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RESEARCH AND EDUCATION

Evaluation of surface characterization and mechanical features of resin-matrix ceramics before and after different surface treatments

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ABSTRACT

Statement of problem. Surface treatments (STs) required for micromechanical interlocking can lead to alterations in the surface characterization and mechanical features of the resin-matrix ceramics (RMCs), which may jeopardize the long-term outcome of an indirect restoration. However, evidence on this issue is lacking.

Purpose. The purpose of this in vitro study was to assess the influence of different STs on the surface roughness (SR), water contact angle (WCA), and flexural strength (FS) of RMCs.

Material and methods. Two hundred rectangular plates (12×14×1 mm) were prepared from 5 different RMC ingots, including a polymer-infiltrated ceramic network (Vita Enamic [VE]), 2 resin nanoceramics (Lava Ultimate [LU], Grandio Blocks [GB]), a flexible nanoparticle-filled resin (GC Cerasmart [GC]), and a reinforced composite resin (Brilliant Crios [BC]). Plates of each RMC group were further divided into 4 subgroups according to the ST applied: Control, no treatment (C); airborne-particle abrasion with aluminum oxide particles (APA); 2W- and 3W-Er,Cr:YSGG laser irradiations (LI^{2W}, LI^{3W}) (n=10 per ST). The SR (Ra) of each plate was recorded with a contact profilometer. WCAs (θ) of distilled water on the plates were determined by using the sessile-drop method. The FS (MPa) of each plate was measured with a universal testing machine. Data acquired for SR, WCA, and FS were statistically analyzed (α=.05). Weibull statistics were also conducted to determine the reliability of each material.

Results. The 2-way ANOVA showed that SR, WCA, and FS values were significantly influenced not only by all tested variables but also by their interaction terms (P<.001). All STs significantly increased the SR values (P<.05). Maximum and minimum SR values were recorded in GC-LI^{3W} (7.06 ±0.16) and GC-C (0.07 ±0.02) groups. After STs, WCA values significantly diminished (P<.05). Maximum and minimum WCA values were recorded in LU-C (61.74 ±2.45) and VE-APA (40.38 ±1.56) groups. All STs significantly reduced the FS values (P<.05). The upper and lower FS bounds were 140.7 ±17.07 and 60.66 ±6.31, respectively, set by VG-C and GC-APA. Weibull distribution indicated that the untreated groups presented the highest m values. Among the treated groups, BC-LI^{3W} demonstrated superior reliability (m=14.04).

Conclusions. APA for LU, LI^{2W} for VG and BC, and LI^{3W} for GC and VE can be preferred. Although APA increased the SR and provided more wettable surfaces, it caused considerable loss of FS. Therefore, LI can be recommended as a safer ST for RMCs. (J Prosthet Dent 2022;127:928.e1-e8)

Computer-aided design and computer-aided manufacture (CAD-CAM) technology has led to the rapid commercialization and diversification of preprocessed blocks used in the fabrication of indirect restorations.[1-4] Resin-matrix ceramics (RMCs) have become popular because of their ease of machinability,[2] good fatigue resistance,[5-7] acceptable wear resistance,[8] low abrasiveness to opposing teeth,[8] promising bond strength, polishability,[9] no-firing requirement, intraoral reparability, enhanced milling damage tolerance, and good marginal adaptation.[2,10-15]

Current RMCs can be divided into those containing a methacrylate-based matrix with dispersed silanated fillers (RMC^{DF}) and those containing a glass-ceramic network, usually presintered, that has been silanated by capillary action and subsequently infiltrated with a resin matrix (RMC^{PICN}).[8-10,16-18] Despite an oversimplification, another classification was suggested by considering inorganic filler content and RMCs were categorized as compact-filled (RMC^{PICN}) or low-filled (RMC^{DF}).[18]

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Clinical Implications

The choice of STs is dependent on the RMC type, and each RMC can require a dedicated ST. For RMCs, laser irradiation can be recommended as an alternative to airborne-particle abrasion. However, the choice of STs affects surface characterization and mechanical features.

RMCs offer different multifunctional monomers that are radically polymerized to produce highly crosslinked 3D polymeric networks with engaging characteristics.[19-23] These monomers have different ratios of C=C, present variable degree of conversion (DC) levels, and are highly potent in the determination of crosslink density and elasticity of the network.[19,20] The shorter the distance between double bonds, the higher the crosslink density, and this tends to decrease the probability of chain reorganization, thereby increasing elasticity modulus.[20] Moreover, the DC level of these monomers can affect the degree of water sorption, mechanical properties, and polymerization shrinkage.[19-23]

The industrial fabrication of RMCs results in better homogeneity, a higher DC of double bonds, minimized flaws and internal defects, and thereby, improved properties.[10-26] However, relatively higher DC leads to reduced free monomers for copolymerization with monomers of the luting cement. Therefore, different micromechanical surface treatments (STs) are required on the intaglio surface of the RMCs before adhesive cementation, to attain a durable bond.[27] However, the effect of different STs on the surface and mechanical properties of RMCs is unclear.

