SPECTROPHOTOMETER ANALYSIS OF CAD-CAM ZIRCONIA REINFORCED LITHIUM SILICATE AND LITHIUM DISILICATE GLASS CERAMICS

Sherine A. Saad[1] *BDS*, Yousreya A. Shalaby[2] *PhD*, Amir S. Azer[3] *PhD*,
Fatma M. El-Sharkawy[4]*PhD*

ABSTRACT

INTRODUCTION: Matching dental ceramic translucency is the optimal esthetic goal in restorative dentistry. Several types of ceramics evolved over the years in an attempt to optimize physical mechanical and optical properties of the previous types.
OBJECTIVES: The aim of this study is to compare and analyze light transmission, light reflection and light absorption of high translucency zirconia reinforced lithium silicate ceramic, low translucency zirconia reinforced lithium silicate ceramic, high translucency lithium disilicate glass-ceramic and low translucency lithium disilicate glass-ceramic.
MATERIALS AND METHODS: Serial cutting of the E.max cad and Vita suprinity blocks was done using isomet 4000 micro-saw microtome. Ten ceramic specimens were obtained for each material, 5 of which were 1.5 mm thick and the other 5 were 1 mm thick to be veneered by 0.5 mm of the corresponding veneering material according to manufacturer's instruction. Spectrophotometric analysis was carried out for the forty ceramic specimens.
RESULTS: Light transmission for the four groups of zirconia reinforced lithium silicate was significantly higher than their corresponding groups of lithium disilicate ($p<0.005$). Light reflection and light absorption for the four groups of zirconia reinforced lithium silicate was significantly lower than their corresponding groups of lithium disilicate ($p<0.005$). Veneering increased light transmission and light reflection however it decreased light absorption for both materials significantly.
CONCLUSIONS: Translucency of zirconia reinforced lithium silicate is better than lithium disilicate. Veneering improved optical properties for both zirconia reinforced lithium silicate and lithium disilicate.
KEYWORDS: Spectrophotometer, translucency, zirconia reinforced lithium silicate, lithium disilicate.

1- BDS, MS, Faculty of Dentistry, Alexandria University.Egypt.
2- Professor of Fixed Prosthodontic,Conservative Department, Faculty of Dentistry, Alexandria University.Egypt.
3- Researcher of Photometry Department, National Institute of Standards, Cairo, Egypt.

Corresponding author:
E-mail: sherine.anwarsaad@gmail.com

INTRODUCTION

Esthetic is the sense of perception, judgment and taste concerning beauty. It is one of the primary factors for the patients to seek for the dental care. Knowledge of esthetic principles helps the dentist to achieve a successful prosthodontics restoration which provides in addition to an excellent long-term function a beautiful smile (1).

Generally, the microstructure of advanced ceramics has many features. Three critical components of ceramic microstructure are phase boundaries, grains, and pores. Examples of phase boundaries in dense ceramics are interfaces among crystalline grains and between crystalline grain and a glassy phase (2).

Dental ceramics also have varying degrees of translucency. The translucency of porcelain is dependent on how light scatters, absorbs, reflects and transmits through the ceramic material. This is dependent on the crystal number inside the core matrix, the particle size of the crystals and their chemical composition as compared to the incident light wave length (3).

Glass-based systems with crystalline second phase porcelain presented excellent esthetics combined with good resistance, owing to incorporation of several crystalline materials in the glassy matrix (4). E.max cad a lithium disilicate based ceramic was developed for cad cam restorations due to its preferable machining properties (5,6).

A new group of machinable ceramics has recently been introduced for CAD/CAM techniques, zirconia-reinforced lithium silicate (ZLS) ceramics with 8-10% by weight zirconium oxide incorporated in lithium disilicate matrix providing superior mechanical and optical properties (7).

Researchers have used reflectance spectrophotometery to evaluate light transmission, light reflection and light absorption (8).

