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Surface Roughness and Wear Resistance of Different 3D Printed and Milled Hybrid Ceramic Materials

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Abstract

Aim: This study evaluates the surface roughness and wear resistance of two types of 3D-printed permanent materials and CAD/CAM milled material. Materials and Methods: A total of 120 rectangular-shaped samples were fabricated from 3D-printed hybrid materials (Crowntec and VarseoSmile) and one CAD/CAM milled hybrid material (Vita Enamic). 90 samples (14×12×5 mm) were used for the surface roughness test, and the roughness measurements were performed at the baseline and after storage in different staining solutions for 1 week using a 2D profilometer while 30 samples (14×12×5 mm) were used for wear test and the real weight of each sample was measured at the baseline and after subjecting to wear using (MT 4003, TRIBOMETER, USA) wear device. The data were subjected to statistical analysis using a two-way analysis of variance (ANOVA) and post-hoc least significant difference (LSD) tests with a significance level of 0.05. Results: Crowntec exhibited a statistically higher surface roughness value compared to both VarseoSmile and Vita Enamic, however, VarseoSmile showed statistically greater roughness compared to Vita Enamic. Regarding the wear test, the results showed a significant difference in weight loss between 3D printed and Vita Enamic materials($P<0.05$) with no statistical difference between Crowntec and VarseoSmile. The lowest weight loss was observed in Vita Enamic (1.56 ± .08) and the highest weight loss in VarseoSmile (2.3± .08). Conclusion: 3D printed material exhibits a rougher surface and higher wear when compared to milled material.

Introduction:

The development of subtractive manufacturing techniques for the fabrication of indirect dental restoration has gained popularity and replaced traditional manufacturing methods (1). CAD/CAM technology offers a quicker and easier fabrication method compared to traditional methods (2). Additionally, a significant quantity of raw material is discarded during the milling process, resulting in both economic and environmental implications (3).

Nowadays, there has been an increasing interest in additive manufacturing (3D printing). This method entails the fabrication of items through the sequential deposition of materials, eliminating the necessity for conventional instruments. Consequently, additive manufacturing allows for the production of difficult and complicated designs which impossible to produce with conventional methods (4).

The integration of multiple materials in additive manufacturing, based on CAD data, has a major impact on the overall quality of prostheses, the mechanical properties of printed components, the total cost, and the production time in the field of prosthetic dentistry (5, 6).

The clinical longevity of a restoration is influenced by its surface features. Ideally, the restoration should have a smooth and regular surface, although achieving this is not always feasible (7). A rougher surface resulting from inadequate finishing, polishing, or wear of dental restorations might potentially contribute to plaque collection, higher susceptibility to discoloration, and an increased likelihood of abrasion on opposing natural teeth. In addition, it has been observed that the presence of a roughened surface can decrease the fracture resistance of materials. This is attributed to surface microcracks formation and spread (8, 9).

The issue of restorative wear has become frequent and critical. Restorative materials experience various environments within the oral cavity, subjecting them to significant chemical and physical stresses arising from variations in temperature, functional and parafunctional loads, and exposure to food and beverage-related chemicals. To ensure enduring stability, dental materials must exhibit favourable wear resistance (10).

Furthermore, there is a shortage of studies investigating the physical and mechanical properties of 3D-printed permanent crown materials when subjected to different storage conditions, and how they compare to milled materials. Previously, composite resin materials were predominantly employed for 3D printing provisional crowns and temporary dental restorations used for a limited duration within the oral cavity.

Several companies have introduced various 3D printed materials as permanent crown materials for single crowns, including Crowntec(CT) and Varseo Smile Plus(VS)(11). Therefore, the current study aimed to compare and evaluate the surface roughness and wear resistance of two 3D-printed permanent crown materials and CAD/CAM milled crown material.

The null hypothesis states that there is no statistically significant difference in surface roughness and wear resistance among the different materials.

