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Effect of Hydrothermal Aging on Translucency of Different Types of Zirconia and Lithium Disilicate at Variable Thicknesses

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ABSTRACT

Objective: The aim of this in vitro study was to investigate the effect of hydrothermal aging on translucency parameter (TP) of different zirconia ceramics in different thicknesses.

Material and Methods: This is an in-vitro study in which translucency of six pre-sintered and pre-shaded zirconia materials (In Coris ZI, In Coris TZI, Bruxzir Solid, KATANA HT, KATANA ST, and KATANA UT) was compared to a low-translucency, lithium disilicate glass-ceramic material (IPS e.max CAD LT, Ivoclar Vivadent). The ceramic blocks were cut in the form of plates of dimensions (14x10 mm) and of different thicknesses (0.5, 0.7,1 mm). Thirty specimens of each ceramic material were classified into three groups according to thickness (n=10) such that the total number of specimens is 210. After all zirconia specimens were sintered and lithium disilicate samples were crystallized, TP was determined using dental spectrophotometer VITA Easyshade Compact. Same procedure of translucency measurement was done again after samples were subjected to accelerated autoclave aging.

Results: Paired-Samples T- Test showed that aging caused significant reduction in TP in all materials in all thicknesses. Moreover, there was statistical significant difference ($P < 0.05$) between different ceramic materials where e.max CAD LT showed the highest (TP) and In Coris ZI showed the lowest TP in all thickness groups.

Conclusions: TP was both thickness and material dependent. TP was also affected by LTD.

1. INTRODUCTION

Decades ago, prosthodontic treatment aimed mainly at restoring the lost function. Approaching the end of the last century and with the massive demand for optimum esthetics, unacceptance of the use of metal alloys in the oral cavity evolved, leading to the development of new all-ceramic materials for prosthetic rehabilitations [1,2].

Esthetically matching ceramic restorations should reproduce shape and texture as well as the optical characteristics of natural teeth especially the inherent translucency found in enamel and dentin. Accordingly, translucency of ceramics has been marked as a paramount factor in controlling the esthetic outcome of ceramic restorations [3].

A material's translucency could be measured in several ways, among which is the translucency parameter (TP) which is defined as the color difference of a material of a given thickness over white and black backgrounds, and corresponds directly to common visual assessments. Despite the presence of multiple studies in literature, there is no consensus on the method of choice to quantify translucency of esthetic materials[4].

As much as good esthetics and optical properties of a material have to be considered when choosing a material, favorable mechanical properties, adequate clinical function and longevity should never be over- looked. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) is a popular dental ceramic that satisfies the demand of patients for metal-free esthetic restorations with its good biocompatibility, high fracture toughness, and esthetic advantages compared with metal ceramics for fixed dental prostheses [5].

Limited translucency of conventional yttria-stabilized zirconia coupled with chipping of the veneering porcelain led to serious attempts trying to optimize the production conditions to improve the optical properties. These attempts in turn increased the motivation to use monolithic zirconia restorations[2]. However, in clinical situations ceramic restorations with various thicknesses might be needed based on the different conditions of the tooth to be restored [6]. Since the material's thickness is one of the major factors that affect the esthetic outcome, an accurate knowledge of the relationship between the translucency and thickness of restorative materials is essential. Accordingly, many studies have investigated the relation between the thickness and type of zirconia restorations and the degree of translucency [7-9].

Despite its superior mechanical properties and relatively good esthetics, Y- TZP ceramics are considered vulnerable in vivo because of the phenomenon of low temperature degradation (LTD). However, some studies have been published regarding changes in the optical properties of highly translucent zirconias after hydrothermal treatment, yet results are not quite agreeing[10-15].

Currently, high-translucency monolithic zirconia materials with claims of good esthetics and strength properties are being widely marketed [7]. Our study aimed at investigating the effect of low thermal degradation on translucency parameter (TP) of different zirconia ceramics as well as lithium disilicate in different thicknesses. The null hypothesis was that neither the thickness, the material brand nor the low thermal degradation would have an effect on translucency.

