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Comparison of the Effect of Simulated Gastric Juice on Surface Roughness and Flexural Strength of Three Different Computer Aided Designing Computer Aided Manufacturing Blocks: An In Vitro Study

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Abstract

Purpose: To evaluate the effect of simulated gastric juice on surface roughness and flexural strength of three different CAD/CAM blocks.
Materials and Methods: Resin based ceramic (RBC Group), High impact polymer composite (HIPC Group) and Zirconia (Z Group) as 3 groups were considered for the study (90 samples, 30 samples per group). In each group, 10 samples were evaluated without immersion in gastric juice (Baseline). Remaining 20 samples were immersed for total of 24 hours in simulated gastric juice (pH 1.2). The surface roughness and flexural strength of samples was evaluated at the end of 6 hours and 24 hours. This was repeated for all groups. The data obtained was subjected to One way and Multivariate ANOVA and Tukey HSD tests. The significance level was fixed at 5% ($p<0.05$)
Results: One way ANOVA showed surface roughness of Z group decreased significantly after acid immersion whereas RBC group and HIPC group showed significant increase in the surface roughness after acid immersion. One way multivariate ANOVA revealed statistically significant differences between the groups. Tukey HSD revealed a significant difference from base line to 24 hours across all groups. The surface changes were not significant between 6 hours to 24 hours in Z ($p=0.261$), RBC ($p=0.797$), HIPC ($p=0.401$) and baseline to 6 hours in HIPC group ($p=0.397$). The flexural strength of all the groups decreased significantly after acid immersion. The change in flexural strength from baseline to 6 hours was not significant in RBC ($p=0.123$) and HIPC groups ($p=0.126$) and 6 hours to 24 hours in RBC group ($p=0.096$). Z group showed a significant reduction from baseline to 6, 6 to 24 and baseline to 24 hrs. RBC

	and HIPC showed significant reduction from baseline to 24 hrs; and HIPC from 6 to 24 hrs **Conclusion:** Resin based ceramic is a suitable material in terms of flexural strength and surface roughness in gastric acid regurgitation, followed by Zirconia as the surface roughness does not increase from the baseline. High impact polymer composite can be a suitable restorative material in severe abrasion and erosion cases as it is least affected by acid in terms of roughness.
CC License CC-BY-NC-SA 4.0	***Key words: Resin based ceramic, CAD/CAM blocks, surface roughness, flexural strength, acid regurgitation.***

Introduction:

Tooth surface loss is an irreversible condition that leads to breakdown of tooth structure. It could be physiological or pathological. Tooth surface loss which was once considered an age related phenomenon has now started affecting children and young adults. Changing life styles, social pressure, dietary causes or regurgitation of acids are few of the possible causes. Incidence of tooth surface loss has been on the rise in the recent decades. One of the most common causes of erosion in patients with GERD and bulimia nervosa is due to acid regurgitation(1). The oral symptoms of gastric acid regurgitation represent smooth, glazed spherical surfaces with "cupping" of posterior tips and incisal edges whereas erosion of the posterior teeth and lingual surfaces of the maxillary front teeth are seen in bulimic patients. Furthermore bruxism and clenching are factors that can accelerate pace of erosion due to mechanical wear. (2,3).The main challenges in rehabilitating tooth surface loss in patients with acid regurgitation and bulimia nervosa is to maintain the occlusal vertical dimension and to restore the shape and anatomy of the dentition(4). The ultimate goal of restorative dentistry is to restore missing tooth structure with a material that has similar physical and mechanical qualities like natural teeth. Depending on the severity of the disease direct or indirect restoration might be used to restore tooth surface loss. Rehabilitation in tooth surface loss, should be finely balanced between preservation of existing tooth structure and preparation of tooth to receive a restoration. Hence decision making and selection of material and technique is crucial. In dentistry there are a variety of materials and techniques available for conservative management of tooth surface loss (5). Indirect restorations are recommended when there is a large surface area that needs to be restored and it is difficult to create sufficient interproximal contacts using direct restorative material(5).

