers (SP) and brush-paste techniques (BP) (Figures #10 – 17).

DISCUSSION:

The purpose of this in-vitro study was to evaluate the surface roughness of newer resin-based CAD/CAM materials following milling and post-milling processing. There was a significant difference in material surface roughness after both milling and surface contouring/polishing. Thus, the null hypothesis was rejected.

Finishing a restoration can be thought of as two distinct steps. Contouring involves efficient modification of the restoration contour and removing surface defects. Polishing involves creating an esthetic, light-reflective luster.[24,25] The critical threshold surface roughness for bacterial adhesion has been reported to be 0.2 μm[10], so creating a surface finish smoother than this critical threshold becomes a priority. Several laboratory studies have focused on ceramic polishing, and there is little data available for the new resin-based materials.

Surface roughness of a restorative material is determined by the microstructure produced by the series of mechanical processes used to modify the surface.[23] Many studies on surface roughness have indicated that it is influenced by several factors such as the type, concentration, form, and quantity of inorganic particles in the material in question. Surface roughness, usually measured using confocal laser scanning microscopy or tactile profilometry, as indicated by R_a is a popular and useful metric in dentistry.[28,29] However, it must be noted that different techniques for tactile profilometry exist and, consequently, they may produce different R_a values making direct comparisons difficult. The utility of the mechanical profilometer, the most common method used to measure surface roughness due to its widespread availability and lower cost, is limited by factors such as the spatial dimension of the stylus, sampling rate, measuring force, and by the calibration in the z-axis.[30] Some investigators consider tactile profilometry "adequate" for studying rough surfaces, but others have reservations on its appropriateness in microtopography work.[31]

The limitations of the tactile profilometer discussed above are partly resolved by using a 3D measuring laser microscope (Lext, Olympus, OLS4000). This technology (3D laser) can measure surface roughness over a considerably larger area if compare to tactile profilometry and gives a more accurate representation of surface roughness measurement without relying on combining linear profilometer readings.[32] In addition to giving a more accurate measure of surface roughness, a 3D laser microscope also produce high-resolution images of the surfaces being measured. In this study, two parameters were measured using laser interferometry; Sq (root mean square roughness) and Sa (average roughness). They give a three-dimensional measure of the surface area. A comprehensive map of the restored surface is generated using 3D techniques, a feat not achieved by 2D techniques. Most researchers are content with measuring the Sa parameter, defined as the average of the non-negative values of the surface departures above and below the mean plane within the sampling area, although this approach provides limited information on the restored surface outline. More importantly, relying on the Sa only may result in one arriving at misleading conclusions. In this study, it was discovered that the Sa values were highly correlated to Sq values and as such, only Sa values were used in this study. The most sensitive parameter in material discrimination was used for selecting the parameter to represent the group and this parameter was found to be Sa. Sa quantifies the “absolute” magnitude of surface heights and the most sensitive parameter on the pair-wise material discrimination at the microscale.[33]

Baseline surface roughness values for all samples were measured and recorded following the subtractive milling process. A smoother post-milling surface would be preferable because it may be expected to be easier to create the desired smooth surface. In this study, all samples were milled using an MCX milling chamber (Dentsply Sirona). Significant differences were observed in surface roughness of the samples made from different materials but fabricated using the same CAD/CAM milling instruments. The probable explanation for this observation is that resin-based ceramics contain smaller sized particles, higher filler content, individual material properties or milling strategies that may lead to rougher surfaces.[34]

Several studies have reported that though various finishing and polishing techniques can be used to produce surfaces with acceptable smoothness for both leucite reinforced ceramic and resin-based ceramics, polishing procedures including instruments with diamond abrasive particles have better performance.[7] When polishing steps are applied sequentially using diamond paste it will decrease the surface particle size to achieve a smooth finish. The contouring step is critical to create a smooth surface for polishing, as it is responsible for removing deeper groves and creating a finer surface texture that could easily be refined with the subsequent polishing steps.[35] Therefore, we used the same contouring wheel as a first step to be consistent in simulating the removal of the sprue after milling

A difference in surface roughness exists between resilient ceramics after chairside polishing using different polishing techniques. A recent study reported that although Brilliant Crios and Cerasmart have similar composition but exhibited different surface roughness after polishing. This is due to filler quantity and size.[36] In addition, a difference in shape of the filler which is more rounded and medium fillers for CS and angular shape for BC. This difference in BC is attributed to a balanced mixture of small (Approx. 20nm) and medium filler (approx. 1µm) in resin composite. [34,35,37,38] In the current study, it was demonstrated that, for resilient CAD/CAM material, smoother surfaces can be achieved using the BP technique as well as spiral polishers (SP) than with rubber cup polishers (RC) (Figure 6 -17). In addition to smoother surfaces, BP and SP potentially have other clinical advantages. For instance, these methods can create smooth surfaces without extensively transforming the existing surface anatomy or flattening surface contours. The most consistent method for producing a smooth finish was observed to be the brush-paste (BP) technique. This approach uses a series of increasingly smaller diamond grit pastes with rotating bristle brushes to finish the surface of the restoration materials.

