

RESEARCH AND EDUCATION

Effect of acidic pH on surface roughness of esthetic dental materials



Muhsen Alnasser, BDS, MS,^a Matthew Finkelman, PhD,^b Aikaterini Papathanasiou, DDS,^c Marcelo Suzuki, DDS,^d Ruby Ghaffari, DMD,^e and Ala Ali, BDS, MSc, DSc^f

ABSTRACT

Statement of problem. Exposure to gastric acid in patients with bulimia nervosa and gastroesophageal reflux disease (GERD) causes demineralization of hard tooth structures. This chemical attack also causes the degradation of dental ceramics, which results in increased surface roughness and reduced strength. However, studies comparing the effect of acidic pH on resin matrix ceramic with other computer-aided design and computer-aided manufacturing (CAD-CAM) esthetic materials are lacking.

Purpose. The purpose of this in vitro study was to compare the surface roughness changes of different CAD-CAM restorative dental materials after exposure to acidic pH by using a 3D optical interferometer.

Material and methods. Five esthetic CAD-CAM block materials, a leucite glass-ceramic (IPS Empress CAD), a zirconia (BruxZir Solid Zirconia), a resin matrix ceramic (VITA Enamic), a lithium disilicate glass-ceramic (IPS e.max CAD), and a feldspathic porcelain (VITABLOCS Mark II CAD) were tested. Eighteen specimens were sectioned from CAD-CAM blocks into 2-mm-thick rectangular plates and immersed in 10 mL of 5% hydrochloric acid (HCl) with (pH=2) at 37 °C for 45 and 91 hours. The surface roughness average (Ra) of the specimens was measured by using a 3D optical interferometer before the storage period (baseline), after 45 hours, and after 91 hours of exposure to HCl. Statistical analyses were performed with the Kruskal-Wallis test and the post hoc Dunn test with Bonferroni correction ($\alpha=.05$).

Results. Regarding the comparison of surface roughness changes at different periods of evaluation (baseline, 45 hours, 91 hours), there were no statistically significant differences for lithium disilicate ($P=.063$) or zirconia ($P=.513$). Leucite glass-ceramic, feldspathic porcelain, and the resin matrix ceramic demonstrated statistically significant differences ($P<.001$). For all tests that were statistically significant, greater surface roughness was found at the time point with the longer HCl exposure. Regarding the comparison of materials in terms of change in surface roughness between baseline to 45 hours and baseline to 91 hours, the Kruskal-Wallis test indicated a statistically significant difference among the materials in both cases ($P<.001$). Lithium disilicate and zirconia exhibited the least change in surface roughness among the 5 materials.

Conclusions. Leucite glass-ceramic, feldspathic porcelain, and resin matrix ceramic showed statistically significant increases in surface roughness when they were exposed to simulated gastric acid for 45 and 91 hours. Lithium disilicate and zirconia showed no statistically significant change in surface roughness after exposure to HCl for 45 and 91 hours. (*J Prosthet Dent* 2019;122:567.e1-e8)

Dental erosion is a common cause of tooth damage, which may range from a superficial loss of enamel surface to complete exposure of the dentin.¹ The origin of erosive acid can be intrinsic or extrinsic,¹ but the lower pH of

gastric acid corrodes tooth structure more than an acidic diet.^{1,2}

In an acidic environment, the aqueous corrosion of ceramic glasses occurs because of the selective leaching

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^aResident, Advanced Graduate Education in Implantology, Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, Mass.

^bAssociate Professor, Department of Public Health and Community Service, Tufts University School of Dental Medicine, Boston, Mass.

^cAssistant Professor, Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, Mass.

^dAssociate Professor, Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, Mass.

^eAssociate Professor, Department of Comprehensive Care, Tufts University School of Dental Medicine, Boston, Mass.

^fAssistant Professor, Department of Prosthodontics, Tufts University School of Dental Medicine, Boston, Mass.

Clinical Implications

Zirconia or lithium disilicate ceramic materials should be used to restore teeth in patients with bulimia nervosa or gastroesophageal reflux disease as these materials are minimally affected by acid exposure.

of alkali ions.³ This acid exposure often happens in patients with bulimia nervosa or gastroesophageal reflux disease (GERD).⁴ Bulimia nervosa is a multifactorial disorder characterized by cycles of binge eating followed by compensatory behaviors such as self-induced vomiting or excessive exercise.⁵ GERD is characterized by frequent regurgitation of gastric acid from the stomach into the esophagus or oral cavity.⁶ The prevalence of bulimia nervosa in the United States is between 1% and 3%, and the prevalence of GERD is between 18% and 28%.^{5,6}

Gracis et al⁷ developed a widely accepted system classifying ceramic restorative materials into glass matrix ceramics, polycrystalline ceramics, and resin matrix ceramics, which can also be called resin-modified ceramics. Resin matrix ceramics have some of the advantages of both ceramics and composite resins,⁸ with high flexural strength and elasticity being close to those of dentin because they have a fine structure of feldspathic ceramic and an acrylate polymer network.⁸

