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Evaluation of Some Mechanical and Optical Properties of Zirconia and Lithium Disilicate Materials after Hydrothermal Aging

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ABSTRACT

Background: Dental ceramics have become a very popular material for the manufacturing of fixed dental prosthetics, a new manufactural technique was introduce recently , for construction of new zirconia blank that consist of two generation of zirconia in order to get the benefit of both generation to get more durable an esthetic restoration.

Aims of the study: Evaluate the effects of hydrothermal aging on the flexural strength and translucency for tow type of zirconia and lithium disilicate, and to compare them with each other

Materials and methods: Forty five samples have been prepared from tow type of zirconia (ZirCAD MtMulti (4Y-5Y); ZirCAD Prime (3Y-5Y)) and lithium disilicate (IPS e.max CAD HT). Ten samples was used to test flexural strength form each type dental ceramic (half of them before aging and half after aging); five samples used to test translucency before and after aging. Aging was performed by using autoclave for 7.5 hours at 134^{0}C and 0.2 bar pressure. Data were analyzed using paired t-test; independent t-test and One Way ANOVA Duncan's tests at 5% level of significance also performed.

Results: There is No statically significant difference on flexural strength and significantly decrease on the translucency of both type of zirconia and lithium disilicate after hydrothermal aging. ZirCAD MtMulti had intermediate flexural strength and translucency parameter between ZirCAD Prime and IPS e.max CAD HT before and after aging.

Conclusion: Hydrothermal aging had No effect on flexural strength, and decrease the translucency parameter for all dental ceramic. Lithium disilicate had the lowest flexural strength value and highest translucency. When yttria concentration increases the flexural strength decrease and translucency increase.

Keywords: Translucent monolithic zirconia, Aging, Optical properties, Mechanical properties, Lithium disilicate

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INTRODUCTION

Dental ceramics have become a very popular material for the manufacturing of fixed dental prosthetics, ranging from "veneers, inlays, and on lays to full-crown restorations, implant abutment, screw-retained prosthesis and bridges" [1].

In the group of materials known as particle-filled glass, lithium disilicate is categorized as a glass-ceramic. The commercial formulation known as "IPS Empress 2" was first made available on the market in the 1990s by Ivoclar Vivadent, Schaan. This material was initially offered for sale as ingots, to be used in accordance with the "heat-pressing" fabrication process intended to produce "cores, hot pressed" into a mold. The cores are then veneered with an extremely translucent Fluor apatite ceramic, in order to provide an attractive replication of the optical features of natural teeth [2-4].

In contrast to more conventional glass-ceramics, a new lithium disilicate formulation known as "IPS e.max Press by (Ivoclar Vivadent)" was introduced in 2005; this formulation has superior mechanical qualities and optical characteristics. In addition the prominent, expanding use of CAD-CAM technologies has resulted in the emergence of ceramic blocks intended for milling restorations "IPS emax CAD". Blocks that have been partially pre-crystallized are created in a "purple state". These blocks offer a moderate "flexural strength, which leads to improved cutting efficiency, faster workability, and less tool wear [5].

In this pre-crystallized stage, the milling technique is carried out, and when it is finished, the sample exposed for " heating cycle (840–850 °C for 10 min.) which converts the meta silicate crystals into lithium disilicate (70%)", improving the flexural strength and fracture toughness. The blocks can be found in a variety of levels of translucency and various color degrees were achieved by distributing staining ions in the "glassy matrix" Lithium disilicate, which is categorized as a "glass-ceramic", is one of the most widely used dental ceramic materials because of its good bonding to tooth structure, simple fabrication process, and acceptable aesthetic appearance. When it comes to mechanical resistance, it has been demonstrably shown that lithium disilicate exhibits much lower fracture load values than monolithic zirconia, with bulk fracture being start at the occlusal area [6-8].

In addition to having acceptable mechanical properties and excellent biocompatibility, lithium disilicate also has excellent aesthetic qualities. Because it contains silica, lithium disilicate is also an acid-sensitive ceramic, which results in its strong adhesion to the substrate because of both chemical and micromechanical bonding mechanisms. By using physical processes like alumina particle sandblasting or diamond bur grinding, as well as acid etching, it is possible to create surface micro imperfections, pits, and roughness that are used to mechanically interlock ceramics and resin cement [9].

Zirconia is another type of dental ceramic that is use in dentistry, zirconium's usage in dentistry began in the 1990s with root canal posts and later expanded to prosthetic abutments. However, the opportunity to produce ceramic posterior fixed partial prostheses accelerated the growth of zirconium's use in dental prosthetics. Zirconia restorations have superior esthetics in comparison to conventional porcelain fused to metal restorations because of their great optical qualities and, in particular, since they do not have the black line that conventional restoration created by metal in the cervical region [10].