Another technique that is used in polishing dental surfaces is to use rubber point polishers that consists of a rubber-like, flexible bonded abrasive finishing point with silicon dioxide, aluminum oxide, and polymerized urethane dimethacrylate resin and is used for contouring and initial finishing of the restoration as well as the final polishing using a 0.3 µm aluminous oxide polishing paste. The purpose of including the diamond paste is to enhance the smoothness of the restoration by progressively reducing the particle size of the abrasive.[39] Though rubber point polishers improved smoothness of the resilient ceramics when compared to the newly milled surface, they did not create similarly smooth surfaces of resin-based ceramics when compared to other polishing techniques. This may be due to the abrasive grinding the softer matrix and only able to round the protruding filler particles leading to greater surface roughness.[40,41] Rubber cup polishers have been observed to result in surfaces with high smoothness when used for direct composite resin restorations. However, for resin-based ceramics, there were not as effective in creating smooth surfaces for milled ceramics (Figure 18).

Spiral polishers are diamond-impregnated rubber, reusable polishing system. Spiral polishers produced a lower surface roughness value only for a nanoceramic (Cerasmart). They are popular for polishing on occlusal surfaces and they are designed to adapt to different surfaces with excellent flexibility. A study compared the surface roughness of four different porcelains with different surface treatments such as glazing, polishing with discs, wheels with and without paste. Rubber wheels or sandpaper discs did not produce surfaces as smooth as glazing. Porcelains with lower leucite content tended to present lower roughness compared to those with higher leucite content after being polished with rubber polishers or discs followed by diamond pastes. The study concluded that microstructure and leucite content plays a role in surface roughness.[42]

Additional studies are needed to determine if clinicians can predictably create similarly smooth surfaces on clinical geometry rather than flat surfaces and how long the gloss may be retained intra-orally.

CONCLUSION:

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

1. Statistically significant differences in mean surface roughness exist after milling and polishing. Brilliant Crios, a composite resin had the lowest surface roughness value after milling compared to the resilient ceramics; Lava Ultimate, Cerasmart and Enamic.
2. Rubber cup polishers did not create a clinically smooth surface finish for CAD/CAM resilient ceramic/composite materials.
3. The brush-paste polishers provided the lowest surface roughness value for all groups of resilient ceramics (Lava Ultimate, Cerasmart and Enamic) and a resin-hybrid ceramic (Brilliant Crios) when compared with post milling.
4. Spiral polishers created a smother surface finish for Cerasmart and Lava Ultimate compared to Enamic and Brilliant Crios.

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Table 1: Chairside CAD/CAM Materials

Category	Composition	Brand Name
Glass Ceramics	Feldspathic porcelain	Vitablocs Mark II (Vita Zahnfabrik) Sirona blocs (Dentsply Sirona)
	Leucite reinforced	IPS Empress CAD (Ivoclar Vivadent)
High Strength Ceramics	Lithium Disilicate	IPS e.max CAD (Ivoclar Vivadent)
	Zirconia reinforced lithium silicate	Celtra Duo (Dentsply Sirona) Suprinity (Vita)
Zirconia	Polycrystalline	Cerec Zirconia (Sirona) Katana Zirconia (Katana) Chairside Ziroconia (3M) ZirCAD (Ivoclar Vivadent)
Resilient Ceramics	Nano ceramic	Lava Ultimate (3M) Cerasmart (GC America)
	PICN	Enamic (Vita Zahnfabrik)
Composite Resin	Cross-linked methacrylates/ Reinforced resin composite HT (Bis-GMA, Bis-EMA, TEGDMA)	Brilliant Crios (Coltene) Paradigm MZ 100 (3M ESPE)

Table 2: Materials

CAD/CAM Materials		**Manufacturer**	**Composition**		
			Monomer	**Filler**	**Mass %**
Nano-ceramic	Lava Ultimate (LU)	3M	Bis-GMA, UDMA, Bis-EMA, TEGDMA	SiO_2 (20 nm), ZrO_2 (4-11 nm), aggregated ZrO_2/SiO_2 cluster (0.6 – 10 µm)	80
	Cerasmart (CS)	GC America	Bis-MEPP, UDMA, DMA	Silica (20nm), barium glass (300 nm)	71
PICN	Vita Enamic (EN)	Vita	UDMA, TEGDMA	SiO_2, AlO_3, NaO_3, CaO2, Zirconia, KO2 & boron oxide	86
CAD/CAM Composite	Brilliant Crios (BC)	Coltene	Resin matrix cross-linked with methacrylates	Barium glass+ Amorphous silica + inorganic fillers	71

Table 3: Contouring and polishing techniques

	Spiral Polishers (SP) (FeatherLite by Brasseler)	**Rubber Cup (RC) (Enhance Points by Dentsply Caulk)**	**Brush/Paste (BP) (DiaShine by VH Technology)**
Contouring Sequence	Grey polishing wheel - BH 100B, rubber-reinforced sintered diamond wheel - 10,000 rpm for 40 secs using straight handpiece.		
Polishing Sequence	Green – medium grit at 10,000 rpm for 40 secs using latch low speed handpiece	Finishing points 40-µm aluminum oxide at 10,000 rpm for 40 secs using latch low speed handpiece	Super fine (Pink) diamond paste with soft Robinson brush at 10,000 rpm for 40 secs using straight handpiece. Re-application of product at 20 sec.
	Grey – fine grit at 4,000 rpm for 40 secs using latch low speed handpiece	Finishing points 40-µm aluminum oxide with diamond polishing paste at 10,000 rpm for 40 secs. Re-application of product at 20sec.	Super fine soft (grey) diamond paste with medium Robinson brush at 10,000 rpm for 40 secs using straight handpiece. Re-application of product at 20sec.

