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Effects of Different Storage Conditions on Mechanical Properties of CAD/CAM Restorative Materials

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Efecto de diferentes condiciones de almacenamiento en las propiedades mecánicas de materiales restauradores CAD/CAM

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ABSTRACT: The aim of this study was to evaluate mechanical properties of six new-generation all-ceramic materials for CAD/CAM (Lava Ultimate [LU], VITA Mark II [VM], InCoris TZI [IC], IPS e.max CAD [EM], VITA Suprinity [VS], IPS Empress CAD [EC]) and two different provisional restoration CAD/CAM materials (Telio CAD [TC], Vita CAD-Temp [VC]) after different storage conditions. 36 bar-shaped samples of 4 mm in width and 14 mm in length with 1.2 mm thicknesses were prepared from each material group (N=288). The specimens from each material were kept under three different storage conditions (n=12): under dry conditions at room temperature; 37°C distilled water for 7 days; and 37°C distilled water for 7 days followed by 10,000 thermal cycles. All specimens were subjected to a 3-point flexural test with a crosshead speed of 1.0 mm/min. The specimens were loaded until failure. Twelve fractured specimens after the flexural test from each group were used for the Vickers hardness test (under 300 gf of loading in 15 seconds). The flexural modulus, flexural strength and Vickers hardness values were separately analyzed with two-way analysis of variance, Tukey's multiple comparison tests at a significance level of $p < 0.05$. There were statistically significant differences between materials and storage conditions according to flexural modulus, flexural strength and Vickers hardness values ($p < 0.05$). The flexural strength, flexural modulus and Vickers hardness values of LU, VC, TC, VS and IC decreased after water storage followed by thermal cycling ($p < 0.05$). The mechanical properties of provisional restoration CAD/CAM materials had showed a significantly decrease after water storage followed by thermal cycles but their mechanical properties were acceptable for fabrication of provisional restorations. The mechanical properties of VM, EC and EM were not affected by different storage conditions whereas IC and VS were affected.

KEYWORDS: CAD-CAM; Flexural strength; Hardness.

RESUMEN: El objetivo de este estudio fue evaluar las propiedades mecánicas de seis materiales totalmente cerámicos de nueva generación para CAD/CAM (Lava Ultimate [LU], VITA Mark II [VM], InCoris TZI [IC], IPS e.max CAD [EM], VITA Suprinity [VS], IPS Empress CAD [EC]) y dos materiales CAD/CAM de restauración provisional diferentes (Telio CAD [TC], Vita CAD-Temp [VC]) después de diferentes condiciones de almacenamiento. Se prepararon 36 muestras en forma de barra de 4mm de ancho y 14mm de largo con 1.2mm de grosor a partir de cada grupo de materiales (N=288). Las muestras de cada material se mantuvieron bajo tres condiciones de almacenamiento diferentes (n=12): en condiciones secas a temperatura ambiente; 37°C de agua destilada durante 7 días; y agua destilada a 37°C durante 7 días seguidos de 10.000 termociclado. Todas las muestras se sometieron a una prueba de flexión de 3 puntos con una velocidad de cruceta de 1.0mm/min. Los especímenes fueron cargados hasta el fracaso. Doce muestras fracturadas después de la prueba de flexión de cada grupo se utilizaron para la prueba de dureza Vickers (menos de 300 gf de carga en 15 segundos). Los valores del módulo de flexión, la resistencia a la flexión y la dureza de Vickers se analizaron por separado con análisis de varianza de dos vías, las pruebas de comparación múltiple de Tukey a un nivel significativo de $p < 0.05$. Hubo diferencias estadísticamente significativas entre los materiales y las condiciones de almacenamiento según el módulo de flexión, la resistencia a la flexión y los valores de dureza Vickers ($p < 0.05$). La resistencia a la flexión, el módulo de flexión y los valores de dureza Vickers de LU, VC, TC, VS e IC disminuyeron después del almacenamiento de agua seguido de ciclos térmicos ($p < 0.05$). Las propiedades mecánicas de la restauración provisional Los materiales CAD/CAM mostraron una disminución significativa después del almacenamiento de agua seguido de ciclos térmicos, pero sus propiedades mecánicas fueron aceptables para la fabricación de restauraciones provisionales. Las propiedades mecánicas de VM, EC y EM no se vieron afectadas por las diferentes condiciones de almacenamiento, mientras que IC y VS se vieron afectadas.