Available micromechanical STs include airborne-particle abrasion (APA) and laser irradiation with different output powers (LI^{2W} and LI^{3W}). In both routes, microretentive indentations are generated to increase microroughness, enhance wettability, and facilitate a strong bond by providing micromechanical interlocking.[27-29] In APA, the surface is roughened by abrasive particles.[27] Although a well-established ST,[24,30,31] it can cause surface-damage[31,32] or microcrack formation.[24,33,34] Indentation pattern can be altered by changing particle type and size, propulsion pressure, nozzle proximity to the surface, and processing time.[35] In LI, the surface is roughened by removing the inorganic content of the superficial layer with microexplosions and vaporization.[29] Surface topography can be altered by changing laser type, power output, nozzle proximity to the surface, and irradiation time.[35] Although different lasers have been used to roughen ceramics,[33,35,36] the use of the erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er,Cr:YSGG) laser has recently become popular,[32,36-39] with a hydrokinetic output that decreases the risk of forming a heat-damaged layer.[29,36]

Studies that evaluated the surface characterization and mechanical performance of more recently developed RMCs before and after different STs are scarce. Therefore, the aim of the present study was to test the surface characterization (surface roughness [SR] and water contact angle [WCA]) and mechanical (flexural strength [FS]) features of different RMCs and to analyze how conducted STs (APA, LI^{2W}, and LI^{3W}) would alter these features of RMCs. The research hypotheses were that STs would influence the SR, WCA, and FS of RMCs and that RMC type would influence the SR, WCA, and FS.

MATERIAL AND METHODS

The experimental design and the materials used are presented in Figure 1 and Table 1. Two hundred rectangular plates (14×12×1 mm) were wet-sliced (Micracut 201; Metkon) from 5 different RMC ingots, including a polymer-infiltrated ceramic network (Vita Enamic [VE]), 2 resin nanoceramics (Lava Ultimate [LU], Grandio Blocks [GB]), a flexible nanoparticle-filled resin (GC Cerasmart [GC]), and a reinforced composite resin (Brilliant Crios [BC]). One side of each plate was wet-grounded for 15 seconds with 400-grit silicon carbide abrasive paper on a grinding device (Gripo 2V; Metkon) operating at 100 rpm. The final thickness was adjusted to 1 ±0.01 mm by measuring the plates with digital calipers (Digimatic Caliper; Mitutoyo Corp).

Plates of each RMC group were further divided into 4 subgroups according to the STs applied: Control (C), APA, LI^{2W}, and LI^{3W}. In the C group, plates remained untouched. In the APA group, 50-μm aluminum oxide (Al_2O_3) particles (Korox; Bego) were sprayed at the intaglio surface of each plate for 20 seconds at an air pressure of 0.2 MPa from a distance of 10 mm. In the LI groups, the MG6 sapphire tip of Er,Cr:YSGG laser (Waterlase MD; Biolase) was circulated on the intaglio surface of each plate for 20 seconds on a noncontact hard tissue mode operating at 2 different energy levels (2W and 3W), a repetition rate of 20 Hz, and a pulse duration of 140 μs with water flow of 65% and airflow of 55%.

The SR (Ra) of each plate was recorded in μm with a contact profilometer (Stylus surface roughness tester; Time). Three consecutive measurements were made in different directions by starting from the midpoint of the intaglio surface of each plate at least 0.5 mm away from each other. The profilometer was monitored with a calibrator (SO) before measuring.

WCAs were determined by using the sessile drop method. To the intaglio surface of each plate, a droplet of distilled water was dribbled, and immediately after the water contact, the tangent angle (θ) at the 3-phase contact point on a sessile drop profile was directly measured.

