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Evaluation of Physical and Mechanical Properties of Current Restoration Materials Produced 3D Printers and CAD/CAM

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Abstract: *The present study assesses the surface roughness (SR) and microhardness (Vickers Hardness Number, VHN) of novel resin-filled ceramic and resin composite materials fabricated using 3D printers and CAD/CAM technologies after being subjected to thermal cycling. Permanent resin restorations were fabricated using 3D printers (C; Saremco Print Crowntec, F; Permanent Crown Resin Formlabs, B VarseoSmile Crown Plus Bego) and resin-containing CAD/CAM permanent restorative materials (E; Vita Enamic, Vita, U; 3M Lava Ultimate), with a total of 75 rectangular specimens produced (12 × 14 × 1.5 mm) (n = 15). The SR (Ra, Rz) and MH values of the materials were measured before and after thermal aging, and scanning electron microscopy (SEM) images were obtained following thermal cycling. The dataset obtained from the study was evaluated with a Two-Way Analysis of Variance (Two-way ANOVA) (α = 0.05). There was a broad and statistically significant difference in the SR values of all groups before and after thermal ageing (p < 0.001). In the MH intergroup comparisons, the values of the groups before and after the ageing process were found to be statistically significant (p < 0.001). The highest Ra values were recorded in 3D printed resins, while the lowest values were observed in CAD/CAM-produced materials. Furthermore, the number of samples produced using 3D printers was lower than that produced by CAD/CAM.*

Keywords: *3D printed polymer composites, CAD/CAM ceramic composite materials, permanent resin composite materials*

1. Introduction

The utilisation of 3D printers in dentistry has undergone a substantial increase, largely attributable to advancements in computer-aided design (CAD) and computer-aided manufacturing (CAM), as well as the emergence of innovative technologies that have enabled their integration into the field [1–3]. Resin-matrix CAD/CAM ceramics have recently been introduced to the market as alternatives to glass-ceramics [4]. Resin-infused ceramics (E; Vita Enamic, Vita Zahnfabrik, Bad Säckingen, Germany) and resin nanoceramics (U; Lava Ultimate) are categorised as resin-matrix CAD/CAM ceramics, exhibiting properties that are shared with both glass-ceramics and composite resins [4]. In the fabrication of 3D printed resin nanoceramics, nanohybrid filler particles are dispersed in a urethane dimethacrylate (UDMA)-based matrix. This structure is aimed to be an alternative to glass-ceramics with regard to both mechanical and aesthetic properties [4,5]. Ceramic-filled permanent resin crowns (F; Formlabs, Somerville, MA, USA), ceramic-filled hybrid (hybrid composite) BEGO VarseoSmile Crown plus material (B; BEGO, Bremen, Germany), and resin-based material Saremco print Crowntec (C; Saremco Dental AG) are 3D printed permanent resin-based ceramics [6,7]. The utilisation of 3D printed, resin-based material products represent a recent development in the field of restorative materials, with their application being considered for use in fixed permanent prosthetics [8].

Three-dimensional printers have the capacity to produce polymeric materials in a variety of forms, including powders, filaments, and preformed films [9]. In stereolithography (SLA), a photopolymerised liquid polymer is deposited in layers to create the 3D print, and an ultraviolet laser system is employed to cure the resin [10]. DLP 3D printers have been developed to cure the entire 3D print in a single exposure

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using micromirrors [11]. The DLP (Digital Light Processing) method was employed in the production of C, while the SLA (Stereolithography) method was utilised for B. Despite the similarity in design between DLP and SLA 3D printer models, there are significant differences in the applied light source technology [11].

It is imperative to acknowledge the significance of Surface roughness (SR) and Micro hardness (Vickers Hardness Number, VHN) as critical properties in order to facilitate a comprehensive and successful evaluation of resin ceramics. MH tests and Ra and Rz measurements of SR are standardised and reliable methods, allowing for the comparison of results with those of previous studies [12]. The clinically acceptable Ra value for dental materials is considered to be 0.2 μm [13,14]. Manufacturers' recommendations stipulate that the use of polishing or buffing implements is necessary to achieve a smoother surface [5]. The importance of a smooth outer surface for the long-term use of dentures is well-documented, as it can prevent plaque accumulation and the subsequent discolouration of the denture [15]. Changes in the MH of the material can lead to a decrease in strength and mechanical performance due to structural degradation or solubility of the material [16].