An increase in the surface roughness of ceramic restorations adversely affects strength and increases the wear rate of antagonistic natural teeth.^{1,9-12} A rough surface also causes biofilm bacterial accumulation that leads to gingival disease.^{12,13} The color of the restoration is also affected by the surface roughness because a rough surface reflects less light than a smooth surface.¹⁴ The oral environment affects the mechanical properties of ceramic restorations.¹⁵ Although the normal pH of saliva ranges from 6.8 to 7.2, a carbohydrate intake causes the dental plaque to produce organic acids, resulting in lower pH (around 4.5).¹⁵

Mechanical forces and chemical attack cause the degradation of dental ceramics.¹⁶⁻¹⁸ Ernsberger¹⁹ suggested that chemical corrosion occurs by the diffusion of water molecules to form hydroxyl ions by reacting with nonbridging oxygen atoms in glass. Hydroxyl ions diffuse out with the alkali ions to maintain electrical neutrality.^{16,17,19} Although ceramic materials have good chemical durability, that durability may be affected by the composition of the ceramic material and the pH, the exposure time, and the temperature of the corrosive medium.²⁰

Different surface roughness parameters have been used to measure surface roughness, giving values by

recording the highest peaks and lowest valleys of the surface profile.²¹ In dentistry, roughness average (Ra) has been the most often used²¹⁻²³ and is defined as the arithmetic average of all deviations of the roughness profile from the central line.^{21,24}

Methods of measuring surface roughness include contact stylus tracing, the most common method,²⁵ providing a quantitative measurement of surface roughness,^{21,26} laser profilometry, and 3D optical profilometry. A contact profilometer provides more accurate results in measuring changes in surface height such as assessment of the marginal discrepancies of restorations, but laser profilometry is more accurate for surface texture measurements.²⁵ A 3D optical profilometer is an optical imaging technique for measuring surface roughness.²⁷ A comparison between contact and noncontact profilometry reported that both methods provided a reliable measurement of corrosion.²⁸

A method of simulating gastric acid in laboratory studies to replicate the clinical situation is not well established. Backer et al²⁹ used gastric juice (pH=1.2) for 6 hours and 18 hours to represent 2 and 8 years of exposure to vomiting. Sulaiman et al² used HCl (pH=1.2) for 96 hours at 37 °C to simulate over 10 years of clinical exposure. Another study exposed test materials to acidic solution (pH=3.8) for 24 hours.³⁰ Harryparsad et al⁴ reported that the average daily exposure time of teeth to gastric acid in a patient with bulimia is 15 minutes. This indicates that immersion in HCl (pH=2) for 45 hours and 91 hours represents gastric acid exposure in a patient with bulimia for 6 months and 12 months.⁴

Tooth structure affected by dental erosion can be restored with either direct or indirect restorations. Studies determining the effects of acidic and erosive conditions on these restorations are sparse.² The purpose of the present in vitro study was to compare the surface roughness changes of different computer-aided design and computer-aided manufacturing (CAD-CAM) restorative dental materials after exposure to acidic pH by using a 3D optical interferometer. The null hypothesis was that no statistically significant difference in surface roughness change would be found between different CAD-CAM restorative dental materials after exposure to HCl acid for 45 hours and 90 hours.

MATERIAL AND METHODS

A power calculation was made with statistical software (nQuery Advisor version 7.0; Statistical Solutions Ltd). A sample size of n=18 was adequate to obtain a Type I error rate of 5% and a power greater than 99% for the comparison of materials.

Five esthetic CAD-CAM block materials; a leucite glass-ceramic (IPS Empress CAD; Ivoclar Vivadent AG); a zirconia (BruxZir Solid Zirconia; Glidewell Laboratories);

Table 1. Surface roughness (μm) for each material at each period of evaluation (baseline, 45 hours, 91 hours)

Group	Baseline				45 h				91 h				P
	Mean	$\pm\text{SD}$	Median	IQR	Mean	SD	Median	IQR	Mean	$\pm\text{SD}$	Median	IQR	
Leucite glass-ceramic	1.23	0.66	1.26	1.11	1.65	0.60	1.57	1.08	1.95	0.64	1.98	1.13	<.001
Zirconia	0.54	0.23	0.59	0.34	0.51	0.20	0.50	0.24	0.52	0.19	0.55	0.28	.513
Resin matrix ceramic	0.18	0.22	0.11	0.12	0.43	0.32	0.31	0.30	0.58	0.43	0.46	0.36	<.001
Lithium disilicate	0.13	0.14	0.08	0.19	0.16	0.20	0.07	0.27	0.13	0.15	0.07	0.22	.063
Feldspathic porcelain	0.61	0.60	0.43	0.97	1.08	0.89	0.75	1.75	1.15	0.86	0.93	1.68	<.001

IQR, interquartile range; SD, standard deviation. P values comparing time points for each material (Friedman test).