PALABRAS CLAVE: CAD-CAM; Resistencia a la flexión; Dureza.

INTRODUCTION

With the possibility of using high quality CAD/CAM fabricated materials, dentists and laboratories can produce more durable and aesthetic restorations (1,2). Types of CAD/CAM materials used today are mainly ceramic materials, composite resins, metal alloys and PMMA's. CAD/CAM ceramic materials are feldspathic ceramics, glass ceramics containing leucite and lithium disilicate or yttrium tetragonal zirconia polycrystals. In addition to these materials, nano-hybrid ceramics

and zirconia-reinforced lithium silicate ceramics have been recently introduced (3).

Glass-matrix ceramics are well known for their superior aesthetic properties, biocompatibility, color stability and durability but on the other hand, they have significant disadvantages such as vulnerability to fracture, brittleness and causing unwanted abrasion on the teeth they occlude (4-6). Feldspatic ceramics (Vitablocks Mark II) - a traditional glass-matrix ceramic- are comprised of homogenously distributed 30% fine-grained

feldspar particles in a 3-4 μm particle sized glass matrix. Reinforcement with 35-45% of 1-5 μm (IPS Empress CAD (Ivoclar Vivadent, Liechtenstein) sized leucite particles has let glass ceramic systems achieve better overall flexural and fracture strength values. Despite having similar mechanical properties, fluorescence, light transmission and color characteristics with the natural teeth, leucite reinforced glass ceramics have certain contraindications such as fixed partial dentures (FPDs). On the other hand, excellent outcomes were achieved with laminate veneers, inlays, onlays and crowns (4,7,8). IPS e.max CAD (Ivoclar Vivadent, Liechtenstein) is a lithium-disilicate CAD/CAM material with greater flexural strength (360 MPa) than that of glass-matrix ceramics (4,7).

Most recently, nano-particulate pre-polymerized resin composite restorative material with marketing named as resin nanoceramic (LAVA Ultimate) was introduced by 3M ESPE. This material is claimed to provide composite-like ease of handling and flexibility and porcelain-like surface gloss. Lava Ultimate is made of dispersed or aggregated zirconia-silica nanoparticles (80 wt %) and highly cross-linked polymer (urethane dimethacrylate (UDMA)) as the matrix. The manufacturer claims that the fracture toughness of the nano ceramic material is significantly greater than both feldspathic porcelain and composite materials and also less brittle than feldspathic ceramics (3,9-11). Previous studies commonly claimed that combining ceramic and polymer phases as a pre-polymerized CAD/CAM block granted these materials stability, flexural strength, elasticity and hardness values similar to natural tooth structure (11-13).

In recent years, CAD/CAM zirconia blocks containing yttria stabilized tetragonal zirconia polycrystalline (Y-TZP) were introduced for monobloc zirconia restorations. Monolithic zirconia restorations are used to overcome certain

limitations of ceramic layering over zirconia structures such as chipping in the ceramic layer. By employing yttrium, a stabilizer, it is aimed to stabilize the process of phase transformation, which is specific to pure zirconia during temperature changes. Additionally, one of the most important objectives of Y-TZP used in monobloc zirconia restorations is to obtain high translucency. However, the microstructural properties of this material and the lack of glass matrix lead to lower translucency and aesthetic deficiencies than glass ceramic restorations (10).

Zirconia-reinforced lithium silicate ceramic (ZLS) was conceived by strengthening materials' glass ceramic, (containing fine lithium metasilicate and lithium disilicate crystals: average size: 0.5 - 0.7 μm), with about 10% zirconium dioxide particles by weight. This recently developed ceramic material is advantageous because of its smaller particle size and more homogeneous microstructure. The most important feature that distinguishes this material from other glass ceramic materials is its greater mechanical resistance. Although ZLS is a more recent material, it shows similar results with clinically well-proven lithium disilicate glass ceramics (IPS e.max CAD) (11,14, 15).