Materials and Methods

Sample Grouping

The G*Power 3.1.9.7 software (Franz-Faul-University of Kiel, Germany) was utilized to calculate the sample size. For the surface roughness test, the significance level was set at 0.05, the effect size at 0.4, and the power at 85%. For the wear test, the significance level was set at 0.05, the effect size at 0.65(Large effect size), and the power at 85%. A total of 120 rectangular-shaped samples with dimensions (14×12×5 mm) were fabricated from additive manufacturing and milled technique as shown in Table 1. The samples were categorized into three groups based on the type of hybrid material employed (Crowntec, VarseoSmile and Vita Enamic). 90 samples were selected for the surface roughness study and then each hybrid material group(n=30) was subsequently divided into three subgroups according to various staining solutions (distilled water, tea, and coffee) (n=10). while the

remaining 30 samples (n=10 for each hybrid material)were used for the wear resistance study. An illustrative diagram of the present study is displayed in Fig. 1.

3D-printed sample fabrication

The fabrication of 3D printing samples (Crowntec and VarseoSmile) was carried out utilizing a DLP-based 3D printer (Asiga Composer 1.2.12). The 3D virtual designs were imported sequentially to the 3D printer in the form of STL file format. as in Fig. 2.

The thickness of each layer was set to 50 μm, and all the 3D printing processes were conducted in accordance with the instructions provided by the manufacturer. After printing, a towel soaked in 96% Ethanol Absolut, an alcohol solution, was used to eliminate any remaining resin on the CT samples. VS samples were first subjected to ultrasonic cleaning using a reused ethanol solution (95% Ethanol) and then thoroughly cleaned using a fresh ethanol solution (95% Ethanol).

After drying the samples with an air syringe, the unwanted structures (supports) were removed using a cutting wheel, and the surfaces were sandblasted using 50 μm beads of glass. (Coxo company, China) Under a pressure of (1.5 bar), continue the cleaning process until the white layer that appeared is no more noticeable.

Post-curing process

Samples are subjected to a post-curing process to enhance the mechanical strength of crown materials. This process consists of two cycles. The temperature of each cycle was set to 60ºC, and the time was adjusted to 20 minutes as per the manufacturer's instructions. VS samples were post-curing utilizing a post-curing device (Form cure, Formlabs, USA) according to manufacturer instructions (Bego, 2020). The CT samples were post-curing utilizing a post-curing device (CURIE Ackuretta, Taiwan) according to manufacturer instructions (SAREMCO, 2021) as in Fig. 3.

CAD/CAM sample preparation

The manufacturing of Vita Enamic samples entailed utilizing a customized Hobbymat milling machine to secure the ceramic block. The cutting process was executed utilizing a diamond disc with a thickness of 1mm and a diameter of 30mm. The disc was affixed to a low-speed handpiece and revolved anticlockwise at a speed of 30,000 revolutions per minute (RPM). The milling machine concurrently grasped the ceramic block and spun it in an anticlockwise direction at a speed of 1000 revolutions per minute (RPM). The cutting operation was executed via subaqueous cooling. The thickness of the specimens was measured using a digital calliper manufactured using (Guanglu Instruments, China).

Finishing and polishing

This step was performed for all three groups, as the materials employed in this study do not necessitate additional processing after milling or printing, other than polishing. The grinder/polisher machine was used to grind one surface of all the specimens using silicon carbide abrasive paper with grit sizes of 600, 1000, and 1200. A custom-made acrylic block was used to hold the sample during polishing as in fig. 4. Each paper was applied for 15 seconds at 100 revolutions per minute

Preparation of staining solutions and storage

In the present study, tea and coffee were employed as staining solutions, whereas distilled water was utilized as a control. A total of 200 ml of distilled water was utilized to dissolve the tea bags (1.8g) and coffee sachets (1.8g). The mixture was then heated and transferred into a plastic container. Subsequently, the tea bags and coffee sachets were included. Once the water had been cooled, the samples were positioned at the bottom of a plastic container containing their discoloration solutions. Subsequently, the samples were placed in an incubator set at a temperature of 37 °C for four weeks. Once the discoloration operation was completed, the samples were washed and dried. To mitigate the potential for bacterial and yeast contamination, the staining solution was changed every day(12, 13).