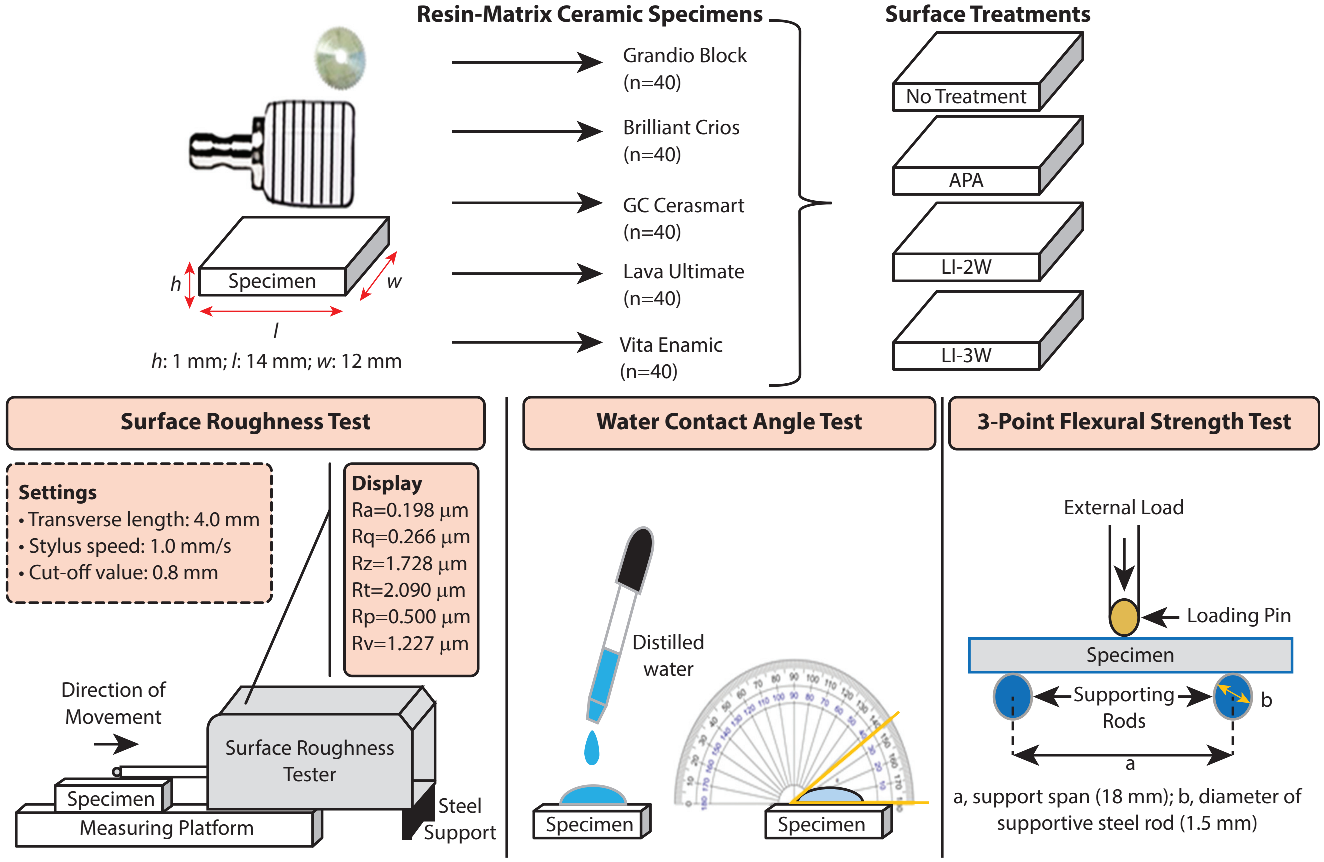

Figure 1. Experimental design. APA, airborne-particle abrasion; LI-2W, laser irradiation with 2.0-Watt power; LI-3W, laser irradiation with 3.0-Watt power.

A table-top universal tester (EZTest; Shimadzu Corp) was employed to study the 3-point FS of the plates by following the International Organization for Standardization (ISO) 6872:200811 guideline. Each plate with a 45-degree chamfer at major edges was positioned on the mechanism. The treated surface of each plate was aligned downward toward the tension side, and the untreated surface of each plate was aligned upward toward the compression side. Plates were loaded with 1 mm/min crosshead speed until failure. FS values (σ) in MPa were calculated over fracture load data by using the following function:

$$\sigma = \frac{3PL}{2wb^2},$$

where P=fracture load in Newton, L=length of test span in mm, w=width of the plate in mm, and b=thickness of the plate in mm. On the data of FS, Weibull statistics were also conducted to determine the reliability of each material. Failure probability was calculated by using the following function (ISO 6872:2015):

$$P_f = 1 - \exp\left[\left(\frac{\sigma}{\sigma_0}\right)^m\right],$$

where P_f=failure probability, σ=FS, σ_0=characteristic strength at fracture probability of 63.21%, and m=Weibull modulus which is equal to the slope of the ln(ln[1/(1-P_f)]) versus that in ln σ plots.

All computations were performed by using a statistical analysis software program (IBM SPSS Statistics, v23; IBM Corp). The data normality was determined with the Shapiro-Wilk test (P>.05), and therefore, parametric 2-way analysis of variance (ANOVA) was conducted to investigate the influence of 2 variables (RMC type and ST) on each parameter (SR, WCA, and FS). The Tukey post hoc test was used for multiple comparisons (α=.05).