CAD/CAM technology is also used to fabricate provisional prosthesis for several years now. CAD/CAM fabricated provisional restoration materials are polymerized at high temperature and optimized pressure under controlled and standardized industrial conditions which can be processed more rapidly and at a lower cost (16,17). This process eliminates the risk of having polymerization shrinkage as in conventional self-cure and visible light-cure resin-based materials. As examples, Vita CAD Temp (VITA) is a highly cross-linked, micro-filled polymer (%14 of micro SiO_2 particles as filler) referred by Vita as MRP (Microfilled Reinforced Polyacrylate) material

(18,19). Telio CAD (Ivoclar Vivadent) is a millable cross linked polymethylmethacrylate (PMMA) material (99.5%) (19,20).

The fracture resistance of these materials under mastication forces depends on their mechanical properties (21). It is important to understand the mechanical properties of the material to estimate the overall behavior under use (22). There are many studies that investigate the mechanical properties and chemical structure of recently developed CAD/CAM materials (3,5,9,11,23,24). However, there are limited numbers of studies that investigate the mechanical properties of CAD/CAM-fabricated provisional materials (25-27).

The most common laboratory tests that are used for characterization of the mechanical stability of dental materials are; flexural strength test and surface hardness test (28,29). However, it should be kept in mind that these restorative materials could be affected by certain conditions such as, occlusion and other intraoral functional forces (6,30).

These tests can also be performed under dry conditions and in humid environments after prolonged storage or after thermal cycling. Furthermore, there is a lack of sufficient data regarding the effect of prolonged usage on materials properties (10,11). Frequent change in the oral cavity temperature can cause restorative materials to either expand or contract, which is all together lead to increasing mechanical stress and fractures that spread rapidly within the material. In the literature, there are many parameters used for aging procedures (22,23,27,31). However, there is no standard bath temperature or number of cycles for thermal cycling procedures (9). Possible reasons for failures in restorations can be; clinician's lack of experience in using the correct indication of the new material, patient related factors such as excessive mastication force and destructive oral habits like bruxism or material related factors such

as the composition of the material which directly affects the long-term survival. Therefore, the aim of this study was to investigate mechanical properties (Vickers hardness and three-point bending tests) of eight different CAD/CAM materials after different storage conditions. The null hypothesis set is that different material types and storage conditions (dry conditions at room temperature, 37°C distilled water for a week and 37°C distilled water for a week followed by 10,000 thermal cycles) have no effect on the flexural strength, flexural modulus and Vickers hardness values of different CAD/CAM materials.

MATERIALS AND METHODS

Six CAD/CAM all ceramic materials (Lava Ultimate [LU], VITA Mark II [VM], IPS e.max CAD [EM], VITA Suprinity [VS], IPS Empress CAD [EC], InCoris TZI [IC]) and two CAD/CAM provisional restoration materials (VITA CAD-Temp [VC] and Telio CAD [TC]) were tested in this study and listed in Table 1.

THREE-POINT BENDING TEST

CAD/CAM blocs were cut using a low-speed water-cooled diamond saw (Mecatome T180, Presi, Grenoble, France) in order to obtain 36 bar-shaped samples with dimensions of 4 mm in width, 14 mm in length and 1.2 mm thicknesses for each material group for three-point bending test (TPBT). A total of 288 specimens were produced in accordance with guidelines of ISO 6872:2015 (32). Monoblock zirconia (IC) group samples were prepared 20% larger in dimension to compensate for the ~20% zirconia sintering shrinkage. EM, VS and IC discs were sintered according to the manufacturer's recommendation. The specimens were polished with P600, P1200, and P2000 silicon carbide sheets (Abramin; Struers). The final specimen dimensions were adjusted ($4.0\pm 0.05\times 14.0\pm 0.05\times 1.2\pm 0.05$ mm) and were confirmed with a digital caliper. After all specimens were polished, thirty six specimens