Table 2. Results regarding the amount of change in surface roughness (μm) $\Delta 45\text{h}$ -baseline and $\Delta 91\text{h}$ -baseline

Group	$\Delta 45\text{h}$ -Baseline				$\Delta 91\text{h}$ -Baseline			
	Mean	$\pm\text{SD}$	Median	IQR	Mean	SD	Median	IQR
Leucite glass-ceramic	0.42	0.36	0.39	0.38	0.72	0.37	0.64	0.46
Zirconia	-0.03	0.15	0.01	0.15	-0.02	0.14	0.01	0.11
Resin matrix ceramic	0.25	0.21	0.21	0.23	0.40	0.27	0.36	0.33
Lithium disilicate	0.03	0.12	0.01	0.08	0.01	0.05	0.01	0.06
Feldspathic porcelain	0.47	0.42	0.28	0.53	0.54	0.42	0.43	0.42
P	<.001				<.001			

IQR, interquartile range; SD, standard deviation. P values comparing materials in terms of Δ 45h-baseline and Δ 91h-baseline (Kruskal-Wallis test).

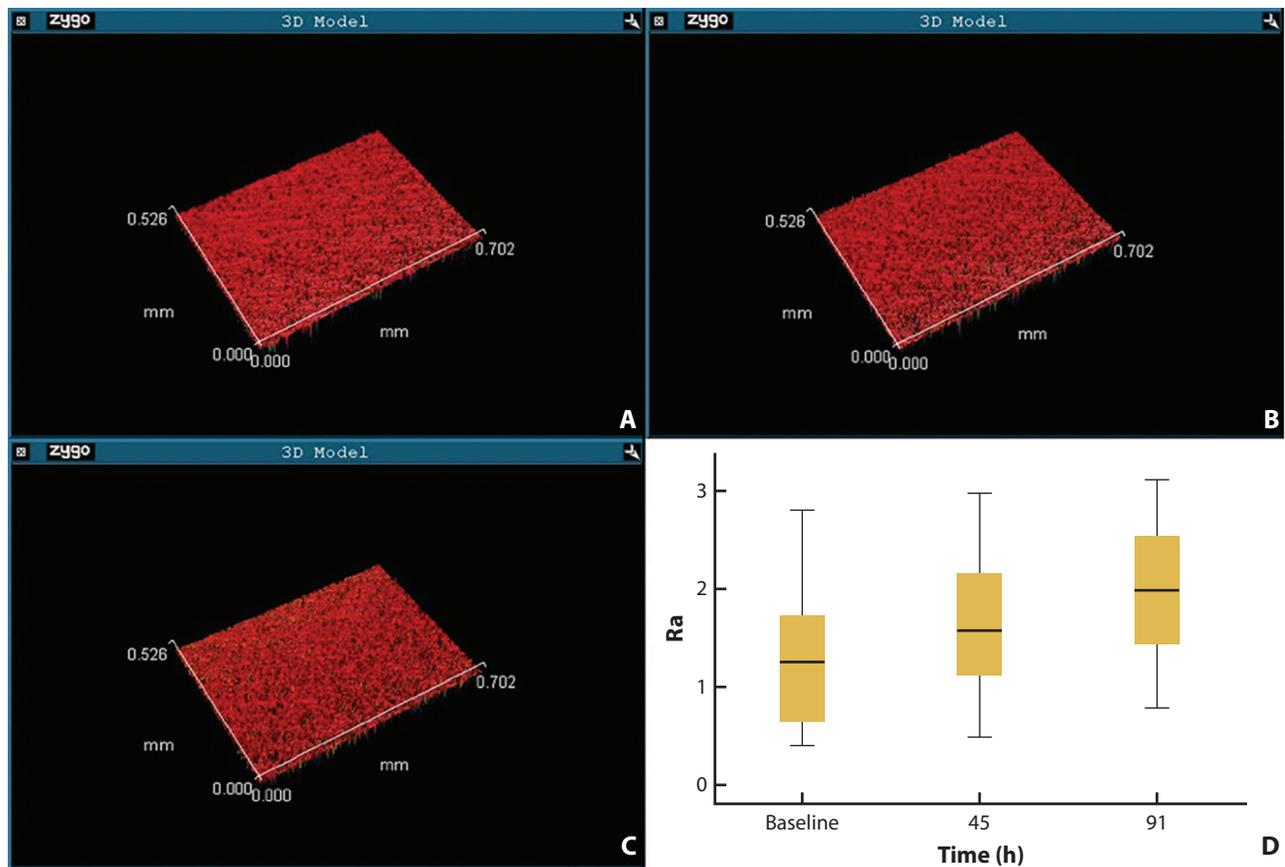


Figure 1. Three-dimensional model of leucite glass-ceramic specimen. A, Baseline. B, 45 hours. C, 91 hours. D, Boxplots of surface roughness average (Ra) in μm at baseline, 45 hours, and 91 hours.

a resin matrix ceramic (VITA Enamic; VITA Zahnfabrik); a lithium disilicate glass-ceramic (IPS e.max CAD; Ivoclar Vivadent AG); and a feldspathic porcelain (VITABLOCS

