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Effect of varying thickness and artificial aging on color and translucency of cubic zirconia and lithium disilicate ceramics

Efeito da variação da espessura e do envelhecimento artificial na cor e translucidez de cerâmicas de zircônia cúbica e dissilicato de lítio

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ABSTRACT

Objective: The aim of this study is to evaluate the effect of varying thickness and artificial aging on the color and translucency of cubic zirconia and lithium disilicate ceramics. **Material and Methods:** A total of 30 square shaped disks (12 mm x 12 mm) were fabricated from the cubic zirconia (Bruxzir Anterior) blank and lithium disilicate blocks (E.max CAD), used in three thicknesses (0.5mm, 0.8mm and 1mm). Portable spectrophotometer Vita Easyshade Advance was used to obtain color coordinates, which were substituted in formulas and used to calculate color change and translucency parameter values before and after aging (thermocycling for lithium disilicate and hydrothermal aging for cubic zirconia). Repeated measures Analysis of Variance (ANOVA) was used to study the effect of ceramic type, thickness, aging and their interaction on mean translucency parameter. Two-way (ANOVA) was used to study the effect of ceramic type, thickness and their interaction on mean color change (ΔE). **Results:** Statistical analysis showed that E.max CAD HT is more translucent than Bruxzir Anterior. Translucency decreased as thickness increased. There was a statistically significant decrease in TP after aging for both materials. Lithium disilicate showed statistically significant greater ΔE when subjected to aging than cubic zirconia, with both ΔE values being clinically imperceptible. As

RESUMO

Objetivo: O objetivo deste estudo é avaliar o efeito de diferentes espessuras e do envelhecimento artificial na cor e translucidez de cerâmicas de zircônia cúbica e dissilicato de lítio. **Material e Métodos:** Um total de 30 discos (12 mm x 12 mm) foram fabricados a partir de um bloco branco de zircônia cúbica (Bruxzir Anterior) e blocos de dissilicato de lítio (E.max CAD) em três diferentes espessuras (0,5mm, 0,8mm e 1mm). Um espectrofotômetro portátil Vita Easyshade Advance foi utilizado para obter as coordenadas de cores, que foram substituídas nas fórmulas e usadas para calcular os valores dos parâmetros de mudança de cor e translucidez antes e depois do processo de envelhecimento (termo ciclagem para dissilicato de lítio e envelhecimento hidrotérmico para zircônia cúbica). A análise de variância de medidas repetidas (ANOVA) foi usada para estudar o efeito do tipo de cerâmica, a espessura, o envelhecimento e a sua interação no parâmetro de translucidez média. Two-way (ANOVA) foi usado para estudar o efeito do tipo da cerâmica, espessura e sua interação na alteração de cor média (ΔE). **Resultados:** a análise estatística mostrou que a cerâmica E.max CAD HT é mais translúcida que Bruxzir Anterior. A translucidez diminuiu com o aumento da espessura. Houve uma diminuição estatisticamente relevante no TP após o envelhecimento para ambos os materiais. O dissilicato de lítio apresentou maior ΔE estatisticamente relevante quando submetido ao envelhecimento quando comparado com a zircônia cúbica, sendo ambos os valores de ΔE clinicamente imperceptíveis. Conforme a espessura aumentou, thickness increased, ΔE decreased. Conclusions: Thickness highly affected translucency and color of ceramics. As thickness increases, translucency parameter decreases and color change becomes less evident. Aging also causes a significant decrease in translucency parameter and induces color change however color changes are imperceptible.

KEYWORDS

Aging; Ceramics; Color; Translucency.

o ΔE diminuiu. **Conclusão:** a espessura afetou expressivamente na translucidez e cor das cerâmicas. À medida que a espessura aumentou, os parâmetros de translucidez diminuíram e a mudança de coloração se tornou menos evidente. O envelhecimento também causou uma diminuição significativa no parâmetro de translucidez das cerâmicas de zircônia cúbica e dissilicato de lítio.

PALAVRAS-CHAVE

Envelhecimento; Cerâmica; Cor; Translucidez.

