Original Article

Effect of Simulated Gastric Acid on Aesthetical Restorative CAD-CAM Materials' Microhardness and Flexural Strength

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Abstract

Background: Gastric acid, which is among erosive substances, gradually rises to the mouth in individuals with reflux and bulimia nervosa disorders, and this causes various effects on dental restorations. **Aim:** The objective of this study is *in vitro* investigation of gastric acid's effect on flexural strength and hardness on aesthetic restorative computer-aided design and computer-aided manufacturing (CAD-CAM) materials. **Materials and Methods:** For this study, four materials have been used, namely Enamic (Vita), Superfect Zir (Aidite) Zirconia, IPS e.max CAD (Ivoclar Vivadent), and Mark II (Vita). From these four different materials, 24 samples with 14 × 4 × 1 dimensions in rectangular prism form are used, which makes a total of 96 samples. One group was separated as the control group, while the rest was allowed to wait at 37°C, 5 ml gastric acid for 96 hours. Hardness value and flexural strengths were measured as pre-exposure and post-exposure to gastric acid. **Results:** There is a statistically significant difference between the groups in terms of the amount of decrease in the mean hardness after exposure to gastric acid compared to pre-exposure values (p: 0,000; $P < 0,05$). There was no statistically significant difference between the groups in terms of the amount of decrease in the post-exposure average flexural strength compared to the pre-exposure value (p: 0.063; $P > 0.05$). There is a statistically significant difference between the groups in terms of the average flexural strength after exposure to the acid. **Conclusions:** According to the data obtained, it was concluded that exposure to gastric acid affects the hardness and flexural strength properties of dental restorative ceramic materials.

Keywords: *Dental ceramics, flexural strength, gastric acid, surface microhardness*

Introduction

Fixed prosthetic restorations have an important place in restorative dentistry. Ceramics have been preferred in fixed prostheses due to their high wear resistance, good color compatibility with natural teeth, low thermal conductivity, good aesthetic properties, and biocompatibility.[1]

Recently, materials produced by computer-aided design and computer-aided manufacturing (CAD-CAM) have been introduced. This technique allows the fabrication of aesthetic monolithic restorations in a single session.[2,3] CAD-CAM blocks that can be milled and produced in industrially standard conditions can be composite, ceramic, or hybrid structures containing several properties of both materials.[4]

There are significant differences between ceramics due to their different chemical compositions and microstructures.[5] All types of ceramics have both internal and external factors that affect their general physical properties. Examples of internal factors

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affecting ceramics are crystal size, geometry, modulus of elasticity, phase transformation, and thermal expansion mismatch. Oral environment, humidity, pH, and loads (cyclic and peak loads) can be given as examples of external factors.[6] The durability of ceramics in the oral environment is affected not only by their composition and microstructure, but also by their acidity. The exposure time to the existing chemical agent and the temperature of the chemical affect the durability.[5]

In the last 20 years, dental erosion has become a topic of interest in dentistry in general, regarding its causes, diagnosis, and process. Acids, regardless of bacterial origin, are considered to be one of the main factors of tooth wear and loss of tooth structure, continuous acid exposure makes the tooth surface more susceptible to etching.[7] Among the most common erosive substances are gastric acid in patients with reflux, citric acid in citrus fruits, phosphoric acids present in fruit juice, liquors, and many carbonated drinks.[8]

These erosive acids may be of intrinsic origin, as in gastric acid, or they may be extrinsic, such as acidic beverages and citrus fruits. Independent of its origin, acids begin to destroy the surface of the tooth and change its structure by time. Gastric juice has a greater degradation effect on tooth structures than dietary acids and has a lower pH value.[7,9]

Gastric juice may reach the oral cavity as a result of bulimia nervosa, gastroesophageal reflux disease or as a result of prolonged severe nausea during pregnancy.[9]