MATERIALS AND METHODS

Serial cutting of the E.max cad (Ivoclar Vivadent AG, Schaan / Liechtenstein) and the Vita Suprinity blocks (VITA Zahnfabrik H. Rauter GmbH & Co.KG Postfach 1338.D-79704 Bad Säckingen. Germany) was done using isomet 4000 micro-saw microtome (Isomet 4000 micro-saw Buehler USA) with 0.5 mm thickness diamond disc. Ten ceramic specimens were obtained for each material and were divided into 8 groups according to the construction technique into:

Group Ia: Ht zirconia reinforced lithium silicate veneered with low fusing fine-structure feldspar ceramic.
Group Ib: Ht zirconia reinforced lithium silicate with crystallizationand glaze firing.
Group IIa: Lt zirconia reinforced lithium silicate veneered with low fusing fine-structure feldspar ceramic.
Group IIb: Lt zirconia reinforced lithium silicate with crystallization and glaze firing.

Group IIIa: Ht lithium disilicate glass veneered with IPS e.maxceram.
Group IIIb: Ht lithium disilicate glass with crystallization and glaze firing.
Group IVa: Lt lithium disilicate glass veneered with IPS e.maxceram.
Group IVb: Lt lithium disilicate glass with crystallization and glaze firing.

Preparation of study specimens

For (Group Ia) and (Group IIa) the ceramic thickness was 1mm and crystallization in ivoclar vivadent P300 furnace was performed following recommended parameters of the manufacturer, then 0.5 mm of VITA VM 11 material (VITA Zahnfabrik H. Rauter GmbH &Co.KGPostfach 1338.D-79704 Bad Säckingen. Germany) was added and firing following the manufacturer's instructions was performed. Finally glazing with vita akzent plus glaze spray (VITA Zahnfabrik H. Rauter GmbH &Co.KGPostfach 1338.D-79704 Bad Säckingen. Germany) was performed following recommended parameters of the manufacturer.

For (Group Ib) and (Group IIb) the ceramic thickness will be 1.5 mm. Crystallization followed by glazing with vita akzent plusglaze spray will be will be performed following recommended parameters of the manufacturer.

For (Group IIIa) and (Group IVa) the ceramic thickness was 1mm and crystallization in ivoclar vivadent P310 furnace was performed following recommended parameters of the manufacturer. Then 0.5 mm of IPS e.max ceram material (IvoclarVivadent AG, Schaan / Liechtenstein) was added and firing following the manufacturer's instructions was performed. Finally glazing with IPS e.max glaze paste (IvoclarVivadent AG, Schaan / Liechtenstein) was performed following recommended parameters of the manufacturer.

For (Group IIIb) and (Group IVb) the ceramic thickness will 1.5 mm. Crystallization, followed by glazing with IPS e.max glaze paste material will be done according the manufacture recommendation.

Preparation of composite specimens

A plastic mold with a hole, 10mm width, 15mm length and 1.5mm thickness, was constructed to form the composite specimens. The mold was filled with A2 composite resin material (Cavex Holland BV P.O. Box 852 2003 RW Haarlem the Netherlands), covered with glass slab to ensure flat surface and cured. The process was repeated to create 40 composite specimens. Finishing of composite specimens was done using soflex discs and finishing cups.

Cementation

Ceramic specimens were etched using 9.5% hydrofluoric acid for 10 seconds then surface was rinsed with water and dried then silane coupling agent was applied and dried with light air for another 10 seconds. Self- etch self-adhesive composite resin cement (Cavex Holland BV P.O. Box 852 2003 RW Haarlem the Netherlands) was then applied on the ceramic specimen and fitted to its corresponding composite specimen. Static load device (Designed by Dr. Amir Azer, Fixed prosthodontic departement, Alexandria university) was used to ensure uniform cement thickness, excess cement was removed using scalpel then light curing of cement and final finishing with soflex discs were done.