of each groups were randomly divided into three subgroups (n=12): the first group of blocks were kept under dry conditions at room temperature ($23\pm 2^{\circ}\text{C}$), the second group of blocks were kept in 37°C distilled water for a week and the third group of blocks were kept in 37°C distilled water for a week followed by 10,000 thermal cycles ($5-55^{\circ}\text{C}$, dwelling time 30 s) using a thermocycling machine (Thermocycler; SD Mechatronics). Each specimen was placed on a 12.0 mm spaced metal fixture and centered under the loading cell. A universal testing machine (Shimadzu AG-50 kNG, Kyoto, Japan) was used for the TPBT with crosshead speed of 0.5 mm/minute. The specimens were loaded until failure. The software (TRAPEZIUM X, Shimadzu Corp, Kyoto, Japan) recorded the maximum load (N) and maximum extension (mm). The following formula was used for flexural modulus (E) calculations in GPa.

$$E=FL^3/4bh^3d$$

On graph, L is the span distance (12.0 mm), b is the width of the specimen at the failure site, h is the thickness of the specimen at the failure site, and d is the deflection at the load F . The flexural strength (σ) was calculated in MPa by using the following formula:

$$\sigma=3F_1L/2bh^2$$

Where F_1 is the maximum load during the flexural test.

VICKERS HARDNESS TEST

Following flexural strength test, twelve fractured specimens were taken into Vickers hardness test. In order not to compromise the hardness evaluation, measurements were undertaken in areas far from the fracture line. Vickers hardness values were measured using the micro hardness testing machine (Shimadzu Micro Hardness Tester HMV-2, Shimadzu Corporation, Tokyo, Japan) under 300

gf of loading in 15 seconds. Five indentations were made on each specimen and the Vickers hardness values were averaged.

STATISTICAL ANALYSIS

The statistical analyses were performed with SPSS for Windows (22.0, SPSS Inc., Chicago, IL, USA). The suitability of the variables to normal distribution was evaluated by Shapiro Wilk test and homogeneity was evaluated by Levene test. It was decided to apply parametric method for both tests considering $p>0.05$ values. The flexural modulus, flexural strength and Vickers hardness values were analyzed separated by using two-way analysis of variance (two-way ANOVA). Material type and storage condition were the main comparison factors and this procedure was followed by Turkey's post-hoc multiple comparisons and $p<0.05$ was considered as significant.

RESULTS

Two-way ANOVA revealed that the material type, storage condition and their interactions were statistically significant for flexural modulus ($p<0.05$), flexural strength ($p<0.05$) and VH ($p<0.05$) (Table 2). The mean results of all test methods (flexural modulus, flexural strength and VH) are presented in Table 3.

FLEXURAL STRENGTH

The flexural strength of VM, EM and EC groups did not change after all storage conditions ($p>0.05$), however LU and VC groups showed significant decrease after all storage conditions ($p<0.05$). The flexural strength of TC, VS and IC groups significantly decreased after water storage followed by thermal cycling when compared to dry storage and water storage ($p<0.05$). IC group showed significantly higher flexural strength compared to the other material groups whereas VC showed the lowest values ($p<0.05$). There was no

statistically significant difference between the LU and EC groups and also between TC and VM groups at the all storage conditions ($p>0.05$) (Table 3).

FLEXURAL MODULUS

The flexural modulus of VM, EM and EC groups did not change after different storage conditions ($p>0.05$), however LU, VC and TC groups showed statistically significant decrease after different storage conditions ($p<0.05$). Flexural modulus of VS and IC groups significantly decreased after water storage followed by thermal cycling when compared to dry storage and water storage ($p<0.05$). IC group showed significantly higher flexural modulus values than the other groups while VC and TC groups showed significantly lower flexural modulus values ($p<0.05$) after all storage conditions. There was no statistically significant difference between the VM and EC and

also between VC and TC groups at the all storage conditions ($p>0.05$) (Table 3).