2. MATERIALS AND METHODS

2.1. Samples Preparation

In this in-vitro study, six pre-sintered and pre-shaded zirconia materials; partially stabilized tetragonal full contour zirconia (In Coris TZI, Bruxzir Solid, KATANA HT), fully stabilized cubic full contour zirconia (KATANA ST, and KATANA UT) and partially stabilized tetragonal zirconia core (In Coris ZI) were compared to a low- translucency lithium disilicate glass-ceramic material (IPS e.max CAD LT, Ivoclar Vivadent) (Table 1). The ceramic blocks were cut in the form of plates of dimensions (14x10 mm) and of different thicknesses (0.5, 0.7,1 mm) using a precision saw (IsoMet 5000, Buehler) under lubrication. Such dimensions are the final dimensions that were to be reached after the 20% shrinkage during sintering for zirconia specimens. Thirty specimens of each ceramic material were classified into three groups according to thickness (n=10) such that the total number of specimens is 210. All zirconia specimens were then sintered in a high temperature furnace (inFire HTC, Dentsply Sirona) according to the specifications of the manufacturer for each material. For sintering, specimens were placed directly in a high- alumina sintering tray with no Zr_2O sintering beads and arranged in such a way that they did not touch. On the other hand, lithium disilicate specimens were crystallized in a special ceramic furnace; Programat P300/G2 (Ivoclar Vivadent, Schaan, Liechtenstein) as recommended by the manufacturer. After sintering and crystallization, the bottom surfaces of all specimens touching the sintering tray were finished and wet polished using waterproof silicon carbide sandpaper (Matador SoftFlex, Germany) of different grit sizes ranging from 320 to 1200 with a grinder-polisher machine (Buehler® EcoMet® 250 Grinder-Polisher and AutoMet® 250 Power Head). This machine adjusts the thickness and provides a perfectly flat smooth surface. The top surfaces of all specimens were left as sintered. Each specimen thickness was measured with a digital caliper (GA182, Grobet Vigor) to ensure the precise final thickness of the specimens in each thickness group.

Table 1 — Ceramic materials evaluated

Group	Material	Type	Composition	Density	Manufacturer
1	InCoris ZI	Y-TZP*	ZrO_2+HfO_2+Y2O3≥99.0%, Y_2O_3>4.5 - ≤ 6.0%, HfO2 ≤ 5%, Al_2O_3 ≤ 0.5%, Other oxides ≤ 0.5%	6.05±0 g cm-3	Sirona Dental Systems
2	InCoris TZI	Full contour Y-TZP	ZrO_2+HfO_2+Y_2O_3≥99.0%, Y_2O_3> 4.5- ≤ 6.0%, HfO_2 ≤ 5%, Al_2O_3 ≤ 0.5%, Other oxides ≤ 0.5%	6.08 g cm-3	Sirona Dental Systems
3	BruxZirFull-Strength Solid	Full contour Y-TZP	4.1%Y_2O_3,4.0%HfO_2, 0.34% Al_2O_3,≤0.01% SiO2, Fe_2O_3, Na_2O_3, balance ZrO_2	6.05 g cm-3	Glidewell Laboratories
4	KATANA HT	Full contour Y-PSZ†	(ZrO_2+Y_2O_3+HfO_2)>99.0%, Y_2O_3>4.5%-≤6.0%, HfO_2≤5.0%, other oxides≤1.0%	6.08 g cm-3	Kuraray Noritake
5	KATANA ST	Full contour Y-PSZ	ZrO_2≤89%,Y2O_3>8%, HfO_2>4%	6.06 g cm-3	Kuraray Noritake
6	KATANA UT	Full contour Y-PSZ	ZrO_2≤89%,Y2O_3>8%, HfO_2>4%	6.06 g cm-3	Kuraray Noritake
7	e.max CAD LT	Lithuim disilicate (CAD-milled)	SiO_2 57.0 – 80.0 %, Li_2O 11.0 – 19.0%, K_2O 0.0 – 13.0%, P_2O_5 0.0 – 11.0%, ZrO_2 0.0 – 8.0%, ZnO 0.0 – 8.0%,Other and coloring oxides 0.0 – 12.0%	2.5±0.1 g cm-3	Ivoclar Vivadent

* Tetragonal zirconia polycrystals (TZP): the whole material is constituted by transformable *t*-zirconia grains. It is a single phase material.

