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Mechanical Characteristics of Composite Resins Produced by Additive and Subtractive Manufacturing

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ABSTRACT

Introduction: The aim of the study was to evaluate the mechanical characteristics of resin composites produced by additive and subtractive manufacturing. Methods: Six composite resin materials produced by subtractive (Vita Enamic-VE, Cerasmart-CE, Lava Ultimate-LU) and additive manufacturing (Varseo Smile Crown plus-VSC, Saremco Print Crowntec-SPC, Formlabs 3B Permanent crown-FLP) were selected. The three-point bending test was performed, and surface hardness of test specimens was measured. Results: The flexural strength values of CE, SPC and LU test groups were found to be statistically higher when compared to VE, FLP and VSC test groups ($p<0.0033$). The modulus of elasticity values of the test specimens was listed as VE>LU>CE>SPC>FLP>VSC. The FLP group [35.11(4.46)] had the lowest surface hardness values, whereas the VE group [252.50 (21.5)] had the highest values. Other groups were listed as LU>CE>SPC>VSC in terms of surface hardness. Conclusions: According to the ISO 6872:2015, the flexural strengths of all resin composites were found to be acceptable for single unit fixed restorations. However, the VSC group's flexural strength is suitable for inlay, onlay, veneer restorations or single-unit anterior fixed dental prostheses. Also, VSC may not be a suitable choice for posterior restorations due to its low flexural strength.

INTRODUCTION

The demand for dental materials with mechanical and aesthetic properties similar to natural teeth is increasing in contemporary restorative dentistry.[1] With the development of digital technology, the production of many restorations such as temporary or permanent single crown, bridge, inlay and onlay from planning to production is carried out with additive manufacturing (AM) and subtractive manufacturing (SM) using intraoral scanners and digital articulators.[2,3] The three-dimensional (3D) design created in the SM technique is obtained by milling from prefabricated blocks.[4] However, SM technique have some important disadvantages, such as the inability to successfully reproduce extremely complex geometries, wasted material of up to 90% and the milling burs need to be replaced after a short time due to the hardness and flexural strength of CAD/CAM blocks. Consequently, to overcome these drawbacks, the question arose whether AM method would be a viable solution for the fabrication of dental restorations.[5] AM technique is based on depositing layers of material; it easily allows detailed morphological productions in areas with complex anatomy that cannot be reached by burs such as fossa and fissures. It is also more economical than the SM technique.[6]

AM technology can produce using many different production techniques.[3] Stereolithography (SLA) method with Digital Light Processing (DLP); probably one of the most popular additive manufacturing systems in the dental industry.[7] The primary distinction between the two procedures is the light source used. When using ultraviolet (UV) laser light in SLA; DLP uses short wavelength (380 nm and 405 nm) visible light.[8] In comparison to traditional SLA, DLP 3D printing is faster since it can print and cure a single layer across the entire build plate in just a few seconds. DLP has another benefit over SLA and other 3D printing technologies in that it uses less material, which lowers production costs.[7]

It is critical to evaluate the mechanical characteristics of the material, such as its flexural strength, elastic modulus, and microhardness, in order to predict its clinical effectiveness and performance.[9] More research are needed *in vivo* and *in vitro* as the literature on the mechanical characteristics of 3D-printed permanent composite resins for dentistry is limited.[10–12]

According to these considerations, this study's objective was to compare the mechanical characteristics of composite resins produced by AM and SM techniques. The null hypothesis of the present study was that the mechanical characteristics (flexural strength, modulus of elasticity, and microhardness) of permanent composite materials produced by additive and subtractive methods would not make a significant difference compared to each other.

METHODS

This study comparatively investigated the flexural strength, modulus of elasticity, and microhardness of permanent composite resins produced by computer-aided AM and SM. Three composite resin materials produced by both subtractive (Vita Enamic-VE, Cerasmart-CE, Lava Ultimate-LU) and three additive manufacturing (Varseo Smile Crown plus-VSC, Saremco print Crowntech-SPC, Formlabs 3B Permanent crown-FLP) were selected for mechanical and surface hardness testing *(Figure 1)*. The minimum specimen size required to be included in this study was calculated at 0.50 effect size, 90% power and α=0.05 error level as n=12 per group (N=72). The materials and their contents used in the study are shown in Table 1.

