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An in vitro study to: evaluate and compare the surface roughness of a CAD/CAM hybrid ceramic " Vita Enamic" and a newly introduced printable hybrid ceramic " Flexcera"

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Aim: evaluate and compare the surface roughness of a CAD/CAM hybrid ceramic "Vita Enamic" and a newly introduced printable hybrid ceramic "Flexcera".

Materials and methods: A total of twenty four square ceramic slices was prepared in a standardized manner; each specimen measured 1 mm thickness, 14 mm length, and 14 mm width. Specimens was divided in to two groups according to the material type; Group A: Vita Enamic and Group B: Flexcera n=12. All samples were subjected thermo-cycling for 5000 cycles at temperatures alternating between 5 and 55 °C. Specimens were tested using a contact surface roughness tester before and after thermocycling, evaluation parameter Ra values were expressed in microns. Statistical analysis was performed using Two-Way Analysis of Variance (ANOVA) was considered for analysing the effect on the outcome, Shapiro-Wilk test, using the built-in Shapiro test function, for normality (Shapiro and Wilk, 1965) and Levene's test using the R "car" package (Fox and Stanford, 2019) to assess the homogeneity of variances in the dependent variable.

Results: Flexcera showed consistently higher surface roughness compared to Vita Enamic, both before and after thermocycling. For both materials, surface roughness increased after thermocycling.

Conclusion: 3D printed hybrid ceramic showed higher surface roughness values than the CAD/CAM milled hybrid ceramic. The 3D printable hybrid ceramic roughness value exceeded the acceptable quantitative threshold value, raising the risk of bacteria accumulation. thermocycling process appears to have a detrimental effect on the surface roughness of both materials, leading to increased roughness after the treatment.

Keywords: CAD/CAM, surface roughness, thermo-cycling and 3D printed.

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Introduction

Patients' aesthetical demands in conjunct with the increasing success of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) have directed to the diversity of the marketed dental ceramic materials. [1]

The tremendous aesthetics and natural appearance of glass-ceramics have led to their broad use. Although, they possess some limitations. With continuous improvements and innovations, resin composites and hybrid materials have turned out to be new substitutions. [1, 2]

Hybrid ceramic restorations, syndicate the benefits of both composite resin infiltration and ceramics. Nowadays a wide range of hybrid ceramic CAD/CAM materials are marketed in the dental market, one such product is VITA Enamic. [3]

Vita Enamic is a CAD/CAM hybrid ceramic material which has been promoted in 2013.

It is a dual system composed of a dominating ceramic matrix (86% weight Feldspar) infiltrated by polymeric materials (UDMA and TEGDMA). [1, 3]

Vita Enamic combines the beneficial characteristics of both ceramic and composite; high strength and wear resistance exhibited by ceramics and the elasticity of composites which leads to a material with high resistance to fracture. [1].

The progressive integration of novel technologies, techniques, and instruments is the dynamic power which influences the drift from conventional and manual workflow to a digitalized one [(4)]. Three-dimensional printing is an additive manufacturing system embraced in the most recent wave of technological advancement. [4]

3D printing technology signifies a more efficient and economical technique than traditional manufacturing ones, through fabricating complex and customized products on claim, without the necessity for large quantities of inventory or specific tools. [4.5]

Recently, a new permanent nano-ceramic printable smiles "flexcera" has been introduced to the dental market place to be used in the production of denture teeth, crowns, inlays, onlays, veneers and bridges. [6]

It is a hybrid nano-ceramic composed of acrylates, methylacrylates, methacrylated oligomers and monomers, photo initiators, colorants, fillers and absorbers. Manufactures claim that it exhibits high; fracture resistance and moisture resistance combined with optimal translucency. [6]

Optimally restorative materials must simulate natural teeth both structurally and functionally, in addition, they must attain their surface polish. As oral environment signifies a complex atmosphere, consequently, restorative materials are subjected to several chemical, biological, mechanical, and thermal changes, which might affect their surface characteristics and mechanical properties. Surface roughness of dental restorations leads increases bacterial adhesion and might contribute to abrasive impairment in the antagonist tooth. [2, 3, 7].