VICKERS HARDNESS

The Vickers hardness values of VM, EM and EC groups did not show any significant differences under different storage conditions ($p>0.05$), however LU and VC groups showed significant decrease after all storage conditions ($p<0.05$). The Vickers hardness values of TC group showed significantly decrease after water storage and water storage followed by thermal cycling compared to dry condition ($p<0.05$). The Vickers hardness values of VS and IC groups significantly decreased after water storage followed by thermal cycling when compared to dry storage and water storage ($p<0.05$). IC group had significantly higher Vickers hardness values compared to other material groups whereas VC and TC had the lowest values ($p<0.05$) (Table 3).

Table 1. The brand names, material types, abbreviations, compositions and manufacturers of the materials used in the study.

Test Material	Material type	Abbreviation	Composition	Manufacturer
Lava Ultimate	Resin nano ceramic	LU	Matrix: Bis-GMA, UDMA, Bis-EMA, TEGDMA Filler SiO ₂ , ZrO ₂ , aggregated ZrO ₂ / SiO ₂ cluster (80wt%)	3M ESPE, Seefeld, Germany
VITA CAD-Temp	Acrylate polymer	VC	Acrylic polymer with 14% microfiller (SiO ₂) MRP=microfilled reinforced polyacrylate	Vita Zahnfabrik, Bad Säckingen, Germany
Telio CAD	PMMA	TC	99.5% PMMA, pigments<1.0%	Ivoclar Vivadent, Schaan, Liechtenstein
VITA Mark II	Feldspar ceramic	VM	56-64% SiO ₂ , 20-23% Al ₂ O ₃ , 6-9% Na ₂ O, 6-8% K ₂ O, 0.3-0.6% CaO, 0-0.1% TiO ₂	VITA Zahnfabrik, Bad Säckingen, Germany
IPS e.max CAD	Lithium disilicate glass-ceramic	EM	57-80% SiO ₂ , 11-19% Li ₂ O, 0-13% K ₂ O, 0-11% P ₂ O ₅ , 0-8% ZrO ₂ , 0-8% ZnO, 0-5% Al ₂ O ₃ , 0-5% MgO, 0-8% Colouring oxides	Ivoclar Vivadent, Schaan, Liechtenstein
VITA Suprinity	Zirconia-reinforced lithium silicate ceramic	VS	56-64% SiO ₂ , 15-21% Li ₂ O, 8-12% ZrO ₂ , 3-8% P ₂ O ₅ , 1-4% K ₂ O, 0-4% CeO ₂	Vita Zahnfabrik H. Rauter GmbH, Bad Säckingen, Germany
IPS Empress CAD	Leucite-based glass ceramic	EC	60-65% SiO ₂ , 16-20% Al ₂ O ₃ , 10-14% K ₂ O, 3.5-6.5% Na ₂ O, 0.5-7% Other oxides, 0.2-1% Pigments	Ivoclar Vivadent, Schaan, Liechtenstein
InCoris TZI	Monoblock zirconia	IC	ZrO ₂ +HfO ₂ +Y ₂ O ₃ ≥99.0%, Y ₂ O ₃ > 4.5 - ≤ 6.0%, HfO ₂ ≤ 5% Al ₂ O ₃ ≤ 0.5%, Other oxides ≤ 0.5%	Sirona Dental Systems GmbH, Bensheim, Germany

Abbreviations: Bis-GMA: bisphenol A-glycidyl methacrylate; UDMA: urethane dimethacrylate; Bis-EMA: ethoxylated bisphenol A-glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; SiO₂: silicon dioxide; ZrO₂: zirconium dioxide; PMMA: Polymethyl methacrylate; Al₂O₃: aluminium oxide; Na₂O: sodium oxide; K₂O: potassium oxide; CaO: calcium oxide; TiO₂: titanium dioxide; HfO₂: hafnium dioxide, Y₂O₃:yttrium Oxide; MgO: magnesium oxide; Li₂O: lithium oxide; P₂O₅: phosphorus pentoxide, ZnO: zinc oxide; CeO₂: cerium oxide.

Table 2. Results of two-way ANOVA.