The test specimens to be produced from CAD/CAM blocks (VE, CE, LU) were wet sliced by a diamond saw (Micracut 201, Metkon, Bursa, Turkey). According to International Organization for Standardization (ISO) 6872:2015 standards, 36 rectangular plates 15 mm long, 4 mm wide and 1.5 mm thick were obtained.[13] Due to the size of the CAD/CAM material blocks, it was not possible to accord with ISO 4049 standards.[14]

A CAD software program (SolidWorks Corp. Concord, MA, USA) was used in the preparation of 3D printing specimens (VSC, SPC, FLP). By designing 3D models with the same dimensions (15 x 4 x 1.5 mm) with the specimens produced by the subtractive method. The master design data were converted to Standard Transform Language (STL) file format and forwarded to the different production methods.

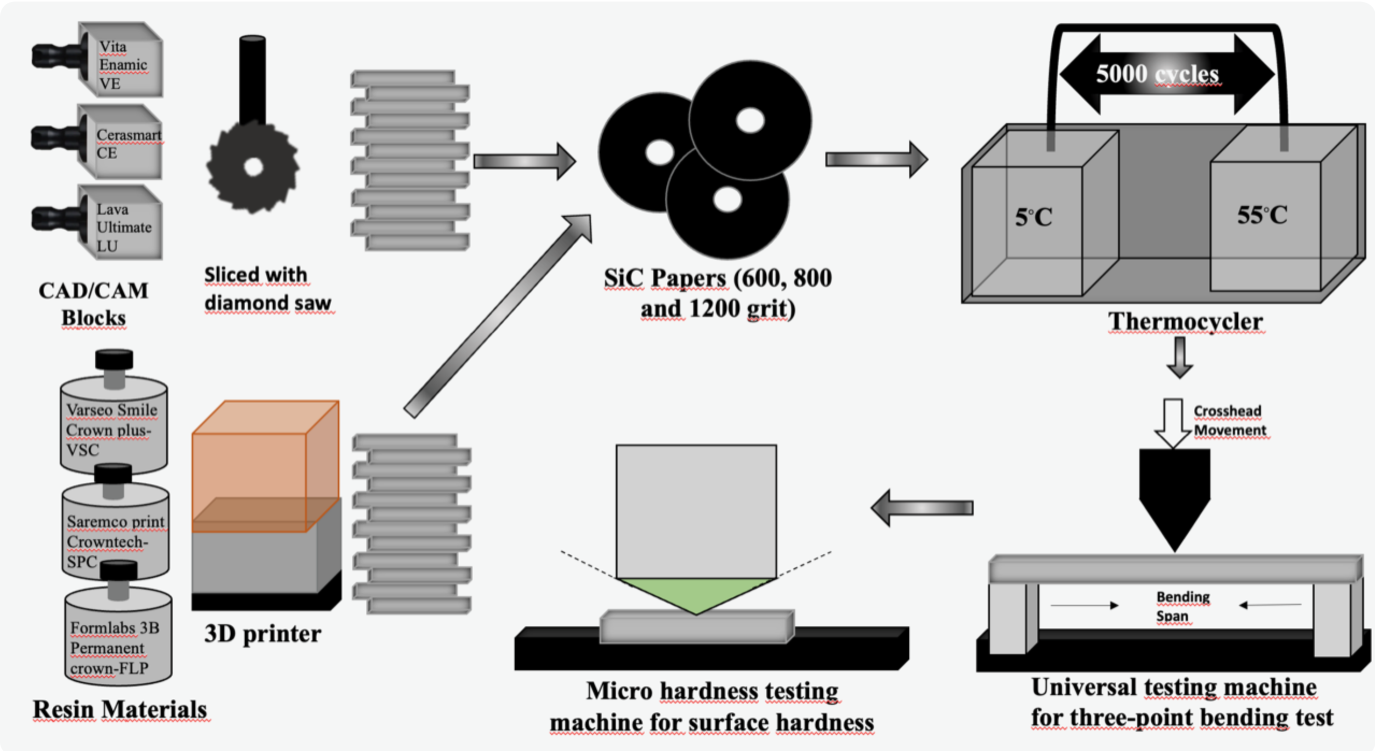

Figure 1: The flowchart of this study.