A number of studies have been conducted on the mechanical properties (MH and SR) of restorations with temporary crown indications produced by 3D printers [17–19]. However, research on materials with permanent crown indications is limited, and no study has yet evaluated the SR and SR of the F, B, C materials produced by 3D printers and the CAD/CAM resin block materials E, U materials compared in this study. The null hypothesis is that there will be no significant difference in the SR AND MH values of CAD/CAM and 3D printed permanent restorative materials before and after thermal cycling.

2. Materials and methods

The present study compares the physical properties of permanent resin restorations produced by 3D printing with those of resin-containing monolithic CAD/CAM materials after artificial ageing. The study was conducted with five distinct materials, as listed below:

3D printed materials:

1- Resin-Based Material Saremco Print Crowntec [SA; Saremco Dental AG] n = 15
2- Ceramic Filled Resin (Permanent Crown Resin, Formlabs, Somerville, USA) n = 15
3- Resin with Ceramic Filler (VarseoSmile Crown Plus, Bego, Bremen, Germany) n = 15

CAD/CAM materials:

1- Resin Infiltrated Ceramic (Vita Enamic, Vita Zahnfabrik, Bad Säckingen, Germany) n = 15
2- Resin Nano Ceramic (3M Lava Ultimate, 3M Deutschland GmbH, Neuss, Germany) n = 15.

The minimum number of samples was set at n = 10, as determined by G Power, based on the measurement times in each group. Sample values in similar studies were n = 10 [6,14], we set the samples to n = 15 to increase the sensitivity of the study. For the study as in similar studies [20–22], 1.5 mm thick (n = 15) 12 × 14 × 1.5 mm sections produced using a 3D printer were compared with CAD/CAM blocks used in CAD/CAM milling systems (Figure 1). The CAD/CAM blocks were cut into square sections of 1.5 mm thickness on a low-speed precision cutting device (Isomet 1000 [Buehler Germany]). Square sections measuring 12 × 14 × 1.5 mm were prepared for each of the five groups (n = 15 in each group), and all were sanded at 600 rpm using a sanding device (Buehler Phoenix Beta Grinder/Polisher, Germany) using a 600-800-1200 grit silicon carbide paper sandpaper (Water Sander) (English Abrasives England), rotated at 90 degrees for surface standardisation.

The designs of the models produced with the 3D printer were created in STL format using AutoCAD 2018 software. Thereafter, the prepared designs were transferred to the 3D printer, and samples of two different brands were produced using SLA (Stereolithography) and DLP (Digital Light Processing) technologies. Subsequent to the fabrication process, the specimens were immersed in isopropyl alcohol for a duration of five minutes, with the objective of ensuring thorough surface cleaning and the removal of excess resin from the unpolymerised surface.

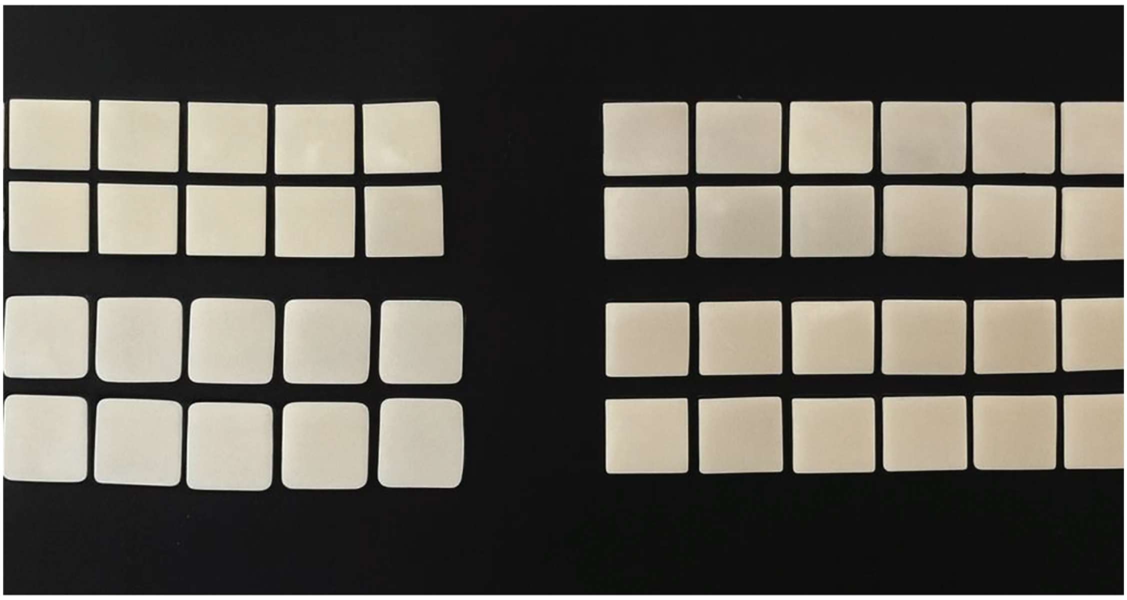

Figure 1. Example representation of the samples used in the study: 12 × 14 × 1.5 mm sections produced using a 3D printer and CAD/CAM milling systems