RESULTS

The 2-way ANOVA showed that SR, WCA, and FS values were significantly affected by all tested variables and their interaction terms (P<.001). The mean SR, WCA, and FS values with the Tukey post hoc test comparisons are presented in Tables 2-4, respectively.

All STs significantly increased the SR values (P<.05). The SR values ranked as follows: LI^{3W}>APA>LI^{2W}>C. GC showed the highest (3.02 ±2.63) and VG exhibited the lowest (1.21 ±0.88) SR values. Except for the difference between the BC and LU, the SR values of all RMCs differed significantly from each other (P<.05). Considering the ST-material interaction, maximum and minimum SR values were recorded in GC-LI^{3W} (7.06 ±0.16)

Table 1. Resin-matrix ceramics used

Material	Category of RMC	Matrix (Organic Part)	Filler (wt %)	Filler (Inorganic Part)	Manufacturer
Grandio Block	RMC^{DF}	Methacrylate	86	ND	VOCO GmbH
Brilliant Crios	RMC^{DF}	Crosslinked methacrylate	70.7	SiO_2: <20 nm, barium glass: <1.0 µm, inorganic pigments (ferrous oxide or titanium dioxide)	Coltène
GC Cerasmart	RMC^{DF}	Bis-MEPP, UDMA, DMA	71	Silica: 20 nm, barium glass: 300 nm	GC Dental Products
Lava Ultimate	RMC^{DF}	Bis-GMA, UDMA, Bis-EMA, TEGDMA	80	Silica (20 nm), zirconia (4-11 nm) nanoparticles, and ZrO_2-SiO_2 nanoclusters	3M ESPE
Vita Enamic	RMC^{PICN}	UDMA, TEGDMA	86	Glass-ceramic sintered network including 58-63% SiO_2, 20-23% Al_2O_3, 9-11% Na_2O, 4-6% K_2O, and 0.1% ZrO_2	VITA Zahnfabrik

Bis-EMA, ethoxylated bisphenol dimethacrylate; Bis-GMA, bisphenol-A-glycidyl methacrylate; Bis-MEPP, 2,2-Bis(4-methacryloxypolyethoxyphenyl) propane; DMA, dimethacrylate; NN, nothing to declare; RMC^{DF}, RMCs consisting dispersed fillers; RMC^{PICN}, RMC consisting polymer infiltrated ceramic network; SiO2, silica; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate; wt, filler weight percentage.

Table 2. Mean ±standard deviation of surface-roughness values (Ra) of RMCs treated with different surface treatments

Surface Treatments	RMC Materials					Total
	VG	BC	GC	LU	VE	
Control	0.17 ±0.05^{b,A}	0.17 ±0.04^{c,A}	0.07 ±0.02^{d,A}	0.37 ±0.19^{c,A}	0.34 ±0.17^{c,A}	0.22 ±0.09^{d}
APA	1.95 ±0.40^{a,B}	2.11 ±0.38^{b,B}	3.21 ±0.51^{b,A}	2.28 ±0.21^{b,B}	1.96 ±0.22^{b,B}	2.30 ±0.34^{b}
LI^{2W}	0.71 ±0.10^{b,C}	1.97 ±0.22^{b,AB}	1.74 ±0.17^{c,AB}	2.33 ±0.33^{b,A}	1.62 ±0.26^{b,B}	1.67 ±0.22^{c}
LI^{3W}	2.02 ±0.65^{a,E}	4.57 ±1.06^{a,B}	7.06 ±0.16^{a,A}	3.77 ±0.56^{a,C}	2.78 ±0.37^{a,D}	4.04 ±0.56^{a}
Total	1.21 ±0.88^{D}	2.21 ±1.68^{B}	3.02 ±2.63^{A}	2.19 ±1.27^{B}	1.68 ±0.92^{C}	2.06 ±1.71

APA, airborne-particle abrasion; BC, Brilliant Crios; GC, GC Cerasmart; LI^{2W}, laser irradiation with 2.0-Watt power; LI^{3W}, laser irradiation with 3.0-Watt power; LU, Lava Ultimate; VE, Vita Enamic; VG, Voco Grandio. Different uppercase letters indicate differences in same row; different lowercase letters indicate differences in same column for each RMC material.

and GC-C (0.07 ±0.02) groups. Except for VG-LI^{2W}, all STs significantly increased the SR values (*P*<.05). The differences between the SR values of the RMCs in the C group were not significant. Among the APA-applied RMCs, only GC showed a higher SR value than others (*P*<.05). In both LI^{2W} and LI^{3W} groups, VG showed a lower SR value than others (*P*<.05).