There are a variety of materials used in a CAD/CAM technology for the management of tooth surface loss. These include ceramics, composites, and resin-ceramics materials(6).Ceramics and resin ceramic materials are improved restorative materials for rehabilitation of tooth surface loss due to its superior esthetics and the capacity to construct full contour crowns. Ceramics have excellent aesthetics and superior mechanical properties. However among all other dental ceramics zirconia has the highest mechanical characteristics. In spite of superior mechanical properties, ceramics are brittle in nature to overcome the brittle nature of ceramics, resins are incorporated to increase the material's flexibility(6,7).These resin matrix ceramics can be classified as resin based ceramics and hybrid ceramics. The resin-based ceramics consist of polymer matrix with at least 80% nano sized ceramic filler particles whereas the hybrid ceramics made of a ceramic network infiltrated with a polymer(8).
Sulaiman T,A et al(9)evaluated impact of gastric acid on surface morphology and optical properties of monolithic zirconia and concluded that monolithic zirconia materials display modest surface modifications, whereas Aditi Kulkarni et al (10) inferred that acid treatment has impact on the surface roughness of porcelain and lithium disilicate, but that there were no changes in the surface roughness of zirconia materials. Simillarly Alnasser M et al (11,12)inferred that zirconia had not changed after being exposed to the acidic pH. Several authors concluded that zirconia is unaffected but a few have seen results of modest surface modification. Backer A.D et al (13)used surface roughness analysis to assess the influence of simulated gastric juice on CAD/CAM resin composites and concluded that gastric acid has a detrimental impact on CAD-CAM resin composite surface roughness.
Various studies has been published on the mechanical behaviour of indirect restorative material in acidic environment. Studies comparing the mechanical properties of resin based ceramic and zirconia material in presence of gastric juice is limited.

Computer-Aided Designing Computer Aided Manufacturing (CAD/CAM) technology has revolutionized dentistry by offering efficient and accurate restoration solutions. However, the longevity of CAD/CAM restorations is influenced by various factors, including the effects of acidic environments in the oral cavity. Hence, it is crucial to determine the appropriate materials for CAD/CAM restorations that can withstand the impact of acidic conditions. In this context, the flexural strength of CAD/CAM blocks is considered as one of the significant mechanical properties that affect the restoration's durability. Moreover, the surface roughness of CAD/CAM restorations influences plaque accumulation, bacterial adhesion, and soft tissue response, making it another important factor to evaluate.
The current study was therefore designed with an aim to compare the impact of simulated gastric juice on surface roughness and flexural strength of three different CAD/CAM Blocks. The null hypothesis was that there would be no change in surface roughness and flexural strength of CAD/CAM resin based ceramic and Zirconia when immersed in simulated gastric juice. The findings of this study could help clinicians in selection of appropriate materials for CAD/CAM restorations that possess superior mechanical and surface properties, ensuring optimal clinical outcomes in gastric regurgitation.

Materials and Methods

Types of CAD/CAM materials used in this study are: Zirconia (Sagemax), Resin Based Ceramics (Brilliant Crios) and High impact polymer composite (breCAM.HIPC) (Table 1).

Table 1. Description of material used

CAD/CAM Material	Brand Name; Manufacturer	Composition
Resin based Ceramics (RBC)	Brilliant Crios, Coltene, UK	BisGMA, BisEMA and TEGDMA as polymer with 70 % inorganic fillers
High impact polymer composite (HIPC)	breCAM.HIPC Bredent, Germany	microceramic filler in crosslinked polymethyl methacrylate network.
Zirconia (Z)	NexxZr T - Sagemax, USA	>91.6% of zirconium oxide (ZrO_2), 5% yttrium oxide (Y_2O_3), <13% hafnium oxide (HfO_2) and <0.15% aluminium oxide (Al_2O_3).

The sample size was calculated using GPower version 3.1.9.2 software, the required sample size with 90% power is 30 per group. A total of 90 square shaped sample of dimension 10mm x 10mm x 2mm were fabricated from three different types of CAD/CAM materials (n=30) (Figure 1).