Aim of the study

Consequently, this study was designed to evaluate and compare the surface roughness of a CAD/CAM hybrid ceramic "Vita Enamic" and a newly introduced printable hybrid ceramic "Flexcera". The null hypothesis stated that the fabrication techniques CAD/CAM and 3D printing" will not affect the surface roughness of hybrid ceramics before and after thermo-cycling.

Materials and methods

Materials used in this study are shown in table (1).

Table 1: materials, manufacturer and lot number.

Material	Manufacturer	Composition	Lot number
Flexcera	Desktop health	**Hybrid Nano ceramic resin;** -Acrylates -Methacrylated oligomers and monomers. -Photo-initiator. -Colorants -Fillers. -Absorbers.	280635b
Vita Enamic	VITA Zahnfabrik H. Rauter	**Ceramic content;** -SiO2. Al2O3, Na2O, K2O, B2O3, ZrO2 and KaO. **Polymer content;** -UDMA (Urethane dimethacrylate) -TEGDMA (Triethylene glycol dimethacrylate)	56020

Sample size calculation

According to a previous study by *Alsilani et al,* [1] roughness was 0.256± 0.002 in vita enamic, compared to 0.248±0.009 according to *Younes et al,* [7]. Using G power statistical power Analysis program (version 3.1.9.4) for sample size determination. [3] A total sample size (n=24; subdivided to 12 in each group) as shown in tale (2), will be sufficient to detect a large effect size (d) =1.22, with an actual power (1-β error) of 0.8 (80%) and a significance level (α error) 0.05 (5%) for two-sided hypothesis test.

Table 2: Sample size calculation Specimens' preparation and grouping

Effect size	α error	Power (1-β error)	Calculated Total sample size	Calculated Sample size per group
1.22	0.05	0.8	24	12

A total of twenty four square ceramic slices was prepared in a standardized manner; each specimen measured 1 mm thickness, 14 mm length, and 14 mm width. Specimens was divided in to two groups according to the material type;

- Group A: Vita Enamic
- Group B: Flexcera

By means of an electric isoMet 4000 microsaw (Buehler, USA), blocks of vita-enamic were cut into square-shaped samples of 1mm thickness. Slicing was performed by Buehler diamond disc (Renfert GmbH, Germany) at a speed of 2500 rpm under water coolant and a feeding rate of 13.7 mm/min. for thickness verification after each cutting procedure, a digital caliper (Mitutoyo IP 65, Kawasaki, Japan) was used to ensure the thickness.

While Flexcera specimens were prepared by the use of LCD based SLA 3D printer (Any cubic photon S), light source: UV integrated light with 405 nm wavelength at a printing speed of 20mm/h and rated power of 50 W, software used to design the 3D-printed shapes was 3Dbuilder 20.0.4.0 Microsoft corporation.

Both groups were polished using (VE-P), mechanical polishing was applied in two stages using the recommended polishing set (Vita Enamic polishing set technical, VITA Zahnfabrik, Bad Sackingen, Germany) until a shiny surface was obtained. The following steps were applied;

Pre-polish with pink polishers: using 7000-10000RPM and light pressure, this was followed by high gloss polish with grey polishers using 5000-8000 RPM and light pressure. Polishers were kept moving around on the surfaces without staying in one place too long avoiding creating grooves or pits

Specimens were prepared after conducting the research ethical committee of MSA university approval with reference number 43104.

Thermo-cycling

To mimic the thermal stresses and ageing of the teeth in the oral environment, all the specimens were subjected to thermo-cycling (Proto-tech, USA) for 5000 cycles at temperatures alternating between 5 and 55 °C with an immersion time of 30 s. A total of 5,000 cycles at 5 °C and 55 °C were

performed, which corresponds to approximately 6 months of clinical use. [2, 8].