† Partially stabilized zirconia (PSZ): a matrix of cubic zirconia embedding transformable *t*-zirconia grains. It is a two phases material.

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2.2 Translucency Measurement

Translucency parameter was determined using a dental spectrophotometer VITA Easyshade Compact (Vita, Zahnfabrik H. Rauter GmbH&Co. KG.), whose CIELab output is based on D65 illuminant and a 2- degree standard observer to resemble the clinical situation. It is engineered relying on large diameter fiber optics arranged in a specific pattern in a stainless steel probe that can both illuminate the tooth and receive internally scattered and reflected light. The single-tooth mode was selected for measurement, and each specimen was measured against both black and white backgrounds. Each time, CIE Lab values were calculated. The EasyShade device was calibrated before each measurement in order to standardize the reproducibility. Each specimen was measured three times on each background and an average was recorded. The translucency parameter (TP) was obtained by calculating the color difference of the specimen over the black and white backgrounds with the following equation;

$$TP = [(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2}$$

Where **L***coordinate represents the lightness-darkness of the specimen where the greater the L*, the lighter the specimen is. The **a*** coordinate expresses the chroma along the red-green axis where positive a* relates to the amount of redness and negative a* relates to the amount of greenness of the specimen. The **b*** coordinate measures chroma along the yellow-blue axis where a positive b* relates to the amount of yellowness while a negative b* relates to the amount of blueness of the specimen. The subscript "B" refers to the color coordinates over a black background and the subscript "W" refers to those over a white background.

2.3. Accelerated Aging

All specimens of each group were subjected to accelerated aging in a steam autoclave (Sturdy SA-260MA- Class B) (Sturdy Industrial Co. LTD, New Taipei City, Taiwan) at 134 ˚C with 2 bars pressure for 7 consecutive cycles (each cycle being 45 minutes) which was clinically representative of approximately 15-25 years of intra-oral service[10]. Same procedure of translucency measurment was carried out again after the specimens were subjected to the accelerated autoclave aging.

3. STATISTICAL ANALYSIS

All data was collected, tabulated and subjected to statistical analysis. Statistical analysis was performed with IBM SPSS Statistics Version 20 for Windows. Data was explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Kruskal-Wallis test was used to compare between the different ceramic types as well as the three thicknesses. The Dunn test was used for pair-wise comparisons when Kruskal-Wallis test is significant and Paired-Samples T-Test to analyze the effect of aging. The significance level was set at $P < 0.05$.

4. RESULTS

The results of the paired-samples t-Test showed that aging had a significant effect on the TP for all samples. Additionally, the Kruskal-Wallis and the Dunn tests showed that the different ceramic materials exhibited statistically significant differences ($P < 0.05$) at all thicknesses except for the following: BruxZir Solid and KATANA HT as well as BruxZir Solid and inCoris TZI when thicknesses of 0.5 and 0.7 mm were used; KATANA UT and e.max LT only for the 0.5 mm thickness; and only inCoris TZI and BruxZir Solid among the 1 mm thick samples.

For all thicknesses, e.max CAD LT showed the highest (TP) values (TP=28.92, 26.63, 23.14) when TP was measured before accelerated aging as well as after accelerated aging (TP=25.16, 23.17, 19.9). On the other hand, In Coris ZI showed the lowest (TP) values before aging (TP=18.54, 14.36, 9.98) as well as after aging (TP=14.46, 10.69, 7.58). (Figure 1).