Table 4: Results

	LavaUltimate	Enamic	Cerasmart	BrilliantCrios
Baseline	0.46 ± 0.05[a]	0.67 ± 0.06[b]	0.79 ± 0.04[c]	0.27 ± 0.02[e]
RC	0.36 ± 0.02[d]	0.29 ± 0.03[e]	0.25 ± 0.07[e]	0.26 ± 0.04[e]
SP	0.09 ± 0.01[f, g]	0.12 ± 0.01[g]	0.04 ± 0.01[f]	0.13 ± 0.01[g]
BP	0.04 ± 0.00[f]	0.05 ± 0.00[f]	0.05 ± 0.01[f]	0.05 ± 0.00[f]

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

Figure 1: CAD/CAM design of the onlay preparation and the flat intaglio surface used for sample fabrication.

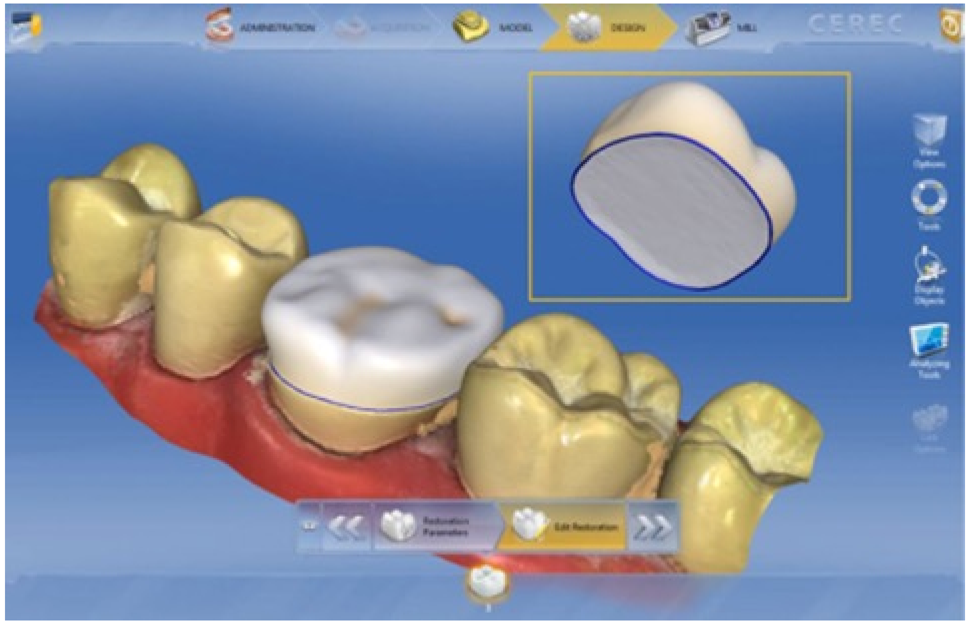


Figure 2: Lava Ultimate (LU) baseline. Surface as milled by diamonds in the MCX milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–30 µm.

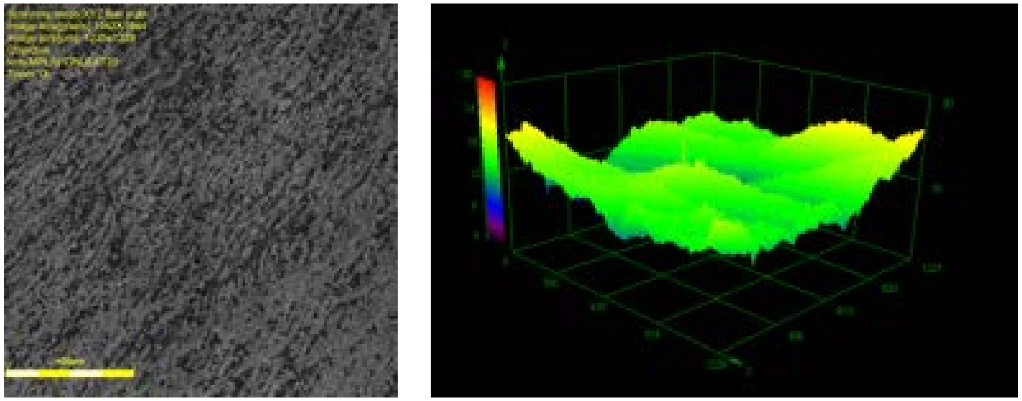


Figure 3: CeraSmart (CS) baseline. Surface as milled by diamonds in the MCX milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–15 µm.

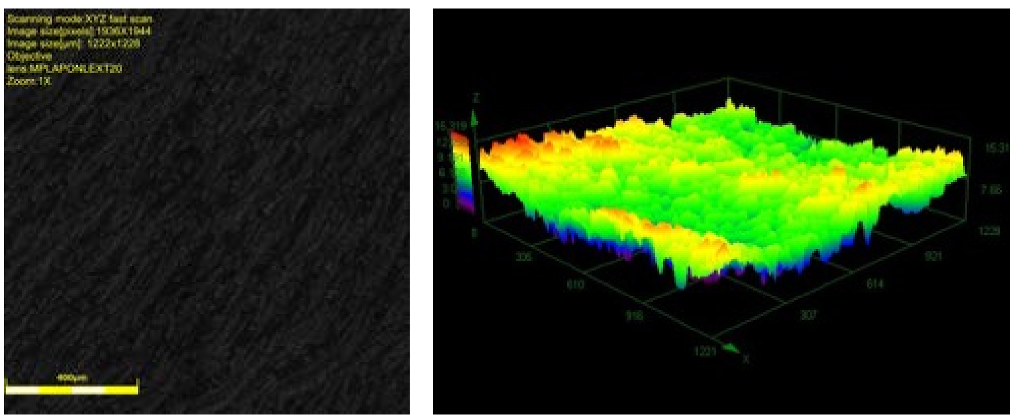


Figure #4: Brilliant Crios (BC) baseline. Surface as milled by diamonds in the MCX milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–30 µm.