All STs significantly lowered the WCA values (*P*<.05). The WCA values ranked as follows: C>LI^{2W}>LI^{3W}>APA. LU (56.14 ±4.83) and BC (55.34 ±4.18) showed the highest WCA values, while VE revealed the lowest WCA value (50.31 ±6.61). Considering interaction, maximum and minimum WCA values were recorded in LU-C (61.74 ±2.45) and VE-APA (40.38 ±1.56) groups. Except for BC-LI^{2W}, all STs significantly reduced the WCA values (*P*<.05). When the STs were compared, the WCA values in the APA group were found to be significantly lower (*P*<.05), excluding GC. The WCA values of the RMCs in the C did not differ significantly from each other, except for LU-VE. In the APA group, only VE showed a significantly lower WCA value than other RMCs (*P*<.05). In LI^{2W} and LI^{3W}, GC and VE materials exhibited lower WCA values than others (*P*<.05).

All STs significantly reduced the FS values (*P*<.05). While APA showed a significantly lower FS value than the laser-treated groups (*P*<.05), there was no significant difference between the FS values of the LI^{2W} and LI^{3W} groups. FS values of the VG and BC were significantly higher than those of GC, LU, and VE (*P*<.05). Considering interaction, the upper and lower FS bounds were 140.7 ±17.07 and 60.66 ±6.31, respectively, set by VG-C and GC-APA. Except for VE, APA significantly decreased the FS values of all RMCs (*P*<.05). LI^{2W} and LI^{3W} did not cause significant differences in FS values, except for LU-LI^{2W}, VG-LI^{3W}, and LU-LI^{3W} groups (*P*<.05).

According to Weibull distribution (Table 5), m values of all experimental groups were ranging from 6.2 to 14.92, and the highest m value (14.92 ±0.35) was calculated for BC-Control. The untreated groups presented the highest m and σ_0 values. Among the treated groups, BC-LI^{3W} offered superior reliability (m=14.04 ±0.33) (Fig. 2).

DISCUSSION

Both research hypotheses were accepted as the results indicated that material type, ST, and their interaction terms led to significant alterations in all tested characteristics. Among nontreated RMCs, LU demonstrated the highest SR value, a finding that can be attributed to factors including that LU is composed of nanoparticles and aggregated nanoclusters, accordingly providing shape diversity.[8,9] Alamoush et al[10] depicted a wide range of filler sizes for nontreated LU in scanning electron micrographs. It has been reported that SR can be affected by filler particle size and shape, percentage of surface area occupied by fillers, and variation in the

Table 3. Mean ±standard deviation of water contact angle values (θ) of RMCs treated with different surface treatments

	RMC Materials					
Surface Treatments	**VG**	**BC**	**GC**	**LU**	**VE**	**Total**
Control	59.10 ±2.81^{a,AB}	59.84 ±2.38^{a,AB}	59.79 ±1.78^{a,AB}	61.74 ±2.45^{a,A}	56.87 ±3.17^{a,B}	59.47 ±2.52^{a}
APA	49.20 ±2.20^{c,A}	50.39 ±2.81^{c,A}	50.41 ±1.90^{b,A}	49.62 ±2.13^{c,A}	40.38 ±1.56^{c,B}	45.00 ±2.12^{d}
LI^{2W}	54.54 ±1.92^{b,AB}	57.03 ±2.02^{ab,A}	49.71 ±2.66^{b,C}	57.09 ±2.17^{b,A}	52.64 ±2.47^{b,BC}	54.20 ±2.25^{b}
LI^{3W}	53.61 ±1.77^{b,AB}	54.11 ±1.91^{b,AB}	48.91 ±2.43^{b,C}	56.09 ±1.67^{b,A}	51.34 ±2.44^{b,BC}	52.81 ±2.04^{c}
Total	54.11 ±4.15^{B}	55.34 ±4.18^{A,B}	52.20 ±4.95^{C}	56.14 ±4.83^{A}	50.31 ±6.61^{D}	53.62 ±5.41

APA, airborne-particle abrasion; BC, Brilliant Crios; GC, GC Cerasmart; LI^{2W}, laser irradiation with 2.0-Watt power; LI^{3W}, laser irradiation with 3.0-Watt power; LU, Lava Ultimate; VE, Vita Enamic; VG, Voco Grandio. Different uppercase letters indicate differences in same row; different lowercase letters indicate differences in same column for each RMC material.