INTRODUCTION

Lithium disilicate materials dominated the field of dentistry due to high simulation of natural teeth and due to long term success. Cubic zirconia is claimed to be a potential competitor and has very similar indications as lithium disilicate. A single zirconia crystal contains three phases (tetragonal, monoclinic and cubic) and zirconia is stabilized using metal oxides in the desired phase [1-3]. According to its microstructural content, zirconia could be classified into fully stabilized (FSZ), partially stabilized (PSZ) and tetragonal zirconia polycrystal (TZP) [4]. A major drawback of zirconia is its high opacity, which is overcome through different strategies. Veneering the zirconia with a more translucent ceramic is an option, however chipping and debonding of the veneering material is a common failure. Monolithic zirconia was developed to overcome this problem. Following this development, improvements in microstructure were conducted leading to enhancement of optical properties [5,6].

Modifications in microstructure and processing techniques, such as controlling grain size, increasing density of the crystals by eliminating pores and reduction of alumina content improved the optical properties of zirconia with minimal effect on mechanical properties. However, the increase in translucency was still not great enough to allow optimal esthetics to be achieved in the anterior region [7,8]. Cubic phase is the most translucent phase of zirconia, due to being isotropic in nature. Increasing the cubic phase content which is obtained by increasing yttria concentration will improve translucency, however a subsequent decrease in mechanical properties is also expected [5,9]. Cubic zirconia does not suffer from birefringence like tetragonal zirconia [10].

Lithium disilicate ceramics mostly marketed as IPS e.max is composed of a crystalline phase (70 %) and a glassy matrix. Coloring ions are dispersed in the matrix and they determine the color of the material after crystallization. Staining and glazing could also be done to reach the final desired color. IPS e.max CAD is available in three different levels of translucencies: High translucency, medium translucency and low translucency. Different translucencies are obtained by varying the size of the crystals, where increasing the size of the crystals causes an increase in translucency [11].

Artificial accelerated aging allows simulation of real-life clinical conditions to which materials are subjected to throughout their service in the oral cavity. Properties of materials, including optical and mechanical properties can be evaluated over time through performing aging over different time periods [12]. Optical properties of ceramics always have the spotlight shed on them whenever subjects are considered for research. ΔE values of less than 3.7 has been reported to be imperceivable in the oral environment [13,14]. Douglas and

Steinhauer, in 2007, [15] stated that ΔE values below 3 are considered clinically imperceptible. ΔE values between 3 and 5 are considered clinically acceptable and ΔE values above 5 are not acceptable and restorations showing a color change of 5 or more have to be remade. According to the Commision Internationale de l'Eclairage, color coordinates are L, a and b (L value stands for degree of lightness, a value is the degree of redness/greenness and b value is the degree of yellowness/blueness). Color coordinates are obtained and substituted into equations to calculate color change (ΔE) [13,14,16]. Translucency of a material is the amount of light passing through a material. The translucency of a dental ceramic also has a close relationship with its microstructure, chemical nature, the amount of crystals, the size of particles, the pores, sintered density and thus the amount of light that is absorbed, reflected, and transmitted.[17] Increase in ceramic thickness is associated with a decrease in translucency [18-20].

Artificial accelerated aging was found to affect the optical properties of cubic zirconia and lithium disilicate ceramics [21-24] and thus the aim of this study was to evaluate the effect of aging on color and translucency of cubic zirconia and lithium disilicate materials when used with different thicknesses. The null hypothesis was that artificial accelerated aging would have no effect on the color and translucency of cubic zirconia and lithium disilicate materials in different thicknesses.

MATERIALS AND METHODS

Two ceramics were used in this study, cubic zirconia (Bruxzir Anterior shaded cubic zirconia 350 Prismatik Dentalcraft, Inc) and lithium disilicate (IPS e.max CAD A3 HT Ivoclar Vivadent, Inch. Schaan, Liechtenstein), fifteen disks each (12 X 12mm). Each material was used in three thicknesses which are 0.5mm, 0.8mm and 1mm. A water cooled diamond cutting blade with a low speed cutting saw (Isomet 4000, BUEHLER LAKEBLUFF, U.S.A) was used to slide the blocks of the cubic zirconia and lithium disilicate. Bruxzir Anterior shaded 350 and HT E.max blocks are commonly used in dental practice and thus these shades were chosen in order to perform a research that would be beneficial in dental application. Cubic zirconia (Bruxzir) is not supplied in different translucencies.

