The Effect of two Crystallization Speeds on optical properties of two Lithium Disilicate Ceramics

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Abstract

Objective: to investigate the impact of heat treatment employing two distinct crystallization (firing) rates on the translucency of various indirect restorative materials.

Materials and methods: A cohort of twenty-eight specimens, each exhibiting a disc-shaped morphology, was meticulously fabricated utilizing two distinct categories of restorative CAD/CAM materials, specifically lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein) and advanced lithium disilicate ceramic (Cerec Tessera, Dentsply Sirona, USA). All specimens were meticulously finished and polished. The samples were divided into two primary groups: 14 specimens of IPS e.max CAD and 14 specimens of Cerec Tessera. Each primary group was systematically partitioned into two subsidiary subsets, each consisting of seven disc-shaped specimens, with the division predicated upon the heat treatment applied. The first subgroup of each material underwent heat treatment in a Programat CS3 furnace (Ivoclar Vivadent, Zurich, Switzerland), while the second subgroup was treated in a Cerec Speedfire furnace (Dentsply Sirona).

For translucency evaluation, A highly precise spectrophotometer was employed to quantitatively determine the L coordinate and contrast ratio values for all specimens.

Results: Compared to Tessera, Emax, which undergoes extended heat treatment cycles as per the manufacturer's guidelines, demonstrated notably enhanced translucency properties (indicated by a lower contrast ratio).

Conclusion: The heat treatment applied during the crystallization of the glass ceramics significantly influenced the translucency of the glass ceramics material.

Keywords: crystallization, translucency, advanced lithium disilicate ceramic

Background

Owing to their superior aesthetic properties, remarkable wear resistance, and excellent biocompatibility, Dental ceramics are extensively utilized within the domain of prosthetic dentistry for the restoration of missing or compromised tooth structures, encompassing crowns, fixed partial dentures, and various other structural elements [1-2]. Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology was pioneered in dentistry by Duret in the early 1970s [3]. The advent of CAD/CAM systems in the creation of dental restorations offers enhanced precision and increased efficiency [4]. Nevertheless, the inherent brittleness of these materials necessitated the development of reinforcements to enhance their physical properties, culminating in the appearance of millable lithium disilicate glass ceramic (IPS e.max CAD; Ivoclar Vivadent) in the early 2000s. [5-6-7]. Despite the fact that lithium disilicate glass ceramic has experienced a substantial surge in popularity since its inception and has emerged as the preferred material over other glass-matrix ceramics [8] the dental market continues to see the frequent introduction of novel materials. Among the latest advancements in glass ceramics is the development of advanced lithium disilicate (ALDS) (CEREC Tessera; Dentsply Sirona), that incorporates lithium aluminum silicate crystals, known as virgilite, [9-10] within the glass matrix. [5-8] According to the manufacturer, the firing process of the matrix facilitates the formation of new virgilite crystals, which are purported to enhance both the structural strength and esthetic properties of the material. The primary advantage of ALDS lies in its reduced firing time when processed using the appropriate induction chairside furnace (CEREC SpeedFire; Dentsply Sirona). However, the firing of this material utilizing a traditional furnace remains feasible and applicabe. [10]

The esthetic success of a ceramic restoration is fundamentally influenced by its translucency and optical characteristics. [11-12] Furthermore, color stability represents a critical parameter for ensuring the longevity of a restoration, [13] as any alteration in color can significantly compromise the quality and acceptability of the restoration. [14-15] However, in addition to optical properties, the durability and performance of a restoration are equally contingent upon mechanical characteristics of the material. [16] Given that the reduced firing cycles associated with advanced lithium disilicate (ALDS) has the potential to significantly enhance the efficiency of chairside dentistry, a comprehensive investigation into how this feature impacts the mechanical and optical characteristics of ALDS would provide valuable insights for clinicians. To the best of the authors' knowledge, only a limited number of studies have explored ALDS [8-17] and these studies have not specifically addressed its optical properties under varying thermal cycles. Moreover, the effects of reduced firing duration on these properties remain largely unexplored.

Ideally, firing processes should preserve the optical characteristics of the restoration. it is imperative that thermal cycles are precisely controlled to uphold the structural harmony between the glassy and crystalline phases, given that even minimal microstructural alterations resulting from the firing process can lead to changes in the mechanical, chemical, or physical properties of a material [18]. Research has demonstrated that, influenced by the particular firing protocol, metal oxides that contribute to the material's chromatic properties may become unstable [19-20], while thermal processing can induce transformations in the material's phase composition [21-22]. Therefore, it is essential to gather data on the impact of heat treatments on the optical and microstructural properties of ceramics. In this context, the current investigation sought to evaluate the impact of different crystallization speeds on optical characteristics of two distinct ceramics engineered for hard machining, each possessing unique microstructural configurations. The primary hypothesis postulated that the optical properties of the investigated materials would remain unaffected by the application of thermal cycles.

