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Influence of Low-Temperature Degradation on Phase Transformation and Biaxial Flexural Strength on Different High-Translucent 4Y-PSZ, 5Y-PSZ, 6Y-PSZ Monolithic Zirconia

Gülsüm Doğru, Handan Yılmaz

Gazi University, Faculty of Dentistry, Department of Prosthodontics, Ankara, Türkiye.

Correspondence Author: Handan Yılmaz
E-mail: hozkula@gmail.com
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ABSTRACT

Objective: This study aimed to investigate the effect of low-temperature degradation (LTD) in phase transformation and biaxial flexural strength of high-translucent yttria partially stabilized zirconia (Y-PSZ) and yttria tetragonal zirconia polycrystalline (3-YTZP).

Methods: A total of 120 new high-translucent 3-YTZP (NMS) and Y – PSZ (KST, KUT, NQ3MS) zirconia disc specimens were manufactured according to ISO 6872 for biaxial flexural strength (14 mm., 1.2 ± 0.02 mm). The specimens from each type of material were divided into 3 subgroups (n:30) according to the LTD in an autoclave at 134 C0 at 2 bar (n:10) (at 5, 20 hour (h)). Specimens without LTD served as the control. Data of the monoclinic phase changes (Xm) and flexural strength were analyzed using two-way ANOVA followed by post hoc MannWhitney U test. Weibull statistics were used to analyze strength reliability.

Results: LTD increased the monoclinic content significantly for NMS and slightly for the KST group. A monoclinic phase was not detected for KUT and NQ3MS groups. The biaxial flexural strength of the NMS group was affected significantly and decreased with an increase in the 20 h aging. For flexural strength values, there was no significant difference in aging times for each of the KST, KUT, and NQ3MS groups. Weibull analysis showed the highest characteristic strength for NMS (1412.9), KST (750.1), NQ3MS(790.5) and KUT (615.2) groups. The Weibull modulus (m) increased in the NMS, KUT, and NQ3MS groups compared with the control group and decreased in the KST group.

Conclusion: LTD caused a significant decrease in the biaxial flexural strength results of the NMS group but did not significantly affect the KST, KUT, and NQ3MS groups' values.

Keywords: High-translucent zirconia, Low-temperature degradation, Phase transformation, Biaxial flexural strength

1. INTRODUCTION

Y-TZP is the most widely used material in the construction of all-porcelain syetems (1,2). Zirconia is a material consisting of 3 different phases.: monoclinic (m), tetragonal (t), and cubic (c)(3). The m phase is a stable phase at low temperatures up to 1170°C and with the increase transforms into a tetragonal phase (4,5) and then at 2370°C into a cubic phase (5). The transformation from the tetragonal phase to the monoclinic phase (t→m) occurs during cooling below about 970°C and 3%-4% volumetric increase forms in the material, that creates compressive stresses (3,4). Thereby, the crack tip closes and more crack propagation is prevented (4). In addition to the positive effect on the crack tip, the t→m transformation decreases mechanical stability (6,7). 3Y-TZP zirconia used in prosthetic dentistry, which is an opaque material and has limited translucency, often contains 3 mol% yttria as a stabilizing element (2,4,8,9). Recently, highly-translucent Y-TZP ceramics have become popular for making monolithic restorations. New methods have been used to improve the translucency of traditional 3Y-TZP zirconia, including increasing the yttria content. Decreasing the addition of alumina from 0.25% to 0.1% can increase translucency, and adding 0.2 mol% La_2O_3 to Y-TZP changes the sintering time and temperature and reduces the grain size. Thus, it also effectively eliminates light scattering and can improve transparency (2,8,10,11).

Another disadvantage of 3Y-TZP restoration is that Y-TZP undergoes a negative phase transformation known as LTD (12,13). In the presence of water at low temperatures, a t→m phase transformation occurs. Thereby, the transformation progresses from the surface to the interior of the material (12,13). LTD causes surface roughness and followed by microcracking (14,15) and negatively affects the mechanical properties of Y-TZP (14-17). The sensitivity of Y-TZP to LTD

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depends on several factors. The transformation is slowed with decreasing grain size and increasing in the stabilizer content (18-21). Also, the rate of phase transformation increases with increased temperature and aging time (14,16,17). However, it may be the surface treatments can induce residual stress and the cubic phase acts as the nucleation site for the t→m transformation (22, 23).

0.25% by mass of alumina (Al_2O_3) was added to the first generation 3Y-TZP to facilitate sintering. However, these zirconia show high opacity due to the birefringence feature of their non-cubic phases (24). Thereby, the Y-PSZ was produced by increasing the yttria content and applying an isotropic cubic phase to tetragonal zirconia (24, 25). The alumina concentration of second-generation PSZ has been reduced and porosity formation has been prevented by sintering at higher temperatures (26). PSZ contains nanosized tetragonal or monoclinic particles in a cubic matrix (27).