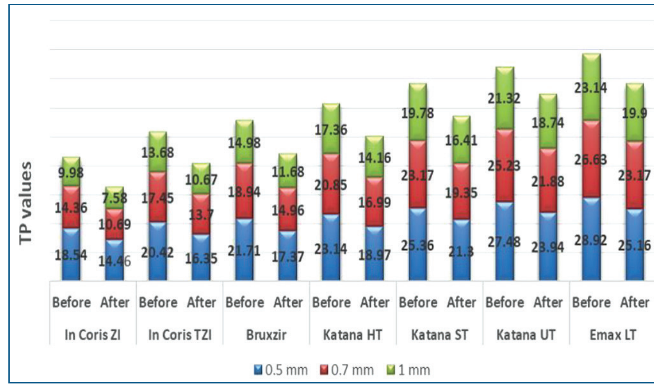

Figure 1: Bar chart showing TP values of the different ceramic materials before and after hydrothermal aging

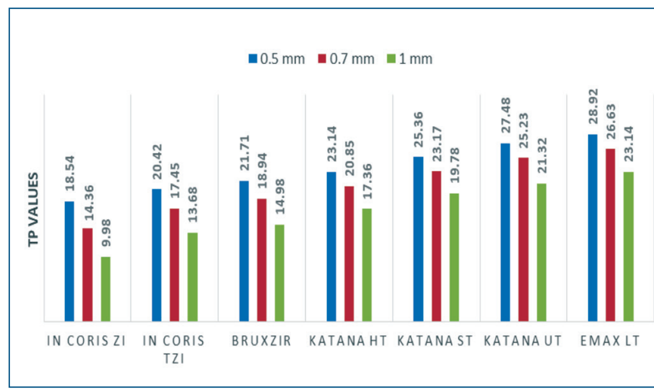

Figure 2: Bar chart showing TP values of the different ceramic materials at the three thicknesses before aging

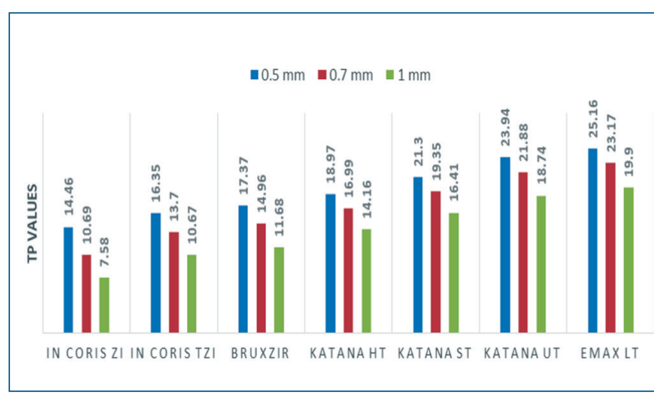

Figure 3: Bar chart showing TP values of the different ceramic materials at the three thicknesses after aging

Considering the effect of thickness, it was shown that thickness had a significant effect over TP for all thicknesses in different materials except between the 0.5 and 0.7 mm thicknesses when KATANA ST, KATANA UT and e.max CAD LT were used. This was true when TP was measured either before or after accelerated autoclave aging (Tables 2,3) and (Figures 2, 3). The percentage of the change in the TP after autoclave aging was minimal for KATANA UT and e.max CAD LT at all thicknesses compared to the other groups (Table 4).

Table 2 — Mean (SD) TP values for different materials at different thicknesses tested before hydrothermal aging.