Surface roughness

Specimens were tested using a contact surface roughness tester (SJ-210 Surface roughness tester Mitutyoyo Japan). Each specimen is fitted to the specimen holder in which the surface to be measured is in horizontal direction, then the specimen holder moves in vertical direction up to the specimen surface just to touch the measuring tip. Device calibration is done using the standard calibration specimen before use the testing parameters were set as follows: measuring distance 12 mm, measuring Speed 0.5 mm/s, returning 1mm/s and a measuring force of 0.75 mN. The stylus profile tip radius WAS 2 micron with a tip angle 60 degree. Evaluation parameter Ra values were expressed in microns. Three measurements were made from the surface of each specimen at a distance 500 microns each. [9] Test was conducted on the samples before and after thermocycling as shown in figure (1).

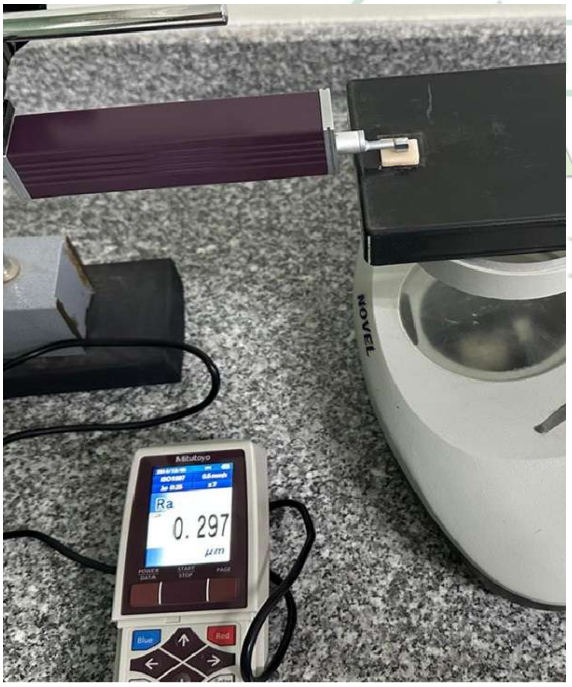

Figure 1: surface roughness testing

Statistical analysis

Initially, a Two-Way Analysis of Variance (ANOVA) was considered for analyzing the effect on the outcome, as it is commonly employed to evaluate the interactions between multiple factors while accounting for their individual effects. However, upon conducting the Shapiro-Wilk test, using the built-in Shapiro test function, for normality, [10] and Levene's test using the R "car" package [11], to assess the homogeneity of variances in the dependent variable, Shapiro test yielded insignificant, but Levene test were highly significant which means that assumptions of two-way ANOVA were violated and this statistical method cannot be used for analysis of the data. According to the literature, ANOVA assumes homogeneity of variance and normality of distribution. When those assumptions are violated, the robustness of ANOVA is compromised.[12, 13] Given these findings, we opted for a Generalized Linear Model (GLM) with a gamma distribution and log link function as an alternative analytical approach. This choice is supported by research demonstrating that GLMs are particularly robust in addressing issues related to heteroscedasticity (lack of homogeneity of variance) and non-normality in data. [14, 15] The Gamma distribution is appropriate for modeling continuous outcomes. By using GLM in this context, our aim was to ensure that our analysis would yield reliable outcomes and interpretable results.

Results

GLM analysis of the surface roughness

The GLM analysis revealed significant differences in surface roughness between the two dental materials. Vita Enamic had 68% lower surface roughness compared to Flexcera. This difference was highly statistically significant ($p<0.001$). Thermocycling was also found to increase surface roughness, with roughness before

thermocycling about 90% of the roughness after thermocycling, representing a 10% reduction in roughness ($p<0.001$) as shown in table (3) and figure (2).

Table 3: Summary of Means and Standard Deviations for Surface roughness by group

Flexcera

Material	Thermocycling	Mean	SD
Flexcera	After	0.307	0.017
	Before	0.276	0.007
Vita Enamic	After	0.097	0.009
	Before	0.075	0.006

- After thermocycling: The mean surface roughness was 0.307 with an SD of 0.017, indicating higher surface roughness compared to the pre-thermocycling condition.
- Before thermocycling: The mean surface roughness was 0.276 µm with an SD of 0.007, showing less variation compared to after thermocycling.

Vita Enamic

- After thermocycling: The mean surface roughness was 0.097 with an SD of 0.009, slightly higher than the pre-thermocycling condition.
- Before thermocycling: The mean surface roughness was 0.075 µm with an SD of 0.006, the lowest surface roughness recorded among all groups.