Fully stabilized zirconia (FSZ) was introduced and controversially compared to the first and second generations, including a cubic phase ratio of up to 53% in their microstructure. Cubic crystals show a larger volume than tetragonal crystals and so light scatters less severely and makes it more translucent (1, 28). For developing translucent zirconia, the ratio of the cubic phase has increased.

The LTD process of zirconia is multifactorial. T→m transformation is largely related to the presence of water or water vapor in the environment, the affinity of the material, the shape, size, and location of the particles, and the stabilizer content (29). After LTD, zirconia material exhibits different mechanical behavior according to the depth of the 't-m phase transformation layer at different degrees depending on its structural content (30). An increase in the amount of monoclinic phase was determined because of the LTD of zirconia at low temperatures (31, 32). The high monoclinic phase amount decreases the flexural strength of the material (33). The null hypothesis is that LTD in newly high-translucent zirconia does not affect the phase transformation and biaxial flexural strength of the material. The aim of this study was to determine the effect of LTD on phase changes and biaxial flexural strength in newly developed high-translucent zirconia and to compare it with high-translucent 3Y-TZP zirconia.

2. METHODS

2.1. Preparation of specimens

Three new high-translucent Y-PSZ; and one 3Y-TZP disc were used and the compositions of the monolithic materials are presented in Table 1. A total of 120 high-translucent zirconia disc specimens were prepared from pre-sintered blocks with a final size of 14.0 mm and 1.2±0.2 mm in thickness, after sintering in accordance with ISO 6872(34). Presinterized disks were shaped by milling using the unit of CAD/CAM system (imes-score 250'i, Onex Dental, Ankara, Turkey). The specimens were obtained in 20%-25% enlarged sizes to compensate for the sintering shrinkage of the system and were sintered (Tabeo – 1/S/Zircon-100, MIHMVOGT GmbH & Co. KG, Stutensee, Germany) according to manufacturer specifications (Table 2). The specimens were finished with silicon carbide paper (800 and 1200 grit) after sintering under water cooling. One surface of all specimens was performed by the same person using diamond medium-grained bur and then fine-grained bur for 30 seconds, (Diacera Medium, Diacera Fine, G&Z Instrumente GmbH, Lustenau, Austria) with a micromotor at 10000 rpm with water cooling.

Table 1. *Materials and their composition used in this study.*

Material	Manufacturer	Composition	Batch Nummer
Katana Zirconia UTML **KUT** (5Y-PSZ)	Kuraray Noritake Dental Inc., Miyoshi, Japonya	ZrO_2 + HfO_2 %87-92 (Y_2O_3) %8-11 Diğer oksitler %0-2	DOZBT
Katana Zirconia STML **KST (**4Y-PSZ)	Kuraray Noritake Dental Inc., Miyoshi, Japonya	ZrO2 + HfO_2 %88-93 (Y_2O_3) %7-10 Diğer oksitler %0-2	EAUWN
Nacera Pearl Q³MS **NQ³MS** (6Y-PSZ)	Doceram Medical Ceramics GmbH, Dortmund, Almanya	Yitriya-stabilize %40 tetragonal, %60 cubic zirkonya polikristal (%6 mol Y_2O_3)	5057862
Nacera Pearl MS **NMS** (3Y-TZP)	Doceram Medical Ceramics GmbH, Dortmund, Almanya	ZrO_2 +HfO_2 + Y_2O_3> %99, Y_2O_3 %4,5-%6	5146158

Table 2.*Sintering parameters used in this study.*

GENERAL SINTERING PROGRAM	KST / KUT	NQ³MS / NMS
High temperature	1550ºC / 2822 º F	1500ºC
Time	2 hour	2 hour
Temperature increase rate	10°C / 18°F minute	8° C / minute
Temperature decrease rate	– 10°C / – 18°F minute	– 8° C / minute

Nacera Pearl Multi Shade (NMS), Nacera Pearl Q3 (NQ³MS), Katana UTML (KUT), Katana STML (KST)

2.2. Low-Temperature Aging

LTD was performed according to the ISO 13356 standard in an autoclave (Eryiğit Steam Sterilizer, Eryiğit Medical Devices Inc., Ankara, Turkey) at 134 C⁰ at 2 bar (n:10) over a period of 5, and 20 h. Specimens without LTD served as the control (Figure 1).

The polished surfaces of the samples in the non-aged group were evaluated as the control group. The specimens were placed on an autoclave tray in a pressure chamber at 134 C⁰ under 2 bar for up 5 and 20 h for the phase transformation.