Surface roughness evaluation

The samples' surface roughness was determined using a calibrated mechanical 2D profilometer surface roughness tester (leeb 432A, Testcoat, USA). The surface roughness measurements were taken for each sample at the baseline and after one week of storage in various staining solutions using a diamond stylus with a 5 μm diameter inserted in a detector. The device comes with a removable transparent base at which a window with an adjustment screw was used to hold the sample, while the device rests above it as shown in Fig. 5. The tracing diamond stylus (with a 5 μm tip radius) was moved across the surface (backwards and forward) in the centre of each sample under a constant load of 4 mN (measuring force) with a speed of 0.5 mm/sec and a cut-off value of 0.8 mm. Calibration was checked with a standard (Ra = 2.94 μm) before the first use and after every 10 samples. The force applied was lower than 0.004 N. Three measurements were collected and the average was calculated for each sample.

Wear resistance evaluation

The testing device used for wear detection was (MT 4003, TRIBOMETER, USA) which was based on a pin-on-disc approach. The antagonist used in the study was a 4 mm diameter zirconia ball. It was placed at a 15° angle and used to stress the mounted crown material specimens. The cylindrical platform moved along a sliding path during the test as shown in Fig.6 (14). Before testing, the exact weight of each sample was measured using an electronic advanced analytical balance. The sample was fixed in the platform which was determined to rotate for 50,000 sliding cycles while the sample was subjected to a weight of 50 N that was attached to a non-rotating upper arm. Following the completion of the wear testing method, all samples were carefully washed and subsequently dried using a cotton towel as shown in Fig.7. Specimens from each group were chosen randomly for morphological examination using a scanning electron microscope. The sample was fixed to an aluminium mount and lightly coated with a gold-palladium alloy using a sputtering technique. The specimens' surface topography was visualized using field emission scanning electron microscopy (FE SEM) at magnifications of 7000x and 25000x (Figure 8).

Statistical Analysis

The data has been processed and presented using the Statistical Package for Social Science (SPSS version 22). The statistical methods used in this study consisted of the Shapiro-Wilk test to evaluate the normality distribution, a two-way ANOVA to compare groups, Tukey's HSD test as a post hoc analysis to compare subgroups, and a paired t-test to compare measures before and after within the same subgroups. A significance level of $p<0.05$ was used.

Results

Surface roughness

The statistical data for the surface roughness section of the study, including the averages, variations, and statistical inferences, are available in Table 2 and Fig. 9. Significant statistical differences were seen across groups both before and after storage in the staining solution. The VE group exhibited statistically the lowest roughness value in comparison to the CT and VS groups. The CT group has a statistically greater roughness value compared to the VS group. The surface roughness of all groups increased after being stored in the staining solution. Coffee demonstrated a statistically greater increase in roughness when compared to both tea and distilled water, whereas tea exhibited statistically higher roughness than distilled water.

Wear Resistance

Regarding the wear behaviour, the mean values, standard deviations, and statistical results of the weight loss recorded in mg for the tested groups after 50000 cycles of chewing simulation were listed in Table 3 and Fig. 10. It can be observed that there were statistically significant differences in the weight loss among groups. The VE group exhibited statistically the lowest wear value compared to CT and VS

groups while CT exhibited statistically lower wear compared to VS group.

Discussion

This paper assessed the surface roughness and wear resistance of specific hybrid ceramic materials used for milling and 3D printing of permanent tooth restorations. Significant differences were observed in the tested properties among the various materials leading to rejection of the null hypothesis.

Surface roughness can affect aesthetics by altering aesthetic restorations' texture, increasing the entering light's dispersion, and influencing color stability (15). All the samples studied exhibited Ra values above the plaque accumulation threshold of 0.2 μm, which is necessary to decrease plaque retention and microbe adherence to dental restorative surfaces. In comparison, they were lower than the clinically unacceptable value of 10 μm (16) (17).