Test method	Source	Sum of squares	df	Mean square	F	Sig
Flexural strength	Material type	1.691E7	7	2415978.948	7.077E3	.000
	Storage conditions	36663.862	2	18331.931	53.696	.000
	Material type*Storage conditions	88258.063	14	6304.147	18.465	.000
Flexural modulus	Material type	180310.119	7	25758.588	4.098E3	.000
	Storage conditions	332.365	2	166.182	26.440	.000
	Material type*Storage conditions	414.740	14	29.624	4.713	.000
Vickers hardness	Material type	5.395E7	7	7706989.570	1.408E4	.000
	Storage conditions	22090.205	2	11045.102	20.182	.000
	Material type*Storage conditions	28518.673	14	2037.048	3.722	.000

Table 3. Mean and SD values for TPBT and Vickers hardness test.

Test method	Condition	LU	VC	TC	VM	EM	VS	EC	IC
Flexural strength (MPa)	Dry	174.57±4.42 ^{Aa}	86.93±2.80 ^{Ba}	125.43±5.25 ^{ca}	128.87±5.41 ^{ca}	376.99±6.24 ^{Da}	302.39±5.22 ^{Ea}	154.62±6.66 ^{Aa}	992.27±50.30 ^{ia}
	Water	163.44±4.15 ^{Ab}	82.68±2.28 ^{Bb}	121.99±3.02 ^{ca}	127.30±3.40 ^{ca}	375.88±6.66 ^{Da}	298.06±4.99 ^{Ea}	153.79±6.56 ^{Aa}	961.94±59.36 ^{ia}
	Water/TC	150.79±6.94 ^{Ac}	77.98±5.98 ^{Bc}	95.51±10.81 ^{cb}	126.71±3.21 ^{Da}	372.12±4.56 ^{Ea}	279.93±7.79 ^{fb}	152.69±2.78 ^{Aa}	848.69±35.78 ^{Gb}
Flexural modulus (GPa)	Dry	10.75±0.21 ^{Aa}	2.60±0.15 ^{Ba}	3.54±0.18 ^{Ba}	38.15±1.77 ^{ca}	53.79±3.06 ^{Da}	62.89±1.78 ^{Ea}	38.87±1.90 ^{ca}	88.96±5.45 ^{fa}
	Water	10.01±0.43 ^{Ab}	2.48±0.13 ^{Bb}	3.29±0.15 ^{Bb}	37.88±1.05 ^{ca}	52.27±1.70 ^{Da}	61.46±2.31 ^{Ea}	37.52±1.01 ^{ca}	84.12±3.99 ^{fa}
	Water/TC	9.14±0.43 ^{Ac}	2.35±0.10 ^{Bc}	3.05±0.22 ^{Bc}	36.83±1.08 ^{ca}	51.11±2.48 ^{Da}	59.00±3.01 ^{Eb}	37.17±1.61 ^{ca}	78.42±3.88 ^{fb}
Vickers hardness	Dry	102.83±1.81 ^{Aa}	25.21±0.82 ^{Ba}	22.04±2.37 ^{Ba}	647.00±12.95 ^{ca}	602.79±6.38 ^{Da}	819.56±7.88 ^{Ea}	610.16±4.55 ^{Da}	1549.56±33.29 ^{fa}
	Water	99.82±1.87 ^{Ab}	23.40±0.57 ^{Bb}	19.52±1.01 ^{Bb}	644.82±9.71 ^{ca}	599.72±6.52 ^{Da}	806.14±8.41 ^{Ea}	609.06±3.01 ^{Da}	1544.80±70.93 ^{fa}
	Water/TC	88.20±1.77 ^{Ac}	21.36±0.59 ^{Bc}	17.54±0.92 ^{ab}	642.56±7.42 ^{ca}	598.64±4.13 ^{Da}	747.88±22.53 ^{Eb}	607.32±3.28 ^{Da}	1437.38±76.99 ^{fb}

*Lower case superscripts correspond the same column, capital superscripts correspond the same line., same letters represent no statistical differences.