Methods

Samples preparation

The protocol for the research project was exempted from review and approval by the Research and Ethics Committee of the Faculty of Dentistry at Ain Shams University in Egypt. with exemption number (FDASU-EM122220)

Specimens in the form of rectangular discs, each measuring 1.5 mm in thickness, were precisely manufactured using two distinct types of restorative CAD/CAM materials, namely lithium disilicate glass-ceramic (IPS e.max CAD; Ivoclar Vivadent, Liechtenstein) (14 samples) and advanced lithium disilicate ceramic (Cerec Tessera; Dentsply Sirona, USA) (14 samples). The samples were meticulously sectioned utilizing a high-precision sawing apparatus (IsoMetTM 4000, Buehler, Dusseldorf, Germany) operating at low speed with continuous water cooling to achieve uniformly flat surfaces. One surface of each specimen was subjected to a mirror-like polishing process, initially with 1200 and 2000 grit silicon carbide paper, and subsequently with 0–2 µm diamond polishing paste (Christensen Roder, Porto Alegre, RS, Brazil), culminating in specimens with a central thickness of 1.5 ± 0.5 mm. All specimens underwent a thorough cleansing process in an ultrasonic bath containing isopropyl alcohol for a duration of 10 minutes.

Specimens corresponding to each type of ceramic material were systematically and randomly allocated into distinct groups, categorized in accordance with specifically predefined firing protocols.

samples were systematically divided into four distinct groups.: 1: IPS e.max CAD fired in a Programat CS3 furnace (LD-P), 2: IPS e.max CAD fired in a Cerec Speedfire furnace (LD-S), 3: Cerec Tessera fired in a Programat CS3 furnace (ALD-P) and 4: Cerec Tessera fired in a Cerec Speedfire furnace (ALD-S).

Material Measurement and analysis

Translucency evaluation:

A quantitative assessment of translucency was conducted after firing using a spectrophotometer against black and white backgrounds.The samples were positioned on a white background then the L* coordinate was determined three times for each sample. The same procedure was repeated against a black background. The mean value derived from the three measurements was subsequently utilized in the calculation of the contrast ratio (CR). [23-24].

CR=Yb/Yw

$Y= [(L* + 16)/116]^{3} \times 100$

where Yb signifies the reflectance measured against the black background and Yw indicates the reflectance measured against the white background. Within these calculations, a contrast ratio (CR) of 0 is interpreted as representing the maximum translucency, whereas a CR of 1 is interpreted as representing the maximum opacity.

Statistical analysis:

Numerical data were expressed as mean and standard deviation (SD). Normality and variance homogeneity were assessed by examining the data distribution and applying Shapiro-Wilk's and Levene's tests, respectively. The data were normally distributed with homogeneous variances. Analysis was conducted using two-way ANOVA. Simple effects comparisons were performed using the ANOVA error term, with p-values adjusted via the False Discovery Rate (FDR) method. The significance threshold was established at $p < 0.05$. the statistical analyses were conducted utilizing R statistical software, specifically version 4.4.2 for the Windows operating system.

Results

Regarding the impact of different heat treatment cycles on translucency and contrast ratio, the influence of various factors and their interplay on the contrast ratio is detailed in Table (3). Only the material type demonstrated a statistically significant impact on the contrast ratio ($p < 0.001$).

Table (3): Impact of various factors and their interplay on the contrast ratio.

Source	Sum of Squares (II)	df	Mean Square	f-value	p-value
Material	0.05	1	0.05	**28.58**	**<0.001***
Firing furnace	0.00	1	0.00	**0.24**	**0.630ns**
Material * Furnace	0.00	1	0.00	**0.92**	**0.344ns**

df degree of freedom, * significant (p<0.05), ns not significant.

- The findings of this study showed that IPS e.max samples (0.62±0.02 in Programat CS3 and 0.64±0.04 in Cerec Speedfire) exhibited significantly higher translucency (i.e., lower contrast ratio) compared to Tessera samples (0.70±0.05 in Programat CS3 and 0.70±0.05 in Cerec Speedfire) ($p < 0.001$) regardless the furnace used. The difference in translucency between samples of the same material fired in both furnaces did not achieve statistical significance (Table 4 & Figure 5).

Table (4): Comparisons and summary statistics of contrast ratio for different variables.

Furnace \ Material	Contrast ratio (Mean±SD)		p-value
	Emax	**Tessera**	
SpeedFire	0.64±0.04	0.70±0.05	**0.004***
Programat CS3	0.62±0.02	0.70±0.05	**<0.001***
p-value	**0.319ns**	**0.719ns**	

* Significant (p<0.05), ns not significant.