Bulimia nervosa is an eating disorder that includes recurrent episodes of eating (uncontrolled consumption of abnormally large amounts of food) followed by inappropriate compensatory behaviors (e.g. self-induced vomiting, abuse of laxatives, fasting, excessive exercise).[10]

Although information on the prevalence of bulimia nervosa is limited, eating disorders are more likely to occur in women during early adolescence or adolescence.[9]

In healthy patients, adequate saliva flow and buffering activity provide protection against acid attacks. However, in patients with bulimia nervosa, there may be a limited time for the protective effect of saliva before erosion occurs, since gastric fluid is in direct contact with dental hard tissues and the pH remains low for a while. For this reason, the buffering effect of saliva on neutralizing the acidic pH may not completely prevent erosion from bulimia nervosa.

Regurgitation, which is defined as the involuntary movement of stomach contents from stomach to mouth, has been accepted as a common cause of severe dental erosion. The common cause of medical conditions that cause gastric acid movement into the oral cavity is gastroesophageal reflux disease. The correlation between gastroesophageal reflux disease and tooth erosion has been reported as follows. It has been reported that reflux was found in later studies in patients with dental erosion, and dental erosion was found in reflux patients afterwards. Based on the findings of this study, it can be concluded that there is a significant interaction between the ceramic surface and an acidic aqueous medium.[11]

There is a limited number of studies examining changes in properties of different materials exposed to acidic environment by simulating erosive changes. As a result of these studies, it was found that the filtered ion concentrations may vary significantly between different material types, at different solution pHs, and at different exposure times.[12-15]

In this study, the effect of gastric acid, an intrinsic erosive agent, on the surface microhardness and flexural strength of four different aesthetic restorative CAD-CAM materials Vita Enamic, Superfect Zir (Aidite) Zirconia, IPS e.max CAD (Ivoclar Vivadent), Vita Mark II was investigated *in vitro*.

The hypothesis of the study is that simulated gastric acid would reduce the surface hardness and flexural strength of different CAD-CAM materials.

Materials and Methods

This study has been conducted in Yeditepe University Faculty of Dentistry, Hard Tissue Laboratory.

In this study, Vita Enamic, Superfect Zir (Aidite) Zirconia, IPS e.max CAD (Ivoclar Vivadent), Vita Mark II CAD-CAM blocks were utilized.

The sample number of the study was calculated with the program named G*Power 3.1.9.2. The sample determined for each group was determined as at least 24 (total 96), with the dimensions of 14 × 4 × 1 mm.

A total of 96 samples, 24 from each group, were produced from four different materials in the form of rectangular prisms with the dimensions of 14 × 4 × 1 mm.

CAD glass blocks were kept horizontally and cut at 400 revolutions per minute with a low-speed cutting device (Isomet 1000, Buehler Ltd., Lake Bluff, IL, USA) in 14 × 4 × 1 mm dimensions under water cooling. One surface of each sample was polished under water cooling (Phoenix Beta Twin Wheel, Buehler Ltd., Lake Bluff, USA) with 800, 1000, and 1200 grit silicon carbide paper. After polishing, the surface thickness of the samples was checked with a digital caliper (Mitutoyo Corp®, Kanagawa, Japan) (±0,1 mm).

Glazing was applied to IPS e.max CAD (Ivoclar Vivadent) samples after sintering.

Glazing was applied to Vita Enamic and Vita Mark II samples.

Sintering process was applied to the Superfect Zir (Aidite) samples.

12 of the 24 samples for each material were separated as the control group, and the remaining 12 samples were exposed to gastric acid.

A generic formula simulating gastric acid was used. The simulated acid was prepared according to Hunt and McIntyre's method to cause erosive lesions in enamel similar to those seen clinically. Hydrochloric acid (HCl) 0.06 M (0.113% solution in deionized water, pH 1.2) was prepared. The pH was monitored every 24 h, and each specimen was immersed, polished surface facing up, in 5 ml of the simulated acid for 96 h in a 37◦C incubator (Memmert BE 500 Incubator, Memmert GmbH + Co. KG, Schwabach, Germany). Then, all samples were cleaned ultrasonically (AS 8772 Ultrasonic Cleaner, General Home Orsay Ltd. Sti., Istanbul, Turkey) in distilled water for 5 minutes.