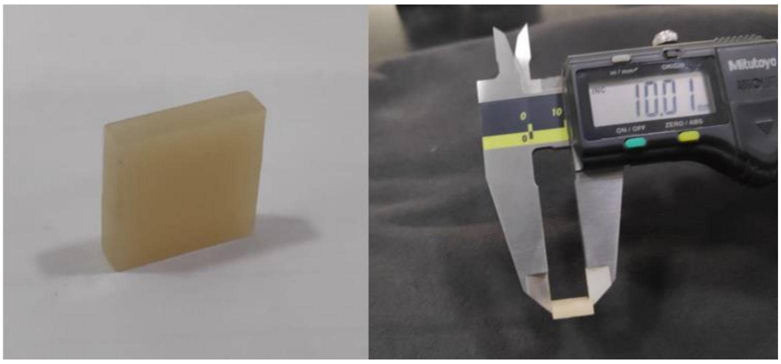

Figure 1. Square shaped samples of dimension 10mm x 10mm x 2mm.

The Zirconia and High impact polymer composite samples were designed in CAD/CAM software (3 shape dental system, Denmark). The design was transferred to the milling software as STL file and final samples were milled in CAD/CAM milling machine (Zenotec Hybrid Select, Weiland Germany). After completion of milling, the zirconia samples was kept for sintering at temperature 1500^{0}C for 8 hours using sintering furnace (Zenotec fire cube, Weiland, Germany). Resin Based Ceramic samples were fabricated using low speed cutting machine (ISOMET; Buehler, Lake bluff, IL). All the samples were polished using diamond polishers (NAIS diamond polishing kit, Bulgaria, EU) and were washed with distilled water in ultrasonic cleanser for 10 min.
Before immersion of the samples into the simulated gastric juice, samples (n=10) were evaluated for the baseline surface roughness and flexural strength using Optical Profilometer (MicroXam-800, KLA TENCOR, USA) and Universal Testing Machine (AG X 50 KN, Shinadzu, Japan) respectively. The simulated gastric juice was prepared using 0.2% (w/v) sodium chloride in 0.7% (v/v) hydrochloric acid (pH 1.2) (12). 20 samples per group were immersed in freshly prepared simulated gastric juice for a total of 24 hours. Following 6 hours

of immersion, half of the samples (n=10) were extracted from simulated gastric juice and evaluated for surface roughness and flexural strength. The remaining samples (n=10) were continued for another 18 hours immersion in simulated gastric juice and were evaluated for surface roughness and flexural strength at the end of 24 hours. In this study samples were immersed in simulated gastric for a total of 24 hours (first for 6 hours and then for another 18 hours) which is, equivalent to two years and eight years of gastric juice exposure respectively, with ≥7 frequency of self-induced vomiting per week reflecting moderate or severe vomiting group (13,14).

For surface roughness the mean averaged values were recorded in micrometre (μm) and Rq parameter was used which represents the sum of the squares of the various heights and depths from the mean line. For flexural strength testing the load was applied constantly at 0.5mm/min crosshead speed with a support span of 8 mm. The samples were loaded axially at the centre with the loading apparatus of 0.2 mm in diameter (Figure 2).

Figure 2: Flexural strength testing using universal testing machine

All samples were subjected to the maximum force until they fractured, and the average flexural strength was determined using the formula described by Harbi F A et al(15).

σ = 3Pl/2wb2

where, P is the fracture load in Newton, l is the distance between supports, w is the width of the specimen, b is the thickness of the specimens.

The data obtained was subjected to statistical analysis using One way ANOVA to compare the mean values of surface roughness and flexural strength among the individual group at three different time intervals. Tukey Post Hoc (Tukey HSD) analysis was done for multiple comparison within the three different time intervals for individual group. MANOVA was used to compared all the groups

Results:

The mean surface roughness measured at baseline and after 6 hours, and 24 hours of immersion, in RBC group is 0.0211 ± 0.00746μm, 0.0302 ± 0.00802μm, and 0.0324 ± 0.00735μm, respectively. Mean surface roughness of the HIPC group is 0.0162 ± 0.00336μm, 0.0180 ± 0.00313μm, and 0.0198 ± 0.00255μm at baseline, 6 hours, and 24 hours of immersion, respectively. Mean surface roughness of the Z group is 0.0725 ± 0.00728μm, 0.0638 ± 0.00770μm, and 0.0587 ± 0.00637μm at baseline, 6 hours, and 24 hours of immersion, respectively (Figure 3).

