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RESEARCH AND EDUCATION

Mechanical and optical properties of monolithic CAD-CAM restorative materials

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ABSTRACT

Statement of problem. Achieving natural tooth appearance with sufficient mechanical strength is one of the most challenging issues of computer-assisted design and computer-assisted manufacturing (CAD-CAM) materials. However, limited evidence is available regarding their optical and mechanical properties for proper and evidence-based material selection in clinical practice.

Purpose. The purpose of this in vitro study was to assess and compare the translucency and biaxial flexural strength of 5 monolithic CAD-CAM restorative materials.

Material and methods. Disk-shaped specimens (n=30) of each material (Lava Ultimate [LU], Vita Enamic [VE], Vitablocs Mark II [VMII], Vita Suprinity [VS], and IPS e.max CAD [IPS]) with a diameter of 12 mm and a thickness of 1.2 ±0.05 mm were prepared. A spectrophotometer was used to measure the translucency parameter. The specimens were then subjected to a biaxial flexure test using 3 balls and loaded with a piston in a universal testing machine at a cross-head speed of 0.5 mm/min until failure occurred (International Organization for Standardization standard 6872). Weibull statistics were used to evaluate the characteristic strength and reliability of each material. Chemical compositions were analyzed using an energy dispersive spectrometer, and microstructural analysis was conducted using scanning electron microscopy. Data were analyzed using 1-way ANOVA and the Tukey honest significant difference test (α=.05).

Results. Significant differences were found among the materials concerning translucency and biaxial flexural strength (P<.05). The highest mean transparency value was obtained in the VS group, whereas the lowest mean value was obtained in the VE group. The VS group produced the highest mean biaxial flexural strength, followed by the IPS, LU, VE, and VMII groups.

Conclusions. Based on the results of the present study, zirconia-reinforced glass-ceramic revealed higher mean translucency and biaxial flexural strength than resin nanoceramic, feldspathic ceramic, lithium disilicate ceramic, and dual-network ceramic. (J Prosthet Dent 2018;119:593-9)

Dental computer-assisted design and computer-assisted manufacturing (CAD-CAM) technology is widely used, as it reduces the number of clinical appointments and manufacturing time needed to produce esthetic ceramic restorations. Clinicians choose ceramic restorations because their chemical stability, esthetics, and biocompatibility are preferable to those of conventional metal-ceramic restorations.[1-3] However, conventional glass-ceramics are inherently brittle, and fractures limit their clinical applications, especially in the posterior region.[4] With the expanding use of dental CAD-CAM systems, ceramics with different compositions have been introduced to solve this problem and satisfy patient demand for natural-looking restorations.

The fabrication of restorations from new materials, such as resin nanoceramic and dual-network ceramic, have shifted to CAD-CAM, which does not require multiple firing. The manufacturers of these materials claim to combine the advantages of both ceramics and composite resins in the same material.[5,6] Indications of the materials include anterior and posterior crowns, veneers, inlays, and onlays. The blocks have several advantages over machinable feldspathic ceramics, including faster milling, increased fracture resistance, and milling damage tolerance. Additionally, restorations can be easily polished and adjusted in a single dental office appointment.[7]

Eliminating the veneered ceramic application and its requisite bond interface can provide a structural

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Materials for this study provided by Vita Zahnfabrik and 3M ESPE.

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Clinical Implications

Zirconia-reinforced glass-ceramic may be a reliable restorative material for a restoration with both optimal esthetics and sufficient mechanical strength.

integrity that helps to extend the clinical lifetime of restorations.[8,9] Lithium disilicate ceramic is one of the monolithic CAD-CAM materials developed to provide exceptional esthetics without requiring a veneering porcelain. The machinable lithium disilicate ceramic, which displays a bluish color in its partially crystallized form, can be easily milled. After milling, restorations undergo crystallization firing to enhance mechanical strength and fulfill the required esthetics.[10] However, its strength may not be optimal for posterior application.[11-13]