Testing the study specimens

The spectrophotometric analysis of the specimens was done using a reflectance spectrophotometer (UV.Shimadzy 3101 PC-Spectrophotometer. Japan) with specimens placed against black background. Light transmission and light reflection were measured using the spectrophotometer, whereas light absorption was calculated according to the following equation:

$A = -\log T$ (9)

Statistical analysis of the data (10)

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp) (11). The Kolmogorov-Smirnov test was used to verify the normality of distribution Quantitative data were described using range (minimum and maximum), mean, standard deviation and median. Significance of the obtained results was judged at the 5% level ($P \leq 0.05$).

The used test was: Mann Whitney test

For abnormally distributed quantitative variables, to compare between two studied groups.

RESULTS

Evaluation of light transmission, light reflection and light absorption of the forty cad-cam zirconia reinforced lithium silicate specimens and their corresponding lithium disilicate glass ceramic specimens using spectrophotometer.

1. Light transmission

The mean value of light transmission for Group Ia was (11.12 ± 5.02), while the mean value of light transmission for Group IIIa was (9.15 ± 4.91), the difference was significant.The mean value of light transmission for Group Ib was (10.11 ± 4.65), while the mean value of light transmission for Group IIIb was(8.09 ± 5.20), the difference was significant.The mean value of light transmission of Group IIa (9.21 ± 4.28)was significantly higher when compared to that of Group IVa (7.14 ± 4.58). Results of Mann Whitney test indicated that the mean value of light transmission for Group IIb (8.68 ± 4.40), was significantly higher than the mean value of light transmission for Group IVb (6.05 ± 4.35). Veneering increased light transmission for all groups significantly. (Table 1) (Figure 1)

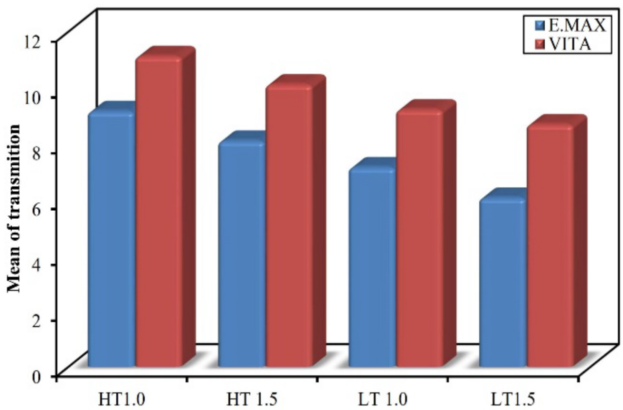

Figure (1): Comparison between the eight groups regarding light transmission

Table (1): Comparison between the eight groups regarding light transmission

Transmission	E.MAX	VITA	p_1
HT 1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	0.05 – 15.04	0.09 – 16.96	
Mean ± SD.	9.15 ± 4.91	11.12 ± 5.02	<0.001*
Median	10.66	12.93	
HT 1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	0.01 – 14.89	0.09 – 15.65	
Mean ± SD.	8.09 ± 5.20	10.11 ± 4.65	<0.001*
Median	9.35	11.75	
P2	0.001*	<0.001*	
LT 1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	0.03 – 13.0	2.03 – 14.54	
Mean ± SD.	7.14 ± 4.58	9.21 ± 4.28	<0.001*
Median	8.14	10.49	
LT 1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	0.01 – 12.12	0.06 – 14.54	
Mean ± SD.	6.05 ± 4.35	8.68 ± 4.40	<0.001*
Median	6.61	10.49	
P2	<0.001*	0.016*	

p_1: p values for Mann Whitney test for comparison between E.max cad and Vita suprinity regarding light transmission

p_2: p values for Mann Whitney test for effect of veneering on E.max cad and Vita suprinity regarding light transmission

*: Statistically significant at $p \le 0.05$

2. Light reflection

The Mann Whitney test showed significant higher light reflection for Group IIIa (35.40 ± 5.91), when compared to Group Ia (28.56 ± 8.41). The mean value of light reflection of Group IIIb (28.85 ± 8.74), was significantly higher than Group Ib (25.79 ± 6.91). Also, the mean value of light reflection for Group IVa was (43.75 ± 8.0), while the mean value of light reflection for Group IIa was (32.53 ± 9.16), the difference was significant. According to results obtained by Mann Whitney test, the mean value of light reflection for Group IVb (38.87 ± 13.50) was significantly higher than that of Group IIa (29.51 ± 8.62). Veneering increased light reflection for all groups significantly. (Table 2) (Figure 2)