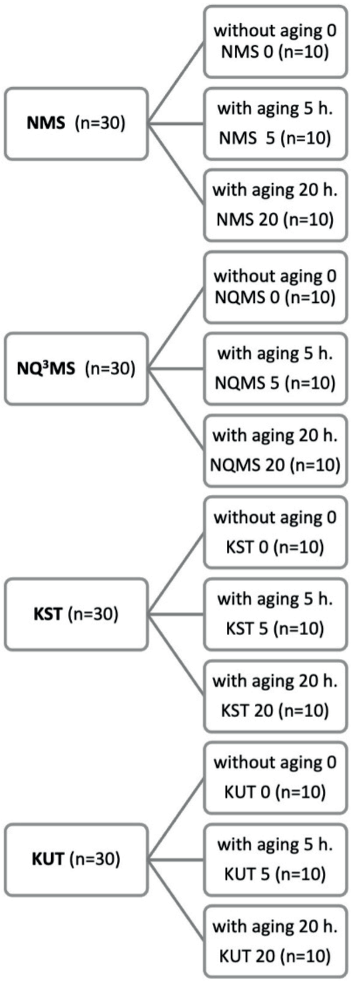

Figure 1. *Schematic represantation of the study design*

2.3. X-Ray Diffraction (XRD) Analysis

Randomly selected specimens from each material were examined to determine the crystalline phases by X-ray diffractometer device (Bruker D8 ADVANCE, Bruker Turkey Ltd.Şti, Ankara, Turkey). X-ray diffraction (XRD) data were collected using a 2θ diffractometer and using CuK α radiation (30mA and 40kV). Spectra were collected in the 2θ with a range of 2040^0at a step interval of 1^0/min. and a step size of 0.020. The monoclinic phase fraction (Xm) and peak intensities of 28 and 30 degrees were analyzed with processing software ORIGIN 2021. The amount of monoclinic phase fraction (Xm) was calculated using the Garvie and Nicholson methodology (35); Equation:

$$X_M = \frac{I_{M(111)} + I_{M(111^-)}}{I_{M(111)} + I_{M(111^-)} + I_T}$$

Xm = the overall intensity ratio of the monoclinic phase

Im1 $(111)_m$ =the intensity of the monolinic peak at 28.2^0

Im2 $(111)_m$ =the intensity of the monolinic peak at 31.5^0

It $(101)_t$ =the intensity of the tetragonal peak at 30.2^0

2.4. Biaxial Flexural Test

Biaxial flexural strength of high-translucent zirconia specimens was performed in a piston-on three ball test using a testing machine (Lloyd Instruments, Ametek Inc, Florida, USA). Discshaped specimens of different Y-PSZ and 3Y-TZP materials were positioned with the treated surface on three supporting balls (3.2 mm. in diameter, seperate on a support circle with a diameter of 10 mm) in a triangular position. An sticking plaster was placed on the compression side of the specimens for uniform load distribution. All disk-shaped zirconia specimens were loaded with a flat punch at a crosshead speed of 0.5 mm/min until failure. The results of the biaxial flexural strength were determined using the equation in accordance with ISO 6872; Q =-0.2387 P (X – Y) /d2

Q: the flexural strength at fracture

P: the total load causing fracture (N)

X = (1+ v) ln (r2/r3)2 + [(1-v) /2] (r2/r3)2 Y

= (1+ v) [1 + ln (r1/r3)2] + (1-v) (r1/r3)2 v:

Poisson's ratio of 0.3 for zirconia

2.5. Statistical Analysis

The conformity of continuous variables to normal distribution was tested with the Shapiro Wilk test. Biaxial flexural strength test data were analyzed using two-way ANOVA (Multivariate General Linear model, Two-way ANOVA) the effect of independent variables on two dependent variables, followed by post hoc Mann–Whitney U test. Correlation analysis of two independent and non-normally distributed variables was performed using Spearman's rho correlation analysis. The significance level was determined as 0.05. Comparative analysis were performed using the SPSS v24 Program (IBM Ltd, Armonk, NY, USA). Weibull analysis was performed using the Minitab (Microsoft Ltd, New Mexico, USA) program and analyzed the variability of flexural strength.

3. RESULTS

The relative amount of monoclinic phase of three different Y-PSZ and one 3Y-TZP were determined by different aging times by XRD analysis.

3.1. XRD Analysis

LTD affected the monoclinic phase results differently in terms of different yttria contents in the microstructure of the investigated materials. The XRD diffraction patterns of the experimental groups are shown in Figures 2a,b and 3a,b. XRD results for control group specimens revealed that only the tetragonal phase and monoclinic phases were not detected. LTD increased the monoclinic content significantly for the NMS group between aging times but slightly increased for the KST group ($p<.05$). The monoclinic phase was not detected for KUT and NQ[3]MS groups and no significant difference was found between aging times. The materials were compared in terms of Xm values according to LTD and the results are shown in Table 3 and in Figure 4.