The lithium disilicate block was cut into the required thicknesses whereas the cubic zirconia block was cut into disks slightly larger than the final required thicknesses to compensate for shrinkage during sintering. (Enlargement Factor of the cubic zirconia blank used=1.2300) The thickness of each disk was verified using a digital caliper.

For cubic zirconia, the specimens were sintered according to manufacturer's instructions at 1530°C with holding time 2.5 hours in a Nabertherm sintering furnace (Nabertherm GmbH. Lilienthal, Germany). Polishing of the specimens was performed using 1200 grit using silicone carbide bur. Glazing and staining to shade (A3) was performed according to manufacturer's instructions.

For lithium disilicate, pre-polishing was done using diamond rubber polisher (Optrafine F, Ivoclar Vivadent) and fine polishing was done using a high gloss rubber polisher (Optrafine P, Ivoclar Vivadent). Crystallization and glazing were performed according to manufacturer's instructions in Programat EP 3010 furnace, Ivoclar Vivadent. All specimens were finally verified again using a digital caliper for the desired thicknesses. The final thicknesses were 0.5mm, 0.8mm and 1mm.

Calculating color change and translucency

Color change measurement:

A portable intraoral digital spectrophotometer Vita Easyshade Advance (VITA Zahnafabrik, Germany) was used to obtain color coordinates (L, a, b). Color measurements were performed by positioning the aperture of the Vita EasyShade spectrophotometer (5mm in diameter) such that it is perpendicular on each disc surface.

All measurements were performed by the same operator. The aperture of the spectrophotometer was in full contact with the surface of the disc. "Tooth single" mode was selected to determine the values of the CIELab coordinates. Three measurements were taken for each specimen before and after artificial aging against white background.

The mean of each parameter (L*, a*and b* values) was calculated and was substituted in an equation to calculate color change (ΔE) of each sample between before and after aging. The Vita EasyShade device was calibrated before every measurement in order to standardize reproducibility.

Color change was calculated using the following formula:

$\Delta E = ([L^*_1 - L^*_2]^2 + [a^*_1 - a^*_2]^2 + [b^*_1 - b^*_2]^2)^{1/2}$.

Where, L^*_1, a^*_1, and b^*_1 stand for the ceramic discs before aging and L^*_2, a^*_2, and b^*_2 stand for the ceramic discs after aging.

Translucency measurement:

The same procedures were repeated to obtain color coordinates over white background and black background to calculate Translucency Parameter. Measurements were done before aging to calculate translucency before aging, then other measurements were taken for the specimens after being subjected to aging to calculate the translucency after aging. Three measurements were taken for each value, and the mean value was used.

After obtaining L, a, b values over white background and over black backgrounds, before aging and after aging, Translucency Parameter could be calculated by substitution of these values into equations. To calculate Translucency Parameter, all the obtained coordinates (over white and black backgrounds) were substituted into the following equation:

$$TP = [(L_b - L_w)^2 + (a_b - a_w)^2 + (b_b - b_w)^2]^{1/2}$$

where b is for black and w is for white.

Translucency Parameter was calculated using this formula before aging using the coordinates obtained before aging, and was calculated again after aging, using the coordinates obtained after aging.

Artificial aging procedures:

Aging of the cubic zirconia specimens

All the 15 ceramic discs were subjected to artificial accelerated aging using autoclave (Midmark, USA), at 134°C, 0.2MPa for five hours according to ISO standards 13356. Each disc was placed in a sterilization pack labelled with the ceramic material type, thickness, and specimen number. After sealing of the sterilization packs, the specimens were placed in the autoclave.

Aging of the lithium disilicate specimens

All the 15 ceramic discs were subjected to thermocycling. They were immersed in 5 °C cold bath and then in 55 °C hot bath for a dwell time of 30 seconds in each bath with a transfer time of 10 seconds in a thermocycling machine (Thermocycler Willytec THE- 1100 SD Mechatronik GmbH, Feldkirchen-Westerham, Germany). They were subjected to 10,000 cycles.