Recently, a zirconia-reinforced lithium silicate ceramic has been introduced which aims to combine the positive material characteristics of both lithium disilicate ceramic and zirconia. The manufacturer claims that the material includes approximately 10% zirconia by weight. The inclusion of zirconia particles in the lithium silicate glass matrix has been reported to reinforce the ceramic structure by providing crack interruption.[14] Additionally, smaller silicate crystals in the lithium silicate glassy matrix result in a high glass content, which may lead to better translucency than that of conventional lithium disilicate ceramics.[15]

Translucency is an important factor in esthetics, as it affects the natural appearance of restorations.[16,17] The translucency of dental materials is usually measured with the translucency parameter (TP), which is defined as the color difference of a material over a white or black backing as measured by a spectrophotometer.[18]

Biaxial flexural strength may be related to the long-term clinical performance of dental materials.[19] Compared with uniaxial flexural strength, it provides more useful data, because dental materials are generally subjected to multiaxial loading during their lifetime in the oral cavity.[20] However, the maximum load that a specimen can withstand before fracture varies, even under standardized test conditions, because of unevenly distributed defects.[21] Weibull statistics can be used to evaluate the structural reliability of dental ceramics and to determine the variability of the strength of a material, thus providing more clinically relevant results.[22]

Both clinicians and manufacturers would like to have a restorative material that combines adequate flexural strength with the optimal translucency required for the fabrication of lifelike restorations in the oral cavity. New monolithic CAD-CAM restorative materials are designed to improve the optical and mechanical properties of restorations. However, the material properties should be confirmed before clinical use, after which the material can serve as one of the clinician's evidence-based material options. Therefore, the purpose of the present study was to investigate and compare the translucency and biaxial flexural strength of 5 monolithic CAD-CAM restorative materials. The null hypothesis was that the type of material would not affect the translucency and flexural strength of the tested materials.

MATERIAL AND METHODS

Monolithic CAD-CAM block materials, including a resin nanoceramic (Lava Ultimate [LU] CAD-CAM Restorative; 3M ESPE), a dual-network ceramic (Vita Enamic [VE]; Vita Zahnfabrik), a feldspathic ceramic (Vitablocs Mark II [VMII]; Vita Zahnfabrik), a zirconia-reinforced lithium silicate ceramic (Vita Suprinity [VS]; Vita Zahnfabrik), and a lithium disilicate ceramic (IPS e.max CAD [IPS]; Ivoclar Vivadent AG), were tested (Table 1). A sample size of 30 in each group for the biaxial flexural strength test was determined, with power analysis to be sufficient to detect a large effect size with 95.7% power. Disk-shaped test specimens with a diameter of 12 mm and a thickness of 1.2 mm were fabricated from 14×12×18 mm blocks using the Cerec system (Dentsply Sirona). Test specimens of IPS and VS underwent a cycle of crystallization for 10 minutes at 850°C or 8 minutes at 840°C in their respective ovens (Programat EP5000; Ivoclar Vivadent AG and Vacumat 4000; Vita Zahnfabrik). Specimen surfaces were polished under water cooling in a polishing machine (LaboPol-25; Struers) with P400, P600, P800, P1000, and P1200 silicon carbide paper (Water Proof SiC Paper; Struers) at 300 rpm.

Table 1. Tested materials

Classification	Brand	Composition*	N	Code	Manufacturer
Resin nanoceramic	Lava Ultimate (A2-HT/14 L)	80% ceramic (69% SiO_2, 31% ZrO_2) 20% polymer (UDMA)	30	LU	3M ESPE
Dual-network ceramic	Vita Enamic (2M2-HT EM-14)	86% ceramic (58-63% SiO_2, 20-23% Al_20_3, 9-11% Na_2O, 4-6% K_2O, 0-1% ZrO_2) 14% polymer (UDMA, TEGDMA)	30	VE	Vita Zahnfabrik
Feldspathic ceramic	Vitablocs Mark II (2M2,CI14)	56-64% SiO_2, 20-23% Al_20_3, 6-9% Na_2O, 6-8% K_2O	30	VMII	Vita Zahnfabrik
Zirconia-reinforced glass-ceramic	Vita Suprinity (2M2-HT PC-14)	56-64% SiO_2, 1-4% Al_20_3, 15-21% Li_2O, 8-12% ZrO_2, 1-4% K_2O	30	VS	Vita Zahnfabrik
Lithium disilicate ceramic	IPS e.max CAD (HT A2/c 14)	58-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-8% ZrO_2, 0-5% Al_20_3	30	IPS	Ivoclar Vivadent AG

*As disclosed by manufacturers.