Thickness (mm)	Mean TP (SD)						
	In Coris ZI	In Coris TZI	Bruxzir	Katana HT	Katana ST	Katana UT	Emax LT
0.5	18.54(1.1)^{eA}	20.42(0.6)^{dA}	21.71(0.8)^{cdA}	23.14(0.5)^{cA}	25.36(0.8)^{bA}	27.48(0.7)^{aA}	28.92(0.9)^{aA}
0.7	14.36(0.9)^{fB}	17.45(0.7)^{eB}	18.94(0.5)^{deB}	20.85(0.5)^{dB}	23.17(0.7)^{cA}	25.23(1.1)^{bA}	26.63(1.0)^{aA}
1	9.98(07)^{fC}	13.68(0.6)^{eC}	14.98(0.8)^{eC}	17.36(0.7)^{dC}	19.78(0.9)^{cB}	21.32(0.6)^{bB}	23.14(0.8)^{aB}

Different small superscripts indicate significance in same row
Different capital superscripts indicate significance in same column

Table 3 — Mean (SD) TP values for different materials at different thicknesses tested hydrothermal aging

	Mean TP (SD)						
Thickness (mm)	In Coris ZI	In Coris TZI	Bruxzir	Katana HT	Katana ST	Katana UT	Emax LT
0.5	14.46(0.6)^{eA}	16.35(0.7)^{dA}	17.37(0.5)^{cdA}	18.97(0.9)^{cA}	21.3(1.0)^{bA}	23.94(0.9)^{aA}	25.16(1.1)^{aA}
0.7	10.69(0.8)^{fB}	13.7(0.7)^{eB}	14.96(0.5)^{eB}	16.99(0.9)^{dB}	19.35(0.8)^{cA}	21.88(0.9)^{bA}	23.17(0.7)^{aA}
1	7.58(0.6)^{fC}	10.67(0.8)^{eC}	11.68(0.7)^{eC}	14.16(0.5)^{dC}	16.41(0.6)^{cB}	18.74(0.5)^{bB}	19.9(0.8)^{aB}

Different small superscripts indicate significance in same row
Different capital superscripts indicate significance in same column

Table 4 — Percentage of TP change for different materials at different thicknesses after low temperature degradation.

Thickness (mm)	%TP change after aging						
	In Coris ZI	In Coris TZI	Bruxzir	Katana HT	Katana ST	Katana UT	Emax LT
0.5	22	19.9	20	18	16	12.9	13
0.7	25.5	21.5	21	18.5	16.5	13.3	13
1	24	22	22	18.5	17	12.1	14

5. DISCUSSION

Translucency is one of the primary factors in controlling esthetics, and it is critical in the selection of dental materials. Yet, other factors must be considered in addition to translucency such as underlying tooth structure, cement opacity and shade, necessary thickness of the restoration, and the location of the tooth in the arch to be restored [16]. However, knowledge of a material's translucency allows the fabrication of natural-looking, esthetic restorations imitating the transition between the higher opacity of dentin and the relative translucency of enamel. When zirconia is considered for an esthetic restoration, its relatively opaque nature compared to other ceramic materials must be addressed. This opacity is mainly due to the size of the crystalline particles, which leads to greater light scattering and less translucency because less light is transmitted through the material[16].

This study aimed at investigating the effect of hydrothermal aging on translucency parameter (TP) of different zirconia ceramics as well as lithium disilicate in different thicknesses. Lithium disilicate was chosen as a control material since it has the nearest translucency to natural teeth. The (TP) was chosen for translucency measurements instead of contrast ratio (CR) because it corresponds directly to the common human visual assessment of translucency [4].

For the above study, all null hypotheses were rejected, so the brand, thickness and accelerated autoclave aging had a significant effect on TP.

It was clear in that study that as the ceramic thickness increased, the TP decreased in all materials. That was well in accordance with what was proved by **Nejatidanesh et al** [17], **Sulaiman et al** [16] **and Bunek SS et al** [18] in their studies. Though translucency parameter decreased as thickness increased in all materials, yet it was still material dependent where corresponding results were shown by **Wang et al** [8]. This could be attributed to the different composition and microstructure of each material where e-max CAD LT had higher TP values than all types of zirconia at each measured thickness which could be rendered to the nature of e.max CAD LT consisting of spindle-shaped lithium disilicate crystals having almost the same refractive index as that of the glassy matrix in which they are embedded [19]. It's well documented that among the primary factors affecting the transparency of polycrystalline ceramics are the differences in grain size, amount of porosity, second phase inclusions, and the difference of refractive indices at the grain boundaries [20]. In our study, it's clear that the nano-crystalline zirconia brands (Bruxzir Solid and Zirconia TZI) exhibited higher translucency values in all thicknesses when compared to the conventional Zirconia ZI. This is well explained by the fact that an opaque polycrystalline ceramic could be made more translucent when the grain sizes are in submicron or nano scale since the light scattering centers decrease when the grain size of Y-TZP is less than the visible wavelength (0.4 to 0.7 μm). Consequently, grain sizes in the submicron scale are among the key factors in producing translucent zirconia dental ceramics [21].

