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Original Research

Optical properties of zirconia-reinforced lithium silicate veneers obtained with CAD/CAM milling and hot-pressing techniques: a comparative *in vitro* study

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Abstract

Background and aims. Dental veneers have become increasingly required among patients, but little is known about the optical properties of veneers obtained from the same ceramic material through different processing techniques.

Methods. In this study we compared the translucency and the opalescence parameters of zirconia-reinforced lithium silicate (ZLS) veneers restorations fabricated through CAD/CAM milling and hot-pressing techniques on the upper central incisor. Eighty specimens divided into 8 groups (n=10) were sectioned (Celtra Duo) and heat pressed (Celtra Press) to obtain 0.8 mm thickness. The optical parameters were calculated from the color difference against different backgrounds. Analysis of variance, one way ANOVA and post-hoc multiple comparison tests were used to evaluate and compare the optical properties of the same material, with a significance level of $p < 0.05$.

Results. The processing method had significant effect on optical parameters. Celtra Duo HT proved to be the material with the highest transparency degree. The hot-pressing technique led to higher opacity than CAD/CAM milling technique.

Conclusions. For a bio-mimetic aesthetic prosthetic restoration, the ceramic materials must have the same translucency and opacity as the real tooth. The results of this study revealed that high translucency ZLS obtained through hot pressing technique was the material of choice, as it fulfilled these requirements.

Keywords: translucency, heat-pressing, CAD/CAM, color stability, dental materials

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Introduction

Nowadays we face an increasing demand for aesthetic restorations and/or non-invasive dental treatments, therefore the aesthetic and mechanical durability are two of the main factors that clinicians consider when selecting dental ceramic materials [1]. Increased demand for aesthetic perfection, minimum invasiveness and durable restorations have resulted in the development of biomimicry-capable materials in the modern era. In this context, various ceramic materials for restorative purposes have been promoted and introduced in dentistry, to achieve the most aesthetically desirable outcomes, due to their superior optical and mechanical properties [2-6]. Ceramic materials are part of the inorganic products class prepared from non-metallic materials through various fabrication techniques, including heat pressing, infiltrated systems or computer-aided design and computer-aided manufacture technology (CAD/CAM) [7,8].

Monolithic restoration materials manufactured by a quick chairside production process with CAD/CAM technology [9,10], can be prepared using different materials such as zirconia, zirconia reinforced lithium silicate ceramic, lithium disilicate ceramic, feldspathic ceramic, ceramic/glass polymer materials and leucite-based ceramic [11]. Due to their multiple advantages (precise reproduction, standardized production process, time saving, full contour restorations, lower costs, stable quality of materials, etc.), the CAD/CAM technology has become widely used among clinicians [12]. In addition, the CAD/CAM technology enjoyed growing popularity also for favorable aesthetics without requiring a veneering ceramic, excellent physical, chemical, and mechanical properties, as well as good biocompatibility and simple clinical technique [11,13-17].

Heat pressing technology is used in dentistry for decades and involves the simultaneous application of heat and pressure onto a previously substrate (matrix) which contains the monolithic restoration material [18]. Due to the absence of a metal substructure, these restorations become translucent, offering to patients an excellent opportunity for achieving life-like aesthetic properties, translucency, color stability and wear resistance [7,19].

In this context, the ongoing quest for all-ceramic restorations that combine aesthetics and strength of a dental material associated with the evolution of novel processing technology, led to the development of reinforced glass-ceramics materials. This glass-ceramics materials, which can be obtained by the controlled precipitation of crystals (to overcome the glass deficiencies) [20,21] and crystallization of glasses (to ensure good mechanical properties) [20,22] in the glassy amorphous phase, can be used either as veneers as well as full anatomic restorations according to ISO 6872. The glass ceramics combine the best of both: aesthetics and strength and it is reported to be described as a biocompatible material [23,24]. This modern glass ceramic material is loaded with zirconia, combining the material properties of zirconia and glass ceramic in a single product [25].

The zirconia-reinforced lithium silicates (ZLS) are a new generation of lithium-based dental composite materials containing around 10% zirconia by weight [26]. Two different zirconia-reinforced lithium silicate ceramics in a pre-crystalized or crystalized form are available on the market: Vita Suprinity PC (Vita Zahnfabrik, Bad Säckingen, Germany) and Celtra Duo (Dentsply Sirona, Hanau-Wolfgang, Germany) [27,28]. To increase strength values, tetragonal zirconia particles are added to the homogeneous glassy matrix of the material. After a process of crystallization, lithium disilicate granules are produced [29]. Crystals of zirconia perform the function of a nucleating agent, but they remain dissolved in the glassy matrix; it is possible to generate a dual microstructure that consists of very small crystals of lithium metasilicate (Li_2SiO_3) and lithium disilicate ($Li_2Si_2O_5$), along with a glassy matrix that contains zirconium oxide in solution [30]. This structural typology was designed in order to combine desirable optical features with higher mechanical characteristics, in comparison to those of other glass-ceramics; nevertheless, to this day, the validity of this premise is still a subject of discussion [31-33].