Zirconia is a polymorphic material that can take on three different shapes depending on the temperature: monoclinic, tetragonal, and cubic. The monoclinic phase of pure zirconia, which is the most stable, is present at room temperature. When the temperature reaches around 1170°C, the monoclinic phase changes into the tetragonal phase, which is accompanied by a volume reduction of roughly 4-5%.While just minor volume changes, when the tetragonal phase transitions into the cubic phase at roughly 2370°C. On cooling, the transformation from the tetragonal to the monoclinic phase starts at 1052 °C .The zirconia tetragonal-to-monoclinic phase transformation is known to be a martensitic transformation [11-13].

The tetragonal phase of zirconia, which is used in dentistry, has historically been stabilized at room temperature by doping the material with 3 mol% yttrium. Tetragonal zirconia polycrystals stabilized with yttria at a 3 mol% concentration (3Y-TZP) show good mechanical characteristics but has low translucency. In an effort to increase the translucency of standard (3Y-TZP) grades, cubic-phase crystal can be stabilized at room temperature by adding 4-5 mol yttria and it's called (4Y-PSZ) or (5Y-PSZ) [14].

In order to benefit from both zirconia generations, a combination of 3Y-TZP and 5Y-PSZ was created by mixing two generations of zirconia (each with a different percentage of yttria) in a single blank. Essentially, a 5Y-TZP with a high translucency in the incisal or occlusal sites is combined with a 3Y-TZP with a high flexural strength in the dentin/body region for improved aesthetics [15].

A new generation of zirconia known as "monolithic zirconia". Monolithic zirconia restorations, according to the manufacturers, has a higher translucency than conventional zirconia and therefore does not need a veneer layer. Without the use of a veneer, the amount of tooth loss and the risk of chipping are reduced [16].

When compared to other ceramic systems, particularly glass-ceramics, zirconia has a higher flexural strength and fracture toughness. Traditional zirconia have a flexural strength of (900 MPa) and this flexural double than that of lithium disilicate. The Mechanical properties of Zirconia's differ from type to other depend on the method of zirconia's stabilization. Although the flexural strengths of dental zirconia drop as the yttria content rises, their hardness is practically constant [17].

When zirconia in its (Y-TZP) forms, zirconia is generally employed as a prosthetic material for indirect restorations. Under the impact of mechanical, thermal, or combined stresses, the adsorbed energy can break some of the atomic bonds in a polycrystalline structure, leading such tetragonal crystals to transform into a stable monoclinic shape. Transition of phases is spontaneous and permanent alteration is referred to as Phase Transformation Toughening (PTT). During PTT the unit cell of monoclinic configuration occupies about 4% more volume than the tetragonal configuration, which is a relatively large volume change significantly increasing the material's compressive stresses [18,19].

This PTT advertised as a paramount advantage, because it allows a kind of self-reparability of zirconia; indeed, it permits to block or at least to hinder the propagation of micro-cracks and fractures within the material. In fact the subsequent volumetric increment of the crystals generates comes within the material at the fracture tip, limiting crack propagation. At room temperature, this transformation is irreversible, localized, and concentrated at the stress-bearing region. And when the limiting impact of the fracture propagation has taken place, zirconia is no longer able to limit cracks further in its monoclinic configuration [20-22].

But even in the absence of stress, contact with water or humidity, such as bodily fluids, can cause the metastable tetragonal phase at the material surface to change.

Kobayashi et al. initially described these phenomena, which is also referred to as "aging" or "LTD". A number of factors, including crystal size, temperature, surface flaws, manufacturing processes, the amount and distribution of stabilizing oxides, mechanical stress, and moisture, all have an impact on the LTD. The LTD is known to deteriorate the features of zirconia, causing the development of micro cracks, a decrease in toughness, increased wear, roughening, and plaque deposition, as well as a severe surface degradation that affects both mechanical and optical qualities [23,24].

Aging occurs through a slow surface transformation to the "monoclinic" stable phase. This transformation begins in individual particles on the surface in the presence of water at relatively low temperatures through stress-induced mechanism. The transformation occurs through nucleation and growth processes. This transformation leads to the distinctive volume increase that will prompt stress in the neighboring grains and micro-cracks. These results in a cascade of transformations, to neighboring grains which increases the transformed zone, offering a way for water to penetrate inside the material Figure, the attempt to minimize the degradation at low temperature (LTD) of 3Y-TZP includes reducing the particle size, increasing the content of a stabilizing oxide, or even the formation of composites with aluminum oxide (Al2O3). The simultaneous occurrence of phase transformation toughening and aging is similar to a two-edged sword: on the one hand, stress-induced transformation improves mechanical characteristics; on the other, low temperature degradation which promotes surface transformation introduces grain pull-up, roughens the surface, and starts cracks [25-27].