Another major source for the opacity of dental zirconia is the presence of alumina that helps averting the formation of pores when green state zirconia is placed in the furnace. The alumina also resides at the grain boundaries and aids in stabilizing the tetragonal zirconia. Since zirconia and alumina have different refractive indices, alumina content may decrease the in-line light transmission when added to zirconia [22]. In the second generation of 3Y-TZP used in dentistry, the alumina content was decreased from 0.25wt%

to 0.05wt%. This 0.05wt% alumina containing 3Y-TZP is more translucent than 0.25wt% alumina- containing 3Y-TZP [23].

Inokoshi et al [24] declared a clear and significant correlation between translucency and the amount of *c*-ZrO2 phase when they compared the translucency of different high translucent zirconias (KATANA ST, KATANA STML, KATANA UTML, Kuraray Noritake; Zpex Smile, Tosoh). In their study, XRD with Rietveld analysis showed that KATANA UTML (Kuraray Noritake), which showed the highest translucency, contained the highest amount of cubic zirconia (*c*-ZrO2) phase (71 wt%), whereas KATANA HT (Kuraray Noritake), the one with the lowest translucency, contained the lowest amount of *c*-ZrO2phase (41 wt%). KATANA STML (Kuraray Noritake) showed about 60 wt% *c*-ZrO2 and fell mid-way, in term of translucency, between KATANA UTML and KATANA HT. The authors explained such results by the fact that the *c*-ZrO2 phase is more translucent than the *t*-ZrO2 phase owing to its isotropic crystal structure which decreases the light scattering that occurs at grain boundaries [12,14]. This isotropic structure of *c*-ZrO2 highly translucent zirconia is different from the anisotropic crystalline structure of the conventional and translucent *t*-ZrO2. Such an anisotropic structure causes reflection and refraction at grain boundaries in different directions and thus reducing light transmittance [22]. As a result the cubic zirconia appears more translucent.

Having previously pointed out, and based on our results, that the change in translucency with changing the thickness was material dependent, it is clear that for KATANA S, KATANA UT and e.max LT which are highly translucent materials, that changing the thickness had an impact on TP only in the high thickness groups. Both Katana ST, Katana UT and e.max CAD LT showed only significant drop in the TP at the thickness of 1mm implicating that with slight changes in thickness only minor changes occur in TP. These results were opposite to what was previously proved by **Wang et al**[8] who stated that the more translucent a ceramic was, the greater the change in TP would be expected as a result of changing the thickness. However, it was obvious that at the 1 mm thickness, the e.max CAD still showed higher degree of translucency than KATANA ST and KATANA UT. Though such result was inconsistent with what was shown by **Baldissara et al** [25] when they compared the translucency of e.max CAD LT and KATANA UT crowns of 1.5 mm thickness, results were in agreement with what was proved by **Harada et al** [12]. However, the translucency of KATANA ST at 1 mm thickness was almost comparable to that of natural teeth knowing that the TP value of human dentin with a thickness of 1.0 mm has been determined to be 16.4 and that of human enamel 18.1[3].

Turning our attention to another aspect, i.e., considering the phenomenon of LTD in zirconia, LTD has been proven to start at the surface and proceeds inwards causing surface uplifting with subsequent surface roughness and esthetic degradation [26]. Yet, limited data regarding changes in the optical properties of highly translucent zirconias after hydrothermal treatment is available [12,13].