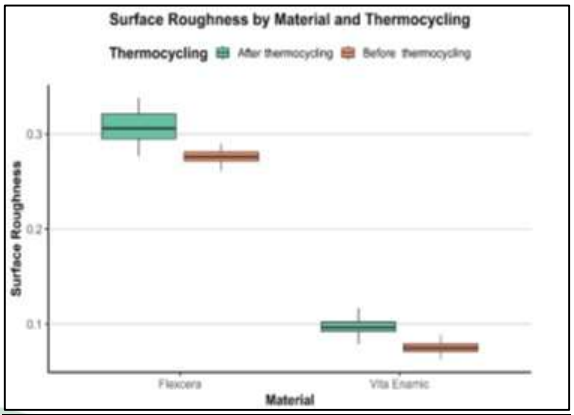

Figure 2: The box plot displays the distribution of surface roughness for two materials, Flexcera and Vita Enamic, under two conditions: before thermocycling and after thermocycling

Pair-wise comparison

The pairwise comparisons presented in table () evaluate the differences in surface roughness between combinations of Material (Flexcera, Vita Enamic) and Thermocycling (Before, After). These contrasts were calculated using Estimated Marginal Means (EMM) with Tukey's HSD adjustments to control for multiple comparisons. The ratios represent proportional differences in mean surface roughness between groups as shown in table (4).

Table 4: Pairwise Comparison between Study Groups using EMM: Thermocycling | Material

Contrast	ratio	SE	df	t.ratio	p.value
After thermocycling Flexcera / Before thermocycling Flexcera	1.113	0.019	140	6.402	**< 0.001**
After thermocycling Flexcera / After thermocycling Vita Enamic	3.156	0.053	140	68.880	**< 0.001**
After thermocycling Flexcera / Before thermocycling Vita Enamic	4.082	0.068	140	84.308	**< 0.001**
Before thermocycling Flexcera / After thermocycling Vita Enamic	2.836	0.047	140	62.478	**< 0.001**
Before thermocycling Flexcera / Before thermocycling Vita Enamic	3.669	0.061	140	77.906	**< 0.001**
After thermocycling Vita Enamic / Before thermocycling Vita Enamic	1.294	0.022	140	15.428	**< 0.001**

The results indicate that the two materials, Flexcera and Vita Enamic, have inherently different surface roughness characteristics. Additionally, the thermocycling process showed to have a high impact on the surface roughness of both materials, leading to increased roughness after the treatment.

Discussion

3D printing has progressively been implemented as an additional manufacturing technique in the dental field. 3D printed restorations have invaded the dental clinics offering restorations with high qualities combined by speedy and easy fabrication. [16]. Recently, a hybrid nano-ceramic 3D printable Flexcera has been introduced, claiming ceramic like strength and outstanding aesthetics, guaranteeing ideal results for both clinicians and patients.[6].

Although there is diversity and increased usage rate of 3D printed materials, studies on their characteristics such as surface roughness are limited.[17]. Surface roughness is considered a crucial factor when describing the surface texture of a material, as well as it plays a vital part in several clinical aspects since it directly affect the microbial adhesion and biofilm development. [16, 18]

Surface properties are not only influenced by the materials composition, but also by their fabrication technique. [18] Accordingly, this study was intended to assess and compare the surface roughness of a CAD/CAM hybrid ceramic material and "Flexcera". The null hypothesis of the study was rejected. Since the fabrication technique significantly affected the surface roughness of hybrid ceramics both before and after thermo-cycling.

In the current study, Vita Enamic was selected as it is considered as a double network structure embracing the excellent features of composite and those of ceramic. [19].

Thermo-cycling, a prevalent artificial aging process, was employed to mimic the thermal changes to which restorations in the oral cavity are subjected to. [17]. Specimens were subjected to 5000 cycles with alternating temperatures between 5 and 55 °C, equivalent to 6 months of clinically.