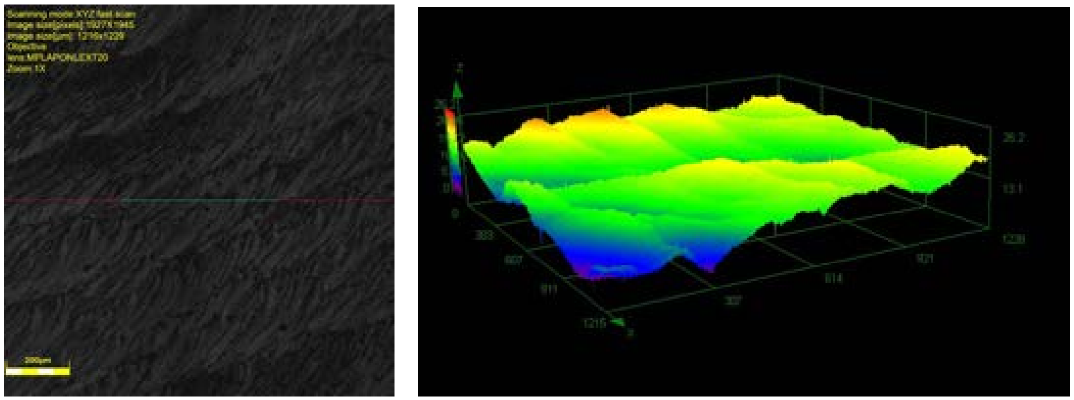


Figure #5: Enamic (EN) baseline. Surface as milled by diamonds in the MCX milling chamber (Sirona Dental). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0–30 µm.

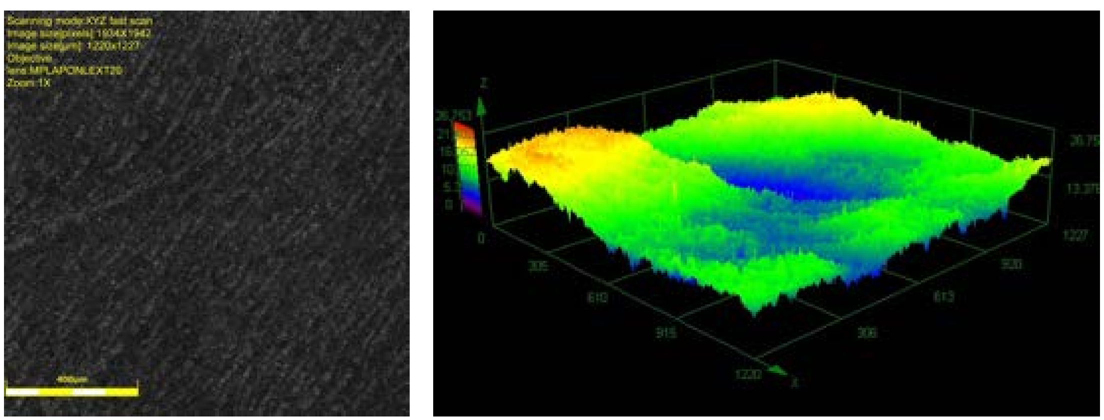


Figure 6: Lava Ultimate (LU) polished with rubber cup (RC). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 - 15 µm.

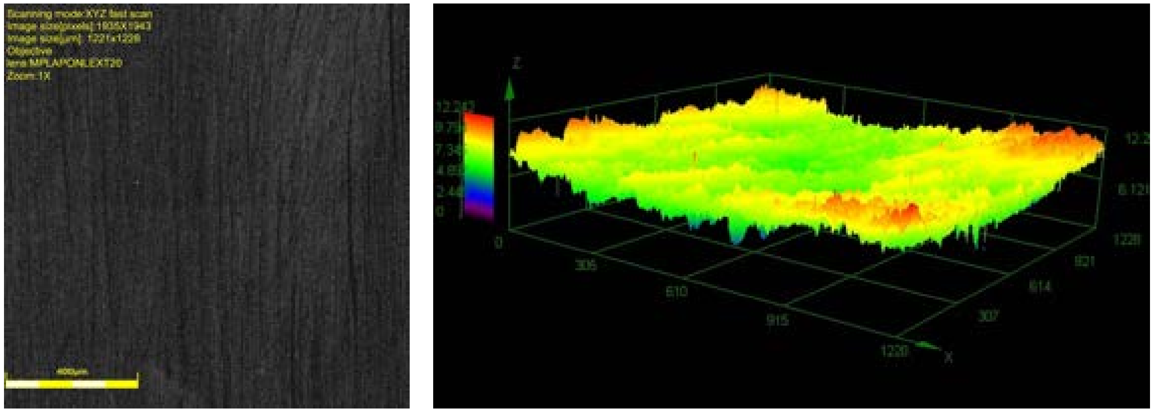


Figure 7: CeraSmart (CS) polished with rubber cup (RC). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 15 µm.