The hardness value and flexural strength were measured before and after exposure to gastric acid. Hardness value was obtained by using the Vickers formula for microhardness (Micromet 5114D®, Buehler Ltd., Lake Bluff, Illinois, ABD). Flexural strength was evaluated in MPa and Newton by using three-point flexural test by using Bluehill Universal (Instron) instrument.

Table 1: Hardness Evaluation

	Hardness Pre-Acid Avrg±SS	Hardness Post-Acid Avrg±SS	Hardness Difference Avrg±SS	²P
Vita Enamic	165.38±2.65[a]	133.13±1.98[a]	32.24±3.22[a]	0.000*
Vita Mark II	374.19±5.17[b]	339.45±8.22[b]	34.74±10.08[a]	0.000*
IPS e.max CAD	496.38±5.64[c]	477.6±4.01[c]	18.78±8.49[b]	0.000*
Zirconia	1478±6.99[d]	1385.72±11.51[d]	92.28±16.36[c]	0.000*
¹P	0.000*	0.000*	0.000*	

¹One-way ANOVA test. ²Paired samples *t*-test. *$P<0.05$. Different letters in the columns indicate inter-group differences

First off all Vickers microhardness was evaluated for 96 samples and then flexural strength was evaluated in MPa and Newton by using three-point flexural test by using Bluehill Universal (Instron) instrument.

While evaluating the findings obtained in the study, IBM SPSS Statistics 22 program was used for statistical analysis. The suitability of the parameters to the normal distribution was evaluated by Kolmogorov–Smirnov and Shapiro–Wilk tests. One-way ANOVA test was used for the comparison of normally distributed parameters, and Tamhane's T2 test was used to determine the group that caused the difference since the variances among the groups were not homogeneous. The Kruskal–Wallis test was used for the inter-group comparisons of non-normally distributed parameters. Paired sample *t*-test was used for in-group comparisons of normally distributed parameters. A P value less than 0.05 was considered to be statistically significant.

Results

There was a statistically significant difference between the groups in terms of pre-acid hardness averages (p: 0.000; $P < 0.05$). As a result of the *post hoc* Tamhane's T2 test performed to determine which group was the origin of the significance; the mean pre-acid hardness of the Zirconia material was significantly higher than the Vita Enamic, Vita Mark II, and IPS e.max CAD materials ($p_{1\text{-}2\text{-}3}$:0.000; $P < 0.05$).

The mean pre-acid hardness of the IPS e.max CAD material was significantly higher than the Vita Enamic and Vita Mark II materials ($p_{1\text{-}2}$:0.000; $P < 0.05$). The mean pre-acid hardness of the Vita Mark II material was significantly higher than that of the Vita Enamic material (p_1:0.000; $P < 0.05$).

There was a statistically significant difference between the groups in terms of post-acid hardness average values (p: 0.000; $P < 0.05$). As a result of the *post hoc* Tamhane's T2 test performed to determine which group caused this

Table 2: Evaluation of Flexural Strength (Mpa)