Mark II CAD; VITA Zahnfabrik) were tested. Eighteen specimens were sectioned from CAD-CAM blocks into 2-mm-thick rectangular plates for each group by using a

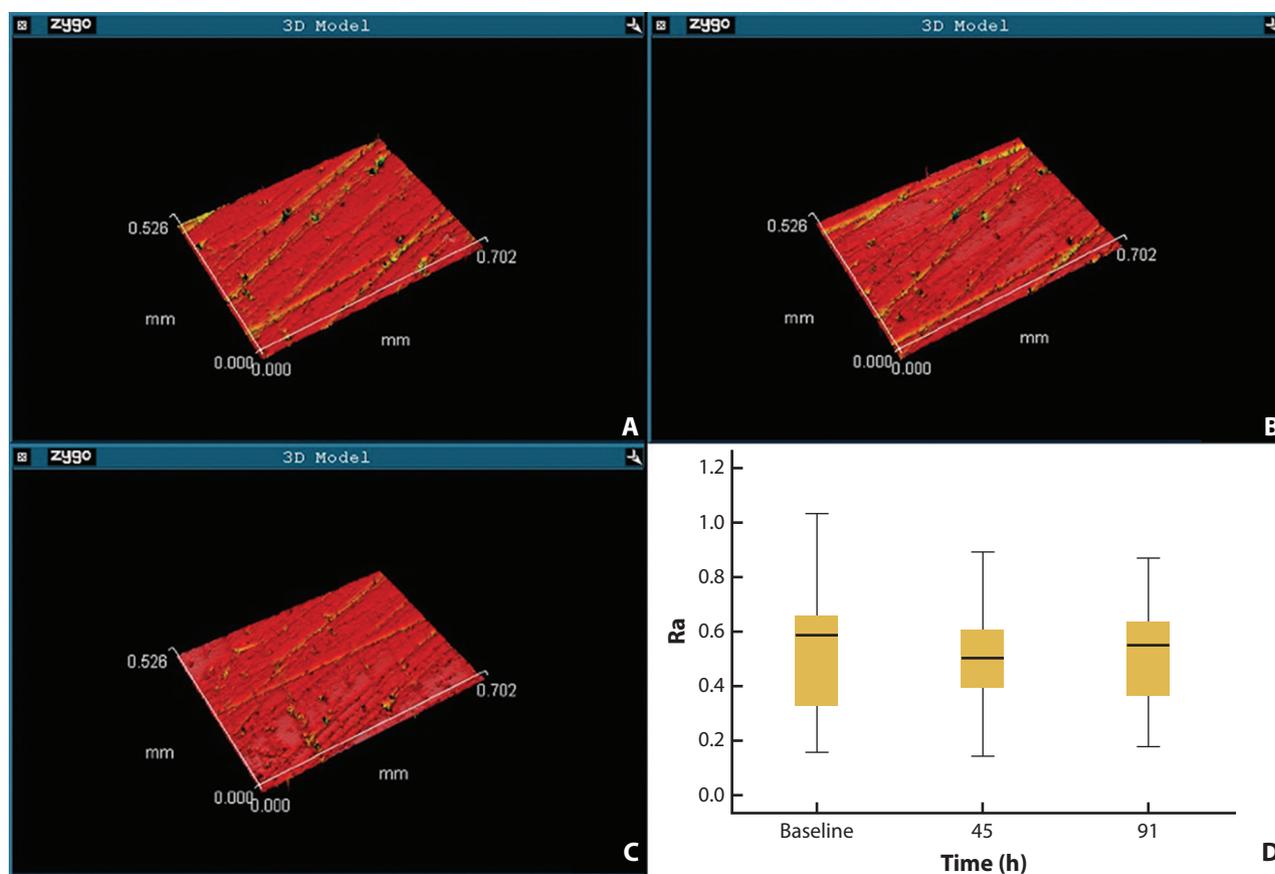


Figure 2. Three-dimensional model of zirconia specimen. A, Baseline. B, 45 hours. C, 91 hours. D, Boxplots of surface roughness average (Ra) in μm at baseline, 45 hours, and 91 hours.

sectioning saw (Isomet 1000; Buehler). The BruxZir zirconia and IPS e.max CAD blocks were cut in the green stage and then sintered according to the manufacturers' instructions. Each specimen was attached to a sample holder using sticky wax (Kerr Corp). To standardize the polishing procedure, the test surfaces of all specimens were flattened and polished under water-cooling in an automatic polishing machine (Ecomet 250; Buehler) with 120-, 240-, 320-, and 600-grit silicon carbide grinding papers at 350 rpm for 120 seconds with an applied force of 13.3 N. The final thickness of each specimen was measured by using digital calipers (Dentagauge 1; Erskine Dental). The specimens were then ultrasonically cleaned in distilled water for 10 minutes, air-dried, and kept at room temperature before testing.