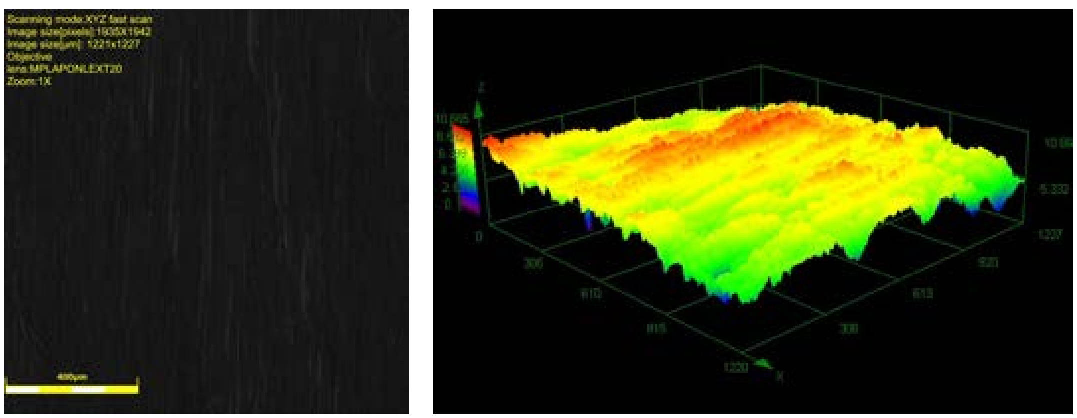


Figure 8: Brilliant Crios (BC) polished with rubber cup (RC). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 15 μm.

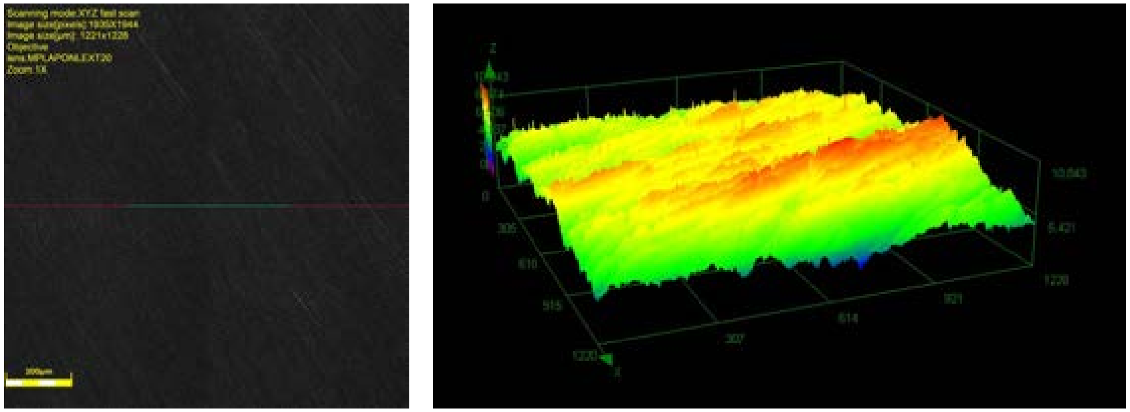


Figure 9: Enamic (EN) polished with rubber cup (RC). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 10 μm.

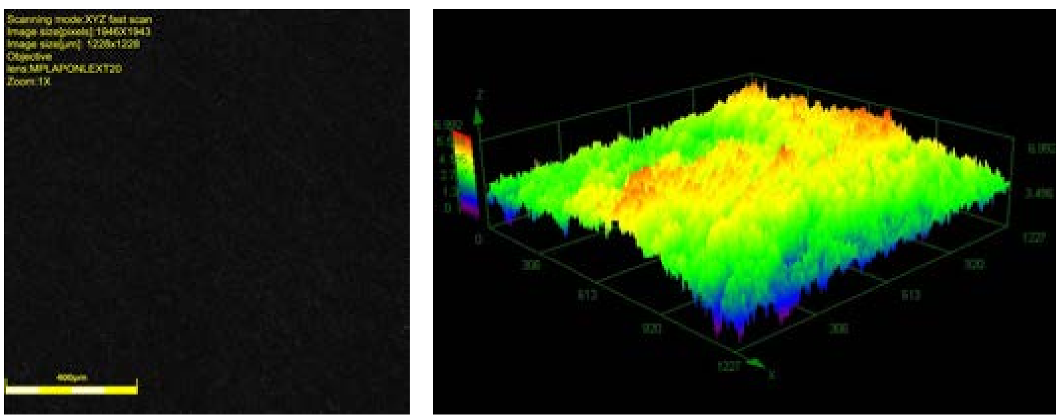


Figure 10: Lava Ultimate (LU) polished with spiral polishers (SP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 30 μm.

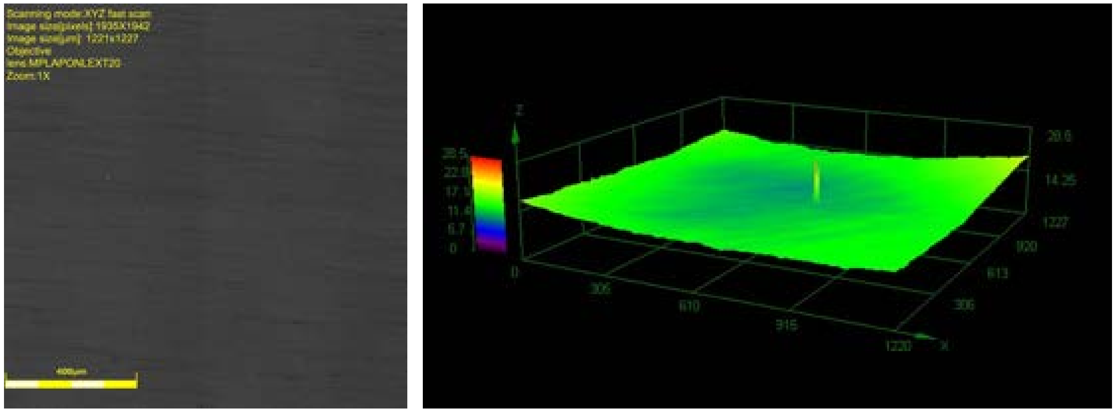


Figure 11: Lava Ultimate (LU) polished with brush paste (BP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 10 μm.