The B materials were produced using a Varseo S printer (405 nm, BEGO, Bremen, Germany) with DLP technology. Conversely, F was prepared with Formlabs Form 3B+ printer (405 nm, Formlabs GmbH, Berlin, Germany) utilising SLA technology. It is noteworthy that both printer systems possess a closed system structure. C materials were produced using the Saremco 3D printer (Asiga Max UV, Australia), which utilises DLP technology. The Asiga Max UV is distinguished by its open production system. The B, C, and F materials were printed with a layer thickness of 50 µm at a 90-degree angle. After the preparation of the samples, the samples were then kept in distilled water in an oven (Memmert, Germany) for 24 h. Initial measurements, SR and MH, were made.

The samples were then subjected to artificial ageing in a thermal cycle device for a total of 20,000 cycles, at temperatures of between 5°C and 55°C, housed in tanks containing cola at both high and low temperatures. Subsequent to this procedure, the samples were subjected to thermal cycling (Salubris Technica, Turkey) for a period of 20,000 cycles, during which the samples were treated with cola. Following the thermal cycling process, SR measurements were repeated following the artificial ageing processes. To simulate the factors encountered by restorative materials in a clinical setting, the specimens were brushed horizontally for 15 s by a single examiner using a manual medium-hardness brush. During the procedure, the toothpaste (Nevadent Complex 3; DENTAL-Kosmetik GmbH) was rinsed under running water and cleaned in water for 10 min before drying [23].

Initial and final SR measurements were performed with a Perthometer S8P (Mahr, Göttingen, Germany). Ra and Rz values were measured at three points on each sample, and the measurements were interpreted with special software (Perthometer Concept 4.0; Perthen Mahr, Göttingen, Germany). Initial and final MH measurements were performed using a device (Buehler, IL, USA) in accordance with the ISO 6507 standard [24]. For each sample, a constant load of 0.98 N was applied to the surface for 15 s, and measurements were taken at three separate locations on the sample (Figure 2). The result was calculated by averaging the three measurements.

The SR measurement values obtained prior to and following the ageing procedures were compared, for which SR images were obtained using scanning electron microscopy (SEM).

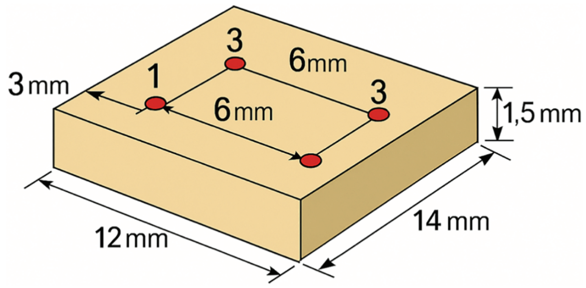

Figure 2. Schematic illustration of the measurement points on the 12 × 14 × 1.5 mm sample for the surface roughness test

Regarding Sample Numbering and Analysis Method:

All samples were uniquely numbered throughout the study. This numbering allowed us to pair the values obtained from each sample before and after the thermal cycle, treating the same sample as a within-subject factor in the analysis. This is a fundamental requirement of repeated measures ANOVA, and we conducted the analysis strictly following this principle. In other words, the post-thermal cycle values were not compared with randomly selected other samples, but rather with the initial values obtained from the exact same sample.

Statistical analysis

The minimum number of samples was set at n = 10, as determined by G Power, based on the measurement times in each group. The data set obtained from the study was subjected to two-way analysis of variance (Two-Way repeated measures ANOVA). The data were analysed using the IBM SPSS Statistics Standard Concurrent User V 26 (IBM Corp., Armonk, NY, USA), a statistical package programme. Descriptive statistics were presented as mean and standard deviation ($\bar{x}$ and ss). The study data were subjected to repeated measurements, the results of which were interdependent. Consequently, a Repeated Analysis of Variance was conducted for one of the factors in a factorial design approach, although the "Syntax" function was utilised as the menu options did not allow a 0.05 probability to be maintained for the initial type I error while conducting multiple comparisons. A Bonferroni test was applied for multiple comparisons, and a Two-way Analysis of Variance for the evaluation of the differences between three or more groups. A Bonferroni test, one of the multiple comparison tests, was used to evaluate any significant differences between the results of three or more groups ($\alpha = 0.05$).