Specimen dimensions were measured using a micrometer (Digimatic Micrometer; Mitutoyo). In total, 150 disk-shaped test specimens with a diameter of 12 mm and a thickness of 1.2 ±0.05 mm were prepared and ultrasonically cleaned (Sonorex Digiplus; Bandelin GmbH) in distilled water for 10 minutes before they were measured.

The translucency of the specimens placed on white or black backings was measured with a reflection spectrophotometer (Color Eye 7000A, Xrite; GretagMacbeth) in the wavelength range of 400 to 700 nm with 10-nm data intervals. Standard Commission Internationale de l'Eclairage (CIE) illuminant D65 and 2-degree observer function were used. Standard black (CIE L*=7.60, a*=0.45, b*=2.44) and white (CIE L*=88.83, a*=–4.95, b*=–6.07) disks were used to calibrate the spectrophotometer before each measurement. Spectrophotometric data were recorded in CIELab color values. All measurements were made from 5 different areas of each specimen, and the average value was recorded. The TP value was determined by calculating the color differences of the specimens over a white or black backing with the following formula: $TP=([L*B - L*W]^2 + [a*B - a*W]^2 + [b*B - b*W]^2 0^{1/2})$, where B refers to the color coordinates over a black backing and W to those over a white backing. Additionally, L* refers to the brightness, a* refers to red-green, and b* to yellow-blue.[23] Higher TP values correspond to materials with higher translucency, whereas lower TP values correspond to materials with lower translucency. TP values can range from 0 (for a totally opaque material) to 100 (for a totally transparent material).

When the translucency measurements were completed, specimens were subjected to a biaxial flexure test following International Organization for Standardization (ISO) 6872 using a universal testing machine (Shimadzu AG-IS; Shimadzu Corp).[24] Disk-shaped specimens were symmetrically placed on 3 stainless steel balls with a diameter of 3.2 mm and positioned 120 degrees apart on a circle with a diameter of 10 mm. The specimens were then loaded by a 1.2-mm-diameter piston on the center of the specimen with a cross-head speed of 0.5 mm/min until fracture occurred. The fracture load for each specimen was recorded, and the following formulas were used to calculate biaxial flexural strength:

$$\begin{aligned} S= &- 0.2387P(X-Y)/d2;\ X=(1+v)\ \mathrm{In}(r_2/r_3)^2 \\ &+([1-v]/2)(r_2/r_3)^2;\ \text{and } Y=(1+v)\left(1+\mathrm{In}[r_1/r_3]^2\right) \\ &+(1-v)(r_1/r_3)^2, \end{aligned}$$

where S=biaxial flexural strength (MPa); P=fracture load (N); d=disk specimen thickness at fracture site (mm); v=Poisson ratio (0.25); r_1=radius of support circle (5 mm); r_2=radius of loaded area (0.6 mm); and r_3=radius of the specimen (6 mm).

Table 2. Mean ±SD translucency parameter values

Materials (n=30)	Translucency Parameter*
LU	30.0 ±0.9[a]
VE	16.0 ±0.6[c]
VMII	29.0 ±0.7[a]
VS	31.0 ±1.0[a]
IPS	26.0 ±0.6[b]

IPS, IPS e.max CAD; LU, Lava Ultimate; VE, Vita Enamic; VMII, Vitablocs Mark II; VS, Vita Suprinity. *Same superscript letters represent groups with no statistically significant (P>.05) differences according to 1-way ANOVA with Tukey honest significant differences post hoc test.

Polished surfaces of the specimens were coated with Au-Pt (SC7620 Sputter Coater; Quorum Tech) before scanning electron microscopy (SEM) analysis was conducted (EVO LS 10; Zeiss). An energy dispersive spectrometer (EDS) equipped SEM was used for a chemical composition analysis. Five different locations were examined, and their average values were calculated.