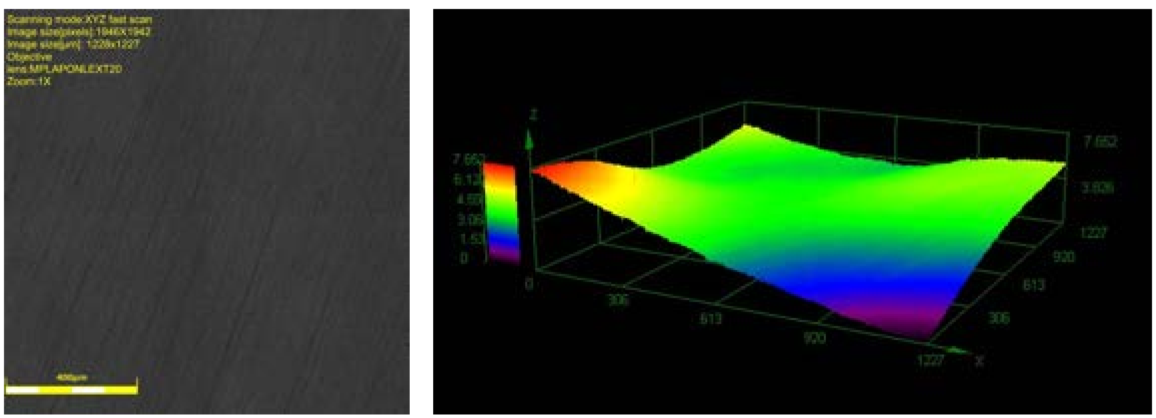


Figure 12: CeraSmart (CS) polished with spiral polishers (SP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 30 µm.

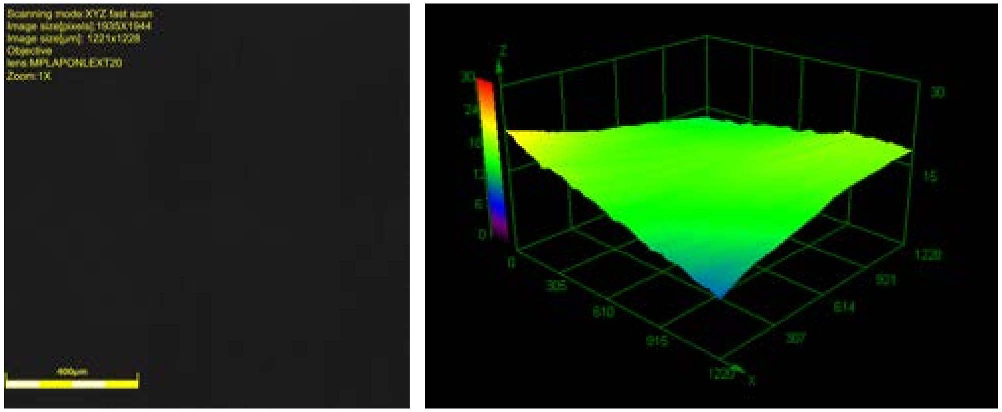


Figure 13: CeraSmart (CS) polished with brush paste (BP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 10 µm.

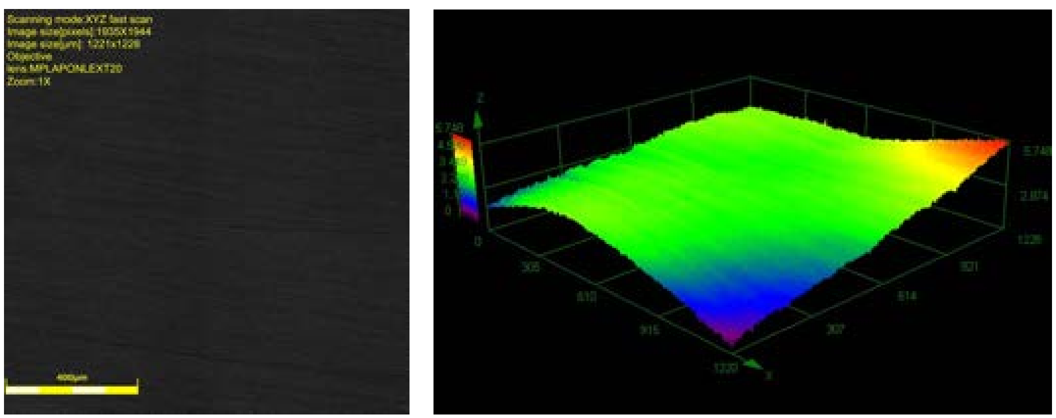


Figure 14: Brilliant Crios (BC) polished with spiral polishers (SP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 15 µm.