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed parametric distribution. Data were presented as mean, standard deviation (SD) and 95% Confidence Interval for the mean (95% CI) values. Repeated measures Analysis of Variance (ANOVA) was used to study the effect of ceramic type, thickness, aging and their interaction on mean TP. Two-way Analysis of Variance (ANOVA) was used to study the effect of ceramic type, thickness and their interaction on mean (ΔE). Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

Translucency Parameter:

Whether before or after aging using Lithium Disilicate or cubic Zirconia; 0.5 mm showed the statistically significantly highest mean TP. A statistically significantly lower mean TP was found with 0.8 mm thickness. 1 mm thickness showed the statistically significantly lowest mean TP. Whether before or after aging using Lithium Disilicate or cubic Zirconia; 0.5 mm showed the statistically significantly highest mean TP. A statistically significantly lower mean TP was found with 0.8 mm thickness. 1 mm thickness showed the statistically significantly lowest mean TP. Whether with Lithium Disilicate or cubic Zirconia at 0.5, 0.8 or 1 mm thicknesses; there was a statistically significant decrease in mean TP after aging. (Table I, Figure 1)

Table I - The mean, standard deviation (SD) values and results of repeated measures ANOVA test for comparison between TP values before and after aging with different interactions of variables

Ceramic type	Thickness	Before aging		After aging		P-value	Effect size (Partial eta squared)
		Mean	SD	Mean	SD		
Lithium Disilicate	0.5 mm	27.4	0.4	26.4	0.3	<0.001*	0.681
	0.8 mm	21.9	1	20.7	1.1	<0.001*	0.745
	1 mm	19.8	0.4	19.1	0.6	<0.001*	0.558
Cubic Zirconia	0.5 mm	18.7	0.6	17.6	0.6	<0.001*	0.732
	0.8 mm	14.1	0.3	13.1	0.2	<0.001*	0.659
	1 mm	12	0.1	11.2	0.2	<0.001*	0.567

*: Significant at p ≤ 0.05.

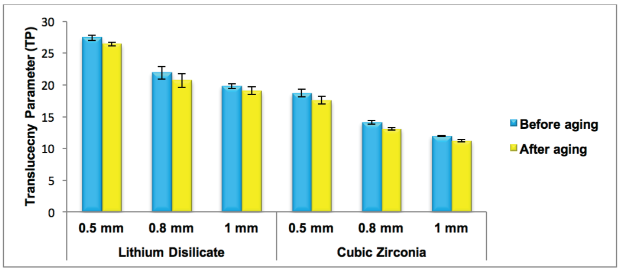

Figure 1 - Bar chart representing mean and standard deviation values for TP before and after aging with different interactions of variables.

Color change (ΔE):

Either at 0.5, 0.8 or 1 mm thicknesses; Lithium Disilicate showed statistically significantly higher mean ΔE than cubic Zirconia. With Lithium Disilicate; 0.5 mm showed the statistically significantly highest mean ΔE. A statistically significantly lower mean ΔE was found with 0.8 mm thickness. 1 mm thickness showed the statistically significantly lowest mean ΔE. While with cubic Zirconia; there was no statistically significant difference between 0.5 and 0.8 mm thicknesses; both showed statistically significantly higher mean ΔE than 1 mm thickness. (Table II, Figure 2)

Table II - The mean, standard deviation (SD) values and results of two-way ANOVA test for comparison between ΔE values of different thicknesses with each ceramic type

Ceramic type	0.5 mm		0.8 mm		1 mm		P-value	Effect size (Partial eta squared)
	Mean	SD	Mean	SD	Mean	SD		
Lithium Disilicate	1.26 ^{A}	0.03	0.78 ^{B}	0.07	0.66 ^{C}	0.05	<0.001*	0.870
Cubic Zirconia	0.55 ^{A}	0.11	0.51 ^{A}	0.13	0.32 ^{B}	0.05	<0.001*	0.511

*: Significant at p ≤ 0.05, Different superscripts in the same row are statistically significantly different.

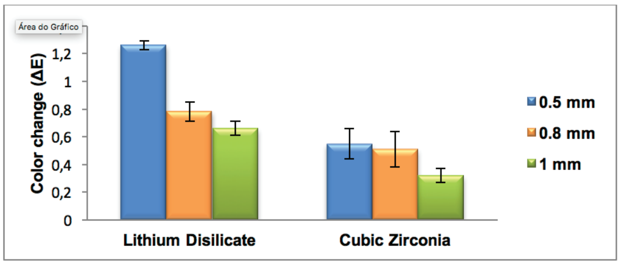

Figure 2 - Bar chart representing mean and standard deviation values for ΔE of different thicknesses with each ceramic type.