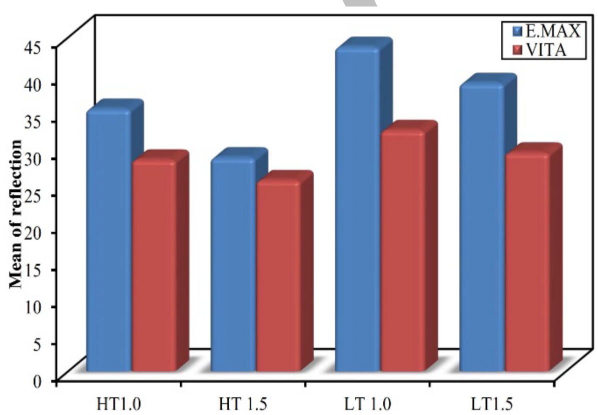

Figure (2): Comparison between the eight groups regarding light reflection

Table (2): Comparison between the eight groups regarding light reflection

Reflection	E.MAX	VITA	p_1
HT1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	16.23 – 40.20	9.16 – 35.27	
Mean ± SD.	35.40 ± 5.91	28.56 ± 8.41	<0.001*
Median	37.73	32.05	
HT 1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	9.01 – 35.97	8.30 – 31.04	
Mean ± SD.	28.85 ± 8.74	25.79 ± 6.91	<0.001*
Median	32.41	28.64	
P_2	<0.001*	<0.001*	
LT 1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	17.87 – 49.87	9.26 – 39.46	
Mean ± SD.	43.75 ± 8.0	32.53 ± 9.16	<0.001*
Median	46.72	36.32	
LT1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	7.86 – 50.56	9.12 – 36.16	
Mean ± SD.	38.87 ± 13.50	29.51 ± 8.62	<0.001*
Median	45.32	33.18	
P_2	<0.001*	<0.001*	

p_1: p values for Mann Whitney test for comparison between E.max cad and Vita suprinity regarding light reflection

p_2: p values for Mann Whitney test for effect of veneering on E.max cad and Vita suprinity regarding light reflection

*: Statistically significant at $p \le 0.05$

3. Light absorption

The Mann Whitney test showed significantly lower difference when the mean light absorption of Group Ia (-0.95 ± 0.38) was compared to that of Group IIIa (-0.81 ± 0.50). Results showed that the mean light absorption value for Group Ib (-0.90 ± 0.39) was significantly lower than Group IIIb (-0.62 ± 0.75). Moreover, Significant difference was found between mean value of light absorption of Group IIa (-0.89 ± 0.27) which was lower than Group IVa (-0.61 ± 0.64). The mean light absorption value of Group IIb (-0.81 ± 0.45) was significantly lower than that of Group IVb (-0.43 ± 0.82). Veneering decreased light absorption for all groups significantly. (Table 3) (Figure 3)

Table (3): Comparison between the eight groups regarding light absorption

Absorption	E.MAX	VITA	p
HT 1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	-1.18 – 1.30	-1.23 – 1.05	
Mean ± SD.	-0.81 ± 0.50	-0.95 ± 0.38	<0.001*
Median	-1.03	-1.11	
HT 1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	-1.17 – 2.0	-1.19 – 1.05	
Mean ± SD.	-0.62 ± 0.75	-0.90 ± 0.39	<0.001*
Median	-0.97	-1.07	
P_2	0.001*	<0.001*	
LT 1.0	**(n= 5)**	**(n= 5)**	
Min. – Max.	-1.11 – 1.52	-1.16 – -0.31	
Mean ± SD.	-0.61 ± 0.64	-0.89 ± 0.27	<0.001*
Median	-0.91	-1.02	
LT 1.5	**(n= 5)**	**(n= 5)**	
Min. – Max.	-1.08 – 2.0	-1.16 – 1.22	
Mean ± SD.	-0.43 ± 0.82	-0.81 ± 0.45	<0.001*
Median	-0.82	-1.02	
P_2	<0.001*	0.016*	

p_1: p values for Mann Whitney test for comparison between E.max cad and Vita suprinity regarding light absorption

p_2: p values for Mann Whitney test for effect of veneering on E.max cad and Vita suprinity regarding light absorption