Since it is difficult to simulate LTD in the laboratory and having proved that autoclave treatment could induce some degree of aging, autoclave aging was proposed as a good method to perform an accelerated test for low temperature degradation (LTD) [27]. Since **Chevalier et al** [10] reported that 1hour of autoclaving at 134°C had- theoretically- the same effect as 3 to 5 years in vivo, samples-in the current study- were subjected to autoclave aging for approximately 5 hours at 134°C and 2 bar.

Based upon our results, the effect of aging was clear in all thicknesses in different materials which might be due to the existence of internal pores and impurities within the structure associated with the process of spontaneous transformation of the metastable tetragonal phase to the monoclinic phase taking place during LTD. Such process is known to cause volume expansion of the grains, inducing surface roughening, and micro cracking [28]. However, the effect of aging was less pronounced in e.max CAD and the cubic higher translucency zirconia type (KATANA ST and KATANA UT) due to material structure where the grain boundaries of cubic zirconia are less vulnerable to water attack than those of tetragonal zirconia and thus cubic high translucency zirconia is less liable to low thermal degradation. This could be referred to the higher concentration of oxygen vacancy in grain boundary space-charged layers than that of tetragonal zirconia, and the smaller grain-boundary area in cubic zirconia. Increasing the yttria stabilizer content, which is one of the well-known tactics frequently employed in suppressing the degradation, could also be of major role in decreasing the vulnerability of cubic zirconia grains to LTD [29].

Putra et al [14] have previously studied the effect of aging on transmission percentage of several brands of highly translucent zirconias. They stated that the amount of monoclinic transformation as a result of hydrothermal degradation was brand dependent and so was the transmission percentage after low temperature degradation. They showed that KATANA ST showed minimal surface changes and increase in monoclinic phase when subjected to low temperature degradation. On the other hand, hydrothermal degradation did not affect the lithium disilicate material that maintained its high light transmittance capability throughout the entire aging treatment. That was partially opposite to our results where lithium disilicate showed reduction in translucency after aging treatment, yet that reduction was minimal. Lithium disilicate has been reported to be liable to suffer from slow crack propagation when subjected to aging through cyclic fatigue. Autoclave aging of lithium disilicate is thus considered a method of aging that might have caused slow crack propagation inside the material, facilitating water penetration inside the material and consequently the dissolution of the silica network. Such a process would have likely caused decreased crystallinity of the material with a subsequent decrease in the TP [30]. However, the highest drop in TP was noted in conventional Y-TZP (InCoris ZI) when subjected to hydrothermal treatment. Many authors showed that increased grain size causes the tetragonal phase to be less stable and thus increases the susceptibility for LTD. According to multiple studies, critical grain size- i.e. the grain size below which t-m transformation is greatly impeded - of 55-360 nm was defined [31,32].

According to results obtained from this study, it was clear that (e.max.CAD) LT still showed better translucency than the highly translucent zirconia. Although the difference in translucency at 1mm thickness is only 14%, yet it might affect the esthetic outcome of highly esthetic anterior restorations. Since different types of zirconia showed significant differences in their translucencies, it might be recommended that the conventional Y-TZP (Zirconia ZI) could be used in cases where high masking ability such as a restoration over a metallic implant abutment. On the other hand, the highly translucent zirconia (KATANA ST and KATANA UT) and ax CAD LT would be highly recommended in anterior esthetic restorations since they could mimic the inherent translucency of enamel and dentin.

Further research is yet needed to assess the effect of the abutment stump color, cement thickness and other factors on translucency. Also, more in vivo studies are needed to evaluate the impact of occlusal forces and oral conditions on the degradation rate of the highly translucent zirconia and its effect on the optical properties of the material.

6. CONCLUSIONS

Within the limitations of the current study, it was concluded that translucency parameter was affected by both material brand and thickness where it increased with decreasing the thickness for all materials. TP was also negatively affected by LTD in all thicknesses in different materials. e.max.CAD was still more translucent than the highly translucent zirconia used in all thicknesses.

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