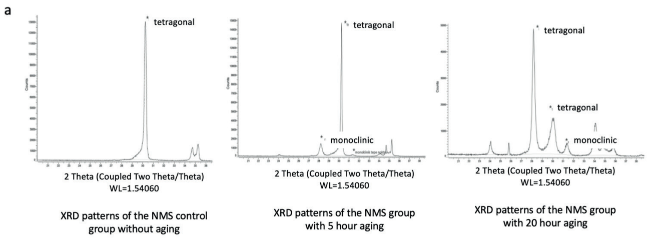

Figure 2a. *X-ray diffraction patterns of the NMS group after LTD with aging times.*

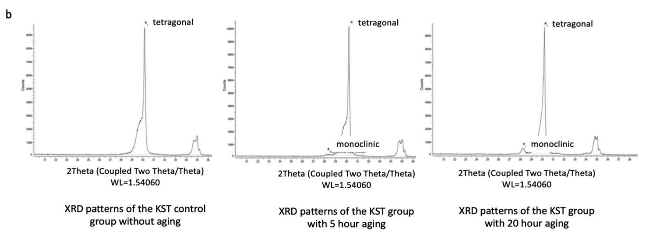

Figure 2b. *X-ray diffraction patterns of the KST group after LTD with aging times.*

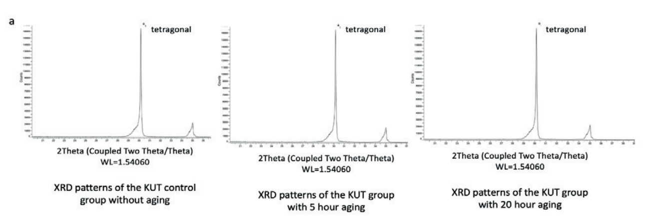

Figure 3a. *X-ray diffraction patterns of the KUT group after LTD with aging times.*

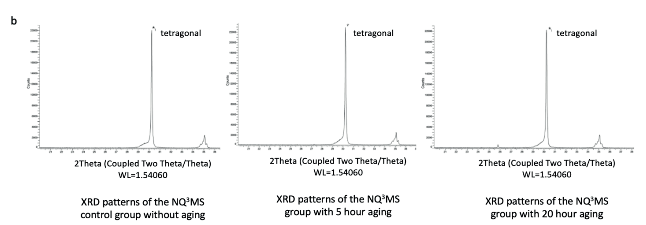

Figure 3b. *X-ray diffraction patterns of the NQ3MS group after LTD with aging times.*

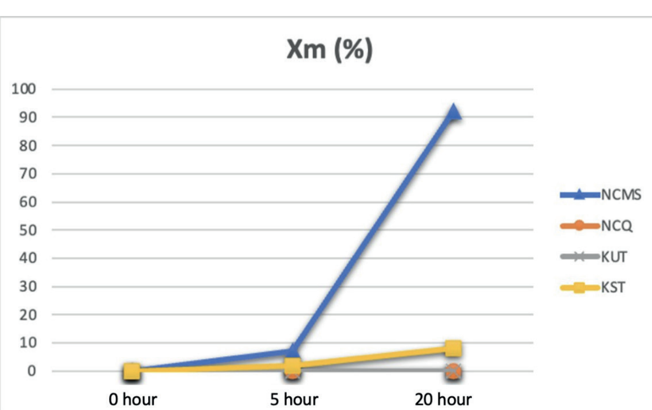

Figure 4. *Mean monoclinic phase fraction Xm (%) of the investigated materials after LTD.*

Table 3. *Summary of m-phase fraction (Xm in%) of the investigated materials*

m-phase Xm (%)							
Groups	**LTD**	**Mean**	**SD**	**Min.**	**Max.**	**χ^2**	**p^***
NMS	0 hour	0 ^{a}	0	0	0	19.538	<.001
	5 hour	7 ^{b}	5	0	16		
	20 hour	92 ^{c}	1	92	93		
KST	0 hour	0 ^{a}	0	0	0	20.000	<.001
	5 hour	2 ^{b}	0	2	3		
	20 hour	8 ^{c}	2	5	9		
KUT	0 hour	0 ^{a,b}	0	0	0	4.000	.126
	5 hour	0 ^{a,c}	0	0	0		
	20 hour	0 ^{b,c}	1	0	2		
NQ^{3}MS	0 hour	0	0	0	0	–	–
	5 hour	0	0	0	0		
	20 hour	0	0	0	0		

There is no statistically significant difference between Kruskal Wallis test heat treatment measurements, Mann-Whitney U test: posthoc pairwise comparisons, and mean Xm (%) values of groups with common lowercase letters. Nacera Pearl Multi Shade (NMS), Nacera Pearl Q3 (NQ^{3}MS), Katana UTML (KUT), Katana STML (KST), low-temperature degradation (LTD), standard deviation (SD).