Table 1. Materials used in the study and their compositions.

Material type	Trade name (Group code)	Resin Matrix	Inorganic Filler	Filler Percentage %	Lot No.	Manufacturer
Hybrid ceramic	Vita Enamic (VE)	UDMA, TEGDMA	Feldspar ceramic enriched with aluminum oxide	86	77171	Vita Zahnfabrik, Bad Sackingen, Germany
Composite resin	Lava Ultimate (LU)	BisGMA, UDMA, BisEMA, TEGDMA	Silica and zirconia nanoparticles and nanoclusters	80	N674339	3M ESPE Dental Products, St. Paul, MN
	Cerasmart (CE)	BisMEPP, UDMA, DMA	Silica and barium nanoparticles	75	N670408	GC Corp., Tokyo, Japan
3D-printed composite	Saremco Print Crowntec (SPC)	BisEMA	Dental glass and silica	30-50	D830	Saremco Dental AG; Rebstein, Switzerland
	Varseo Smile Crown plus (VSC)	4 0 isopropylidiphenol, ethoxylated and 2-methylprop-2enoic acid	Silanized dental glass	30-50	600272	Bego, Bremen, Germany
	Permanent crown (FLP)	4,4'-isopropylidenediphenol, ethoxylated and 50-75% esterification products of 2-methylprop-2-enoic acid	Silanized dental glass	30-50	600163	Formlabs, Somerville, MA, USA

(Bis-GMA: bisphenol A diglycidylether methacrylate; Bis-MEPP: 2,2- Bis (4-methacryloxypolyethoxyphenyl) propane; UDMA: urethane dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; Bis-EMA: ethoxyl ated bisphenol-A dimethacrylate; DMA: dimethacrylate)

VE, CE, LU test groups were not post-cured, but VSC, SPC, FLP test groups were post-cured as described below.

Group FLP; SLA-based 3D printer Formlabs 3D (Somerville, Massachusetts, USA); Group VSC; DLP-based 3D printer Varseo XS (Bego, Bremen, Germany); and Group SPC; DLP-based 3D printer Asiga Max UV (Asiga, Anaheim Hills, CA, USA), which they were produced in accordance with the manufacturer's instructions. The 3D test specimens were produced vertically to the platform and at a layer thickness of 50 µm. The test specimens' post-processing was done in accordance with the manufacturer's instructions.

Following a thorough cleaning and washing in isopropanol 98% for a period of two to three minutes, using ultrasonic technology, the Otoflash G171 device (NK Optik, Baierbrunn, Germany) was used to cure the light with 4000 lighting exposures while being in a nitrogen oxide gas atmosphere. Group VSC's post-treatment procedures included washing the specimens with an unheated, 96%-concentrated ultrasonic ethanol jar for 3 minutes, followed by another 2 minutes in a new ethanol bath with the same concentration. The specimens were removed from the ethanol bath and dried using compressed air. The Otoflash (Bego, Bremen, Germany) was then pressurized with nitrogen gas (1.0–1.2 bar), producing 1500 flashes while performing at 10 light frequencies per second. Test specimens for Group FLP's post-treatment were submerged in Form Wash (Formlabs, Somerville, MA, USA) and rested for 3 minutes in isopropyl alcohol (IPA 99%) to remove residual resin. Then they were given at least 30 minutes to dry. Then, they post cured twice as recommended in Form Cure (Formlabs, Somerville, MA, USA), 390–405 nm, at 60°C for 20 minutes.

For each group, twelve specimens were fabricated (n = 12; 6 groups). The size of the all of test specimens was measured with a digital caliper (Mitutoyo Corp, Tokyo, Japan) and silicon carbide papers (SiC; Buehler GmbH, Düsseldorf, Germany) with grit 600, 800 and 1200 were used by a researcher for standardization. Then, thermocycle (SD Mechatronic Thermocycler, Julabo GmbH, FT 200, Seelback, Germany) was applied to all specimens in distilled water (5000 cycles, 5°C / 55°C thermal application and 30 s waiting time) for artificial aging. Afterward, all specimens were ultrasonically (Steris Reliance Sonic 250, Soma Tech Intl, USA) cleaned in distilled water for 10 min.