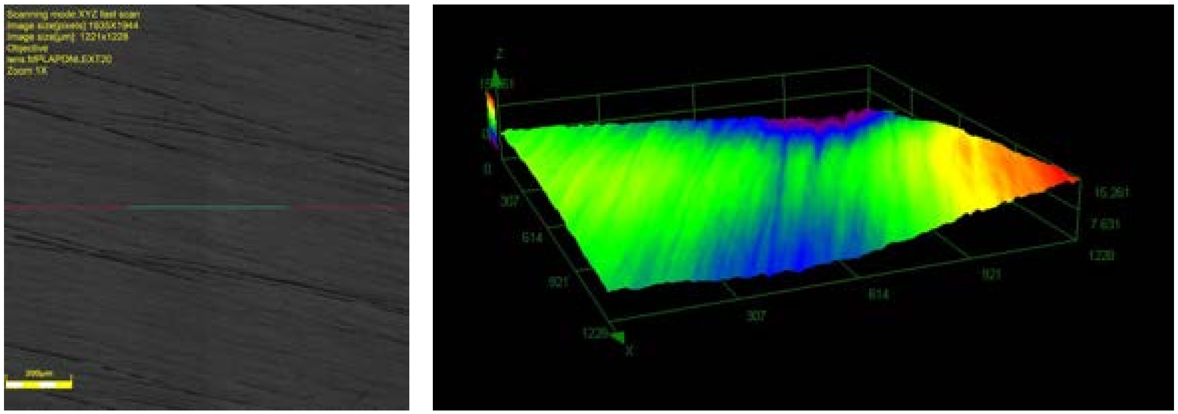


Figure 15: Brilliant Crios (BC) polished with brush paste (BP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 30 µm.

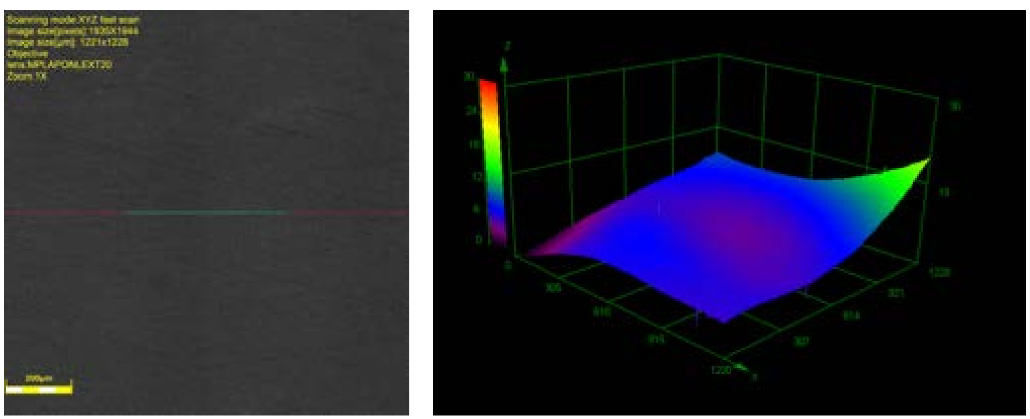


Figure 16: Enamic (EN) polished with spiral polishers (SP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 15 µm.

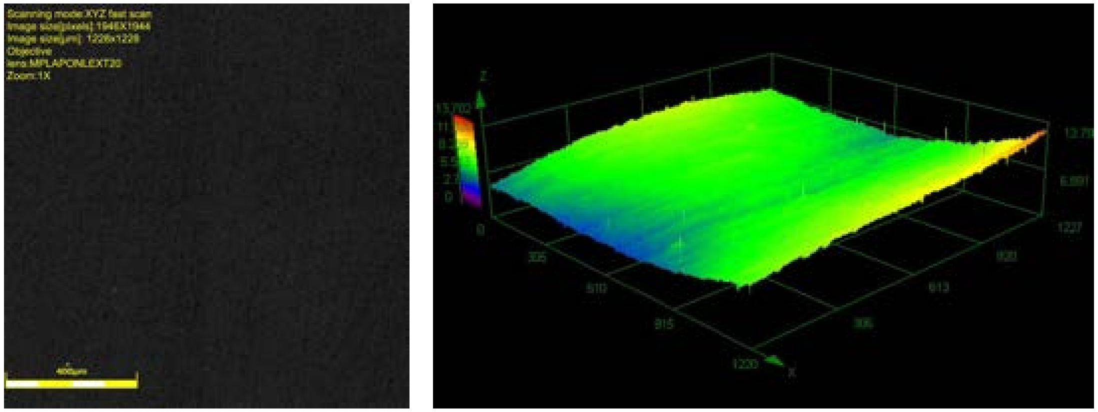
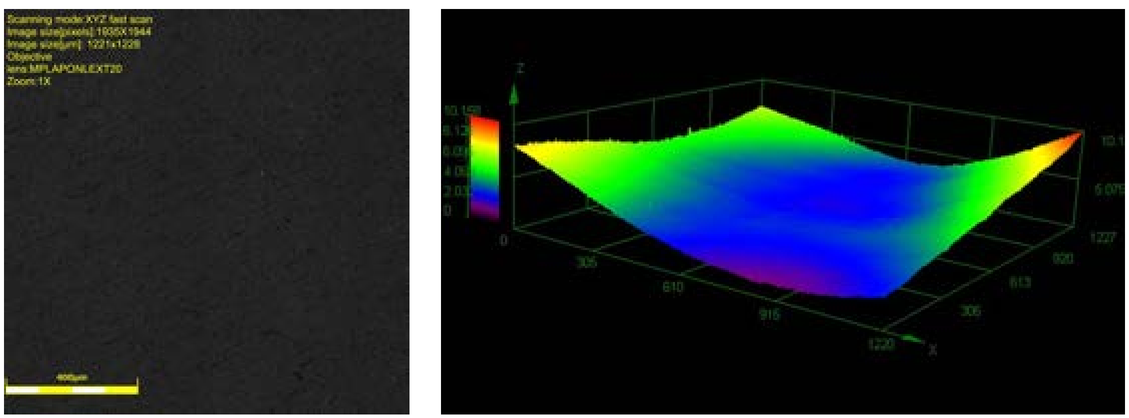