*: Statistically significant at $p \le 0.05$

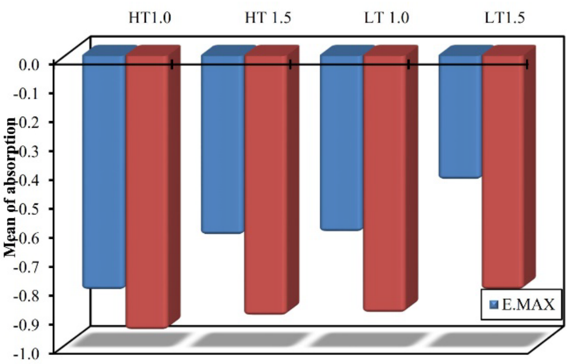

Figure (3): Comparison between the eight groups regarding light absorption

DISCUSSION

Translucency is the relative amount of light transmission or diffuse reflectance from a substrate surface (12). For translucent materials most of the incident light is transmitted and some is absorbed, whereas less translucent materials tend to reflect and absorb light falling on it (13). Ceramic translucency can be affected by many factors including thickness, micro structure, number of firing cycles, type and thickness of underlying cement (14-16).

In the present study thickness of all A_2 ceramic specimens was fixed at 1.5mm. Ceramic specimens were cemented to A_2composite resin specimens using cavex composite resin cement and static load device was used to confirm uniform cement thickness in all specimens. Reflectance spectrophotometer has been reliable method in evaluating light transmission, light reflection and light absorption of CAD-CAM Zirconia reinforced lithium silicate and lithium disilicate glass ceramics.

All these variables were fixed in all study specimens so that the composition of the testing materials would be the only contributing factor in the study results.

Regarding the light transmission it was found that Group I (Ht ZLS) had higher mean value of light transmission than Group III (Ht lithium disilicate), also GroupII (Lt ZLS) reported higher mean value of light transmission than Group IV (Lt lithium disilicate). This might be due to the enhancement of the ZrO_2 particles to the crystallization kinetics of the crystal phases; during crystallization process ZrO_2 particles act as active centre of nucleation resulting in a more homogenous crystalline structure with finer grain size (0.5µm) of vita suprinity when compared to that of lithium disilicate with coarser needle-shaped crystals and average grain size of (1.5 µm).

This was in accordance with the results obtained by Bahgat , et al (17) who investigated the effect of addition of zirconia to lithium disilicate ceramics on translucency and bonding ability to resin cements using two adhesive strategies. For translucency measurements (ΔE) was measured using a spectrophotometer, and concluded that under the test conditions, zirconia-reinforced lithium disilicate ceramic demonstrated better translucency and shear bond strength than lithium disilicate glass ceramic.

Regarding the effect of ZrO_2 on crystallization process and subsequently on properties of lithium disilicate, the results of this study are in agreement with that obtained by Apel et al (18) who used differential scanning colorimetry, X-ray diffractometry and scanning electron microscopy in order to obtain significant results. He found that after first crystallization phase lithium metasilicate was present as the main phase in all the glasses with its highest content at ZrO_2 free glass, and as ZrO_2 content increases lithium metasilicate content decreases. After the second crystallization step, all the samples contained lithium disilicate as the main crystal phase and had same inversely proportional ratio with ZrO_2 content. He concluded that addition of ZrO_2 resulted in much smaller finer crystals and thus resulting in more translucent glass ceramic with better optical properties.