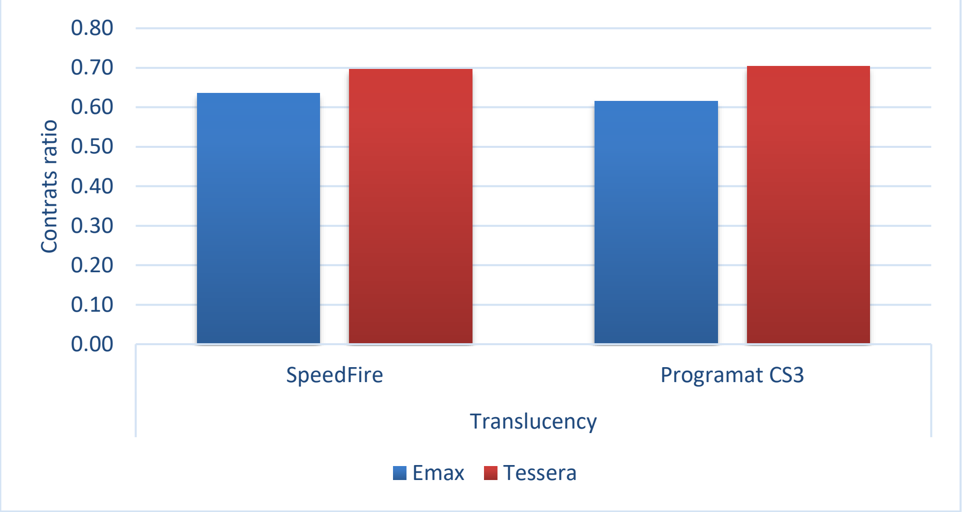

Figure (5): Bar chart showing average contrast ratio for different variables (A).

Discussion

After the advent of the first lithium disilicate ceramic was issued in 2013, several lithium-based ceramics have been developed, and these glass ceramics now dominate the dental restoration market. Nevertheless, it is imperative to acknowledge that substantial disparities exist in their microstructure, degree of crystallinity, chemical composition, and mechanical characteristics. These distinctions must be carefully taken into account when choosing and assessing materials for specific dental treatment scenarios [25]. The newly developed advanced lithium disilicate (CEREC Tessera) offers superior clinical performance in monolithic restorations, rapid fabrication, a reduced firing duration (4:30 minutes), and excellent esthetics. Considering the potential advantages in processing efficiency and esthetic outcomes, research evaluating the optical and mechanical properties of this innovative material is essential to inform its clinical applications. Consequently, the primary aim of this investigation was to assess the impact of two different crystallization speeds on the translucency of two glass ceramics, aiming to understand the impact of these alternative thermal treatments on the final esthetic of these materials.

The failure of crystallization firings to effectively mitigate hard machining damage, along with the potential adverse effects of these cycles on machined glass ceramic materials [26], highlights the necessity for further research into alternative thermal regimens. One hypothesis tested was that longer crystallization cycles would not result in further remediation of artificially induced surface imperfections compared to shorter cycles. Microscopic images (Figures 2&3), depicting the defect area both prior to and subsequent to thermal treatment, suggest that the healing of defects seems to be more markedly evident with the longer crystallization cycles used for IPS Emax ceramic compared to the shorter cycles for Cerec Tessera. Our

The impact of crystallization firings on the esthetic outcome of final restoration along with the potential adverse effects of these innovative thermal treatment cycles on glass ceramic materials [26], highlights the necessity for further research into alternative thermal regimens. One hypothesis tested was that, with longer crystallization cycles the optical properties of the investigated materials would remain unaffected compared to shorter cycles.However, our results showed that IPS Emax samples had significantly higher translucency (lower contrast ratio) than Tessera samples. These findings consistent with the findings of a study by Demirel et al. (2022) [27], that reported significant disparities in translucency among tested groups, with IPS e.max CAD having the highest translucency parameter (TP) value, followed by advanced lithium disilicate with normal glaze duration and then reduced glaze duration. A prior investigation into the topographical characteristics of advanced lithium disilicate observed that the material displayed fissures of varying depths prior to obligatory heat treatment, which subsequently vanished following the firing process. [28]. The gradual rise in temperature in a conventional porcelain furnace may have enhanced glassy matrix fusion, resulting in higher TP values compared to induction chairside furnaces. Additionally, the manufacturer of ALDS has indicated that decreased firing durations facilitate the crystallization of new virgilite crystals [29], which may explain the lower TP values of ALDS-S (reduced glaze duration) in comparison to ALDS-N (normal glaze duration).

A limitation of this study is that it focused on only two glass ceramic materials currently available in the market and evaluated the effect of different crystallization speeds using just two dental furnaces. Additional research is needed for a more comprehensive understanding of the impact of the new glass ceramic material and these innovative thermal treatments on the optical properties of these esthetic material.

Conclusions

The heat treatment cycle used for the crystallization of ceramic materials can significantly translucency of the final restoration. Longer heat treatment cycles led to enhanced translucency, regardless of the furnace used.

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