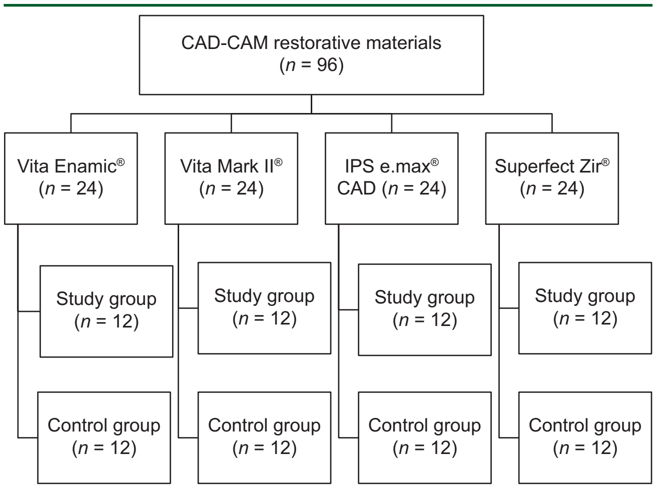
	Flexural Strength (Mpa) Pre-Acid Avrg±SS	Flexural Strength (Mpa) Post- Acid Avrg±SS	Flexural Strength (Mpa) Difference Avrg±SS (median)	²P
Vita Enamic	182.63±20.26[a]	129.38±22.03[a]	53.26±32.34 (46.5)[a]	0.000*
Vita Mark II	100.97±14.43[b]	77.88±10.08[b]	23.09±15.31 (22.3)[a]	0.000*
IPS e.max CAD	303.65±39.16[c]	233.35±34.87[c]	70.29±46.51 (61.7)[a]	0.000*
Zirconia	1017.02±153.37[d]	963.52±216.19[d]	53.50±314.70 (79.7)[a]	0.000*
P	¹0.000*	¹0.000*	³0.063	

¹One-way ANOVA test. ²Paired samples *t*-test. ³Kruskal–Wallis test. *$P<0.05$. Different letters in the columns indicate inter-group differences

significance, the mean post-acid hardness of the Zirconia material was significantly higher than the Vita Enamic, Vita Mark II and IPS e.max CAD materials (p_{1-2-3}:0.000; $P < 0.05$). The mean post-acid hardness of IPS e.max CAD material was significantly higher than that of Vita Enamic and Vita Mark II materials (p_{1-2}:0.000; $P < 0.05$). The mean post-acid hardness of the Vita Mark II material was significantly higher than that of the Vita Enamic material (p_1:0.000; $P < 0.05$).

There was a statistically significant difference between the groups in terms of the amount of decrease in the mean hardness after acidity compared to pre-acid values (p: 0.000; $P < 0.05$). The mean decrease in the hardness of the Zirconia material was significantly higher than that of Vita Enamic, Vita Mark II, and IPS e.max CAD materials (p_{1-2-3}:0.000; $P < 0.05$). The mean hardness reduction of the IPS e.max CAD material was significantly lower than that of the Vita Enamic and Vita Mark II materials (p_1:0.001; p_2:0.002; $P < 0.05$). There was no significant difference between Vita Enamic and Vita Mark II in terms of the amount of decrease (p: 0.965; $P > 0.05$).

Table 3: CAD-CAM restorative materials



For all groups, the decrease observed in post-acid hardness values is statistically significant (p: 0.000; $P < 0.05$).

There was a statistically significant difference between the groups in terms of the mean flexural strength after acid exposure (p: 0.000; $P < 0.05$). As a result of the *post hoc* Tamhane's T2 test performed to determine which group caused this significance, the mean flexural strength of Zirconia material after acid exposure was found to be significantly higher than that of Vita Enamic, Vita Mark II, and IPS e.max CAD materials (p_{1-2-3}:0.000; $P < 0.05$). The mean post-acid flexural strength of the IPS e.max CAD material was found to be significantly higher than the Vita Enamic and Vita Mark II materials (p_{1-2}:0.000; $P < 0.05$). The mean post-acid flexural strength of the Vita Enamic material was significantly higher than that of the Vita Mark II material (p_1:0.000; $P < 0.05$).

There was no statistically significant difference between the groups in terms of the amount of decrease in the post-acid average flexural strength values compared to the pre-acid values (p: 0.063; $P > 0.05$).

For all groups, the decrease observed after acid exposure compared to the pre-acid flexural strength level is statistically significant (p: 0.000; $P < 0.05$) [Tables 1-4].