Moreover, Sen and Us (19) concluded that zirconia reinforced lithium disilicate revealed the highest mean translucency and biaxial flexural strength compared with the other tested materials and that optical and mechanical properties seem to be affected by the chemical composition and structural differences of the materials. 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. This was in the light of the report that chemical composition, grain size, crystalline structure, pores, and additives affect the translucency of dental ceramics (20-22).

Since contrast ratio is the ratio of reflectance of material and determinant of opacity, similarly reflection is a determinant of opacity. Therefore, reflection can be described in terms of contrast ratio (23,24).

Multiple studies which evaluated Optical properties of cad-cam ceramic systems using translucency parameter and contrast ratio concluded that there is a strong correlation between both parameters; as translucency parameter increases, contrast ratio decreases (25-27).

The results of this study showed that the mean value of light reflection of Group I (Ht ZLS) was lower than the mean value of light reflection of Group III (Ht lithium disilicate). Group II (Lt ZLS) also reported lower mean value of light reflection than Group IV (Lt lithium disilicate), this is in accordance with the results of, Apel et al (18) who studied the effect of addition of ZrO_2 on the optical properties of lithium disilicate glass ceramic, and concluded that contrast ratio decreases with increase in the ZrO_2 content. Therefore, reflection decreases by increasing ZrO_2 content, improving translucency and optical properties of zirconia reinforced lithium silicate glass ceramic as compared to lithium disilicate glass ceramic.

Bahgat, et al (17) and Sen and Olcer (19) also concluded that translucency parameter of ZLS was higher than that of lithium disilicate glass ceramic, consequently contrast ratio and mean value of light reflection of ZLS was lower than that of lithium disilicate glass ceramic, these outcomes are in agreement with results of this study.

Good translucency requires a material with low mean value of light absorption and low scattering of the incident light. This can be obtained by satisfying either of two criteria. The first criterion is satisfied when all the crystalline phases and the residual glass have closely matched indexes of refraction. The second criterion for low scattering is satisfied in the case where the crystal size is much smaller than the wavelength of light (28). The results of the present study can be explained by the satisfaction of the second criterion; the greater mean value of light absorption of lithium disilicate as compared to zirconia reinforced lithium silicate may be due to the smaller particle size of ZLS than lithium disilicate as compared to incident light (20).

Dias, et al (29) who measured light irradiance and performed spectrophotometric analysis on hot pressed and hot pressed veneered glass ceramics, stated that the amount of light being absorbed, reflected and transmitted depends mainly on the amount of crystals within the glassy matrixand the size of the particles compared with the incident light wavelength (30,31). This may explain results of this study.

However, Heffernan, et al (32) stated that difference between refractive index of crystals and refractive index of glassy matrix they are embedded in affected light scattering the most; the greater the mismatch in refractive indexes the greater the light absorption and scattering. Refractive index of lithium disilicate, zirconium oxide and glassy matrix are 1.55, 2.20 and 1.50 respectively (28,33). This was in contrary with the results of this study where ZLS showed significantly lower mean value of light absorption, the difference may be due to that zirconium oxide content in In ceram Zirconia is approximately 85% by volume (34). Whereas, that for zirconia reinforced lithium silicate is 8-10% by volume, moreover the finer crystalline structure of ZLS compared to other zirconia containing ceramics provides it with finer optical properties.

Regarding the effect of veneering on optical properties, results of the present study showed significant increase in mean value of light transmission for both lithium disilicate and zirconia reinforced lithium silicate. This may be due to the composition of the veneering material; for lithium disilicate e.max ceram is a nanoflurapatite glass ceramic which has similar optical properties to that of enamel and thus improve optical properties of the material (35,36).

Kelly JR, et al, 2008 (37) who stated that dental ceramics that best mimic optical properties of enamel and dentin are those of amorphous structure and high glass content; those known as feldspathic ceramics.This may explain why Vita Vm11 which is a low fusing fine structure feldspar ceramic with no fillers in its matrix caused significant increase in the mean value of light transmission of ZLS (38).