The ultimate objective of aesthetic dental restorations in prosthetic dentistry is to replicate the form, shade, surface texture, translucence, opalescence, and fluorescence of a patient's natural teeth [34]. Similar to other biological tissues, light that reaches a tooth's surface is reflected, diffused, absorbed, and transmitted [15]. Thus, for satisfactory cosmetic outcomes, it is necessary to control the light absorption, reflection, and transmission of dental ceramic materials in order to obtain favorable shade matching of the restorations [35,36].

Optical properties, translucency and color maintenance are important parameters due to the desired aesthetic result of the ceramic restoration throughout their functional lifetime, which is mainly influenced by translucency and color [37]. In addition to this parameters, surface texture/treatment, ceramic thickness, or processing techniques, can also influence the optical properties and thus the natural-looking long-term aesthetics of the restoration [15,38-41]. Regarding the processing techniques, the ZLS dental material is typically produced fully crystallized and sold as ingots, which, when heated, turn viscous and it is pressed using a lost wax method, making it ideal for the heat pressing technique [42]. Through CAD/CAM systems, the ZLS dental material is milled from ceramic blocks [43].

Based on the above affirmations, it is essential to evaluate both the optical properties of monolithic ceramic restorations to enhance their aesthetics value as well as the processing method of restoration, to avoid a possible influence of this on the optical parameters. Therefore, the purpose of this study was to evaluate if there are differences between the optical properties regarding the ZLS prosthetic restorations obtained through different methods, respectively by heat pressing or CAD/CAM milling. The null hypothesis was that the processing techniques would not affect the optical properties of monolithic glass-ceramics dental materials, meaning that the pressed and milled prosthetic restoration would have the same optical properties.

Methods

Specimens' preparation

Two types of monolithic glass ceramic materials of zirconia-reinforced lithium silicate, fabricated by two different methods, were prepared, and tested for relative translucency and opalescence. The zirconia-reinforced lithium silicate (Celtra) veneers were fabricated by heat-pressing (Celtra Press) and CAD/CAM manufacturing blocks (Celtra Duo) and their chemical composition is listed in table I.

Table I. Materials used in the study

Restoration material	Class of ceramic	Processing method	Manufacturer	Chemical composition	Translucency/ Shade
Celtra Duo	zirconia-reinforced lithium silicate ceramic (ZLS)	CAD/CAM milled	Dentsply (Dentsply Sirona, DeguDent, GmbH, Hanau-Wolfgang, Germany)	SiO_2 (59%), Li_2O (20%), ZrO_2 (12%), and Pigments (< 10%): phosphorus oxide (5%); cerium dioxide (2%); aluminium oxide (1.9%); terbium oxide	HT/A1
Celtra Duo		CAD/CAM milled			LT/A1
Celtra Press		Hot-pressed		SiO_2 (59.3%), Li_2O (14.5%), ZrO_2 (9.3%), and Pigments (< 15%): phosphorus oxide (4.9%); terbium oxide (3.3%); aluminium oxide (3%); boric oxide (2%); potassium oxide (1.2%); sodium oxide (0.2%); magnesium oxide (0.01%)	HT/A1
Celtra Press		Hot-pressed			LT/A1

The low (LT) and high translucent (HT) available on the market were analyzed for both Celtra Press and Celtra Duo veneers. A total number of 80 veneers were manufactured, divided into eight groups (n=10) according to the processing method applied to them, the translucency used and the surface treatment. All veneers were made of shade A1 blocks and pressed ceramics.

An acrylic central incisor of a typodont model was prepared for a ceramic veneer with standard reduction.

To avoid thickness errors and ensure uniform thickness across all veneers, the same design was used for both milled and pressed veneers. CAD/CAM software (CEREC software, Dentsply Sirona) was used to create the veneers design.

Milled ZLS veneers were cut out from partially crystallized ceramic blocks with diamond particle burs mounted on the milling machine (CEREC inLab MC X, Dentsply Sirona, USA).

For ZLS pressed veneers, a precise thickness and design were achieved by milling 40 wax veneer models at the CAD/CAM system. Using this wax patterns, the ZLS pressed veneers were made by the lost-wax and heat-press technique. In accordance with the directions provided by the manufacturer, the specimens obtained by hot-pressing (n=40), were ultrasonically cleaned in distilled water for 15 minutes, followed by a fully crystallization process using a ProFire2 press furnace (DeguDent, Hanau, Germany) with a starting temperature of 700°C, a heating rate of 40°C/min, and an ending temperature of 860° respectively, for 30 min/each temperature. The pressure time was 3 min, at 2.7 bar.