Data sets were analyzed using statistical software (IBM SPSS Statistics v20; IBM Corp). Results of the TP and biaxial flexural strength tests were analyzed separately for each material using 1-way ANOVA and the Tukey honest significant difference test (α=.05). The Student *t* test was used to determine which specific pairs of means were significantly different. Weibull statistical analyses were performed using the biaxial flexural strength data to evaluate the characteristic strength and Weibull modulus of each material.

RESULTS

The mean and standard deviation values of the TP are summarized in Table 2. The TP values of the groups ranged from 16 (VE) to 31 (VS). The mean TP value of the VS was significantly higher than the TP values of the IPS and VE (P<.001). The general ranking of the mean TP values for the tested materials was VS > LU > VMII > IPS > VE.

The mean and standard deviation values of the biaxial flexural strength and Weibull parameters, including the Weibull modulus and characteristic strength, are presented in Table 3. The maximum mean value of the biaxial flexural strength was recorded in the VS group, which was significantly different from those of the IPS, LU, VE, and VMII groups (P<.05). The lowest mean biaxial flexural strength was obtained in the VMII group (P<.05). According to Student *t* test results, a statistically significant difference was calculated between LU and VE. The LU group showed higher biaxial flexural strength than that of VE (P<.05). The Weibull modulus of the materials ranged from 5.1 to 11.3, and the highest Weibull modulus was calculated for VMII, followed by the IPS, VE, VS, and LU groups. The Weibull distribution

Table 3. Biaxial flexure test results

Material (n=30)	Mean ±SD Biaxial Flexural Strength (MPa)*	Weibull Modulus	Weibull characteristic Strength (MPa)
LU	243 ±27^{c}	5.1	265
VE	174 ±13^{d}	9.7	191
VMII	97 ±8^{e}	11.3	102
VS	510 ±43^{a}	8.8	532
IPS	415 ±26^{b}	10.7	429

IPS, IPS e.max CAD; LU, Lava Ultimate; VE, Vita Enamic; VMII, Vitablocs Mark II; VS, Vita Suprinity. *Different superscript letters indicate statistically significant differences of materials according to 1-way ANOVA with Tukey honest significant differences post hoc test. ($P<.05$).

plots of biaxial flexural strength with an accuracy of 95% using the maximum likelihood estimation method are presented in Figure 1.

Scanning electron microscopy images of the materials showing the differences in morphology and grain size are presented in Figure 2. The average values of the chemical components taken from EDS analysis are presented in Table 4. EDS analysis confirmed that the chemical constituents of each material were in accordance with those claimed by the manufacturers, except that Li was not found in VS or IPS and Zr was not detected in VE or IPS.

DISCUSSION

The null hypotheses were rejected as significant differences for both translucency and biaxial flexural strength were found among the materials.

Translucency is a determining factor in material selection and is an essential optical property, especially for restorations in the esthetic zone. Restorations with optimal translucency are required for the fabrication of lifelike restorations.[16,17,25] However, it is not always desirable in clinical situations, such as restoring discolored teeth or metal posts and cores that need to be covered with a material which has lower translucency and higher masking ability.[26] Therefore, clinicians should be familiar with the translucency of newly introduced monolithic CAD-CAM materials when they choose the most appropriate material for a specific clinical situation. The translucency of dental ceramics is reported to be affected by chemical composition, grain size, crystalline structure, pores, and additives.[16,17,25] In the present study, statistically different values were obtained for the materials concerning TP values. The highest mean TP value was obtained in the VS group followed by the LU, VMII, IPS, and VE groups. Few studies have reported the TP values of newly introduced monolithic CAD-CAM restorative materials.[15,17,27] In a recent study, Awad et al[15] compared the TP values of various CAD-CAM materials and reported a significant difference between lithium disilicate ceramic and zirconia-reinforced glass-ceramic. Zirconia-reinforced glass-ceramic was reported to have a higher mean TP value than lithium disilicate ceramic. The researchers explained the difference in translucency between the materials by grain size and crystalline structure differences. After crystallization, the crystals in zirconia-reinforced glass-ceramic have a mean grain size of 500 to 700 nm, which has been reported to be 4 to 8 times smaller than lithium disilicate crystallites in lithium disilicate ceramic.[13-15] The SEM images made from the polished surfaces confirm the microstructural differences in grain size and morphology (Fig. 2). Additionally, smaller silicate crystals in the lithium silicate glassy matrix of VS result in a high glass content, which was thought to be effective on the better TP values.[15]