Using a universal testing machine (Lloyd-LRX, Lloyd Instruments, Fareham, Hampshire, England), a three-point bending test with a support span of 12 mm and a speed of 1 mm/min was used to measure the flexural properties.[13]

Using the three-point bending findings, the following formula was used to compute the flexural strength (σf):

$$\sigma f = \frac{3Fl}{2wh^2}$$

where *F* is the maximum load during the flexural test, *l* the roller span (12 mm), *w* the width (4 mm), and *h* the height (1.5 mm) of the bar.

Using the three-point bending findings, the following formula was used to compute the flexural modulus (E_f):

$$Ef = \frac{Fl^3}{4\,wh^3d}$$

where *F* is the load, *l* the roller span (12 mm), *w* the width (4 mm) and *h* the height (1.5 mm) of the bar, the deflection associated with load F is represented by d.

Using a micro hardness testing machine (Shimadzu HMV Corporation, Tokyo, Japan), the specimens' surface hardness was determined. Vickers hardness tester was used with a 1 kgf load and a 10 second dwell time. For each specimen, three indentations were made at random location. The hardness values were then automatically determined by the machine. The average of the measured hardness values was taken. Microhardness tests were performed on test specimens that had already undergone a three-point bending test.

Statistical analysis was performed using the SPSS (Version 27.0 IBM) package program. Whether the data conformed to the normal distribution or not was evaluated by Kolmogorov-Smirnov test, Shapiro-Wilk test and graphical approach. The Kruskal-Wallis test was used to evaluate the difference between the groups, and the Mann-Whitney U test was used to compare the groups that caused the difference. Unless otherwise indicated, results with a p-value of 0.05 were considered statistically significant. In order to check for type I errors, Bonferroni correction was applied to every conceivable multi comparison. (p values < 0.0033 after Bonferroni adjustment were deemed statistically significant.)

RESULTS

Descriptive statistical data of flexural strength, modulus of elasticity, and surface hardness of the test specimens are presented in the Table 2. The statistical comparison of mechanical characteristics values for the test specimens between groups is summarized in Table 3.

The highest flexural strength value was found in group CE [218.90 (92.04) MPa], while the lowest was found in group VSC [87.83 (18.94) MPa]. All of groups were listed as CE>SPC>LU>VE>FLP>VSC. Group SPC was statistically higher when compared to other 3D printing groups (FLP, VSC) (p<0.0033). When compared pairwise, the CE-SPC, CE-LU, and LU-SPC groups did not differ statistically significantly from one another (p>0.0033).

Elastic modulus values of test specimens were followed in VE>LU>CE>SPC>FLP>VSC test groups, respectively, from highest to lowest. The highest modulus of elasticity values were found in the group VE [25.86 (4.78) GPa], while the lowest value was found in the group VSC [4.99 (0.79) GPa]. When the CAD/CAM blocks were compared to the composites produced with a 3D printer, the modulus of elasticity was statistically higher. In addition, elastic modulus value of group SPC was statistically higher among 3D printing groups. There was a statistically significant difference in the modulus of elasticity between the other groups except for the VSC-FLP (p<0.0033).

The highest surface hardness values were observed in the group VE [252.50 (21.5) VHN] and the lowest in the group FLP [35.11(4.46) VHN]. All test groups were listed as VE>LU>CE>SPC>VSC>FLP. When the CAD/CAM blocks were compared to the composites produced with a 3D printer, the surface hardness values were statistically higher. There was no significant difference between SPC-VSC and VSC-FLP test groups in pairwise comparisons between groups (p>0.0033).

DISCUSSION

In this study, mechanical characteristics such as flexural strength, modulus of elasticity, and surface hardness of composite resins produced by SM and AM technique for permanent restorations were investigated. The null hypothesis for this study that there would be no difference in the mechanical characteristics of composite resins produced by the SM and AM technique was rejected. Considering the data obtained from the study; additively produced composite resins (except group SPC) were found to be lower than those of subtractive according to flexural strength. The modulus of elasticity and surface hardness values have been observed that composite resins (VE, LU, CE) manufacturing with SM were significantly higher when compared to AM produced ones (SPC, FLP, VSC).