3.2. Biaxial Flexural Strength

The comparisons of the materials in terms of flexural strength values according to the LTD are shown in Table 4. LTD affected the biaxial flexural results differ in terms of different yttria contents in the microstructure of the materials. LTD resulted in a significant decrease in flexural strength values of the NMS group. The biaxial flexural strength values of the NMS group (1344.2) was significantly decreased with an increase in the 20 h aging time (1091.8 MPa). The flexural strength values of KST (4Y-PSZ), KUT (5Y-PSZ), and NQ^{3}MS (6Y-PSZ) were not significantly affected by LTD. For strength values, there was no significant difference in aging times for each of the three KST (728.9, 696.4, 640.4), KUT (554.1, 557.6, 566.4), and NQ^{3}MS (665.9, 733.1, 717.7 MPa) Y-PSZ groups. Mean biaxial flexural strength values of different Y-PSZ and 3-YTZP materials after LTD are shown in Figure 5.

Table 4. *Mean values and standart deviatioans (SD) of the biaxial flexural strength (MPa)*

Flexural Strength (MPa)							
Groups	**LTD**	**Mean**	**SD**	**Min.**	**Max.**	**χ^2**	**p^***
NMS	0 hour	1344.2 ^{a}	154.2	1161.4	1672.5	11.400	<.001
	5 hour	1248.3 ^{a}	66.8	1158	1340.6		
	20 hour	1091.8 ^{b}	97.7	946.3	1239.6		
KST	0 hour 5	728.9 ^{a,b}	48.7	642.8	792.7	5.600	.072
	hour	696.4 ^{a,c}	114.5	532.9	856.7		
	20 hour	640.4 ^{b,c}	75.6	538.8	755.3		
KUT	0 hour	554.1 ^{a,b}	146.7	398.7	853.4	0.600	.814
	5 hour	557.6 ^{a,c}	156.3	406.6	794		
	20 hour	566.4 ^{b,c}	81.1	432.5	730.2		
NQ^{3}MS	0 hour	665.9 ^{a,b}	92.1	486.9	756.9	4.200	.514
	5 hour	733.1 ^{a,c}	142.1	547.4	1001		
	20 hour	717.7 ^{b,c}	62.9	604.9	823.4		

There is no statistically significant difference between Kruskal Wallis test heat treatment measurements, Mann-Whitney U test: posthoc pairwise comparisons, and mean flexural strength (MPa) values of groups with common lowercase letters. Nacera Pearl Multi Shade (NMS), Nacera Pearl Q3 (NQ^{3}MS), Katana UTML (KUT), Katana STML (KST), low-temperature degradation (LTD), standard deviation (SD).

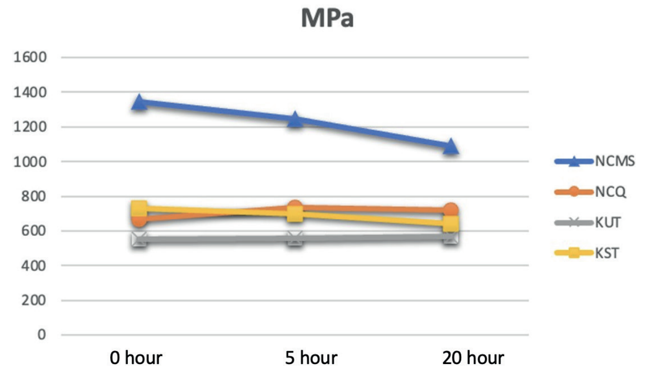

Figure 5. *Mean biaxial flexural strength values and standart deviatioans (SD)(MPa) of the investigated materials after LTD.*

3.3. Weibull Analysis

The Weibull statistical analysis is presented in Table 5 and Figures 6a,b and 7a,b. Weibull analysis showed the highest characteristic strength for NMS 1412.9 and KST 750.1 in the control group and for NQ³MS 790.5 and KUT 615.2 MPa in the 5 h aging group. The Weibull modulus (m) of NMS, KST, KUT, and NQ³MS was between 8.8–13.3, 18.8–9.4, 4.1–9.4, 10.5–13.2 respectively. While m values increased in the NMS, KUT, and NQ³MS groups, they decreased in the KST group. There was no statistically significant difference between the characteristic strength values of the KUT and NQ³MS groups.