3. Results

Table 1 shows that the differences between the groups were statistically significant at both the initial (0th) and final (1st) measurements ($p < 0.001$). At the 0th measurement, there were no significant differences between the F, U, and E groups, whereas the other groups showed clear differences. Among all groups, B had the highest average value, while F, U, and E had the lowest.

At the 1st measurement, no significant difference was observed between groups B and C, but significant differences existed among the other groups. As shown in Table 2, group F had the highest average value at the 1st measurement, while group E had the lowest.

In all groups, the results showed a statistically significant increase from the 0th to the 1st measurement ($p < 0.001$), with all groups recording higher mean values at the 1st measurement compared to the 0th (1st > 0th).

Table 3 shows that the differences between the groups were statistically significant at both the 0th and 1st measurements ($p < 0.001$). At the 0th measurement, all groups differed from each other. Group E had the highest average value, while group B had the lowest.

Table 1. Comparison of microhardness of Bego, Form Labs, 3M Lava Ultimate, Vita Enamic and Saremco samples at different measurement times

	GROUPS										Test Statistics‡	
	Form Labs		**3M Lava Ultimate**		**Bego**		**Vita Enamic**		**Saremco**		***F***	***p***
	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*		
0	60.16^{a}	1.28	178.24^{b}	5.25	28.38^{c}	1.07	274.81^{d}	6.56	106.43^{e}	8.35	6948.897	**0.001**
1	46.09^{a}	1.38	119.76^{b}	3.35	20.31^{c}	0.49	239.32^{d}	7.15	42.42^{a}	1.78	5723.305	**0.001**
Test Statistics‡	70.39		1217.064		23.181		448.01		1457.659			
p	**0.001**		**0.001**		**0.001**		**0.001**		**0.001**			

Note: The symbol "x" represents the mean, while "ss" represents the standard deviation. Standard deviation is a statistical measure of the dispersion of a set of data around its mean. Two-way analysis of variance in repeated measures. Comparisons between the groups at each measurement time point are presented in section ‡. Within-group comparisons of measurements in each group are indicated through the use of superscripts^{a,b}, and ^{c,d}, which indicate groups with statistically significant differences in each measurement. Groups with the same superscript are statistically indistinguishable.

Table 2. Comparative analysis of Surface Roughness (Ra) of Bego, Form Labs, 3M Lava Ultimate, Vita Enamic, and Saremco Parameters at measurement times 0 and 1

	GROUPS										Test Statistics‡	
	Formlabs		**3M Lava Ultimate**		**Bego**		**Vita Enamic**		**Saremco**		***F***	***p***
	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*		
0	0.06^{a}	0.01	0.06^{a}	0.00	0.13^{b}	0.01	0.06^{a}	0.00	0.12^{c}	0.00	526.211	**0.001**
1	0.21^{a}	0.00	0.12^{b}	0.00	0.17^{c}	0.00	0.10^{d}	0.00	0.17^{c}	0.00	894.809	**0.001**
Test Statistics‡	5262.61		943.34		476.564		378.33		618.372			
p	**0.001**		**0.001**		**0.001**		**0.001**		**0.001**			

Note: The symbol "x" represents the mean, while "ss" represents the standard deviation. Standard deviation is a statistical measure of the dispersion of a set of data around its mean. Two-way analysis of variance in repeated measures. Comparisons between the groups at each measurement time point are presented in section ‡. Within-group comparisons of measurements in each group are indicated through the use of superscripts^{a,b}, and ^{c,d}, which indicate groups with statistically significant differences in each measurement. Groups with the same superscript are statistically indistinguishable.

Table 3. Comparative analysis of Surface Roughness (Ra) of Bego, Form Labs, 3M Lava Ultimate, Vita Enamic, and Saremco Parameters at measurement times 0 and 1

	GROUPS										Test Statistics‡	
	Formlabs		**3M Lava Ultimate**		**Bego**		**Vita Enamic**		**Saremco**		***F***	***p***
	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*	$\bar{x}$	*ss*		
0	0.06^{a}	0.01	0.06^{a}	0.00	0.13^{b}	0.01	0.06^{a}	0.00	0.12^{c}	0.00	526.211	**0.001**
1	0.21^{a}	0.00	0.12^{b}	0.00	0.17^{c}	0.00	0.10^{d}	0.00	0.17^{c}	0.00	894.809	**0.001**
Test Statistics‡	5262.61		943.34		476.564		378.33		618.372			
p	**0.001**		**0.001**		**0.001**		**0.001**		**0.001**			

Note: Standard deviation is a statistical measure of the dispersion of a set of data around its mean. Two-way analysis of variance in repeated measures. Comparisons between the groups at each measurement time point are presented in section ‡. Within-group comparisons of measurements in each group are indicated through the use of superscripts^{a,b}, and ^{c,d}, which indicate groups with statistically significant differences in each measurement. Groups with the same superscript are statistically indistinguishable.