Table 4. Mean ±standard deviation of flexural strength values (MPa) of RMCs treated with different surface treatments

	RMC Materials					
Surface Treatments	**VG**	**BC**	**GC**	**LU**	**VE**	**Total**
Control	140.7 ±17.07^{a,A}	123.59 ±9.50^{a,A}	95.19 ±9.12^{a,B,C}	102.47 ±8.57^{a,B}	82.88 ±6.72^{a,C}	108.97 ±10.20^{a}
APA	86.03 ±15.88^{c,A}	89.75 ±12.93^{b,A}	60.66 ±6.31^{b,B}	74 ±8.90^{b,A,B}	76.06 ±9.15^{a,A,B}	77.3 ±10.63^{c}
LI^{2W}	135.19 ±18.94^{a,b,A}	124.09 ±12.94^{a,A}	83.10 ±15.35^{a,B}	72.25 ±6.88^{b,B}	75.28 ±7.16^{a,B}	97.98 ±12.25^{b}
LI^{3W}	121.13 ±16.44^{b,A}	122 ±10.13^{a,A}	89.47 ±12.16^{a,B}	71.41 ±9.80^{b,B}	78.75 ±8.81^{a,B}	96.55 ±11.47^{b}
Total	120.76 ±27.11^{A}	114.86 ±18.38^{A}	82.11 ±17.11^{B}	80.03 ±15.53^{B}	78.24 ±8.28^{B}	95.20 ±26

APA, airborne-particle abrasion; BC, Brilliant Crios; GC, GC Cerasmart; LI^{2W}, laser irradiation with 2.0-Watt power; LI^{3W}, laser irradiation with 3.0-Watt power; LU, Lava Ultimate; VE, Vita Enamic; VG, Voco Grandio. Different uppercase letters indicate differences in same row; different lowercase letters indicate differences in same column for each RMC material.

interparticle spacing.[40] Second, the Bis-GMA monomer found only in LU may have been effective in offering the highest SR value. In Bis-GMA, the hydroxyl groups on the backbone and the π-π coactions given by the aromatic rings give rise to the increased viscosity and cause the polymer to remain at a low DC level (39%). Its lower DC ratio tends to change the surface characterization[25,41] as SR is also dependent on DC level.[40] Among nontreated RMCs, the lowest SR value belongs to the GC. This can chiefly be attributed to its nanometer-sized filler particles. It is well-known that fillers of smaller size can be adhered to the resin matrix, thus depicting a smoother surface finish.[40] Also, fillers in GC do not offer shape diversity like LU.[8,9]

In all surface-treated RMCs, VE and VG demonstrated relatively lower SR values. This can be translated to that the SRs of VE and VG were less altered after STs and correlated with their high microhardness values. Alamoush et al[10] reported microhardness values of 203.1 kg/mm^2 for VE and 121.8 kg/mm^2 for VG. When STs are applied, a rough transformed zone is formed on the surface of the material depending on its hardness, and stiff structures prevent the deepening of this transformed zone. The stiffness of the VE can also be related to its monomeric structure. TEGDMA copolymer is combined with UDMA in VE and has been recommended to be used as a reactive diluent because of its lower molecular weight (286.3) and lower viscosity that aids in filler incorporation and permits the polymeric network to reach a higher DC level (75.7%).[19,20,42] TEGDMA also has the highest concentration of double bonds offering the highest crosslink density and ability to form the tightest networks. The least decrease in SR values after APA was also observed in VE. Al_2O_3 abrasive particles presumably are less effective on the surface of VE because of its increased microhardness.[10] In the APA and LI^{3W} groups, the highest SR value was for the GC; while in the LI^{2W} group, the highest SR value was for LU. Both findings can be explained by the fact that they are 2 nanoceramics[43] included in this study, and their nanometer-sized filler particles might be more susceptible to STs. The maximum SR values were observed in RMCs treated with LI^{3W}, followed by APA and LI^{2W}. The slightest change affecting the inorganic portion caused a substantial alteration in surface roughness, and LI^{3W} provided increased alteration.

A goniometer and the direct imaging sessile drop method have been used to monitor the wettability of a surface.[12,44,45] The present study demonstrated that in the C group, LU and VE showed the highest and lowest WCAs, respectively, possibly because these materials have the highest SR values among the C group measurements. However, among treated RMCs, no correlation was observed between SR and WCA. Consistently, Sturz et al[46] and Çakmak et al[12] did not find a correlation between WCA and SR values and reported that the microchemical structure of the material, alterations in matrix composition and filler fraction, and inhomogeneous surface caused by the fillers contribute to this finding. All STs, specifically APA, reduced WCAs.