*Significantly different at p <0.05

DISCUSSION

Laboratory settings should mimic the intraoral conditions to assess the clinical performance of dental materials. For this purpose, materials are exposed to various aging methods in dental research. The thermal cycling process is one of these methods, which imitates the intraoral conditions, as the samples are exposed to a humid environment facing temperature changes (3,31). This process affects the chemical, mechanical and physical properties of restorative materials due to the hydrolysis of the components caused by water absorption and the expansion-shrinkage caused by the hot-cold passages (33,34). In order to investigate the effects of different storage conditions on the mechanical properties of CAD/CAM materials, the first group of samples were kept in dry conditions, the second group was stored in 37°C distilled water for a week and the third group was stored in 37°C distilled water for a week followed by 10,000 thermal cycles. According to the current outcomes, different material type and storage conditions affected the flexural strength and hardness of CAD/CAM-fabricated provisional restoration materials. Therefore, the null hypothesis of the study was rejected.

In this study, TPBT was applied to the all samples to evaluate the flexural strength and flexural modulus. Similar to the results of the current study, there are some studies that indicate that thermal cycling aging reduces the flexural strength of LU, VC and TC materials (3,11,27,35). Water storage softens the polymers by causing water penetration into the resin matrix of the composite resin blocks (36). For provisional restoration materials, this reduction can be explained by the penetration of water into the gaps between the polymer chains and by separating them from each other. Flinn *et al.* (23) reported that aging reduced flexural strength of monolithic zirconium materials because of zirconia is more prone to aging in presence of water. The authors

think that residual stresses, chemical composition and cubic phase in the microstructure of zirconia causes a transformation from tetragonal phase to monoclinic phase. The neighboring grains of the transformation site go through a volume increase which results in microcrack formation. These microcracks create suitable sites for water to channel into the ceramic (37). In accordance with their results, the flexural strength of IC, which is a monolithic zirconia decreased after thermal cycling in the current study. In addition, zirconia-reinforced lithium silicate ceramic material (VS) showed lower flexural strength after thermal cycling when compared to dry condition and water storage. However, similar with the results of the current study, Lauvahutanon *et al.* (3) found that the flexural strength of VM material was not affected by different storage conditions because their ceramic network structure did not absorb water.

According to the TPBT results, the obtained ranking for materials' flexural strength from highest to lowest was as follows: IC, EM, VS, LU, EC, VM, TC and VC at different storage conditions. There were no significant differences between EC and LU and also between VM and TC after all storage conditions. Stawarczyk *et al.* (38) reported that resin nano ceramic has lower flexural strength than lithium disilicate ceramic, similar with the current study. Sonmez *et al.* (11) reported that there was no significant difference between VM and EC before and after thermal cycling. On the contrary, in the current study the flexural strength of EC (leucite-based ceramic) and LU (resin nano ceramic) showed higher flexural strength values than VM (feldspar ceramic) at different storage conditions. Qin *et al.* (39) stated that VM does not have a regular crystal structure (XRD analysis) and therefore its flexural strength was low. Thornton *et al.* (35) reported that resin-containing materials have higher flexural strength so they could endure the masticatory forces better. In the current study, it was observed that flexural strength of LU material was higher than VM, but not different than EC.

Among the provisional restoration materials, the flexural strength of TC was higher than VC after different storage conditions. Yao *et al.* (27) reported that the flexural strength of TC was higher than VC before and after thermal cycling which is similar to the current study results. TC blocks consist of 99.5% cross-linked PMMA and has high strength. TC is a prefabricated monomethacrylate based PMMA, which consists of long chain, linear molecules with minimal intermolecular crosslinking and has high strength. On the other hand, VC is an acrylate polymer that contains vinyl groups, which consists of two, double bonded carbon atom attached to its carbonyl group. Acrylates easily form polymers due to their double bonded structures and their highly reactive nature which enables them to exhibit lower strength during polymerization (27). According to ISO for polymer-based crown and bridges materials flexural strength should be at least 50 MPa (40). According the results of the current study the flexural strength of CAD/CAM provisional restoration materials is high enough.