At the 1st measurement, there was no significant difference between groups F and C, but all other groups showed significant differences. Again, group E had the highest mean, and group B had the lowest.

Across all groups, the difference between the 0th and 1st measurements was statistically significant ($p < 0.001$), with the 0th measurement values being higher than the 1st in all groups (0st > 1th).

100× (left) and 1000× (right) SEM Images of the specimens used in the study are shown at Figures 3–7.

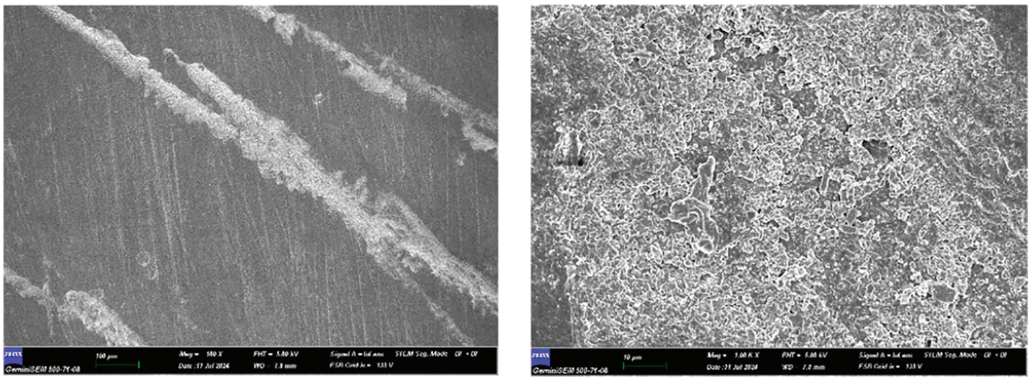

Figure 3. Permanent crown resin (Formlabs, Somerville, MA, USA) 100× (left) and 1000× (right) scanning electron microscopy (SEM) images

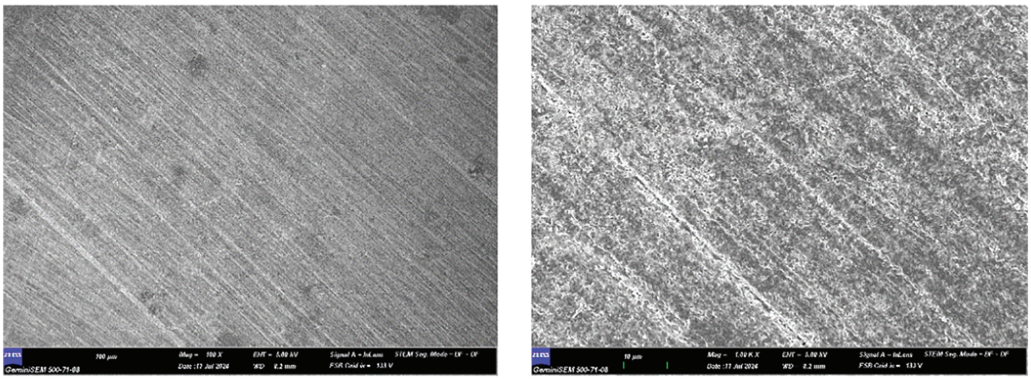

Figure 4. VarseoSmile crown plus (Bego, Bremen, Germany) 100× (left) and 1000× (right) scanning electron microscopy (SEM) images

4. Discussion

Based on the findings of the study, the null hypothesis can be rejected. A significant difference was noted in the SR of the materials ($p < 0.001$), and a significant difference was noted in the measured MH values recorded before and after the thermal cycle ($p < 0.001$). A comparison of the materials following ageing revealed an increase in SR and a decrease in MH values, suggesting that the ageing process led to changes in the mechanical and physical properties of both the CAD/CAM and 3D printed samples. The differences in results of the samples under investigation may be attributed to the specific type and quantity of particles constituting the material composition, as well as the distinctive characteristics of the materials themselves.