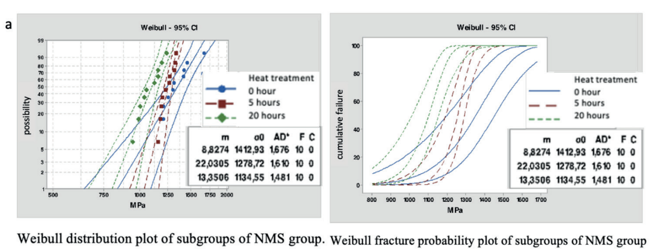

Figure 6a. *Weibull distribution and fracture probability plots of NMS group after LTD.*

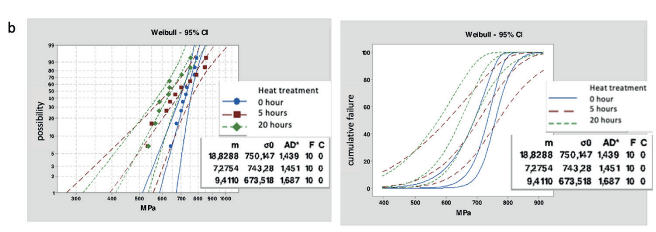

Figure 6b. *Weibull distribution and fracture probability plots of KST group after LTD.*

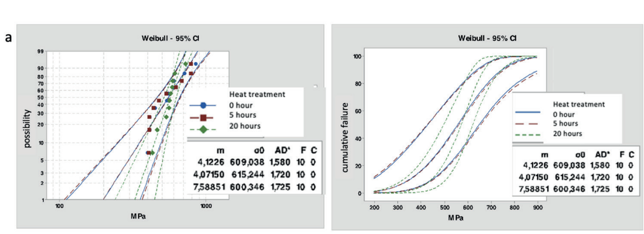

Figure 7a. *Weibull distribution and fracture probability plots of KUT group after LTD.*

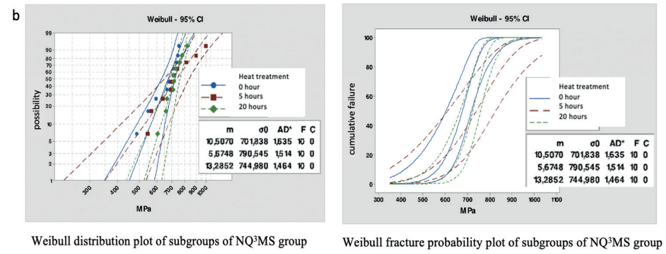

Figure 7b. *Weibull distribution and fracture probability plots of NQ3MS group after LTD.*

Table 5. *Biaxial flexural strengths (SD), and Weibull parameters of the investigated materials with the Weibull statistical method*

Groups	NMS		NQ³MS		KUT		KST	
LTD	m	σ_0	m	σ_0	m	σ_0	m	σ_0
0 hour	8.82^{a}	1412.9^{a}	10.50^{a}	$701.8^{a,b}$	$4.123^{a,b}$	$609.0^{a,b}$	18.829^{a}	750.1^{a}
5 hour	22.03^{b}	1278.7^{b}	5.675^{b}	$790.5^{a,c}$	$7.275^{a,c}$	$615.2^{a,c}$	7.275^{b}	743.3^{b}
20 hour	13.35^{c}	1134.6^{c}	13.285^{c}	$745.0^{b,c}$	$9.411^{b,c}$	$600.3^{b,c}$	9.411^{c}	673.5^{c}

There is no statistically significant difference between the values of groups with common lowercase letters in the same column. Nacera Pearl Multi Shade (NMS), Nacera Pearl Q3 (NQ³MS), Katana UTML (KUT), Katana STML (KST), characteristic strength (σ_0), weibull modulus (m), low-temperature degradation (LTD).

4. DISCUSSION

The null hypothesis of this research is that the LTD in new high-translucent monolithic zirconia systems does not affect the monoclinic phase change and the biaxial flexural strength of the investigated materials. High-translucent NMS and KST materials were affected by LTD in terms of phase transformation, while high-translucent KUT, and NQ³MS materials did not show phase changes after LTD. The flexural strength values of the NMS group were affected by LTD, but the KST, KUT, and NQ³MS groups were not affected. The null hypothesis was partially rejected.

The high yttria and cubic phase content of the materials used in the study have many advantages. KUT is known as ultra-translucent zirconia (36) and 8%-11% of its content is Y_2O_3(37). Kwon et al. reported that this ultra-translucent material can therefore be used for restorations in the anterior region and is a wear-resistant material (38). KST is referred to as super translucent zirconia (36). This material, which contains 7%-10% Y_2O_3, provides light transmittance similar to that of natural teeth. According to the manufacturer's information, both KUT and KST can be used in single-tooth restorations, and up to three unit bridges (37). NQ³MS, contains 40% tetragonal and 60% cubic zirconia and 6 mol% Y_2O_3 according to the manufacturer's information. NQ³MS is an ultra-high translucent zirconia (6Y-PSZ) and indicated for monolithic single crowns and restorations of up to three units (39). Studies have shown that these materials with high yttria content do not undergo t→m phase transformation due to their good stabilization (25, 37, 40, 41). The absence of this transformation also protects zirconia from the negative effects. Zang et al. concluded that the material did not undergo a t-m transformation, and thus its transparency increased, but its strength decreased (8). However, the study results suggest that nanocrystalline zirconia potentially exhibit both desirable translucency and mechanical properties (1, 2, 8).