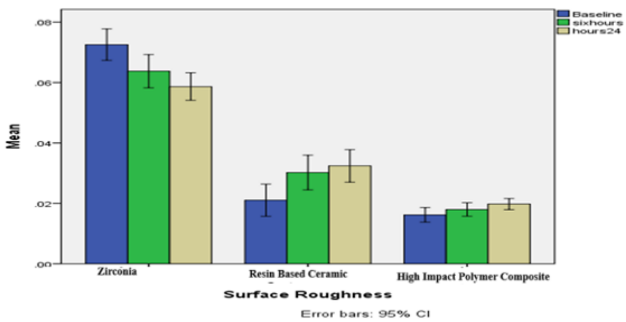

Figure 3: Comparative mean surface roughness of Z group, RBC group, HIPC group at baseline and after 6 hours and 24hours of immersion

The Z group showed significant decrease in the surface roughness after acid immersion whereas RBC group and HIPC group showed significant increase in the surface roughness after acid immersion.
One way multivariate ANOVA revealed statistically significant differences ($p<0.05$) in the surface roughness of Z group, RBC group and HIPC group before and after acid immersion. (Table 2)

Table 2: Multivariate ANOVA for Surface Roughness of Z group, RBC group, HIPC group at baseline and after 6 hours and 24 hours immersion.

Factors	Dependent Variable	Mean Square	F value	P value
Z, RBC, HIPC	Baseline	.010	243.677	.000
	6 hours	.006	126.358	.000
	24 hours	.004	113.568	.000

The surface roughness between 6 hours to 24 hours in Z (p=0.261), RBC (p=0.797), HIPC (p=0.401) and baseline to 6 hours in HIPC (p=0.397) groups were not significant.

Mean value of flexural strength measured at baseline and after 6 hours, and 24 hours immersion, in RBC group is 160.5100 $\pm$ 18.8240MPa, 145.2090 $\pm$ 11.13946MPa, and 128.9605 $\pm$ 19.20867MPa, respectively. The mean flexural strength of the HIPC group is 88.7758 $\pm$ 4.81562MPa, 82.5892 $\pm$ 7.88261MPa, and 70.6226 $\pm$ 7.42803MPa at baseline, 6 hours, and 24 hours of immersion, respectively. At baseline, 6 hours, and 24 hours of immersion, the mean flexural strength of the Z group is 1145.5158 $\pm$ 28.15195MPa, 741.2776 $\pm$ 18.92399MPa, and 710.6977 $\pm$18.91297MPa, respectively. (Figure 4)

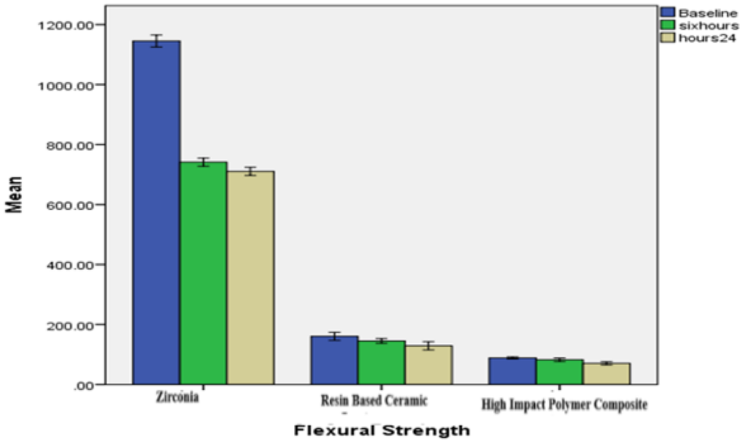

Figure 4: Comparative mean flexural strength of Z group, RBC group, HIPC group at baseline and after 6 hours and 24 hours of immersion

One way multivariate ANOVA revealed statistically significant differences ($p<0.05$) in the flexural strength of Z group, RBC group and HIPC group before and after acid immersion (Table 3)

Table 3: Multivariate ANOVA for flexural strength of Z group, RBC group, HIPC group at baseline and after 6 hours and 24 hours immersion

Source	Dependent Variable	Mean Square	F	Sig.
Factors (Z, RBC, HIPC)	Baseline	3486802.748	8940.014	.000
	6 hours	1321815.706	7284.869	.000
	24 hours	1252529.427	4806.028	.000

The flexural strength from baseline to 6 hours in RBC (p=0.123) and HIPC group (p=0.126) and 6 hours to 24 hours in RBC group (p=0.096) was not significant.