Heffernan (32) in 2002 studied the effect of veneering and glazing on six all ceramic materials concluded that veneering increased the opacity of all ceramic core materials and referred this to the increase in specimen thickness, reflectance at the interface between core and veneering porcelain, porosity between the layers, and any changes in the constituent core material with additional firing cycles. This may explain the significant increase in the mean value of light reflection as a result of veneering for both lithium disilicate and zirconia reinforced lithium silicate.

Results of this study were also in accordance with results obtained by Dias, et al (29) who concluded that one of the main factors affecting optical properties of veneered materials are the pores trapped between the veneer layer and the ceramic layer were the difference in the refractive index of the pore (1.00) and that of the glassy matrix may lead to significant light scattering effect. Furthermore, he noted increase in reflectance at the core veneering interface.

Smaller finer particles of the veneering material compared to the core ceramic material results in a more glossy glazed surface, which subsequently result in greater surface reflection, this may also explain the significant increase in mean value of light reflection after veneering of both test materials in the present study (39).

When comparing mean value of light absorption, results of this study showed significant decrease in light absorption in veneered specimens compared to those of non- veneered specimens. For ZLS removing 0.5 mm of the zirconia reinforced lithium silicate, in order to retain total thickness of specimen, and replacing it with feldspathic Vita Vm11 seemed to improve optical properties by reducing light scattering and light absorption. This can be explained by the fact that feldspathic glass has the most superior optical and esthetic properties compared to all other ceramic groups (40,41). Similarly, the nano-flurapatite e. max ceram having optical properties similar to that of enamel tends to enhance the optical properties of veneered lithium disilicate specimens (35,36).

Moreover, Da Cunha, et al (42) who studied a case of cliedocranial dysplasia and aimed for the best treatment protocol concluded that using lithium silicate glass ceramic as core material and topping it with Vita Vm11 improved esthetics significantly, this was in accordance with results of the present study.

CONCLUSION

Based on the results of the present study the following conclusions can be drawn:

1- Translucency of zirconia reinforced lithium silicate is better than lithium disilicate.
2- Veneering improved optical properties for both zirconia reinforced lithium silicate and lithium disilicate glass ceramics.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Davis LG, Ashworth PD, Spriggs LS. Psychological effects of aesthetic dental treatment. J Dent. 1998;26:547-54.
2. Amelinckx S, Dekeyser W. The Structure and Properties of Grain Boundaries. In: Seitz F, Turnbull D (eds).Solid state physics, advances in research and applications. Academic Press; 1959. p 325-499.
3. McLean JW, Hubbard JR, Kedge MI. The science and art of dental ceramics. Chicago: Quintessence Pub. Co.; 1980.
4. McLaren EA, Cao PT. Ceramics in dentistry—part I: classes of materials. Inside Dent.2009;5:94-103.
5. Zheng X, Wen G, Song L, Huang XX. Effects of P25 and Heat Treatment on Crystallization and Microstructure in Lithium Disilicate Glass Ceramics. Acta Mater. 2008;56:549–58.
6. Xiao Z, Zhou J, Wang Y, Luo M. Microstructure and Properties of Li2O-Al2O3-SiO2-P2O5 Glass-Ceramics. Open Mater Sci J. 2011;5:45–50.
7. Krüger S, Deubener J, Ritzberger C, Höland W. Nucleation kinetics of lithium metasilicate in ZrO2-bearing lithium disilicate glasses for dental application. Int J Appl Glass Sci. 2013;4:9-19.
8. Blum P. Reflectance spectrophotometry and colorimetry. PP Handbook .1997:2-11
9. Swinehart DF. The Beer-Lambert Law. J Chem Educ. 1962;39:333.
10. Kotz S, Balakrishnan N, Read CB, Vidakovic B. Encyclopedia of statistical sciences Hoboken, N.J.: Wiley-

Interscience; 2013. Available at: http://www.credoreference.com/book/wileyenstsc.