Aim of the Research

Study the effects of artificial aging on the flexural strength and translucency of ZirCAd Prime (3Y-5Y) dental zirconia with ZirCAD MtMulti (4Y-5Y) dental zirconia and lithium disilicate (IPS e.max CAD HT).

Compared the flexural strength, and translucency properties of lithium disilicate (IPS e.max CAD HT), ZirCAD MtMulti (4Y-5Y) dental zirconia, and ZirCAD Prime (3Y-5Y) dental zirconia [28].

MATERIALS AND METHODS

The samples that prepared in this study from tow type of dental zirconia (ZirCAD Prime (3Y-5Y)), (ZirCAD MT Multi (4Y-5Y)) and one type of lithium disilicate (IPS e.max HT). Forty five samples were divided into two main groups according to the type of test to be done.30 samples for flexural strength test 10 from each type dental ceramic materials; half of the samples from each type of dental ceramic material were undergone artificial aging. 15 samples for translucency test 5 from each type of zirconia and lithium disilicate where tested before aging and after aging [29].

The sample for three-point flexural strength have a rectangular cross section and the dimensions of sample are 1.5mm (+0.02 mm) thickness × 4mm (+0.02 mm) width x 16 mm(+0.02 mm) length , ISO 6872-201. Sample design for translucency test, is squared in shape and the dimension of sample for translucency test is 1.5mm thickness × 10mm width x 10 mm length [30-32].

For aging of the samples, each sample put inside the glass test tube and put all the tubes in the stainless steel rack, for aging we used autoclave unit (model B, Max 8A, Runda, China). Following ISO 13356 - 2015 recommendations, then test tube rack with sample put inside the autoclave unit under a pressure of 2.1 bars with a temperature of 134°C for 7.5 hours of *in vitro* aging equivalent to approximately 20 years in the oral cavity, 30 samples aged at same time according to ISO 13356-2015.

For three point flexural strength test the universal testing machine (Gester GT-K03B / China) used to this test, the base of the machine , consisting of support rollers 2.5 mm, in diameter to support the sample while testing . The desistance between the centers of the two rods where the sample placed is 12 mm; the load shall be applied at the midpoint between the supports by means of a third roller. A universal testing machine and specimens were loaded at a cross head speed of 1 mm/min while the base was stable. the maximum load of sample fracture was record in newton (N) and should be transferred to (Mpa) so formula describe in ISO 6872-2015was used as follow F=3PI / 2wb^2

P is the breaking load, in newton's.

I is the test span (center-to-center distance between support rollers), in millimeters.

w is the width of the specimen.

b is the thickness of the specimen.

Colorimeter was used to determine the Translucency Parameter (TP), the test specimen's two types of zirconia and one type of lithium disilicate placed on white or black backings. All specimens were measured at four predetermined sites, using bi-directional (45°/0°) measuring geometry with CIE illuminant D65 brightness and 2° observer function ISO (28642- 2016) against the white and black background. The Translucency Parameter (TP) was calculated by the following formula:

TP = ([Lb-Lw]2+[ab-aw]2+[bb-bw]2)1/2.

L: The lightness value, also referred as differences in color parameter lightness

a: Axis is represent to the green-red coordinate.

b: Axis represents the blue-yellow coordinate.

(Lb: Lights placed on black); (Lw: Lights placed on white); (ab: a axis placed on black); (aw: an axis placed on white), (bb: b axis placed on black); (bw: b axis placed on white)

A higher TP value means higher translucency. A TP of 100 describes the color difference between black and white for a fully transparent material. In contrast, a TP of 0

Table 1: Descriptive Statistics for All Groups of Ceramics Materials and Their Effect on Flexural Strength.

	n	Mean	Std. Deviation	Minimum	Maximum
Zir Cad prime non aged	5	820.026	65.2742	718.7	898.48
Zir Cad prime aged	5	807.59	50.3243	732.8	849.9
Zir Cad Mt Multi non aged	5	700.744	93.21084	537.15	767.83
Zir Cad Mt Multi aged	5	643.844	97.97604	498.26	767.83
IPS e.max cad non aged	5	337.412	21.156	310.33	366.33
IPS e.max cad aged	5	315.106	17.308	219.66	337.63

Table 2: Descriptive Statistics for All Groups of Ceramics Materials and their Effect on Translucency Test.

	n	Mean	Std. Deviation	Minimum	Maximum
Zir CAD prime non aged	5	5.576	0.11059	5.46	5.76
Zir CAD prime aged	5	5.078	0.0563	5.01	5.16
Zir CAD Mt Multi non aged	5	5.764	0. 12012	5.65	5.93
Zir CAD Mt Multi aged	5	5.212	11234	5.05	5.31
IPS e.max CAD non aged	5	11.442	0. 15255	11.32	11.69
IPS e.max CAD aged	5	11.168	0. 06760	11.1	11.28

characterizes a totally opaque material without any color difference against a white and black background [33].