FLEXURAL STRENGTH

In this study, the flexural strength properties of permanent composite resin materials produced by SM and AM techniques were carried out in accordance with ISO 6872:2015 standards with a three-point bending test. The geometry of the specimens that need to be prepared for the three-point bending test is different for restorative composite resins[14] and ceramics.[13] Because of the size CAD/CAM blocks being limited, ceramic geometry was used for this study.

Flexural strength is defined as the ability to endure under load deformation when compressive stress and tensile stress are combined.[15,16] Flexural strength is one of the important

Table 2. Descriptive statistical values of test materials.

		Mean	Std. Deviation	Median	The Interquartile Range	Min.	Max.
Flexural strength (MPa)	VE	157.08	17.66	160.46	29.79	127.51	187.46
	LU	203.61	37.41	196.25	60.86	146.28	265.68
	CE	219.73	57.97	218.90	92.04	103.59	309.68
	SPC	217.15	25.42	210.68	42.08	184.23	272.15
	VSC	87.89	23.10	87.83	18.94	42.70	133.56
	FLP	127.49	16.18	125.48	26.75	98.65	154.00
Modulus of Elasticity (GPa)	VE	26.42	2.94	25.86	4.78	22.11	31.84
	LU	17.25	3.61	16.26	5.01	12.41	25.92
	CE	12.15	2.78	12.48	4.04	6.92	15.68
	SPC	8.33	0.93	8.21	1.23	6.86	10.06
	VSC	6.79	6.17	4.99	0.79	4.09	26.27
	FLP	6.28	0.56	6.32	0.67	5.19	7.23
Surface microhardness (VHN)	VE	256.22	17.31	252.50	21.50	229.67	291.33
	LU	121.70	16.30	116.50	31.17	106.13	150.33
	CE	81.19	10.56	79.43	14.28	62.67	97.67
	SPC	47.62	7.44	45.56	7.32	38.70	63.90
	VSC	45.78	14.45	40.33	19.13	29.00	77.93
	FLP	35.48	2.81	35.11	4.46	31.33	40.70

Table 3. The statistical comparison of mechanical properties values for the test specimens between groups.

Test groups	Flexural strength (MPa)	Modulus of Elasticity (GPa)	Surface microhardness (VHN)
VE	160.46 (29.79)	25.86 (4.78)	252.50 (21.5)
LU	196.25 (60.86)^{B,C}	16.26 (5.01)	116.50 (31.17)
CE	218,90 (92.04)^{A,B}	12.48 (4.04)	79.43 (14.28)
SPC	210.68 (42.08)^{A,C}	8.21 (1.23)	45.56 (7.32)^{a}
VSC	87.83 (18.94)	4.99 (0.79)*	40.33(19.13)^{a,b}
FLP	125.48 (26.75)	6.32 (0.67)*	35.11(4.46)^{b}
p values	<0.0033	<0.0033	<0.0033

The data were expressed as median (IQR). Each test has undergone statistical analysis on its own.
The same symbols and letters indicated as superscript in a column are not statistically significant (p>0.05).

properties in determining the mechanical characteristics of composite resin materials.[15] It has been determined that the flexural strength values of both CAD/CAM milling and 3D printing composite materials used in our study are in accordance with the ISO standard (ISO 6872:2015). Inlay, onlay and single unit anterior fixed restorations with all the test materials used in the study; except from VSC, single unit posterior fixed dental prostheses can be made. VSC may not be a suitable choice for posterior restorations due to its low flexural strength.

A monomer and a photo-initiator are the components of the liquid resin used in printing. When UV light activates the photo-initiator, it transforms the monomer into a polymer, creating bonded chains at the macromolecular level. However, due to the rapid mechanism of layer-by-layer formation, this process results in an insufficient cure density throughout each layer added. This ultimately minimizes the effectiveness of long chain crosslinking, lower double bond formation affects its mechanical properties.[17] On the other hand, in CAD/CAM milling blocks produced under high temperature and pressure, longer double bonds are formed, the distance between the molecules is reduced and a denser structure is obtained[18]. Thus, the amount of residual monomer is less with high monomer conversion.[16] In line with the results obtained from the study, the relatively lower mechanical properties of 3D printed resins compared to milling resins may be due to the presence of residual monomer. The relatively better mechanical properties of SPC than other 3D printing resins (FLP and VSC) can be explained by the different post-processing that strengthens their final polymerization.