The final thickness of all the obtained veneers (milled and hot-pressed) were recorded by one investigator using a digital calliper (0.8 ± 0.02 mm) (Digimatic Indicator 0001 to 2o; Mitutoyo). The resulted veneers received two different kinds of surface treatment: polishing and glazing. Before color measurements, all the specimens were cleaned in an ultrasonic bath (10 min) with distilled water and dried using absorbent paper.

Spectrophotometric readings

The color differences of the hot-pressed vs. milled veneers were evaluated by reading the parameters on a white (W) and a black (B) background, by using a spectrophotometer (Vita Easyshade V, Vita Zahnfabrik). To facilitate the spectrophotometric measurements, the typodont model on which the veneer preparation was made was duplicated in the laboratory. This allowed for the creation of two identical models, one in white gypsum and one in black gypsum, on which the veneers were positioned to determine their color coordinates, as shown in figure 1.

According to the manufacturer guidelines, the spectrophotometer was calibrated before each measurement, and all measurements were made by the same investigator, in the same location and under the same brightness conditions, using Vita Easyshade V (VITA Zahnfabrik, Bad Säckingen, Germany) spectrophotometer. The spectrophotometrically determinations were used to analyze the middle third of one central incisor, with the goal of ensuring that the effectuated determination was concentrated around the major body of the tooth to circumvent the influence of the translucent incisal edge. For recording the CIELab coordinates of the ceramic veneers, the dental spectrophotometer was set to the Tooth Single mode. First, the initial color of the background substrate was performed, under a standard D65 light source illuminate, which corresponds to average daylight. Second, the specimens were positioned on the backgrounds without an underlying medium, and the CIELab values (L*, brightness; a*, red-green value; and b*, yellow-blue value) were measured. For each specimen, three measurements were made against each background.

Figure 1. The preparation and design of veneers for spectrophotometric evaluation: A – milled veneer; B – hot pressed veneers; C – veneer placed on black model; D – veneer placed on white model.

Translucency parameter

The capacity to enable light to pass through without being scattered is called translucency [44]. The translucency parameter is often evaluated in conjunction with the contrast ratio (CR) [45]. Using the following equation, the values of the translucency parameters (TP) were calculated by the color difference of the same specimen measured against the white and black background (Eq. (1)):

$$TP = \left[\left(L_B^* - L_W^*\right)^2 + \left(a_B^* - a_W^*\right)^2 + \left(b_B^* - b_W^*\right)^2\right]^{1/2}$$

Eq. (1)

in which: TP: translucency parameter (0-100); L* - the lightness; a* - the red-green axis; b* - the yellow-blue axis; B/W - color coordinates over the black and white backgrounds [46].

When the TP value is higher, the ceramic specimen will have more translucency [15].

Contrast ratio

The CR indicates the reflectance of a dental material with a specific thickness, being considered as a second method to evaluate the translucency. However, being an indirect measure of translucency, it is only suitable for dental materials with more than 50% reflectance transmission [47]. The spectral reflectance (Y) was determined using the L* values (Eq. (2)):

$$Y = \left(\frac{L^* + 16}{116}\right)^3 \cdot Y_n$$

Eq. (2)

For simulated object colors, the specified white stimulus is typically one that resembles a perfect reflecting diffuser, normalized so that Y_n equals 100 by a common factor [15]. Using the Y values of the specimens captured on black (Y_B) and white (Y_w) backgrounds, the contrast ratio (CR) was calculated as follows [34]:

$$CR = \frac{Y_B}{Y_W}$$

Eq. (3)

When performing this analysis, at higher translucency the CR range is from 0 (transparent) to 1 (opaque).

Opalescence

Opalescence is the scattering of light on short wavelengths, as it passes through an object, resulting in a bluish hue under reflected light and a brown-red hue under transmitted light [48]. Materials with opalescent characteristics that mimic the natural dentition can be used to produce compelling esthetic restorations that are difficult to detect. In order to determine the value for the opalescence parameter (OP), the following equation was applied [49]:

$$OP = \left[\left(a_B^* - a_W^*\right)^2 + \left(b_B^* - b_W^*\right)^2\right]^{1/2}$$
Eq. (4)

Statistical analysis

Statistical inference was performed using the MedCalc statistical software. The Kolmogorov-Smirnov test for normality was conducted on the whole set of data and indicated that the TP values obtained for all four groups of materials and the CR values were non-parametric while the OP values were parametric. The nonparametric data sets underwent a Kruskal-Wallis test, while the parametric data set underwent a One-Way ANOVA test. The level of significance was set to $p < 0.05$.