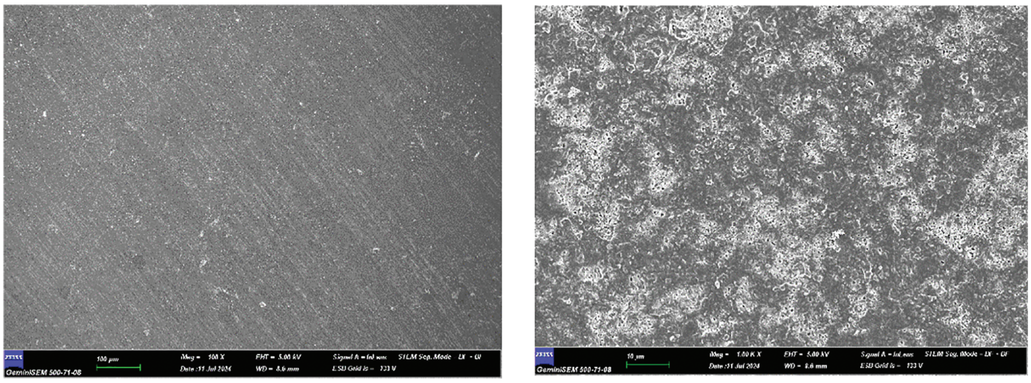

Figure 5. Saremco print crowntec [SA; Saremco Dental AG] 100× (left) and 1000× (right) scanning electron microscopy (SEM) images

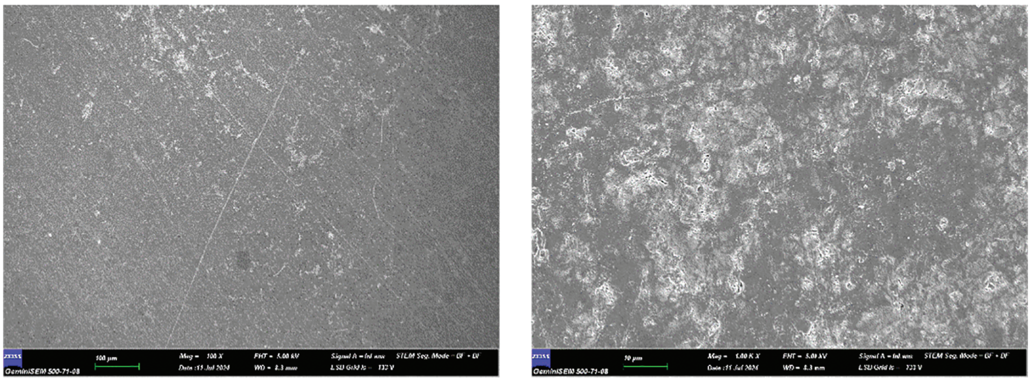

Figure 6. Lava ultimate (3M Deutschland GMBh, Neuss, Germany) 100× (left) and 1000× (right) scanning electron microscopy (SEM) images

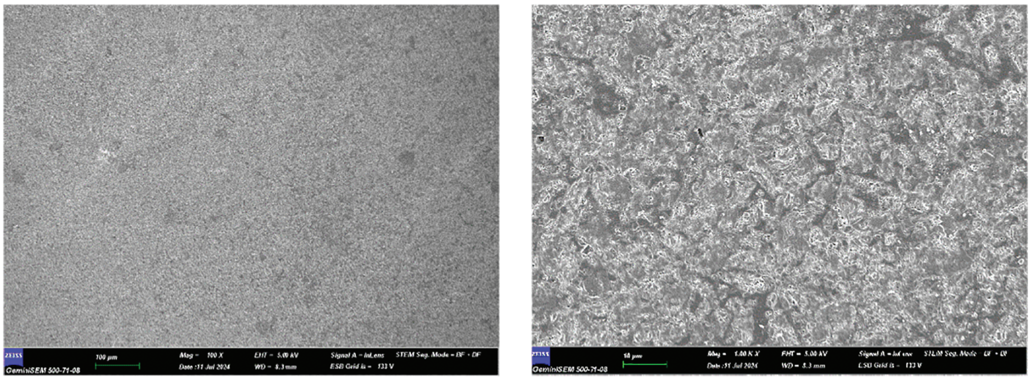

Figure 7. Vita Enamic (Vita Zahnfabrik, Bad Säkingen, Germany) 100× (left) and 1000× (right) scanning electron microscopy (SEM) images