RESULT

The result of flexural strength test of dental ceramic material (ZirCAD Prime (3Y-TZP&5Y-TZP), ZirCAD MT Multi (4Y-TZP&5Y-TZP) and IPS e.max CAD HT) show slight decrease in flexural strength but no significant difference appear between the non-aged and aged sample as shown in tables. ZirCAD Prime had the higher flexural strength followed by ZirCAD MT Multi and the lowest value recorded for IPS e.max CAD HT before and after hydrothermal aging.

The result translucency parameter of dental ceramic material (ZirCAD Prime (3Y-TZP&5Y-TZP), ZirCAD MT Multi (4Y-TZP&5Y-TZP) and IPS emax CAD HT) show significant difference appear before and after hydrothermal aging and there were decrease in translucency parameter for all dental ceramic material. IPS e.max CAD HT had the higher translucency parameter followed by ZirCAD MT Multi and the lowest value recorded for ZirCAD Prime before and after hydrothermal aging, as shown in tables.

DISCUSSION

One of the main disadvantages of the Y-TZPs is represented by their low-temperature degradation, a superficial aging phenomenon that may take place in the presence of water. This process consists of a slow tetragonal to monoclinic transformation of the grains at the surface, The low-temperature degradation leads to a progressive deterioration of mechanical and optical properties.

In this study the result of flexural strength test of dental ceramic material (ZirCAD Prime (3Y-TZP&5Y-TZP), ZirCAD MT Multi (4Y-TZP&5Y-TZP) and IPS e.max CAD HT) show slight decrease in flexural strength but no significant difference appear between the non-aged and aged sample the finding of current study was in consistent with many researchers, who stated that there were no significant differences in flexural strength before and after hydrothermal aging in autoclaved for 0, 5, and 10 h at 134°C and 0.2MPa when compare three multilayered blocks of zirconia (Katana Zirconia Multi layers ML(3Y-TZP), super translucent multi layers STML (4Y-TZP), and ultra-translucent multi layers UTML(5Y-TZP). Winter et al. (2022) they demonstrated that combined 3Y and 5Y after hydrothermal aging did not significantly affected, whom analyzed the impact of hydrothermal aging (134C,0.2 MPa,2 hours and160 hours), on lithium-disilicate (LiSi2) an it was not affected by hydrothermal aging.

A possible explanation for no change in flexural strength before and after hydrothermal aging is that the three point flexural strength after aging is related to the extension of cracks and the amount of monolithic -phase observe. Because tetragonal to monolithic transformation occurred only on the external surface with shallow depths while the internal flaws were not affected so that the flexural strength values was not affected by the amount of the monoclinic transformation after accelerated aging. Another contributing aspect could be the high-strength 3Y-TZP core's and its “cold isostatic” manufacturing process, which increases material density, as well as the material's high alumina content, which will minimize porosity by reducing grain size and increasing particle density. For IPS e.max CAD (lithium disilicate) ceramic material in this study no significant change in flexural strength before and after hydrothermal aging, because lithium disilicate is not polymorphic in nature, and does not experience water penetration or LTD. As a result, artificial aging had no effect on the flexural strength of lithium disilicate ceramic material. As comparison among the three types of dental ceramic materials examined in the present study for non-aged and aged sample revealed that the Zir CAD Prime (3Y-5Y) had the highest biaxial flexural value for non-aged and aged group followed by Zir CAD MT Multi (4Y-5Y) and the lowest one was lithium disilicate

(IPS e.max CAD HT) [34].

This finding was in consistent with results of studies that found increasing yttria percentage had adverse effect on zirconia flexural strength who evaluate the flexural strength of three different type of dental ML(3Y-TZP), STML (4Y-TZP), and UTML(5Y-TZP) , before and after aging the result was ML(3Y-TZP) specimens showed the highest values of flexural strength and the UTML (5Y-TZP) specimens the lowest three-point flexural strength values in all groups before and after the aging.