Regarding color, the L, a and b values were calculated as the difference between before and after aging. There was no separate color change before aging tested or color change after aging tested. The color change between (before aging) and another value was not measured. Color change was measured as a change of L, a and b values between before and after aging.

DISCUSSION

The aim of this study was to evaluate the effect of different thicknesses and artificial aging on the color and translucency of cubic zirconia and lithium disilicate ceramics. Five specimens were used for each thickness, which was in accordance with other research that used 5 specimens per group [20,25]. The null hypothesis was rejected, since aging was found to have an effect on color and translucency of both materials used in different thicknesses.

Opacity of 3-YTZP has always been a major concern. Increasing the yttria content to 8 mol% will completely stabilize the cubic phase of the zirconia and esthetics will be greatly improved. T-M transformation is not going to take place which means it is more stable over time, however mechanical properties will be detrimentally affected. 5 mol % yttria creates a partially stabilized zirconia with approximately 50% cubic phase, which promises the strength of zirconia and translucency closer to that of lithium disilicate, however further research is required to prove such claims [26,27]

Translucency occurs when light hits an object [28]. As thickness of a ceramic increases, translucency decreases. Crystal size and orientation, refractive indices and the number of grain boundaries are some factors that control light scattering of ceramics [5]. Translucency Parameter is recommended when there is no optical uniformity throughout the thickness of a material [29]. Contrast Ratio measures diffuse reflectance, which does not detect small changes in light transmission when materials present high scattering and absorption coefficients [30].

Vita Easy shade spectrophotometer is a device that is commonly used in the field of dental research. Translucency parameter was used in this study instead of contrast ratio (CR) since it corresponds directly to common visual assessment [8,19,31]. For color measurements, white background was used [31].

Color changes detected by a dental professional may pass unnoticed or not be of concern to the patient [32]. The mean ΔE values used in this study as “clinically imperceptible” ($\Delta E<3$), “clinically acceptable” (ΔE between 3 and 5) and “clinically unacceptable” ($\Delta E>5$) seem to be consistent with the clinical practice considering a non-color expert, which usually is the patient’s condition [31].

Autoclave treatment was used as the method of artificial aging for cubic zirconia in this study, since it was proven to induce some degree of aging [21,33]. Chevalier et al, in 1999, [34] stated that 1h of autoclave at 134°C had theoretically the same effect as 3 to 4 years in vivo. Autoclave aging was used in this study for 5h at 134 °C and 2 bar. This is equivalent to 15 years intraorally. Lughi and Sergo, in 2010, [35] stated that it takes 10 years for 25% of monoclinic to develop, which is the maximum acceptable amount, based on current international ISO standards, which imposes that a maximum of 25 vol. % of monoclinic is present after an accelerated aging test conducted for 5h at 134 °C and 2 bar. In the study of Putra et al in 2017, even extended aging periods resulted in only a small amount of T-M transformation [33].

For lithium disilicate, thermocycling was used as the method of artificial aging, which is a commonly used method in past studies [23,24,36]. These studies have performed 5000 thermal cycles which is equivalent to 6 months intra-orally only. It has been shown that 6 months of thermocycling does not produce a significant color change in lithium disilicate [23,24]. In our study, 10,000 thermal cycles were used between (5-55)°C, which is equivalent to 1 year intra-orally to evaluate color change beyond the minimum used in literature. The samples were immersed in 5°C cold bath and then in 55°C hot bath for a dwell time of 30 seconds in each bath with a transfer time of 10 seconds.

Lithium disilicate and cubic zirconia have different structures and thus aging affects both materials differently. According to literature, the aging procedure which was found effective in causing a change in each material was used.

Translucency

Statistical analysis showed that E.max CAD HT had a statistically significant higher translucency parameter value (22.6) than Bruxzir Anterior (14.5). This could be attributed to the microstructure of lithium disilicate, which is composed of spindle shaped crystals with almost the same refractive index as its surrounding glassy matrix [37].