The result of the present study indicates that the Vita Enamic(VE)showed lower roughness compared to 3D-printed materials.VE blocks are produced using a combination of extremely high temperatures and pressures. It can be assumed that the filler particles in Vita Enamic are better connected to the resin matrix. The reduced size and wide distribution of the nano-fillers may improve the mechanical properties of Vita Enamic. This result was supported by Kumari et al. (2016), who reported that an increase in the filler amount might reduce surface roughness. The results of this study align with the research conducted by Atria et al. (2020), who observed that 3D-printed hybrid resins exhibited a greater degree of surface roughness than traditional and CAD/CAM- resins. Aldahian et al. (2021) assess the effect of the technique on the surface roughness of material fabricated by conventional, CAD CAM and 3D-printed methods and the result indicates that higher roughness was observed in 3D-printed material. CT exhibits higher surface roughness compared to VS which may be attributed to their chemical structure. Although both CT and VS were composite resins made using additive methods and had similar compositions, slight distinctions between the two materials could have contributed to these outcomes. Distinct cracks and lines were apparent during the thermal cycling of coffee, especially in the case of Crowntec and VarseoSmile (18). Coffee causes a higher increase in surface roughness compared to tea and water can be attributed to the acidity present in coffee, which modifies the surface morphology by forming micro-scale and nanoscale pores of different depths. Tea is characterized by its acidity, with a pH of (5.38). It contains components with stronger polarity dissolved first and cannot penetrate inside the hybrid material, resulting in lower surface roughness than coffee (19, 20).

The water's action in tea and coffee decreased the mechanical characteristics of the polymer matrix. The absorption of water caused the expansion of the matrix, which in turn created stress and caused the filler particles to detach and become dislodged, increasing surface roughness(21).

Dental materials can exhibit resistance to wear that is either physiological or pathological. Various factors that contribute must be taken into consideration. Clinically influencing factors consist of nutrition and environmental variables, in addition to malocclusion(22). Severe wear from occlusion can impair both the natural hard dental tissue and the replacement. The restoration's long-term stability may be greatly diminished because of decreased wear resistance(23). The removal of substances from the surfaces of the tested materials can be influenced by various parameters, such as surface hardness, surface quality, and ability to withstand fatigue and breakage(24).

In the presented study 3D-printed hybrid materials (CT and VS) had higher weight loss than milled material (VE). This result may be attributed to the relatively low filler content (about 30-50 wt. %) of inorganic fillers with 0.7 μm particle size present in 3D printed hybrid materials(25). The Long-term storage of 3D-printed in large containers may lead to filler sedimentation, resulting in uneven distribution of ingredients and decreased

mechanical integrity. The distance between particles is expanding. The fillers no longer can shield the composite matrix from deterioration(26).

The greater ceramic content and the pre-polymerization of VE under standardized situations likely resulted in a greater degree of conversion and improved its characteristics (27).

The results of this study were in accordance with a previous study Gad et al. (2023). Türksayar et al. (2023) found that 3D-printed crown materials had higher wear behaviour than milled material. The composition of a material may be related to its wear resistance. The chemical compositions of CT and VS were similar; thus, they may be expected to have similar wear behaviour (28).

SEM analysis detected cracks and small defects on the worn surfaces of the 3D-printed resin samples after exposure to the abrader. The interlayer bonds were severed, resulting in residues that remained connected to the underlying resin layer. This discrepancy can be attributed to the defect in production techniques. The wear areas of the three materials in contact with the zirconia abrader exhibited a relatively smooth surface (29). There are certain limitations in the current study that should be acknowledged as the current study did not consider multiple factors present in the oral environment that may affect the crown materials, such as the forces exerted while biting, the proteins and enzymes found in saliva, and the act of rinsing or cleaning the mouth. Moreover, the specimens' sleek surfaces and lack of morphological grooves were insufficient to replicate the clinical conditions with accuracy. Additional research must be conducted to explore other optical and mechanical characteristics such as the translucency and flexural strength of the material.

Conclusions

1- The surface roughness values of the 3D printed materials exceeded the acceptable limit and were higher than those of VE. CT exhibited a rougher surface in comparison to VS.

2- Coffee subgroups showed a greater roughness when compared to tea and distilled water, whereas tea results in a higher roughness compared to distilled water.

2- Higher wear was observed in 3D-printed materials in comparison to Vita Enamic material, but CT showed lesser wear in comparison to VS.

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The funding for this study was provided by the researchers themselves.

Disclosure statement

There were no competing interests to declare.