Discussion

This study was conducted to evaluate how simulated gastric fluid affects the hardness and flexural strength of different CAD-CAM materials used in dentistry. The hypothesis predicting that simulated gastric acid would reduce the surface hardness and flexural strength of different CAD-CAM materials was confirmed.

Dental ceramics are the most chemically stable restorative materials. However, as a result of this study, in all ceramic groups examined, after immersion in acidic water for 96 hours, changes were observed in terms of microhardness and flexural strength.

Table 4: Specifications of the materials

Brand/LOT Code	Classification	Content	Manufacturer	Sample Size
Vita Enamic® (LOT: 79470)	Polymer infiltrated ceramic	% 86 feldspar ceramic, %14 acrylic polymer	Vita Zahnfabrik, Bad Sáckingen, Germany	14x4x1 mm
Vita Mark II® (LOT: 94090)	Feldspathic glass matrix ceramics reinforced with leucite	% 56-64 SiO_2, % 20-23 Al_2O_3, % 6-9 Na_2O, % 6-8 K_2O, % 0.3-0.6 CaO, % 0-0.1 TiO_2	Vita Zahnfabrik, Bad Sáckingen, Germany	14x4x1 mm
IPS e.max® CAD (LOT: Z00921)	Lithium disilicate ceramic	% 57-80 SiO_2, % 11-19 Li_2O, % 0-13 K_2O, % 0-11 P_2O_5, % 0-8 ZrO_2, % 0-8 ZnO, % 0-5 Al_2O_3, % 0-5 MgO	Ivoclar Vivadent AG, Schaan, Liechtenstein	14x4x1 mm
Superfect Zir® (W191030-1-08)	Polycrystalline ceramics reinforced with Zirconia	% 94-95 ZrO_2, % 4.5-5.5 Y_2O_3, <%0.5 Al_2O_3	Aidite Technologies Ltd., Hebei, China	14x4x1 mm

Basically, dental ceramics have good chemical resistance, but can be affected by various factors. These can be listed as follows: the composition and microstructure of the ceramic, the chemical character of the ceramic material, the chemical character of the abrasive substances to which the ceramic is exposed or acidic agents, exposure time, and temperature.[16]

The degradation of dental ceramics can occur with the effect of mechanical or chemical substances. Exposure of ceramics to corrosive agents causes degradation of the material through selective leaching of alkali metal ions. It leads to decreased stability and flexural strength of the material and the potential for crack development and crack propagation. With the degradation of all ceramic materials, the surface topography changes, resulting in a rougher surface. Therefore, it causes increased plaque accumulation and more wear of opposing teeth. These changes can cause some problems to happen, such as the release of potentially harmful elements due to corrosion or dissolution.[14,17,18]

Environmental conditions may degrade resistance and cause surface degradation as well. Variations in ceramics and processing techniques can cause a decrease in the hydrolytic stability of materials. Alkali metal ions are much less stable in the glass phase than in the crystalline phase.[17]

In some studies, evaluating the effect of simulated gastric fluid or citric acid on different composite resins, the ability of acid to soften the polymer matrix was addressed. Vita Enamic contains a feldspathic ceramic matrix (86% by weight) infiltrated with a low-viscosity copolymer (urethane dimethacrylate and triethylene glycol dimethacrylate).[13,15,19-22]

The reduction in roughness is probably due to the dissolution of the ceramic portion, which constitutes the bulk of the material. The boundaries between the ceramic and polymer parts became more pronounced as a result of the dissolution of the feldspathic matrix by the acid. Moreover, microcracks were observed on the surface of Vita Enamic, revealing that this material was greatly affected by the acid.

In the study of Ramos *et al*.,[23] a change in the size and shape of lithium disilicate crystals was observed after etching with hydrofluoric acid. In this study, pores were observed in this material after acid exposure. This proves the effect of acid on the material surface.