Initially, it was thought that nontreated VE would offer higher FS values as it contains very flexible UDMA in its microstructure.[14] UDMA-containing homopolymer has been reported to have the highest FS value,[19] which strengthened this argument. Moreover, Albero et al[1] reported consistent results. However, VE has a distinct

Table 5. Weibull distribution of all experimental groups

RMC Type	Surface Treatments	M	95%CI for m	σ_0	95%CI for σ_0	Regression Coefficient
VG	Control	9.29 ±0.16	9.13-9.37	153.07 ±14.83	142.46-163.67	0.87
	APA	6.43 ±0.10	6.36-6.50	92.76 ±7.13	87.67-97.86	0.86
	LI^{2W}	8.25 ±0.13	8.13-8.31	146.64 ±12.33	137.83-155.45	0.88
	LI^{3W}	8.62 ±0.15	8.47-8.69	131.59 ±12.38	122.74-140.43	0.86
BC	Control	14.92 ±0.35	14.52-15.02	135.38 ±16.60	123.48-147.21	0.94
	APA	7.99 ±0.12	7.88-8.05	97.21 ±7.00	92.20-102.21	0.91
	LI^{2W}	11.29 ±0.22	11.04-11.36	135.34 ±14.52	125.00-145.76	0.91
	LI^{3W}	14.04 ±0.33	13.68-14.15	133.55 ±16.38	121.84-145.26	0.90
GC	Control	12.11 ±0.26	11.82-12.19	103.90 ±10.94	96.09-111.72	0.94
	APA	11.41 ±0.24	11.13-11.48	66.11 ±6.36	61.57-70.66	0.97
	LI^{2W}	6.2 ±0.04	6.17-6.23	89.21 ±2.43	87.47-90.94	0.98
	LI^{3W}	8.06 ±0.11	7.95-8.10	96.87 ±5.79	92.74-101.01	0.95
LU	Control	14.1 ±0.33	13.72-14.19	112.14 ±13.64	102.39-121.88	0.93
	APA	9.64 ±0.17	9.45-9.70	80.44 ±6.83	75.57-85.32	0.94
	LI^{2W}	12.42 ±0.27	12.11-12.49	78.84 ±7.95	73.16-84.53	0.98
	LI^{3W}	8.43 ±0.15	8.28-8.50	77.48 ±6.20	73.05-81.90	0.89
VE	Control	14.59 ±0.35	14.19-14.69	90.65 ±10.35	83.26-98.05	0.99
	APA	9.86 ±0.17	9.67-9.91	82.67 ±6.66	77.91-87.43	0.97
	LI^{2W}	12.51 ±0.28	12.19-12.59	82.18 ±8.56	76.06-88.29	0.97
	LI^{3W}	10.11 ±0.18	9.91-10.17	85.65 ±6.85	80.75-90.64	0.96

95%CI for the m, confidence intervals for Weibull modulus; 95%CI for σ0, confidence intervals for characteristic strength; σ0, characteristic strength; APA, airborne-particle abrasion; BC, Brilliant Crios; GC, GC Cerasmart; LI^{2W}, laser irradiation with 2.0-Watt power; LI^{3W}, laser irradiation with 3.0-Watt power; LU, Lava Ultimate; m, Weibull modulus; VE, Vita Enamic; VG, Voco Grandio.

fabrication manner, and this makes the material completely different from others. A continuous interpenetrating inorganic phase is responsible for the stiffening of VE.[43] Supportively, in a previous study,[10] VE presented a very high microhardness value. It is thought that this structural stiffness deteriorates the flexion ability and thereby reduces the FS of the material. TEGDMA contained in VE might also contribute to this finding as it increases water sorption, deteriorates general mechanical properties, and increases polymerization shrinkage because of the increased DC level.[19,41] Additionally, the present study found that LU has an average FS among all nontreated RMCs. This is the result of the interplay among antagonistic factors. On one side, the presence of Bis-GMA decreases FS because of the lower DC and crosslink density. On the other side, the stiff backbone of Bis-GMA and strong hydrogen bonding which maintains the conformity of the network structure tend to increase polymer strength.[42] The highest FS values were found for VG and BC, which is possible because of the organic matrix consisting entirely of methacrylate. Other RMCs are composed of dimethacrylate monomers. Among STs, APA was found highly effective on the decrease of FS values. This might be explained by the abrasiveness of the APA which removes not only the organic but also the inorganic portion of the RMCs, but LI is effective only on the inorganic portion and can be regarded as a safer ST.