These findings are in accordance with Kwon et al, in 2018 [27]. Turgut et al, in 2019, [22] also contributed the relatively higher opacity of zirconia to its microstructure having impurities such as pores causing a non-uniformity of refractive indices at the grain boundary, or having particle size which is larger than the visible light wavelength (380-780 nm)2, leading to a large refractive index. However, the results of this study are in contrary to the results of another study by Baldissara et al, in 2018, [38] which concluded that novel cubic zirconia materials in the market are more translucent than lithium disilicate ceramics fabricated for CAD CAM restorations due high cubic and low alumina content of cubic zirconia materials.

According to literature, the presence of a greater number of grain boundaries causes a decrease in translucency [5]. This may explain why greater thicknesses have less translucency values, as shown in this study. There will be a greater number of grain boundaries due to increase in the total volume of the structure. Decrease in translucency parameter with increase in ceramic thickness is a common finding in literature [8,18,19].

There was a statistically significant decrease in translucency parameter after aging for both ceramics, and this was correlated to their microstructure. Lithium disilicate is susceptible to water sorption due to its composite structure and thus, dissolution of the silica network due to aging could take place. Alp et al, in 2018, [24] attributed the decrease in translucency parameter of zirconia-reinforced lithium silicate and lithium disilicate glass ceramic blocks used for CAD-CAM to the water absorption which would eventually lead to dissolution of the silica network, and to the surface properties (glazing or polishing) of the lithium disilicate ceramic.

Even though the increase in cubic phase content results in less aging susceptibility, there is still tetragonal phase interspersed within the cubic zirconia structure. Cubic phase content depends on the amount of yttria stabilization in each material [5,26,39]. Munoz et al, in 2017, [5] stated that the presence of tetragonal phase within the cubic zirconia structure could result in low thermal degradation because the cubic grains tend to attract yttria from the neighbouring tetragonal grains, affecting the metastability of the zirconia structure. This could be a cause for the decrease in translucency parameter in Bruxzir Anterior in the present study, which resulted in decrease in translucency parameter.

Color

Breakdown of metallic oxides found in the structure of ceramics, and formation of peroxide compounds could be the possible cause of color change induced by aging [12]. Lithium disilicate undergoes water sorption as shown in the study by Alp et al, in 2018, [24] and this explains why it is more susceptible to changes due to aging. Cubic zirconia could relatively be less susceptible to aging due to the increase in yttria content and the higher concentration of oxygen vacancies created by the yttria particles which stabilize the zirconia in cubic phase [35].

T-M transformation will take more time or need higher temperatures than for conventional zirconia, since cubic zirconia is more resistant to aging [5,33]. According to Camposilvan et al, in 2018, [39] cubic zirconia used in their study did not undergo aging (T-M transformation) even up to 54 hours of aging and according to Putra et al, in 2017, [33] T-M transformation in cubic zirconia was detected after 100 hours of aging. This could explain why cubic zirconia is less susceptible to aging than lithium disilicate, even though color change after aging was still significant due to the presence of tetragonal phase and thus T-M transformation could take place.

The results of this study showed that color change decreases as thickness increases. This is in agreement with many studies including a study conducted by Acar et al, in 2016, [23] and also Pires et al, in 2017, [40] who concluded that increasing the thickness of ceramic increases its opacity, hinders light transmission, causes greater light scattering and reduces its translucency. This results in hindering the effect of the substrate and likewise, color change measured from the surface of samples will also be less evident in larger thicknesses. However, these results are in contrary to the results of another study conducted by Gurdal et al, in 2018, [36] who found that thickness did not have a significant effect on ΔE of different materials used for CAD CAM, which include IPS e.max CAD.

CONCLUSIONS

Under the limitations of the present study, the following conclusions could be made:

1. Lithium disilicate (Emax CAD HT) used at different thicknesses has greater translucency than cubic zirconia (Bruxzir Anterior).

2. Thickness has a crucial effect on color and translucency of ceramics. As thickness increases, translucency parameter decreases and color change becomes less evident.

3. Aging has an obvious effect on translucency parameter and color of lithium disilicate and cubic zirconia. It decreased the translucency parameter and causes color change however all color changes induced are not perceptible.

4. Lithium disilicate is more susceptible to aging than cubic zirconia and thus it witnessed greater color change.

Clinical Implications: Lithium disilicate (E.max CAD HT) and cubic zirconia (Bruxzir Anterior) could possibly be used in the anterior region at 0.5mm, 0.8mm and 1mm while retaining their optical properties, as their color change after being subjected to artificial aging was not clinically perceptible.

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