Figure 17: Enamic (EN) polished with brush paste (BP). Left image = 2D surface image; right image = 3D surface roughness laser image with a scale of 0 – 10 µm.



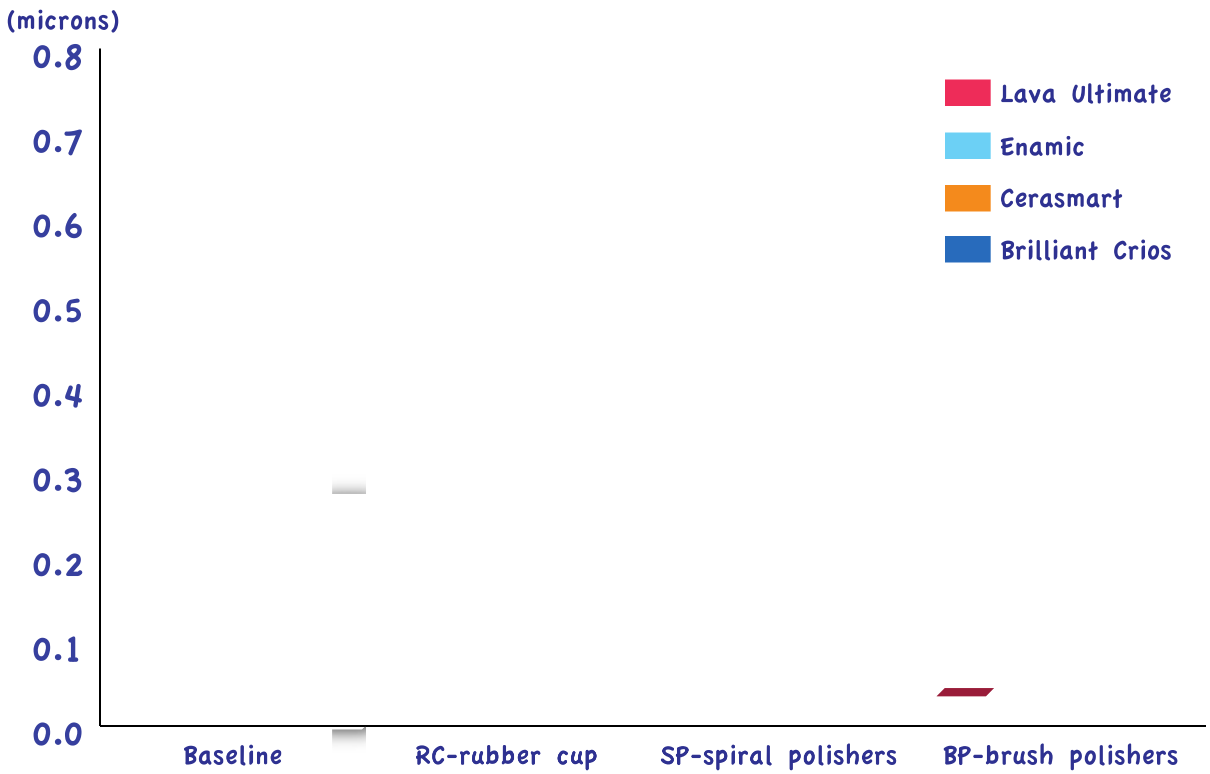


Figure 18: Bar Graph of all resin-based ceramics before and after surface treatment

Table 1: Chairside CAD/CAM Materials

Category	Composition	Brand Name
Glass Ceramics	Feldspathic porcelain	Vitablocs Mark II (Vita Zahnfabrik) Sirona blocs (Dentsply Sirona)
	Leucite reinforced	IPS Empress CAD (Ivoclar Vivadent)
High Strength Ceramics	Lithium Disilicate	IPS e.max CAD (Ivoclar Vivadent)
	Zirconia reinforced lithium silicate	Celtra Duo (Dentsply Sirona) Suprinity (Vita)
Zirconia	Polycrystalline	Cerec Zirconia (Sirona) Katana Zirconia (Katana) Chairside Ziroconia (3M) ZirCAD (Ivoclar Vivadent)
Resilient Ceramics	Nano ceramic	Lava Ultimate (3M) Cerasmart (GC America)
	PICN	Enamic (Vita Zahnfabrik)
Composite Resin	Cross-linked methacrylates/ Reinforced resin composite HT (Bis-GMA, Bis-EMA, TEGDMA)	Brilliant Crios (Coltene) Paradigm MZ 100 (3M ESPE)

Table 2: Materials

CAD/CAM Materials		**Manufacturer**	**Composition**		
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Surface Evaluation of Resilient CAD/CAM Ceramics after Contouring and Polishing

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