Previous studies differed regarding the translucency of lithium disilicate ceramics and silicate ceramics. Some studies reported a significant difference, as did the present study.[16,27] However, other studies reported no significant differences.[26] Researchers explained the translucency differences among the materials by referring to the materials' chemical compositions.[17,27] According to the findings of EDS analysis, VMII had an Al content of approximately 15% by weight, which was thought to be responsible for its more opaque appearance. Furthermore, the differences in shade and translucency among the tested materials might also have affected the results.[16,27] Industrially prefabricated blocks of various shades and translucencies ranging from low to high translucency are available. High-translucency blocks of A2 color were chosen for the present study.

The lowest mean TP value was obtained in the VE group, and the mean TP value of the material was significantly lower than that of LU. Based on their compositions, these materials have been categorized as a new class of dental CAD-CAM restorative material, but few publications evaluating their optical properties are as yet available.[15,17,27] The LU group contains zirconia/silica nanoparticles embedded in a highly cross-linked resin matrix, whereas VE is a double-penetrating polymer-infiltrated ceramic network. The higher translucency values of the LU material could be explained by nanometer-sized filler particles. The authors stated that particles with diameters smaller than the wavelength of visible light cause less scattering of light and increased light transmission, thereby improving translucency.[25] Additionally, the lower TP values of the VE group could also be explained by the alumina content. The VE material had an Al content of 8.31% by weight (Table 4). Noort et al[10] reported that increased alumina content led to decreased translucency. Consequently, chemical composition, crystalline content, grain size, and microstructural differences in the materials seem to be responsible for the differences among the TP values.

The biaxial flexure test is one of the primary methods used to investigate the fracture strength and long-term clinical performance of dental materials before they can