The roughness average (Ra) which is known as the arithmetic mean roughness value, which is the most frequently used parameter for describing the surface roughness in the dental field. [3, 17, 20] Ra gives a representative approximation of surface roughness with easiness of measuring combined with the availability of the machine and reasonable cost.[14] Ra is evaluated quantitatively through profilometry and qualitatively by scanning electron microscopy (SEM). Recent studies have specified Ra of dental materials set a quantitative threshold value of 0.2 µm. A Ra above 0.2 µm is proposed to rise risk of bacterial accumulation, though attaining lower than this is assumed to have no effect.[3,17, 21]

Profilometers are available in two types; contact and non-contact. The Non-contact device scans the surface by the usage of a light beam or lasers. Nevertheless, inaccurate values might be indicated with lustrous surfaces, resulting from the scattered reflected rays. [20] Consequently, a contact device was utilized in the current study as it directly touches the specimen's surfaces.

Results of our study showed that; before thermocycling Vita Enamic exhibited a significantly lower mean surface roughness of 0.075, While, Flexcera had a higher mean surface roughness of 0.276. After thermocycling Vita Enamic showed statistically lower mean surface roughness of 0.097, while flexcera demonstrated mean surface roughness of 0.307.

A statistical difference was found in the comparison before and after themocycling within each material.

Thermocycling, a common artificial aging technique, was employed to simulate changes in the oral cavity while eating and drinking. Water and thermal changes during thermocycling deteriorates composite resins organic matrix structure, which in return exhibits a notable impact on their surface roughness. [17]

Results indicated that flexcera mean surface roughness before and after thermocycling, both exceeded the clinically acceptable limit of Ra = 0.2 µm. However, none of the groups' mean surface roughness values reached the clinically unacceptable level of 10 µm.

3D printing is considered an additive manufacturing technique which involves fabrication by layering, these layers causes a staircase effect, resulting from the curing and depositing successive layers of the material till the 3D printed prosthesis is shaped. This staircase effect results in amplified surface roughness. Furthermore, the thickness of the layer and the build angle influence the degree of this stair case effect which will consequently affect the surface roughness. This was in accordance with *El-Nogoomi et al in 2023.* [22]

In addition, *Zakarya et al in 2024,* [20] studied the surface roughness of 3D printed composites with different building angles (0, 45 and90 degrees) and compared it to a CAD/CAM composite materials. The CAD/CAM milled presented lower surface roughness in comparison with 3D-printed composite material. They concluded that, the layering technique building angle had a great impact on the stair case effect which directly influenced the surface roughness.

Moreover, *Prause et al in 2024,* [23] examined the microstructures of Vita enamic and a 3D hybrid material by means of micro-computed tomography and scanning electron microscopy. Their results indicated; irregular distribution of the fillers combined with some agglomerations in the 3D printed material, in addition to, a noticeable layered macrostructure with some spherical pores resulting from the printing process. Whereas the vita enamic showed homogenous fillers distribution. This might explain the decreased roughness of vita enamic.

However, *Bozo˘ gulları et al in 2023,* [17] evaluated the surface roughness composite based permanent restorative material manufactured by additive technique and compared it with composite-based blocks "Vita Enamic" manufactured by subtractive approach after thermo-cycling. They concluded that the two evaluated materials exhibited acceptable surface roughness which was equal to or below the quantitative threshold value of 0.2 µm. Adding to that, the 3D printed composite resins displayed similar or lower Ra values than the milled CAD/CAM materials.

This in vitro study had some limitations; the lack of anatomical structures since the tested specimens had flat surfaces. Moreover, specimens were not exposed to saliva with its constituents, occlusal and brushing forces to which the prosthesis are exposed to in the clinical actuality.

Conclusion

Within the limitations of this study it could be concluded that:

3D printed hybrid ceramic showed higher surface roughness values than the CAD/CAM milled hybrid ceramic. The 3D printable hybrid ceramic roughness value exceeded the acceptable quantitative threshold value, raising the risk of bacteria accumulation. thermocycling process appears to have a detrimental effect on the surface roughness of both materials, leading to increased roughness after the treatment.

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Data availability
Data are available upon request

Ethical approval
Approval was conducted from MSA research ethics committee with reference number #43104.

Conflicts of interest
None.

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