Discussion

The main goal of this in vitro study was to compare the effect of simulated gastric juice on surface roughness and flexural strength of different CAD/CAM materials. The study was an observational prospective study with a sample size of 90, based on 95% confidence level and 90% power. There is no apparent consensus in literature on the real time acid simulation and the coresponding time to recreate an in-vivo model when it comes to corrosive acid concentration and immersion time. The ISO standard 6872 solubility test for dental ceramics recommends 4% acetic acid solution and a 16 hour exposure time at 80 °C. In an in-vitro set up it may require 22°C for 22 years to induce same degree of brakdown. Concentration of acid used, the time of immersion and the temperature all play a role in in-vitro simulation of corrosive efefcts of acids on surface roughness of dental ceramics. Based on Hunt and McIntyre's approach, a stronger aicd (HCl, pH 1.2) was used as an ageing solution in the rpesent study, and the total immersion time was 24 hours, corresponding to 8 years of vomiting exposure.

The null hypothesis of the present study, that the surface roughness and flexural strength of CAD/CAM resin based ceramic and zirconia would be the same when immersed in simulated gastric juice, was rejected by the findings because the surface roughness and flexural strength of CAD/CAM resin based ceramic and zirconia were not same ($p=0.000$, $p<0.05$).

Surface characteristics play an important role in clinical durability of restorative materials because surface degradation brought on by chemical solution will impact the quality of material and lead to plaque accumulation, tooth surface loss and discoloration. The results of current study reveals that RBC group and HIPC group demonstrate increased surface roughness after acid exposure. This would be because the exposure of resin based ceramic material to acidic environment can increase the parameters of diffusivity, absorption of water and solvability, which speed up the degradation process and cause the matrix to expand, creating pores and intermolecular gaps within the material from which the fillers can escape, leading to mass loss and a change in surface roughness(13). Surface roughness of the Z group was decreased after immersion compared to baseline values. This might be because of their strong polycrystalline microstructure and lack of a glassy phase, which make more resistant to acid assault.

The surface roughness changes between 6 hours and 24 hours were not significant in all the groups. The changes noticed are more immediately after immersion in Z group and RBC group, except HIPC group (baseline to 6 hours) and subsequent changes are slow. Initial slow surface change in HIPC group (baseline to 6 hours) can probably be due to the lesser penetration of acid which lead to minimal degradation of interfacial bond. Slower changes in the surface roughness of both RBC and HIPC (6 hours to 24) can be probably due to release of superficial filler particle as result degradation of coupling agent whereas for zirconia it can be due to the polycrystalline nature of the material(12,13,16).Although the surface roughness of zirconia was reduced after 6 and 24 hours of acid immersion in the current study, the results are statistically significant (p value =0.000), indicating that minimal surface alteration has occurred in the Zirconia group after acid immersion resulting in smoother surface. Hence changes in surface of zirconia after gastric immersion has not been detrimental. However even if Z showed decreased surface roughness it was still highest in terms of roughness values compared to RBC and HIPC.

According to Picos et al(17) surface roughness of enamel is 0.00969µm. The surface roughness value after acid immersion in Z group, RBC group, HIPC group was 0.0587 ± 0.00637µm, 0.0324 ± 0.00802µm and 0.0198 ± 0.0025µm respectively. The surface roughness of all the three material were not comparable, it can lead to abrasion of enamel. However the surface roughness value of dentin is 0.0307µm. The surface roughness value of RBC group is comparable with dentin whereas surface roughness of Z group was very high and was low for HIPC group. Therefore RBC group will be better restorative material when opposing dentin that will not lead to abrasion of dentin compared to Z group. For HIPC group there is a chances of material undergoing wear as surface roughness is lower than dentin. Thus it can be considered if the opposing tooth has tooth surface loss with exposure of dentin.