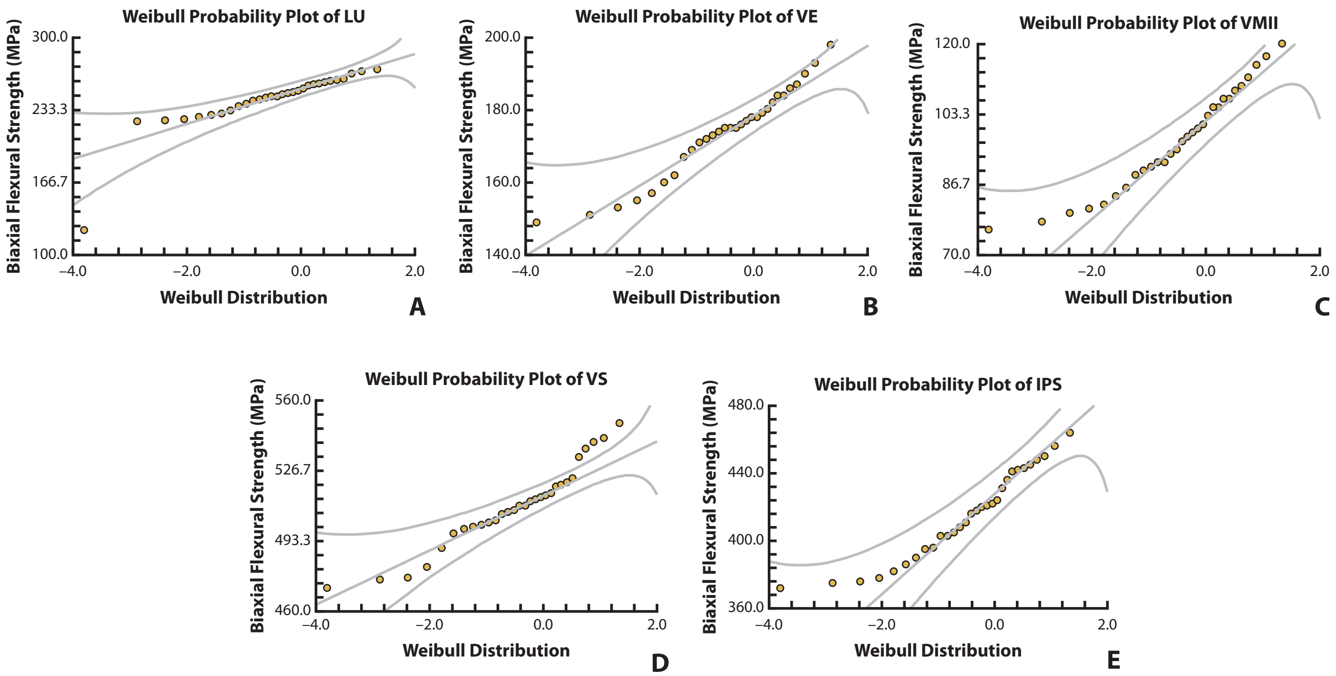

Figure 1. Weibull probability plots of materials. A, LU, Lava Ultimate. B, VE, Vita Enamic. C, VMII, Vitablocs Mark II. D, IPS, IPS e.max CAD. E, VS, Vita Suprinity.

be recommended for clinical use. Statistically different biaxial flexural strength values were obtained for each tested material in the different material classes of the present study. The VS group produced the highest mean biaxial flexural strength value, followed by the IPS, LU, VE, and VMII groups. The results obtained in the present study were consistent with those of previous studies.[9,12-14] Recently, Elsaka and Elnaghy[14] investigated the mechanical properties of zirconia-reinforced glass-ceramic and lithium disilicate ceramic. Zirconia-reinforced glass-ceramic had a significantly higher flexural strength value than lithium disilicate ceramic, which they attributed

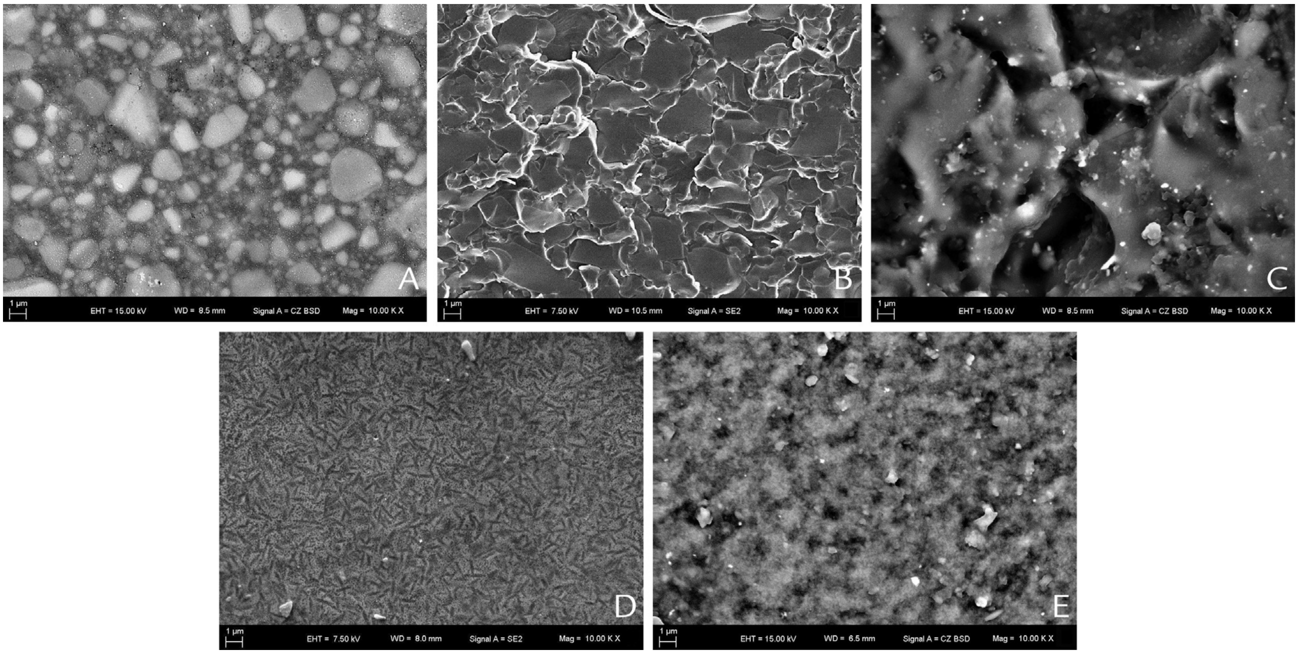

Figure 2. Scanning electron micrographs of polished surface specimens (original magnification ×10 000). A, LU, Lava Ultimate; B, VE, Vita Enamic; C, VMII, Vitablocs Mark II; D, IPS, IPS e.max CAD; and E, VS, Vita Suprinity.