All specimens from each material group were immersed in Petri dishes filled with 10 mL of 5% HCl with (pH=2) (Dr Clark Digestive Power; Self Health Resource Center) and placed in an incubator (Thermo Fisher Scientific) at 37 °C for 45 hours and 91 hours, equivalent to 6 months and 1 year of exposure to HCl in a patient with bulimia.⁴ After each step, the specimens were rinsed with deionized water and air-dried. Each specimen was tested before exposure (baseline), after 45 hours of exposure to HCl, and after 91 hours of exposure to HCl.

For the quantitative analysis, a profilometric evaluation was performed. The surface roughness average (Ra) of the specimens was measured by using a 3D optical interferometer (ZygoNewView 600; Zygo Corp) at baseline, after 45 hours, and after 91 hours of exposure to HCl. A silicone mold was made for each material group with a 5-mm hole created in the center with a disposable punch (Uni-Punch; Premier Dental Products) to standardize the test area and facilitate the analysis of the same test area before and after exposure. Light and focus were adjusted automatically. A field of view $526 \times 702 \mu\text{m}^2$ was acquired by using an objective with $\times 1$ zoom and $\times 10$ magnification to cover an area of 0.37 mm^2 . The images were captured with 640×480 high-resolution and were analyzed by using a software program (Metro Pro; Zygo Corp).³¹ The analysis control panel was adjusted to remove sudden $2.50\text{-}\mu\text{m}$ or higher spikes to fill missing data points by using adjacent valid data points.³¹ The surface roughness values were recorded in micrometers (μm). For the qualitative characterization of wear patterns, the specimens' test areas were visually examined with a 3D image of the surface profile.

The Friedman test was used to analyze the difference in surface roughness between the periods of evaluation for each material. The Wilcoxon signed-rank test with

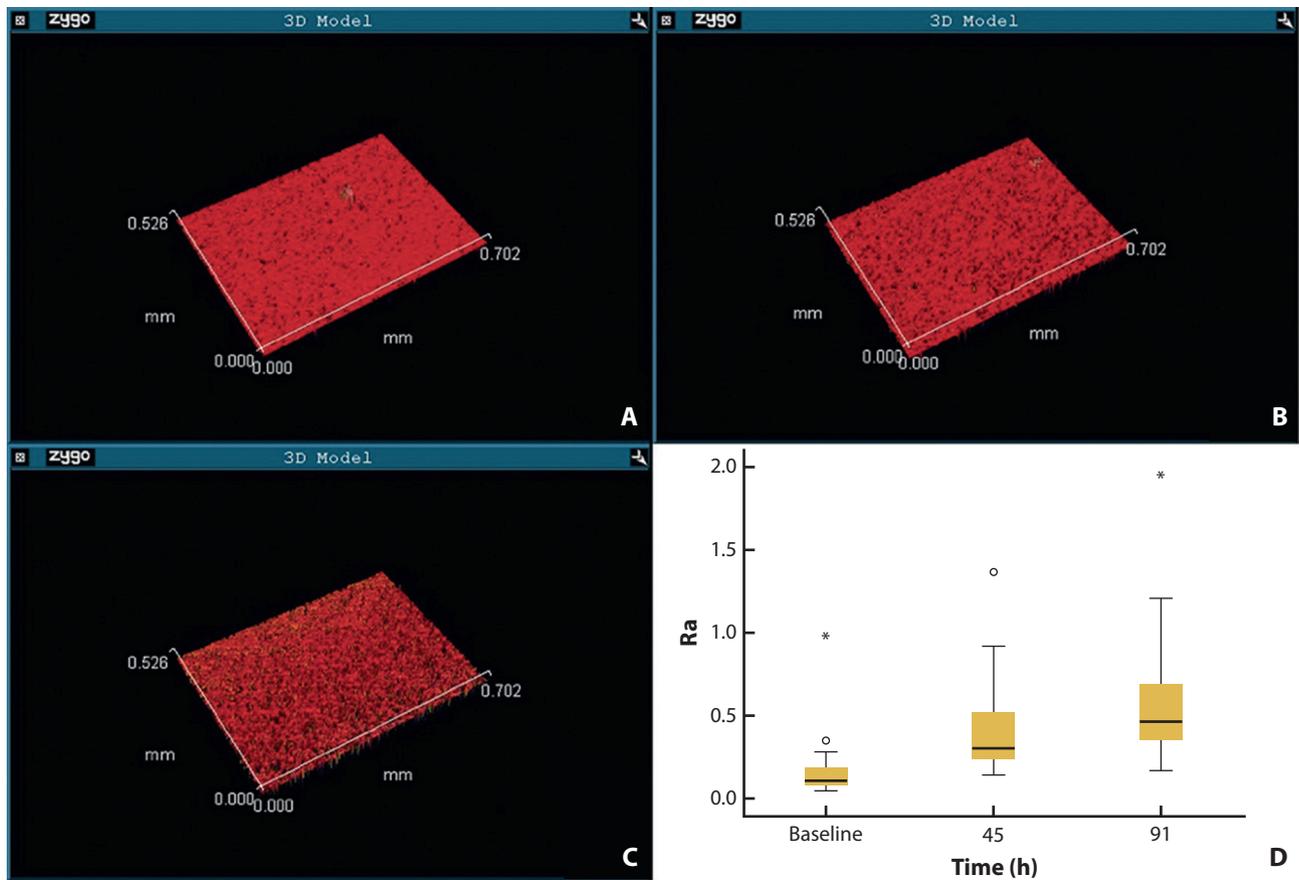


Figure 3. Three-dimensional model of resin matrix ceramic specimen. A, Baseline. B, 45 hours. C, 91 hours. D, Boxplots of surface roughness average (Ra) in μm at baseline, 45 hours, and 91 hours.