Following polishing, none of the tested specimens exhibited a Ra value greater than the clinically acceptable threshold value of 0.2 µm [6]. It should be noted, however, that variations were observed in the Ra values of the different materials. Following thermal ageing, the highest mean Ra value (0.21 µm) was recorded for F compared to the 0.17 µm value recorded both for B and C among the 3D printed samples, while the lowest mean value was recorded as 0.10 µm for E (U 0.12 µm) among the CAD/CAM samples. Similar studies [6,7] have reported that materials produced with CAD/CAM exhibit lower SR after thermal ageing than 3D printed materials ($p < 0.001$). In a study conducted by Al-Qahtani et al. [25] comparing the SR of ceramics produced using either a CAD/CAM or a 3D printer, the highest Ra value was observed in the 3D printed samples (5.77 ± 0.60 µm), while the lowest was noted in the CAD/CAM group (3.68 ± 0.42 µm). Çakmak et al. [6] compared CeraSmart, produced using a CAD/CAM system, with C and B, and reported the Ra values of GC CeraSmart produced with CAD/CAM (0.1 ± 0.01*) to be similar to Saremco Crowntec (0.19 ± 0.11) and Bego VarseoSmile Crown Plus (0.16 ± 0.01*), or less than those of 3D printed composite resins. In their study, they compared resins with temporary crown indications. In a study conducted by Karaoglanoglu et al. [7], the SR of the CAD/CAM groups (CeraSmart 270 GC 0.154 ± 0.01) was reported to be significantly lower than that of the 3D printed group (Saremco Crowntec 0.195 ± 0.02, Formlabs Permanent Crown 0.195 ± 0.02). In their study comparing 3D printer images with permanent crown indications, the brand of resin-based CAD/CAM ceramic they chose for the study is different from that of this study. Although these studies [6,7,25] were conducted with different brands of materials, they reached the same conclusion that 3D printer-produced resins exhibit higher roughness than resin-based CAD/CAM restorative materials. Due to differences in the methods and techniques used in the studies, we were unable to make numerical comparisons.

Although 3D printing is generally expected to produce smoother surfaces due to the absence of mechanical milling, the increased surface roughness in 3D printed samples observed in this study may be attributed to several factors. First, the layer-by-layer fabrication in additive manufacturing can create a stair-step effect, especially on curved or angled surfaces, leading to increased roughness [26]. Second, the post-processing and polymerization protocols may be less efficient compared to industrial CAD/CAM processes, affecting surface uniformity [27]. Finally, the specific formulation and filler content of the resins used in 3D printing may also contribute to differences in surface texture compared to resin-matrix CAD/CAM blocks, which undergo high-pressure industrial polymerization that enhances homogeneity and surface quality [28].

In a study comparing the SR of 3D printed ceramics, the Formlabs samples achieved a value of 0.21 µm following coke thermal cycling, which was close to the clinically acceptable 0.20 µm threshold [13]. Other materials were found to exhibit acceptable Ra values. Nevertheless, a difference of 0.01 µm in the average Ra value of Formlabs (0.21 µm) can be considered clinically insignificant [6]. While B,C, and F are all additively manufactured composite resins with similar compositions [7], F achieved a higher Ra value than the other 3D printed samples which can be attributed to the production technique, being manufactured using the SLA method, whereas C and B were manufactured using the DLP method.

The results of the study revealed a statistically significant difference in MH values across all the tested groups before and after thermal ageing ($p < 0.001$). The 3D printed samples (C 42.42 ± 1.78, B 20.31 ± 0.49, and F 46.09 ± 1.38) scored lower MH values than their CAD/CAM counterparts (E 239.32 ± 7.15; U 119.76 ± 3.25). Concurring with the results of the present study, Karaoglanoglu et al. [7], reported the MH values of the CAD/CAM group (CeraSmart 270, 103.8 ± 2.7, Grandio Blocs, 192.8 ± 4.7) in their study to be higher than those in the 3D printed group (Saremco Crowntec 29.9 ± 1.2, Formlabs Permanent Crown 36.6 ± 1.7). In a study conducted by Grzebieluch et al. [29] in which the mechanical properties of 3D printed resin and resin-based CAD/CAM blocks were examined, the 3D printed restorations were found to exhibit lower values than CAD/CAM blocks. Bora et al. [30] reported that the 3D printed resin restorations (C&B MFH, Ceramic Crown, OnX and OnX Tough) in their study achieved significantly lower MH values than conventional and CAD/CAM resin composites (Lava Ultimate) and ceramic materials ($p < 0.001$). In a study conducted by Digholkar et al. [12], the temporary polymethylmethacrylate (PMMA) samples created with CAD/CAM exhibited lower MH values than 3D printed samples. Furthermore, a study conducted by Al-Qahtani et al. [25] found that the values of provisional restorative resins produced with 3D printers were comparable to those of their CAD/CAM produced specimens. The reason why Al-Qahtani's result is different from other studies [12,29,30] and this study may be that the materials it is compared were different restorative resins from other studies and our study.