Weibull analysis measures the structural reliability of the FS of the experimental groups by m and σ_0. The m value depicts the structural homogeneity of the material considering the strength distribution. As m increases, the reliability of the material increases.[1,14] Different ceramics exhibit m values ranging from 5 to 15. The σ_0 presents the strength value by which 63% of the tested specimens would fracture.[13] The untreated RMCs presented the highest m and σ_0 values, indicating STs may endanger structural reliability. Moreover, VG-APA and GC-LI^{2W} were the 2 groups demonstrating the lowest m values, translating that they may not be the most suitable groups for restorations in stress-bearing areas. The σ_0 of VG-C is different from the rest. A greater force (a force between 142.46 and 163.67 MPa) is required to have the same probability of fracture as other experimental groups (Table 5).

Limitations of this study included that a single material group (RMC) was studied. Different material groups may present different results. Second, only WCA was evaluated. However, the calculation of surface energy might alter the findings. Third, surface topography assessment with a scanning electron microscope was not performed. Therefore, future studies are needed to better assess the clinical performance of RMCs.

CONCLUSIONS

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

1. Surface treatment, RMC material type, and their interaction terms had a significant influence on the surface roughness, water contact angle, and flexural strength data.

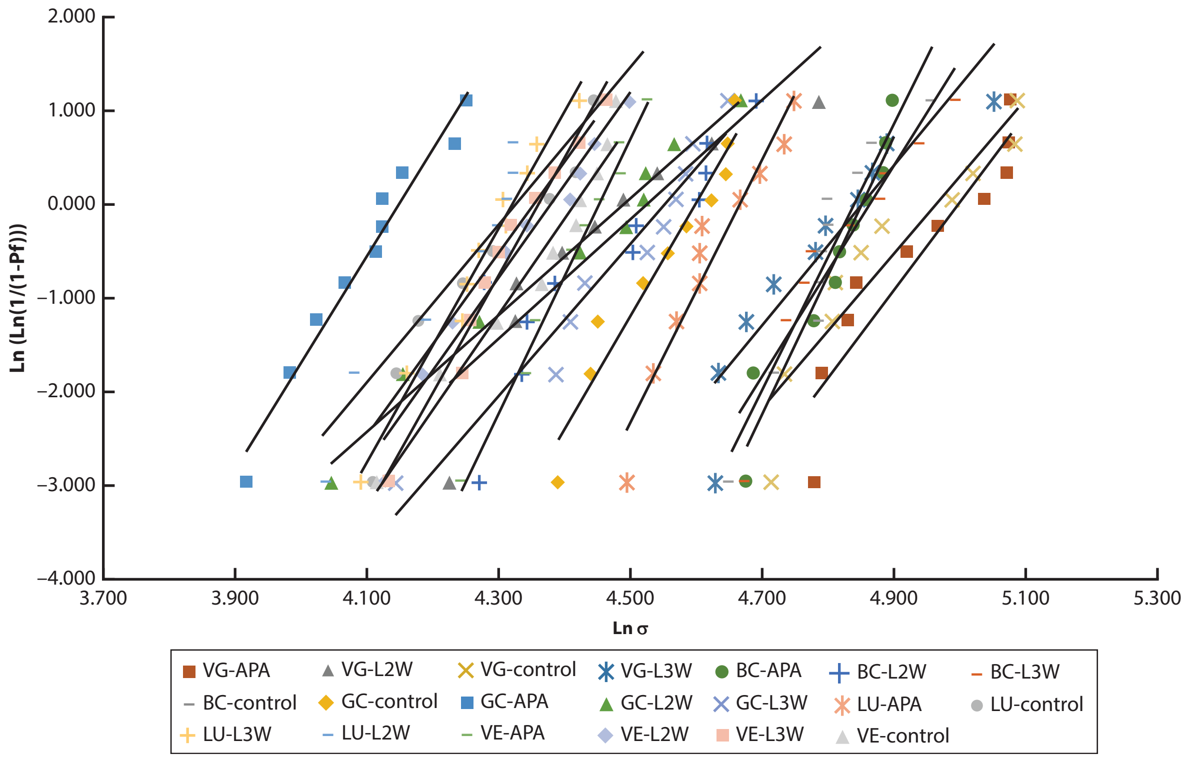

Figure 2. Weibull graphics of experimental groups. APA, airborne-particle abrasion; BC, Brilliant Crios; GC, GC Cerasmart; LI2W, laser irradiation with 2.0-Watt power; LI3W, laser irradiation with 3.0-Watt power; LU, Lava Ultimate; VE, Vita Enamic; VG, Voco Grandio.

2. The surface roughness of untreated RMCs was similar. LI^{3W} exhibited the highest surface roughness values.
3. The wettability of RMCs was mostly enhanced after airborne-particle abrasion.
4. The most substantial decrease in flexural strength values occurred after airborne-particle abrasion. In Vita Enamic, the surface treatments did not affect flexural strength. In all surface treatments, the flexural strength values of Voco Grandio and Brilliant Crios were higher than those of other RMCs.

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