The LTD of zirconia materials is applied under laboratory conditions to evaluate their effectiveness and predict their long-term behavior. Studies using an autoclave as hydrothermal aging at 134 °C, 2 bar pressure for 20 h have shown that 20 h in the autoclave supports an extensive t→m phase transformation (13, 42). Pereira et al. investigated the effects of LTD on Y-TZP and evaluated the behavior of the material to be used in the clinical setting according to the ISO 13356. It is also reported that aging in an autoclave at 134 °C, 2 bar for 5 h sufficiently ensures that the m phase content is not more than 25% (43). Zhuang et al. reported that the 20 h LTD would correspond to 30 to 80 years at body temperature (44). In this study, LTD was applied to the samples in an autoclave for 5 and 20 h to examine the flexural strength effects. Pereira et al.(45) investigated the effects of LTD using diamond burs and found an Xm value of 53.33% for the control group after 20 h with Y-TZP samples. It is thought that the reason why the relative monoclinic phase amounts of the NMS group (93%) were higher in this study, especially for the 20 h group, is that the Y-TZP blocks used in their study contain Al_2O_3. The NMS group used in this study does not contain Al_2O_3 order to increase translucency. For the KST, KUT, and NQ[3]MS groups with high yttria content was no monoclinic phase transformation was observed in the non-aged, 5, and 20 h aging groups. The high resistance of these materials to aging may be related to the higher stabilizer content (4%,5%, and 6 mol%) and thus the elimination of the phase transformation mechanism. Additionally, many cubic crystals in their microstructure may have eliminated the phase transformation (25, 36).

Kou et al.(46) evaluated the effect of LTD on two different high-translucent (DD cubeX2 and Prettau Anterior) zirconia on phase transformation and flexural strength and found that after 10 h of LTD, DD cubeX2 showed a significant reduction in flexural strength, but Prettau Anterior showed no significant difference increase in flexural strength. The phase composition for both unaged and aged specimens of both DD cubeX2 and the Prettau Anterior constitute 99% cubic or tetragonal zirconia.

Pereira et al.(36) assessed different high-translucent zirconia (Katana ML/HT, STML, UTML) after 20 h of LTD. They reported that LTD increased the monoclinic content for ML/HT and did not affect STML and UTML, similar to the KUT and NQ[3]MS groups in this study after 20 h. Also, Pereira et al. added that aging for 20 h did not affect the characteristic strength of KST and KUT. The flexural strengths of the new KST, KUT, and NQ[3]MS groups were significantly lower than those of the NMS group. The NMS group (1344.2) significantly decreased only with an increase in the 20 h aging time (1091.8). However, the strength values of KST, KUT, and NQ[3]MS were not significantly affected by LTD. Kwon (38), Pereira (36), and Reyes (47) similarly stated in their previous studies that high-translucent zirconia has lower flexural strength than 3Y-TZP. It is thought that KST, KUT, and NQ[3]MS with higher stabilizer (Y_2O_3) content have lower results due to the disappearance of the transformation mechanism and because a large amount of cubic phase increases translucency but decreases mechanical strength.

Flinn et al.(48) evaluate the effect of LTD behavior on the strength values of 4 different translucent zirconia (BruxZir, Prettau, Katana ML, and Katana HT13) and reported that after aging for 200 h, the monoclinic phase increased to 76.1% for Prettau, 76% for BruxZir, 35.8% for Katana HT13, 33.2% for Katana ML. They concluded that the flexural strength values of BruxZir and Prettau decreased significantly during the aging period, but no statistically significant change in Katana ML and Katana HT13 zirconia. For both Prettau (8.27% Y_2O_3) and BruxZir (9.75% Y_2O_3) zirconia materials, the monoclinic phase amount was more than 50% after 200 h of aging. In this study, the monoclinic phase of the NMS zirconia after 20 h aging was 92%. The mean flexural strength values of Prettau and BruxZir decreased with an increase in the monoclinic phase and are similar in terms of the decrease in the strength values of the NMS zirconia after 20 h aging. The Katana ML (10.95% Y2O3) and Katana HT13(10.91% Y_2O_3) zirconia with higher yttria content exhibited less LTD.