This may be due to the presence of residual monoclinic grains that operate as compression zones in conjunction with the larger tetragonal grains, these materials have a higher flexural strength and a wider shielding zone at the crack tip, while due to the high proportion of cubic phase compared to tetragonal phase, both of which have little effect on zirconia toughening, the 5Y-PSZ demonstrated reduced resistance. The flexural strength values are thus lower than those of samples with 3 mol%.Y2O3. While lithium disilicate, small needle-shaped crystals embedded in a glass matrix, that can be explained why the lithium disilicate have the lowest flexural strength.

According to the result of this study the translucency parameter of dental ceramic material (ZirCAD Prime (3Y-TZP&5Y-TZP), ZirCAD MT Multi (4Y-TZP&5Y-TZP) and IPS emax CAD HT) show significant difference appear before and after hydrothermal aging and there were decrease in translucency parameter, as shown in tables.

This finding was in consistent with other studies, who stated that there were decrease Translucency Parameter (TP) of zirconia after aging in autoclave for 5h at 134C and 0.2 Mpa when evaluate the effect of hydrothermal aging on of different zirconia ceramics (In Coris ZI (3Y-TZP) , In Coris TZI (3Y-TZP), Bruxzir Solid (3Y-TZP) , KATANA HT (3Y-TZP) , KATANA STML (4Y-TZP), and KATANA UTML (5Y-PSZ). Also with Lümkemann, & Stawarczyk, who stated that the effect of the hydrothermal aging on zirconia and lithium disilicate related to aging hours, when compare translucency of different brand of dental zirconia (5Y-TZP, 4Y-TZP, 3Y-TZP) and lithium disilicate before and after hydrothermal aging the result was reduced the (TP) over the aging time for all tested materials aging protocol was performed in autoclave at (134 °C, 0.2 MPa) and for 0,2,5,10, 20, 40, and 160 hours [35].

The possible explanation of decrease in translucency For ZirCAD Prime (3Y-5Y) and ZirCAD MT Multi (4Y-5Y) after hydrothermal aging, due to aging created a generalized irregular surface with micro retentive areas on the surface, micro cracking act as porosity which scattering of light thereby decrease translucency. For lithium disilicate the possible explanation of decrease in translucency of after aging could be that after aging, selective ion leaching may induce porosity, this porosity resulting in changing in translucency.

As comparison among the three types of dental ceramic materials examined in the present study for non-aged and aged sample revealed that the translucency parameter (TP) of the lithium disilicate (e.max CAD ht) was the highest one followed by Zir CAD MT Multi (4Y-5Y) and the Zir CAD Prime (3Y-5Y) was the lowest one and the result was same after hydrothermal aging.

These findings were in agreement with study made by who compare the Translucency Parameter (TP) of 5Y-ZP (Katana UTML) with 3Y-TZP (Katana HT) and lithium disilicate (e.max CAD). The result was that the lithium disilicate have the height translucency parameter (TP) followed by 5Y-ZP (Katana UTML) and the lowest one was 3Y-TZP (Katana HT).

This observation might be explained by the fact that IPS e.max CAD (lithium disilicate) had a higher TP than all varieties of zirconia pointed to the nature of lithium disilicate, which consists of spindle-shaped lithium disilicate crystals with nearly the same refractive index as the glassy matrix in which they are embedded. As opposed to lithium disilicate, zirconia is opaque in nature and this opacity is mostly caused by the size of the crystalline particles, which results in increased light scattering and fewer translucencies.

For ZirCAD MT Multi, the TP is greater than for ZirCAD Prime, this could be accounted for by the fact that the cubic zirconia phase has a higher transparency than the tetragonal zirconia phase due to its isotropic crystal structure, which reduces light scattering at grain boundaries. In contrast to the tetragonal zirconia's anisotropic crystalline structure, this reduces light transmittance by causing reflection and refraction at grain boundaries in different directions [36].

CONCLUSION

Within the limitation of this study it has been concluded the following:

Hydrothermal aging for 7.5 hour had no effect on flexural strength of both zirconia and lithium disilicate. While had decrease translucency parameter of both zirconia and lithium disilicate.

Lithium disilicate had the lowest flexural strength value and highest translucency as compared to both type of zirconia before and after aging.

When yttria concentration increase the flexural strength decrease and translucency increase, (3Y-TZP&5Y-PSZ) zirconia shows the highest flexural strength and lowest translucency value before and after aging. While (4Y-PSZ&5Y- PSZ) zirconia has shown intermediate a flexural strength and translucency values, between Lithium disilicate and (3Y-TZP&5Y- PSZ) zirconia.

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