Bonferroni correction was used for post hoc comparisons. The change in surface roughness between baseline and 45 hours ($\Delta 45\text{h-baseline}$) and the change between baseline and 91 hours ($\Delta 91\text{h-baseline}$) were calculated. The $\Delta 45\text{h-baseline}$ and $\Delta 91\text{h-baseline}$ values were compared among the material groups by using the Kruskal-Wallis test, with post hoc tests again conducted with the Dunn test and Bonferroni correction. Statistical software (IBM SPSS Statistics, v22; IBM Corp) was used for the analysis.

RESULTS

The surface roughness results (mean, standard deviation, median, and interquartile range) for each material at each period of evaluation are shown in Table 1. The Friedman test showed no statistically significant differences for lithium disilicate ($P=.063$) or zirconia ($P=.513$) at the different periods of evaluation. Leucite glass-ceramic, feldspathic porcelain, and resin matrix ceramic had statistically significant differences ($P<.001$). Leucite glass-ceramic had statistically significant differences at all time points. Feldspathic porcelain and resin matrix ceramic showed statistically significant differences between

baseline and 45 hours and between baseline and 91 hours when the Bonferroni correction was used.

Results regarding the amount of change in surface roughness at the $\Delta 45\text{h-baseline}$ and the $\Delta 91\text{h-baseline}$ are shown in Table 2. In both measurements, the Kruskal-Wallis test indicated a statistically significant difference among the 5 materials ($P<.001$), with lithium disilicate and zirconia exhibiting the least change in surface roughness.

Boxplots of Ra and 3D models for each material group at each test time are presented in Figures 1-5. Leucite glass-ceramic, feldspathic porcelain, and resin matrix ceramic showed changes in surface topography with increased pore depths and valleys after exposure to HCl. Lithium disilicate and zirconia showed almost no change in surface topography after immersion in HCl.

DISCUSSION

The purpose of this in vitro study was to compare the surface roughness changes of different CAD-CAM restorative dental materials after exposure to gastric acid. The null hypothesis was rejected as some materials were affected more in terms of surface roughness than other materials.