Table 4. Findings of EDS analysis (weight%)

	Material				
Element	**LU**	**VE**	**VMII**	**VS**	**IPS**
Carbon	29.45	27.65	1.85	1.05	1.63
Oxygen	37.08	37.85	44.92	52.1	54.31
Silicon	20.16	17.9	25.29	27.52	37.98
Aluminum	-	8.31	14.98	1.28	2.28
Sodium	-	4.78	6.2	-	-
Potassium	-	3.5	6.75	2.34	3.79
Zirconium	13.21	-	-	15.7	-

EDS, energy dispersive spectrometer; IPS, IPS e.max CAD; LU, Lava Ultimate; VE, Vita Enamic; VMII, Vitablocs Mark II; VS, Vita Suprinity.

to the zirconia fillers used to reinforce the glassy matrix of the material. The strength values reported were comparatively lower than the values obtained in the present study, which could be explained by different specimen dimensions and testing conditions applied in the studies. The 3-point flexure test used in the study by Elsaka and Elnaghy[14] tends to produce lower values than the biaxial flexure test. Furthermore, the biaxial flexural strength values for both materials in the present study were higher than the values claimed by the manufacturers, possibly because different testing methods and specimen dimensions were used.

A significant difference was found between the LU and VE materials in relation to the biaxial flexural test results. Results were different from the published data for these materials: whereas some studies reported significant difference between the materials in accordance with the present study,[7,28] others reported no significance.[5] The 3-point flexure test was performed in these, and the differences between the results could be due to the specimen dimensions, especially as the thickness varied among the studies.[5,7,28] Both LU and VE were produced to combine the advantages of ceramics and polymers.[6,29] Although these materials are classified similarly, they are manufactured differently. The composition of the resin matrix, size, and distribution of the filler particles are thought to be responsible for the differences in strength.

The lowest biaxial flexural strength value was obtained in the VMII group. VMII is a feldspathic ceramic material containing a weak glass matrix and irregularly shaped crystalline phases such as silica, potash, and alumina, which are more brittle than the zirconia-reinforced ceramics.[3,20] Furthermore, LU and VE showed better flexural strength than VMII, revealing that the presence of a resin matrix would create a toughening mechanism in the microstructure.

Weibull statistics are generally used to characterize the structural reliability of brittle materials.[21] The Weibull characteristic strength presents the strength value by which 63% of the tested specimens would fracture. Additionally, the Weibull modulus determines the variability of strength and provides information on the structural homogeneity of a material.[22] In the present study, the Weibull modulus ranged from 5.1 (LU) to 11.3 (VMII). A lower Weibull modulus means greater variability and less reliability in strength. The Weibull modulus of dental ceramics has been reported to range from 5 to 15.[30]

This in vitro investigation could not completely simulate clinical conditions. Therefore, further research of the optical and mechanical properties of monolithic CAD-CAM restorative material is needed, especially by simulating the variables of the intraoral environment to make definitive clinical recommendations. In vivo studies assessing the clinical complications, biocompatibility, wear, microleakage, color stability, and survival rate of the materials are also essential to validate their clinical use.

CONCLUSIONS

Based on the results of the present in vitro study, the following conclusions were drawn:

1. The translucency and flexural strength were affected by the type of CAD-CAM restorative material.
2. Zirconia-reinforced glass-ceramic revealed the highest mean translucency and biaxial flexural strength compared with the other tested materials.
3. Zirconia-reinforced glass-ceramic may be a reliable restorative material, but in vivo studies are required to validate clinical use.
4. The optical and mechanical properties seem to be affected by the chemical composition and structural differences of the materials.
5. Results of the present study may be helpful to determine which monolithic CAD-CAM restorative material is more translucent or has higher biaxial flexural strength and where it could be used to enhance esthetics and mechanical strength.

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