The results obtained from our study can be associated with the chemical structure of the materials used. Different filler particles and their amounts also affect the final properties of the material.[19] According to the information given by the manufacturers, the particle size of VSC, SPC and FLP test materials is 0.7 µm and the amount of inorganic filler is 30-50% by weight. This filler ratio is lower than CAD/CAM milling composites. For the 3D printing process to continue with liquid fluidity and to prevent the material from settling to the bottom of the tank, it must have a relatively low filler content.[12]

Thin layers of composite resin were gradually cured until the desired shape was achieved to create test specimens using 3D printing. The final product's surface and mechanical qualities can be considerably impacted by the layers' thickness and orientation.[18] In this study, specimens were printed in 90° orientation. Thus, it was ensured that the applied force for the flexural strength test was parallel to the layers. The polymerization shrinkage was reduced by decreasing the layer thickness, which was chosen as 50 µm. However, this additive manufacturing process of specimens can create voids within or between successive layers. This results in a weaker mechanical structure. Kebler *et al.*,[20] reported that the bonds between the layers are the weakest bonds, which can be easily separated by shear forces. The reason for the lower flexural strength of the FLP and VSC experimental groups may be associated with this weak structure.

However, the fact that the flexural strength of the SPC showed as high values as the nanoceramic test specimens (CE and LU) produced by the SM technique can be attributed to its chemical composition. In addition, it can be explained by less voids between layers and higher adhesion compared to the other two 3D printing (FLP, VSC) groups. Furthermore, the flexural strength of the SPC showing higher values than the VE produced by the milling method can be attributed to the chemical composition of the material. VE test material, a porous ceramic network (86% by weight) structure, was infiltrated with polymeric resins using polymer-infiltered-ceramic network (PICN) technology.[15] Other research have found that a drawback of polymer-infiltrated ceramics is the comparatively low flexural strength of VE despite the high filler concentration.[12,15] The connection between the resin matrix and the ceramic skeleton is to responsibility for this. This may be more difficult to get the sintered porous ceramic matrix to adhere to the interface during resin infiltration.

SLA printers solidify the resin liquid layer-by-layer using a microlaser point. DLP printers perform liquid polymerization via a digital mirror device that controls the curing laser.[21] Park *et al.*,[22] investigated the flexural strengths of three-unit temporary fixed restorations produced by SLA and DLP techniques. They showed that these two groups did not significantly differ from one another. The SPC group showed the highest value for flexural strength (DLP technique). This group was followed by FLP (SLA technique) and VSC (DLP technique) groups, respectively. The reason for the high flexural strength of the SLA group may be related to the surface morphology of the printed object.[22] Fouda *et al.*,[18] investigated the mechanical properties of denture base materials produced by 3D printing and CAD/CAM milling. They reported that among the 3D printing test specimens, the highest values were in the specimens produced with DLP (ASIGA DentaBase), followed by SLA (FormLabs Prosthetic Base LP) and DLP (Prosthetic 3D+). They also stated that there was no significant difference in DLP and SLA techniques[18]. More studies are needed on permanent composite materials such as different print production techniques, layer thickness, print direction.

According to prior research, smooth-surfaced intraoral dental materials are linked to increased flexural strength[23,24] (Gad *et al.*, 2022; Dai *et al.*, 2022). One study found that polishing and other surface treatments had no effect on the groups tested's modulus of elasticity. These results can be explained by the fact that, as opposed to surface characteristics, the material composition and degree of transformation have a greater impact on the 3D-printed photosensitive resin's modulus of elasticity (Dai *et al.*, 2022). According to Chinelatti *et al.*,[25] polishing increased the hardness of the composite resins that were evaluated significantly (Chinelatti *et al.*, 2006). Given the aforementioned researches, it is reasonable to assume that polishing would have increased the flexural strength and hardness values of the specimens surfaces used in our analysis, while leaving the modulus of elasticity unaffected. Additional research is required to determine how various orientation directions and polishing techniques affect mechanical and surface qualities.