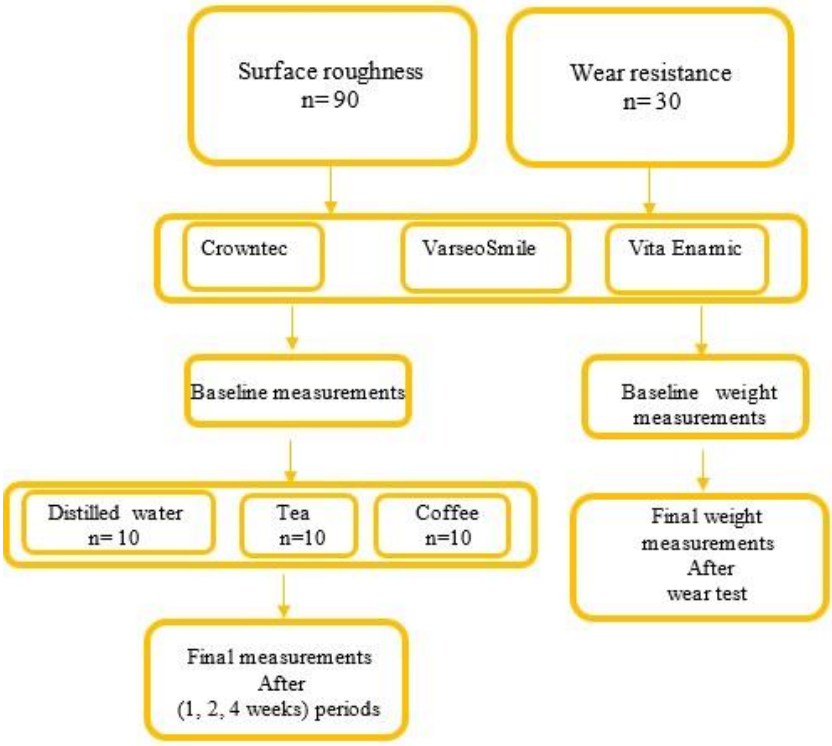

Figure 1. Summary of study design.

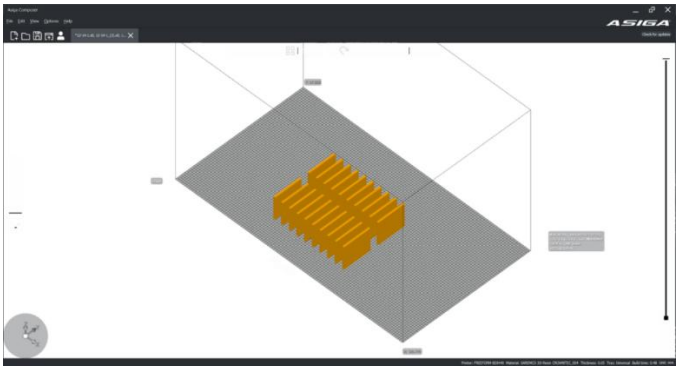

Figure 2. Design of 3D printing samples with Max UV (version 385) program.

Figure 3. Post curing of 3D printed samples

for CT. CURIE Ackuretta: Formlabs post-curing device for VS; B:A

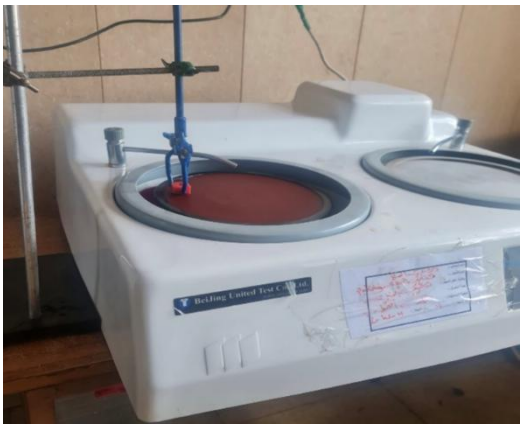

Figure 4. The polisher machine with the ceramic sample was fixed in its place using a metal holder.

Figure 5. Surface roughness measurements of the samples with a 2D profilometer.

Figure 6. Pin on disc wear device and the sample was fixed at the cylindrical platform.