Harada et al.(49) investigated the effect of LTD for 50 h on the phase change and flexural strength of 5YZ and 3YZ and reported that 5YZ was found to be more resistant to LTD than 3YZ. After 50 h of LTD, no significant changes in the characteristic strengths of 5YZ and 3YZ were observed similarly to this study for the KUT and NQ[3]MS groups. The reason for this is thought to be the longer aging period applied by Harada et al.

Pittayachawan et al.(7) reported that the Weibull analysis used commonly statistical methods to examine the strength reliability and variability because of defects in the material. They also added that some studies have also expressed m values of some ceramics in the range of 5–15.

In their study, the Weibull modulus was determined as 9.3–12.9 for Lava (Y-TZP) zirconia.

In this study, the Weibull modulus of the NMS group, with lower yttria content, determined, was higher than the Weibull modulus of high-translucent PSZ. Weibull analysis showed the highest characteristic strength for NMS(1412.9) and KST(750.1) on the control and for NQ[3]MS (790.5) and KUT (6152) in the 5 h group. Weibull modulus (m) of NMS, KST, KUT, and NQ[3]MS were between 8.8–13.3, 18.8–9.4, 4.1–9.4, 10.5–13.2 respectively. Weibull m values increased in the NMS, KUT, and NQ[3]MS groups, but decreased in the KST group. The Weibull modulus results in this study are in the range of 5–15 and acceptable for dental ceramics. Zhang et al.(10) investigated two different PSZ with different mol% yttria contents and found that 5YSZ showed lower strength and with lower Weibull modulus. A similar weibull modulus result was found in this study only for the KST group.

Nakamura et al.(50), examined the effects of the LTD for 10 and 100 h on the phase transformation and strength properties of colored and non-colored 3Y-TZP zirconia. They reported that the LTD affected the strength values of non-colored 3Y-TZP but unaffected colored 3Y-TZP. In their study, the flexural strength results increased after 10 h but decreased after 100 h of the LTD. Similar to this study, for the NMS group, the strength values significantly decreased with an increase in the 20 h aging. The m value of the non-aged NMS group in this study was 8.8–13.3 and similar results (8.3-10.8) were reported by Nakamura et al. for non-aged 3Y-TZP. Pereira et al. reported that the Weibull modulus increased with the characteristic strength of Y-TZP specimens after 20 h of aging (36). In contrast to Pereira et al., in this study, the m value increased for the NMS, KUT, and NQ^3MS groups, and the characteristic strength of the KST and NMS groups decreased significantly.

This in vitro study evaluated the long-term use of new high-translucent monolithic zirconia restorations. LTD caused a significant decrease in the biaxial flexural strength results only for the NMS group but did not significantly affect the KST, KUT, and NQ^3MS groups with higher yttria content. It was seen that the presence of the cubic phase in high-translucent materials has two advantages: increased translucency and low resistance to temperature degradation. The flexural strength results of the high-translucent zirconia tested in this study were the minimum accepted value for class 5 restorations in fixed prostheses according to ISO 6872 and were more than 500 MPa.

For high-translucent 3 Y-TZP, it was determined that the tetragonal phase could transform into the monoclinic phase in a humid environment without mechanical stress. This probably caused microcracks and reduced mechanical strength.

The present study has some limitations. Clinical oral conditions can not be simulated. The LTD test is applied to in vitro conditions, in order to evaluate their effectiveness and long-term behavior because of the time-consuming and difficult experiment. Before the LTD process, one surface of all samples was polished by the same person with one type of zirconia polishing set for standardization. This study performed only an in vitro static test. Another limitation of this study was that the effect of different surface treatments and high-translucent zirconia with different yttria contents was not investigated. High-translucent zirconia materials obtained from only two manufacturers were evaluated. The effect of LTD on different surface treatments and high-translucent materials with different yttria contents can be used for future studies. It may be important to conduct in vitro experiments with dynamic loading to evaluate the effect of mechanical forces in the oral environment.

5. CONCLUSION

With the limitations of this study, the following conclusions were made:

1. LTD increased the monoclinic phase significantly for NMS and slightly in the KST group, but no monoclinic phase was detected in the KUT and NQ^3MS groups.
2. LTD resulted in a significant decrease in flexural strength values of the NMS group but did not significantly affect the values of the KST, KUT, and NQ^3MS groups.
3. Weibull analysis showed the highest characteristic strength for NMS and KST on the control, and KUT, NQ^3MS on the 5 h aging. Weibull m values increased in the NMS, KUT, and NQ^3MS groups, but decreased in the KST group.
4. The flexural strength values of the NMS (3Y-TZP) group caused a significant decrease after 20 h, but no significant changes were measured in the KST (4Y-PSZ), KUT (5YPSZ), and NQ^3MS(6Y-PSZ) groups.

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