According to the results of the current study, the flexural modulus of LU, VC and TC materials significantly decreased after water storage and water storage followed by thermal cycling. However, Blackburn *et al.* (9) revealed that the flexural modulus of VM and LU materials were not affected by either 5,000 or 10,000 thermal cycles. Similar to this study, flexural modulus of VM was not affected by the thermal cycles, but flexural modulus of LU was affected. Lauvahutanon *et al.* (3) reported that the flexural modulus of the LU material decreased after the thermal cycling, but the flexural modulus of VM increased after 7 days of deionized water immersion. In the current study, flexural modulus of IC and VS decreased after water storage followed by thermal cycling when compared to dry condition and water storage. This result may be an outcome of water absorption in zirconia materials mentioned before (23).

Awada *et al.* (5) found that the flexural modulus of EC was lower than VM and LU material. In the current study, the flexural modulus of LU material was lower than all materials except provisional CAD/CAM materials. The low modulus of LU material is due to the continuous phase of the polymer (41). IC material showed the highest flexural modulus followed by VS material. Similar with the results of the current study, Belli *et al.* (41) found that zirconia ceramic showed the highest Young's modulus followed by VS, EM, VM, EC and LU, respectively. The percentage of zirconium oxide in the structure increases the mechanical properties of these materials (30).

According to the results of the current study, Vickers hardness values of LU, VC and TC materials significantly decreased after water storage and water storage followed by thermal cycling. Lauvahutanon *et al.* (3) and Sönmez *et al.* (11) reported that, the hardness value of LU decreased after the aging process, which is similar to the current study findings. This material contains a resin matrix and it absorbs water after aging with the thermal cycle. By this way the Vickers hardness decreases. The water absorption of PMMA and acrylic polymer may be a possible explanation for the reduction in hardness after different storage conditions of provisional restoration materials (42). Vickers hardness values of VS and IC materials were significantly affected after the water storage followed by thermal cycling. Ageing of zirconia can have effects on its mechanical properties (43). However, the VH values of other ceramic materials did not change. This may be due to the high inorganic content of these ceramic materials.

According to the results of the current study, it was found that IC showed the highest hardness value while provisional restoration materials VC and TC showed the lowest hardness values. The highest hardness value of the IC material

can be explained by the zirconia content of the material. The lowest hardness value of provisional restoration materials could be explained by their acrylic content. The hardness value of zirconia-reinforced lithium silicate ceramic material VS is lower than IC. This difference can be explained by VS does not contain crystalline zirconia, only contain zirconia powder same as many composite resins (41). Sonmez *et al.* (11) reported that LU showed the lowest hardness value among the all ceramic materials which is similar to this current study result. The LU material has a lower hardness value than the ceramics as a consequence of resin content and, its hardness decrease after storage conditions because it shows water absorption (3). The reason for the high hardness of ceramic materials compared to the LU material may be due to their high inorganic content (44). Sonmez *et al.* (11) reported that the hardness of VM and EC is higher than IPS e.max CAD and they revealed that the hardness of these materials was not affected by thermal cycling. In the current study, hardness of VM material was higher than EM and EC materials and different storage conditions did not affect the VH values of VM, EM and EC materials. This may be due to the fact that the differences between the crystal structures of the materials. Previous studies have indicated that the chemical content and the crystal structure of the materials affect the hardness value (11,45).

Performing this current study under in vitro conditions was one of the limitations, but the results still provide guidance for clinicians. Clinicians should be careful when choosing LU, VS and IC in long-term restorations. While provisional CAD/CAM materials can be considered mechanically safe. Restorative materials do not age within the mouth due to thermal effects only, chemical and mechanical effects also cause aging.

Further new studies are needed to investigate the mechanical and chemical effects acting in the oral environment as well as their color stability and marginal adaptation. Clinical studies are needed to confirm in vitro studies.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions were drawn:

The flexural strength, flexural modulus and Vickers hardness of LU, VC, TC, VS and IC decreased after water storage followed by thermal cycling.

The mechanical properties of VM, EC and EM, which are glass ceramic CAD/CAM materials were not affected by different storage conditions.

IC showed the highest flexural strength, flexural modulus and Vickers hardness values compared to other materials whereas VC showed the lowest values.

The mechanical properties of provisional restoration CAD/CAM materials showed significantly decrease after water storage followed by thermal cycles, but their mechanical properties were acceptable for fabrication of provisional restorations.

DISCLOSURE STATEMENT

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