The comparison of 3D printed materials in the present study reveals F (46.09) and C (42.42) to have the highest values among the tested materials, while the difference between C and F was not statistically significant. The higher values can be attributed to the presence of cross-linked monomers and inorganic fillers in the composite resins used in the 3D printed specimens, which increase wear resistance and reduce polymerisation shrinkage [12,19,31]. Concurring with the results of the present study, Gül Aygün et al. [32] also reported the highest values in the Formlabs sample among the six different 3D printed materials they assessed (Formlabs, DWS Systems, Asiga, Dentafab Mega, Dentafab Vega, Photon 3D Printer).

For the present study, the samples were continuously exposed to acid without daily rinsing to simulate prolonged exposure to carbonated beverages in the oral cavity. In a study conducted by Backer et al. [33], the effects of prolonged exposure to acidic beverages were investigated over 7 (T1) and 28 (T2) days. In the literature, a study by Gale and Darvell [34] stated that 10,000 thermal cycles correspond to approximately 1 year of clinical use [35]. On this basis, 20,000 cycles can be considered to simulate approximately two years of natural use [36]. In the present study, 20,000 cycles of thermal aging were performed on the coke sample. In our study, the acid exposure method was modeled based on commonly used accelerated aging approaches in the literature. The continuous immersion protocol was chosen as a controlled *in vitro* method to evaluate the long-term resistance of restorative materials against acidic environments. The aim of this method is to simulate the cumulative effects of repeated acid exposures in the oral environment. Although materials are exposed to acids for short durations under routine clinical conditions, the continuous immersion method accelerates this effect, allowing for more observable outcomes [37]. In light of our findings, it can be concluded that the resistance of the material to forces and rigidity diminish as a consequence of the ageing process induced by cola and the thermal cycling of the tested material. It is important to note that universal acceptability thresholds have yet to be established [38]. Cola was selected for analysis due to its capacity to accelerate changes as a result of its acidic components [39]. The present study differs from similar studies [2,6,23] in its application of 20,000 thermal cycles to the samples.

This study's limitations include its *in vitro* design, which did not account for the uncertainties of the oral environment, such as high non-axial chewing forces, frequent temperature fluctuations, salivary flow, plaque accumulation, and acid exposure. Among the study's limitations is the use of only cola for thermal aging, given that other materials, such as coffee and orange juice, can also affect restorative resins. In the oral environment, only the polished surfaces of the crown materials come into contact with liquids, whereas in the laboratory study, all surfaces of the material were in contact with liquids. Furthermore, the shape of the brush used during the comparison and the cleaning materials used may influence the results. All of this mechanical exposure may alter the MH and SR values of the material after thermal aging. Furthermore, three 3D printed and two CAD/CAM-fabricated materials were used in the study, and this should be taken into account when interpreting the results.

5. Conclusion

Within the parameters of the study, the 3D printed samples had lower values compared to the CAD-CAM samples. However, in terms of SR, higher roughness values were observed in the 3D printed samples. Further clinical studies are needed to gain a more comprehensive understanding of the observations of the present study. Furthermore, the mechanical properties of 3D printed polymers for use in dentistry require further investigation to ascertain their suitability as long-term restorative materials. Even if 3D printed dental resin materials are indicated for permanent crowns, dental professionals should consider the shortcomings of 3D printed materials when choosing them over CAD/CAM-produced resin materials for clinical use.

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Author Contributions: The authors confirm contribution to the paper as follows: study conception and design: Elifnur Güzelce Sultanoğlu; data collection: Berk Yüzbaşıoğlu; analysis and interpretation of results: Elifnur Güzelce Sultanoğlu, Berk Yüzbaşıoğlu; draft manuscript preparation: Elifnur Güzelce Sultanoğlu, Berk Yüzbaşıoğlu. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: The data that support the findings of this study are available from the Corresponding Author, [Elifnur Güzelce Sultanoğlu], upon reasonable request.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study.

Abbreviations

MH	Vickers Hardness Number, VHN
3D	3 Dimensional
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
SEM	Scanning Electron Microscopy

References

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