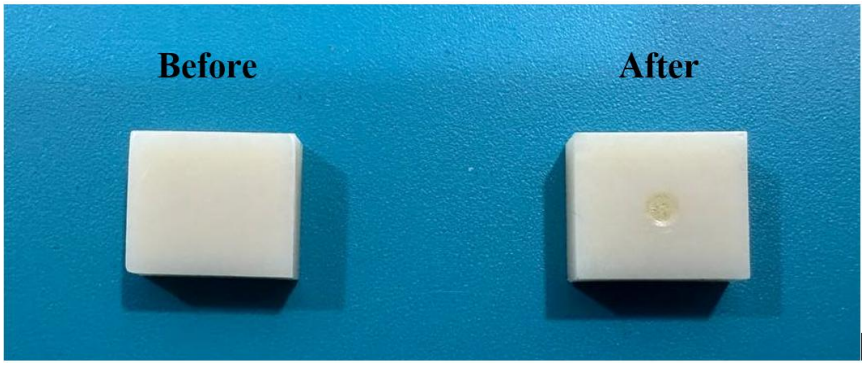

Figure 7. Sample before and after wear test.

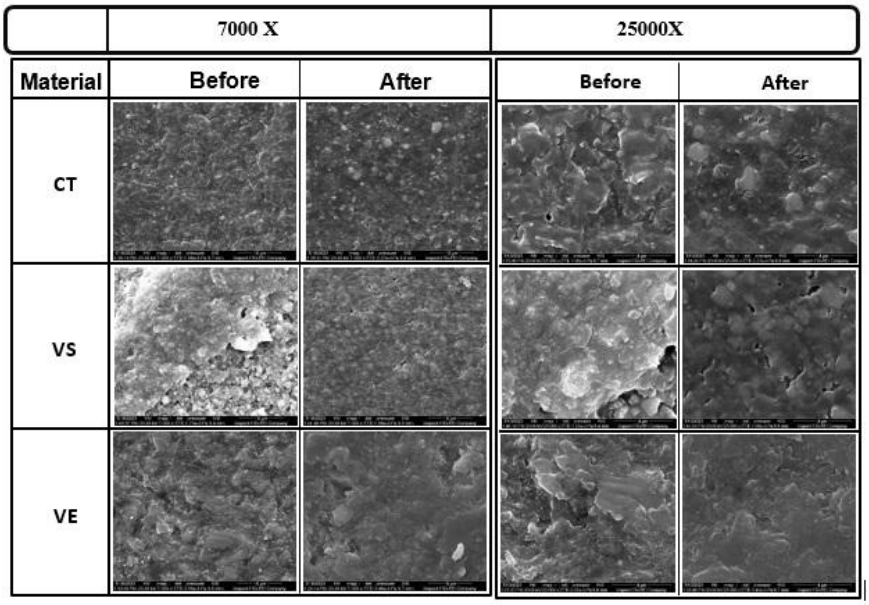

Figure 8. Field emission scanning electron microscopy for each material before and after the wear test.

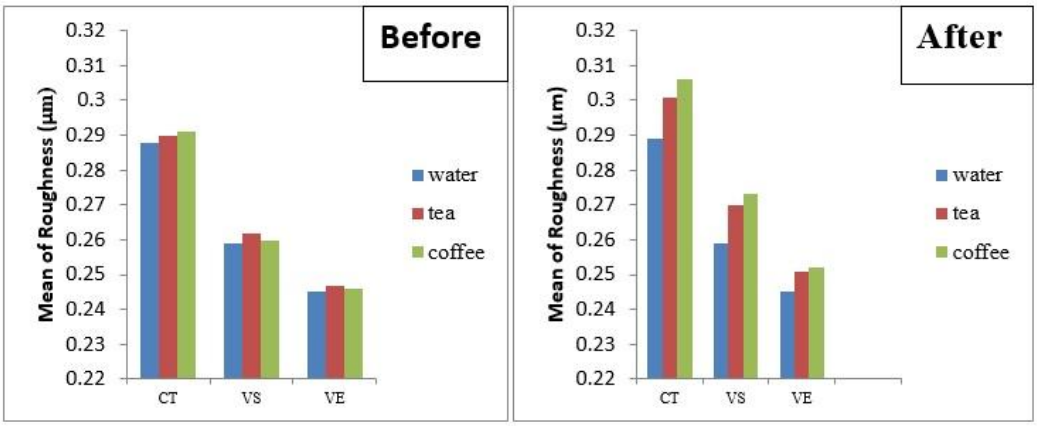

Figure 9. Bar chart demonstrating the differences in surface roughness among groups.