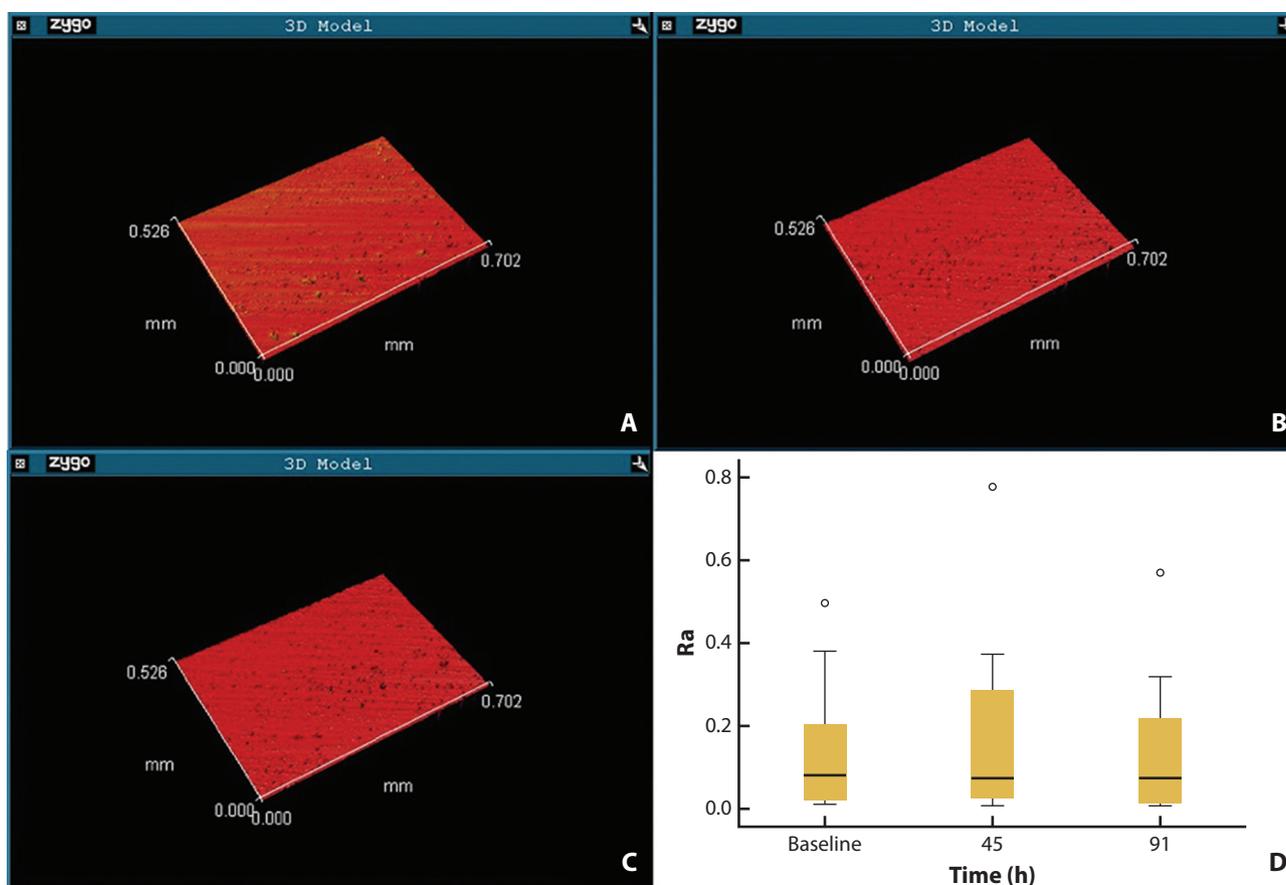


Figure 4. Three-dimensional model of lithium disilicate specimen. A, Baseline. B, 45 hours. C, 91 hours. D, Boxplots of surface roughness average (Ra) in μm at baseline, 45 hours, and 91 hours.

Roughness average (Ra) was used in the present study to compare the surface roughness of the different materials. At baseline, lithium disilicate and resin matrix ceramic demonstrated the lowest surface roughness, while leucite glass-ceramic showed the highest surface roughness. The present study was consistent with that of Harryparsad et al,⁴ who reported that lithium disilicate has less baseline surface roughness than leucite glass-ceramic and feldspathic porcelain. However, another study found no significant difference in baseline surface roughness between lithium disilicate and either high leucite ceramic or feldspathic ceramic.²³ However, the specimens in that study were glazed after polishing, which was not the case for the present study.

An increase in the surface roughness of ceramic restorations reduces restoration strength and results in nonuniform stress distribution.^{1,9} Quirynen et al¹² reported a clear association between plaque accumulation and surface roughness. A rough surface will also change and affect the color and appearance of a restoration by reflecting an irregular and diffuse pattern of light.¹⁴

The surface roughness of lithium disilicate and zirconia was not significantly affected by the HCl immersion. Leucite glass-ceramic, feldspathic porcelain, and

resin matrix ceramic showed a significant increase in surface roughness after exposure to gastric acid. Regarding the amount of change in surface roughness ($\Delta 45\text{h}$ -baseline and $\Delta 91\text{h}$ -baseline), lithium disilicate and zirconia were resistant to acid corrosion.

Few studies have tested the effect of gastric acid on the surface roughness of esthetic dental materials. Backer et al²⁹ reported that gastric acid negatively affected the surface roughness of 2 brands of CAD-CAM composite resin. One study reported that exposure to HCl had no significant effects on different glass-ceramic materials but that the exposure time was relatively short (24 hours) and the pH of the corrosive solution (pH=3.8) was higher than that in the present study.³⁰

The local composition and microstructure of the restorative material are the main reasons for surface roughness changes.³ VITA Enamic consists of a hybrid structure with 2 interpenetrating networks of feldspathic ceramic particles and polymer.⁷ Increases in the surface roughness of resin matrix ceramic after exposure to HCl acid can be explained by hydrolysis of the methacrylate ester bonds in the resin matrix of polymer-based materials when they are exposed to acidic solution.²⁹ The main reason for surface roughness changes in this