The flexural strength is the property of a material that allows to resist chewing loads and it has a significant impact on the longevity of a restoration in the oral cavity(18). Increased flexural strength of a material allows for minimally invasive treatment with minimal thicknesses of material(19). In the present study results showed that RBC group and HIPC groups demonstrate lower flexural strength values after acid exposure. This could be because of breakdown of filler-matrix interactions in an aqueous acidic environment(20). Immersion in an aqueous acidic environment causes the interfacial silane coupling agent, which provides molecular bonding with the resin structure and fillers, to hydrolyze because it softens the polymer and allows water to enter the resin matrix(21). Following acid exposure, the flexural strength of the Z group showed a reduction. According to Ardlin et al(22), Zirconia specimens were resistant to 4% acetic acid reflux for 168 hours without degrading the flexural strength. However in the current study the flexural strength of zirconia was significantly reduced after 6 hours and 24 hours of acid immersion in gastric juice. These discrepancies could be due to the use of different zirconia materials.

The changes in flexural strength between baseline to 6 hours was not significant in RBC and HIPC group and 6 hours to 24 hours in RBC group. The changes noticed in the flexural strength was not immediate in RBC and HIPC groups which can be probably due to minimal degradation of interfacial bond. Subsequent changes are slow in RBC group (6 hours to 24 hours). The reason why filler degrades more slowly may be due to a higher ratio of silane to filler volume(13).

The flexural strength value of enamel and dentin is in the range of 60-90MPa and 270-360 MPa respectively(23).The flexural strength value of RBC (128.9605±19.20867) was compatible to dentin after 24 hours of acid immersion whereas flexural strength of Z group (710.6977±18.91297) was higher than dentin and HIPC group (70.6226±7.42803) was lower than dentin. Thus it can be inferred that that Zirconia and Resin based Ceramic will be better material to withstand masticatory forces compared to high impact polymer composite in thinner sections. As the flexural strength value of high impact polymer composite is lower, there is a chances of material undergoing fracture.

The study was performed in an invitro setup and has limitations. The samples were not exposed to saliva to fully mimic the oral environment. Longer periods of study in a clinical set up can validate the findings. Acid exposure was based on earlier studies. Further other ageing factors such as thermocycling and mechanical loads can be taken into account. Further studies can be done taking into consideration aging factors for better knowledge of the characteristics and degradation of ceramic restorations and resin based ceramic restoration. The presence of saliva and other types of acidic or alkaline foods in the oral cavity, together with gastric juice, may have an impact on the clinical results of the current investigation.

Limitation also include, several factors that could affect the properties and durability of these materials after exposure to gastric juice, like restoration design, location, oral hygiene, and diet. Future studies on these factors could provide more comprehensive insights into the clinical implications of the findings. Overall, the study contributes to our understanding of how dental materials perform under gastric acid exposure, providing valuable information for clinicians in selecting appropriate restorative materials for patients who might be susceptible to gastric acid reflux or other conditions resulting in gastric acid contact.

Conclusions

Resin based ceramic is a suitable material in terms of flexural strength and surface roughness in gastric acid regurgitation, followed by Zirconia as the surface roughness does not increase from the baseline. High impact polymer composite with lower surface roughness can be a suitable restorative material in severe abrasion and erosion cases as it may not harm opposing teeth

Clinical Implications: Occlusal rehabilitation in patient with acid regurgitation can be done with Resin based ceramic and Zirconia. High impact polymer composite with lower surface roughness can be a suitable restorative material in severe abrasion and erosion cases.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee of SRM medical college hospital & research center (protocol code 1815(A)/IEC/2019 and date of approval 25/10/2019).

Informed consent statement: Not applicable.

Data Availability Statement: Data sharing is not applicable to this article.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

CAD/CAM	Computer-aided design/ computer – aided manufacturing
GERD	Gastroesophageal reflux disease
STL	Standard Triangle Language
RBC	Resin based Ceramics
HIPC	High impact polymer composite
Z	Zirconia

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