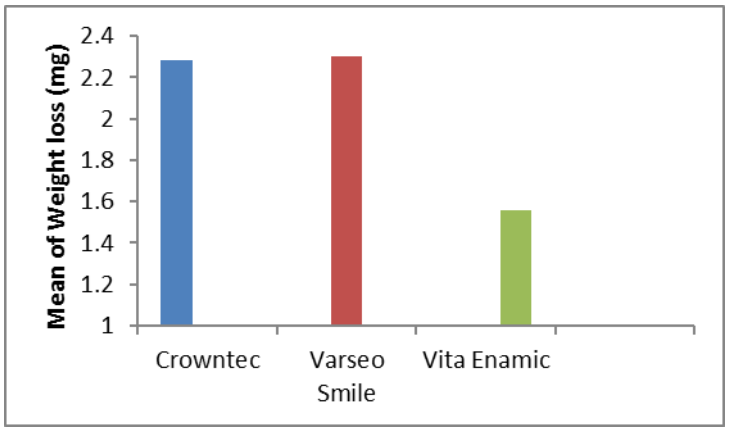

Figure 10. Bar chart demonstrating the differences in wear among groups.

Table 1. The materials employed in the present study.

Material	Composition
Crowntec (Saremco) Ceramic-filled hybrid material	Bis-EMA, Dental glass and silica fillers (30-50%), Initiators, Inhibitors, and color pigments
VarseoSmile Crown plus (Bego) Ceramic-filled hybrid material	-Esterification products of 4.4'-isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid. Silanized dental glass, methyl benzoyl formate, diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide. The total content of inorganic fillers (particle size 0.7 μm) is - 30 – 50 % by mass.
Vita Enamic (Vita Zahnfabrik) Hybrid ceramic material	-The polymer part: 66% (UDMA) and 33% (TEGDMA). -The ceramic part: Silicon dioxide (58-63%), Aluminum oxide (20-23%), Sodium oxide (6-11%), Potassium oxide (4-6%), Boron trioxide (0.5-2%), Calcium oxide (<1%), Titanium oxide (<1).

Table 2. Descriptive and statistical analysis of surface roughness among groups.

Groups	Before	After
	Mean+SD	Mean+SD
Cr water	.288 ^{Aa} ± .005	.289 ^{Aa} ±.005
Cr tea	.290 ^{Aa} ± .004	.301 ^{Ab} ±.004
Cr coffee	.291 ^{Aa} ± .006	.306 ^{Ab} ±.007
Vs water	.259 ^{Ba} ± .008	.259 ^{Ba} ±.008
Vs tea	.262 ^{Ba} ± .008	.270 ^{Bb} ±.008
Vs coffee	.260 ^{Ba} ± .007	.273 ^{Bb} ±.007
Vita water	.245 ^{Ca} ± .006	.245 ^{Ca} ±.006
Vita tea	.247 ^{Ca} ± .006	.251 ^{Ca} ±.007
Vita coffee	.246 ^{Ca} ± .008	.252 ^{Ca} ±.008

*The uppercase letters demonstrate the difference among different materials, and the lowercase letters demonstrate the difference within each material group.
CT: Crowntec
VS: VarseoSmile crown plus
VE: Vita Enamic

Table 3. Descriptive and statistical analysis of weight loss (mg) among groups.

Groups	Mean + SD
Crowntec	2.28 ^{A} ± .09
VarseoSmile	2.3 ^{A} ± .08
Vita Enamic	1.56 ^{B} ± .08

*The uppercase letters demonstrate the difference among different materials.
CT: Crowntec
VS: VarseoSmile crown plus
VE: Vita Enamic

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