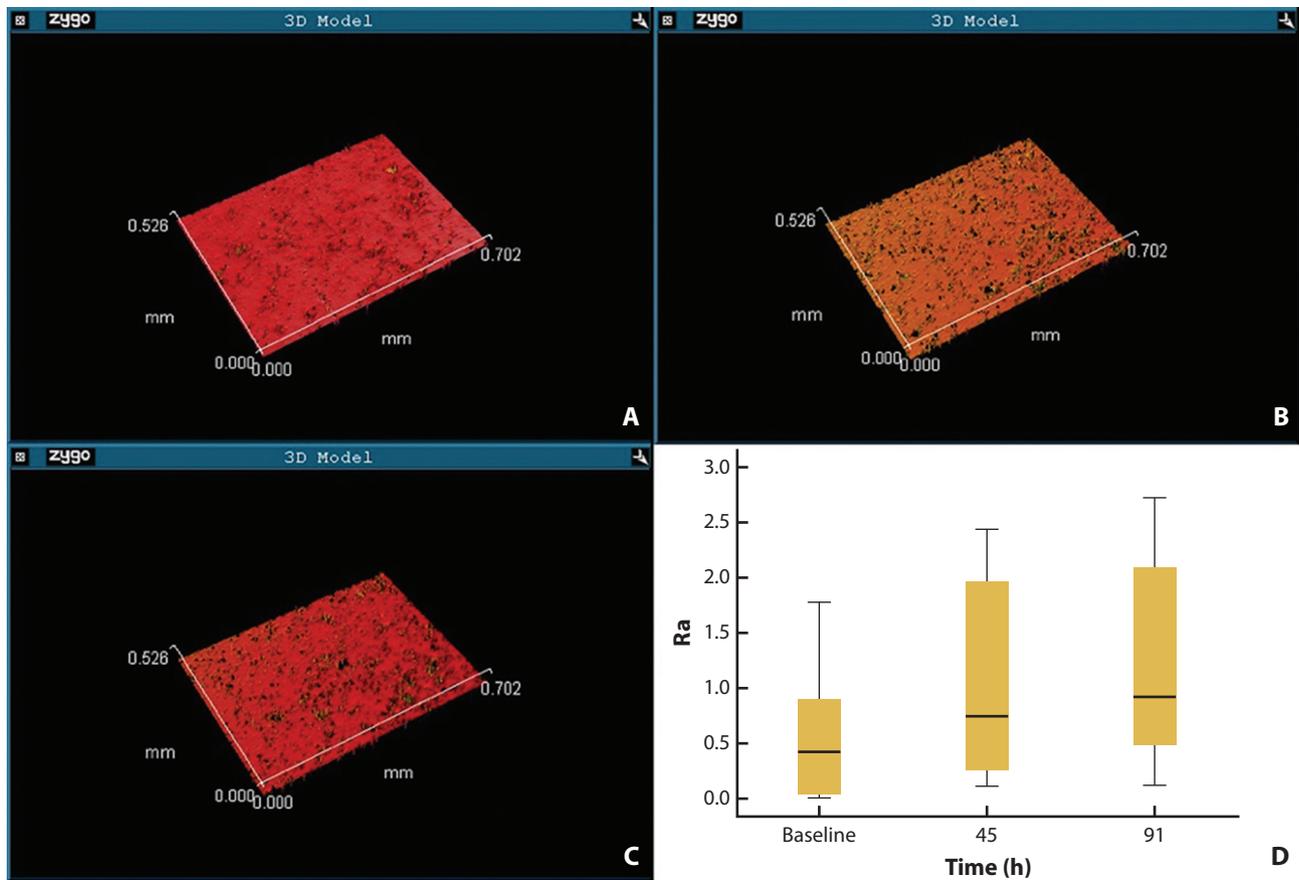


Figure 5. Three-dimensional model of feldspathic porcelain specimen. A, Baseline. B, 45 hours. C, 91 hours. D, Boxplots of surface roughness average (Ra) in μm at baseline, 45 hours, and 91 hours.

material is the detachment or release of inorganic fillers that are attached to the resin matrix as coupling agents connecting the organic and inorganic components together.²⁹

According to Harryparsad et al,⁴ the size of glass particles lost in glass-ceramics during acid exposure is directly proportional to the amount of surface roughness change. Thus, because the grain size of leucite glass-ceramic (1 to 5 μm) and feldspathic porcelain (4 μm) is larger than that of lithium disilicate (0.2 to 1.0 μm), they show more surface roughness change than lithium disilicate.⁴ Another study found that lithium disilicate showed a significant increase in surface roughness compared with different types of zirconia when they were exposed to HCl for 96 hours.² However, the present study found that both lithium disilicate and zirconia showed no significant change in surface roughness after exposure to HCl for 45 hours and 91 hours. The pH of HCl used in the study by Sulaiman et al² was more acidic (pH=1.2), and the exposure time was longer (96 hours).

Limitations of the present study include that only 1 surface roughness parameter (Ra) and that a

2-dimensional value was used. It provides no information about surface profile characteristics.^{21,23} Additionally, the role of saliva in the oral cavity was not considered as it is difficult to apply in in vitro studies. Another limitation of this study is that the specimens were polished but not glazed. Glazing test materials before exposure to the corrosive solution will mimic the clinical situation and will give more accurate results; however, a previous study found no clinical significant difference between polished and glazed porcelain surfaces in terms of surface smoothness and characteristics.³² Another study indicated no statistically significant difference in surface roughness between fine polished and glazed zirconia, but there was a statistical significant difference between fine polished and glazed veneered zirconia.³³

CONCLUSIONS

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

1. Leucite glass-ceramic, feldspathic porcelain, and resin matrix ceramic showed a statistically significant increase in surface roughness when they were

exposed to simulated gastric acid for 45 hours and 91 hours.

2. Lithium disilicate and zirconia showed no statistically significant change in surface roughness after exposure to HCl for 45 hours and 91 hours.
3. Anatomic zirconia and lithium disilicate ceramic materials are more resistant to HCl exposure than other glass matrix and resin matrix ceramics.

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Corresponding author:

Dr Muhsen Alnasser
 Department of Restorative Dentistry and Biomaterials Sciences
 Harvard School of Dental Medicine
 188 Longwood Avenue, Boston, MA 02115
 Email: muhsen_alnasser@hsdm.harvard.edu

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