11. Kirkpatrick LA, Feeney BC. A simple guide to IBM SPSS statistics for version 20.0. Student ed. Belmont, Calif.: Wadsworth, Cengage Learning; 2013.
12. Cal E, Guneri P, Kose T. Comparison of digital and spectrophotometric measurements of colour shade guides. J Oral Rehabil. 2006;33:221-8.
13. Bahgat S, Basheer R, El Sayed S. Effect of Zirconia addition to lithium disilicate ceramic on translucency and bond strength using different adhesive strategies. EDJ. 2015;61:4519-33.
14. Apel E, van'tHoen C, Rheinberger V, Höland W. Influence of ZrO 2 on the crystallization and properties of lithium disilicate glass-ceramics derived from a multi-component system. J Eur Ceram Soc.2007;27:1571-7.
15. Sen N, Us YO. Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthet Dent.2018;119:593-9.
16. Lee YK. Influence of scattering/absorption characteristics on the color of resin composites. Dent Mater. 2007;23:124-31.
17. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent. 2002;88:4-9.
18. Vichi A, Carrabba M, Paravina R, Ferrari M. Translucency of ceramic materials for CEREC CAD/CAM system. J EsthetRestor Dent. 2014;26:224-31.
19. Powers JM, Dennison JB, Lepeak PJ. Parameters that affect the color of direct restorative resins. J Dent Res. 1978;57:876-80.
20. Miyagawa Y, Powers JM, O'Brien WJ. Optical properties of direct restorative materials. J Dent Res. 1981;60:890-4.
21. Nogueira AD, Della Bona A. The effect of a coupling medium on color and translucency of CAD-CAM ceramics. J Dent. 2013;41(Suppl 3):e18-23.
22. Barizon KT, Bergeron C, Vargas MA, Qian F, Cobb DS, Gratton DG, et al. Ceramic materials for porcelain veneers. Part I: Correlation between translucency parameters and contrast ratio. J Prosthet Dent. 2013;110:397-401.
23. Spink LS, Rungruanganut P, Megremis S, Kelly JR. Comparison of an absolute and surrogate measure of relative translucency in dental ceramics. Dent Mater. 2013;29:702-7.
24. Beall GH, Pinckney LR. Nanophase glass-ceramics. J Am Ceram Soc 1999;82:5-16.
25. Dias MC, Piva E, de Moraes RR, Ambrosano GM, Sinhoreti MA, Correr-Sobrinho L. UV-Vis spectrophotometric analysis and light irradiance through hot-pressed and hot-pressed-veneered glass ceramics. Braz Dent J. 2008;19:197-203.
26. Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. Int J Prosthodont. 2001;14:316-20.
27. Zhang Y, Griggs JA, Benham AW. Influence of powder/liquid mixing ratio on porosity and translucency of dental porcelains. J Prosthet Dent. 2004;91:128-35.
28. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. J Prosthet Dent. 2002;88:10-5.
29. Wood DL, Nassau K. Refractive index of cubic zirconia stabilized with yttria. Appl Opt. 1982;21:2978-81.
30. Helvey GA. Inside Dentistry. Classification of dental ceramics.Washington Crossing, PA : AEGIS Communications Partnership;2013. p 62-80
31. Kern M, Thompson VP, Beuer F,Edelhoff D, Frankenberger R,Kohal RJ, et al. All ceramic at a glance. 3rd ed. 2017.
32. IvoclarVivadent. Scientific Documentation IPS e.max® Ceram.
33. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc. 2008;139(Suppl):8s-13s.
34. VITA Zahnfabrik H. Vita Suprinity working instructions. 2015.
35. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. Dent Clin North Am. 2007;51:379-97.
36. Binns D. The chemical and physical properties of dental porcelain. In: McLean JW (ed). Proceedings of the First International Symposium on Ceramics. Chicago. 1983.
37. Kingery WD, Bowen HK, Uhlmann DR. Introduction to ceramics. 2nd ed. New York: John Wiley and Sons; 1976.p646-89.
38. Da Cunha LF, Mukai E, Hamerschmitt RM, Correr GM. Fabrication of lithium silicate ceramic veneers with a CAD/CAM approach: a clinical report of cleidocranial dysplasia. J Prosthet Dent. 2015;113:355-9.