In the study of Grzebieluch *et al.*,[12] in which they compared the mechanical properties of CAD/CAM milling and 3D printing composite resins, they found the flexural strength values of the VSC group to be higher than our study. This may be due to the fact that the test specimens were subjected to thermalcycling in our study. Thermocycling can be applied under standard laboratory conditions as an artificial aging method consisting mainly of water immersion and temperature change for mimics intraoral conditions.[26] 5000 cycles were applied with 30 s dwell time at 5°C-55°C. These cycles applied correspond to 6 months of clinical use.[27,28]

Zimmermann *et al.*,[10] investigated the fracture load of composite resins produced by SM and AM technique using different material thicknesses. They found that 3D printed crowns withstand similar loads as other composites, regardless of occlusal thickness. But it would be incorrect to directly compare the current study to studies looking at the fracture load of fixed restorations made in the form of crowns or bridges.[10,11]

MODULUS OF ELASTICITY

A mechanical characteristic of a material connected to stiffness is the modulus of elasticity, which is the inclination of the stress-strain curve inside the proportional limit. The amount of deformation within the material is directly affected by an external load. A material used in the posterior area where masticatory loads are high must have sufficient modulus of elasticity.[1] In our study, the modulus of elasticity of the composite resins produced with 3D printer was significantly lower than those produced with CAD/CAM milling. The modulus of elasticity value of the LU test group was approximately similar or close to the modulus of elasticity (16-20 GPa) reported for natural dentine.[15] When the LU test material is evaluated in this respect, it will provide clinical benefit due to its biomimetic feature. The VE test group's modulus of elasticity was higher when compared to normal dentine, while the ELS, VSC and FLP's modulus of elasticity group were significantly lower.

MICROHARDNESS

The relative resistance of a material to an external indentation force is known as surface hardness.[15,29] In this study, the surface hardness of the specimens was determined using the Vickers hardness test. This test is an easy-to-use procedure that may be performed to determine the hardness of a wide variety of materials. One of the important advantages is that the indentation shape stays the same when applied to various loads or various tested materials. On the other hand, the surface area is determined microscopically by the operator with the naked eye. Therefore, the hardness assessment of materials is subjective.[9]

The hardness values of the test groups are listed as VE>LU>CE>SPC>VSC>FLP. Considering the results of our study, composites produced with 3D printing may be wear more than milling. The highest value that can be explained due to the ceramic structure was found in the VE group. According to the surface hardness values obtained from present study, the PICN block (VE) has higher wear resistance than the composite nanoceramic blocks (CE and LU). Goujat *et al.*,[30] evaluated the hardness values of four different CAD/CAM milling composite materials. Ranking of hardness values between groups (VE>LU>CE) was similar between our study and the study of Goujat *et al.*[30] However, the hardness values of the test materials in our study were higher than their study. The reason for this that may be related to the application time of force. While 20 seconds were applied in their studies, 10 seconds were applied in our study.

Additionally, a material's wear may be connected to its hardness. Lower hardness materials could be more prone to wear. The low hardness and modulus of elasticity for prefabricated CAD/CAM blocks indicates that they are susceptibility to milling.[30,31] Based on this information with the data obtained from our study, it can be deduced that CE produced by the SM technique can be milled more easily, whereas VE can be milled more difficult.

One of the limitations of this study is that all test specimens were subjected to thermal cycling. Therefore, a comparison with the group that did not apply thermal cycling could not be made. The effect of the thermal cycling process on the evaluated parameters of the test specimens could not be investigated either. Another limitation is that the specimens used in this study have bar geometry and are different from those used in clinical settings. Therefore, further studies are required by producing crown- or bridge-shaped specimens simulating different clinical scenarios.

CONCLUSIONS

Within the limitations of this study,

1. Both CAD/CAM milling (VE, LU and, CE) and 3D printing (SPC, FLP, VSC) composite materials are acceptable for inlay, onlay and single unit fixed restorations according to ISO 6872:2015 standards. However, the flexural strength values of the test specimens do not meet the ISO criteria for fixed partial dentures. Also, VSC may not be a suitable choice for posterior restorations due to its low flexural strength.
2. The modulus of elasticity value of the LU test group was very similar to dentine. The LU test material may provide clinical benefit due to this biomimetic feature.
3. VE test group showed the highest hardness value and wear resistance can be expected to be higher than other test specimens.

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