In the study by Sulaiman *et al*.,[11] there was substance loss for IPS e.max CAD after gastric acid exposure. In their study with different Zirconia materials among Prettau (PRT, Zirkonzahn), Zenostar (ZEN, Ivoclar), Bruxzir (BRX, Glidewell), Katana (KAT, Noritake), and FSZ Prettau Anterior (PRTA, Zirkonzahn), it is reported that the most weight loss was seen in PRTA. It was found that the IPS e.max CAD material which they used as the control group showed three times more weight loss than the Zirconia materials.

A systematic review reported a 24% prevalence of dental erosion in patients with GERD and that 33% of patients with dental erosion had such a disorder.[24]

According to Saksena *et al*.,[25] the buffering effect of saliva on acid neutralization cannot completely prevent erosion resulting from GERD.

In the study of Marlon E.M Cruz *et al*.,[9] IPS e.max CAD exhibited about three times more weight loss than monolithic Zirconia materials after exposure to HCl. In terms of microhardness value, IPS e.max CAD was found to be higher than Vita Enamic.[9]

In contrast to acid exposure, the type of material has a greater effect on determining the hardness of the material. According to the result of Albero *et al*.'s[26] study, IPS e.max CAD was reported to be harder than Vita Enamic.

In our study, the sequence of hardness values for CAD-CAM materials we used before simulated gastric acid exposure was Zirconia, IPS e.max CAD, Vita Mark II, Vita Enamic. After acid exposure, the hardness value in all groups decreased, but this sequence did not change. Zirconia, which is frequently used in dentistry, has the highest hardness value because of its polycrystalline structure. Although it decreases after acid exposure, it has still the highest hardness value.

The sequence of flexural strength values for CAD-CAM materials we used before simulated gastric acid exposure was as follows: Zirconia, IPS e.max CAD, Vita Enamic, Vita Mark II. The flexural strength of all groups decreased after acid exposure, but this sequence did not change.

However, it should be noted that this study has some limitations:

During the consumption of acidic foods or beverages in daily life, the acidic agents used in the study remain in contact with the ceramics for only a short time before being washed away by saliva.[27-29] In addition, this study did not take the role of saliva into account. Besides, the oral cavity offers a different testing environment. For example, the presence of water, temperature changes in the oral cavity, and pH levels also significantly affect the properties of restorations.

Therefore, to understand the effect of acidic agents on ceramics better, long-term clinical follow-up studies are needed.

Conclusions

Considering the limitations of this study, the following conclusions can be drawn:

1. Gastric acid causes a decrease in the bending strength and hardness values of all ceramic materials.
2. Gastric acid has different effects on different ceramic materials.
3. In terms of the hardness, the material least affected by gastric acid exposure was IPS e.max CAD.
4. IPS e.max CAD restorations can be preferred to minimize the negative effects of gastric acid in patients with GERD and bulimia nervosa.
4. According to the evaluation of post-acid mean flexural strength and post-acid mean hardness of Zirconia and IPS e.max CAD restorations can be preferred in patients with GERD and bulimia nervosa.

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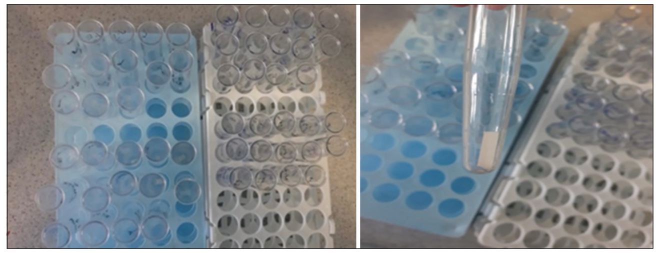
The photographs of study and control groups

Vita Enamic® samples (upper left), Vita Mark II® samples (upper right)

IPS e-max® CAD samples (bottom left), Superfect Zir® samples (bottom right)



The photographs: Samples of the study groups

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Conflicts of interest

There are no conflicts of interest.

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