Results

Optical properties

The values of the TP, CR and OP are depicted in figures 2, 3 and 4. The Kruskal–Wallis test indicated that there is a statistically extremely high significant difference regarding the TP values between the analyzed groups ($p < 0.0001$), both the polished and the glazed veneers. The same statistically relevant result was obtained for the CR values ($p < 0.0001$). The One-Way ANOVA indicated that there was a statistically relevant difference also between the OP values of the analyzed groups ($p < 0.001$). The Student-Newman-Keuls test for all pairwise comparisons was also executed on the parametric data alongside the post-hoc analysis (Conover) for the non-parametric data.

Regarding the TP parameter, Celtra Duo HT proved to be the material with the highest degree of transparency from all four polished groups (mean value: 19.505±0.1) and all four glazed groups (median: 21.672±0.2). When comparing translucency (low or high), it seems that Celtra Press LT (mean value: 18.22±0.09) had greater transparency than Celtra Duo LT (mean value: 17.75±0.18), in the polished group. In the glazed groups, the same result regarding translucency were recorded, Celtra Press LT (median: 19.2±0.08) having a greater transparency than Celtra Duo LT (median: 18.52±0.1). Glazed Celtra press HT exhibited the greatest TP value (median: 21.672±0.2).

Regarding the polished veneers, both the CAD/CAM ceramic veneers (Celtra Duo) as well as the hot-pressing veneers (Celtra Press) have the same value when it comes to CR value, regarding the two materials with high translucency (HT). The same can be said about the dental materials with low translucency (LT). When analyzing the glazed veneers, the CR values underwent a slight modification, the CR becoming smaller than on the polished samples.

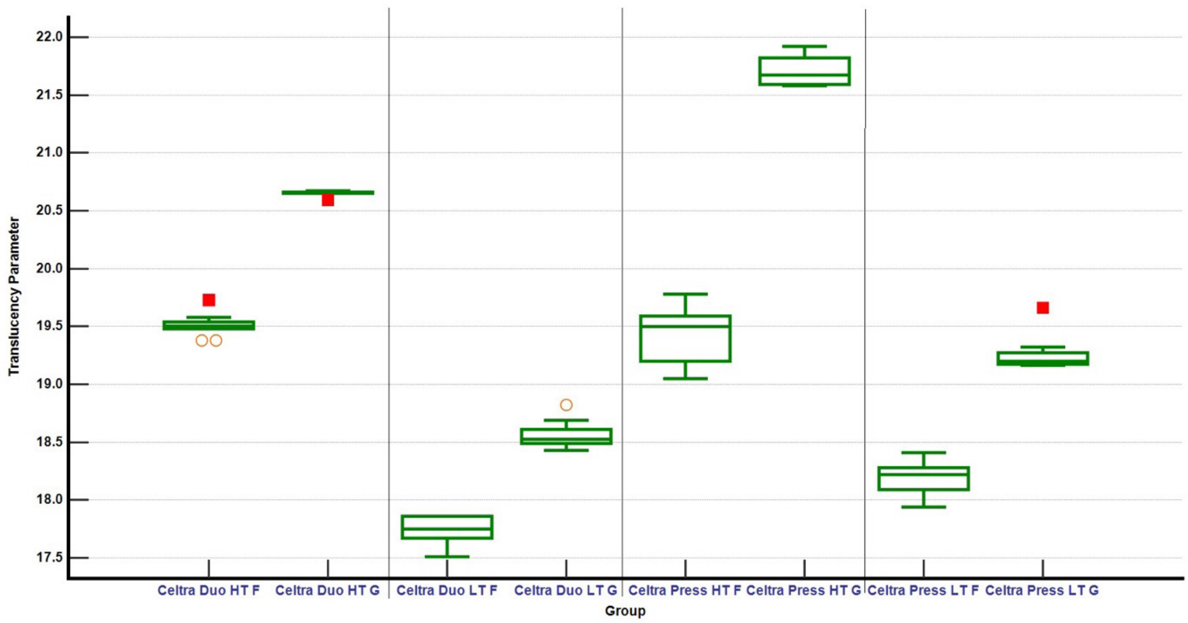

Figure 2. Variation of translucency mean values as function of processing method and translucent degree used. "F" - polished veneers, "G" - glazed veneers.

Although the OP values are reasonably comparable, when comparing the polished veneers groups between themselves, it has been observed that ZLS veneers obtained by hot-pressing technique have a higher opacity than ZLS ceramic veneers obtained by CAD/CAM milling technique, which have a lower opacity (mean value: 6.97±0.09 vs. 5.79±0.18). When comparing the glazed groups with the polished ones, it has been observed that ZLS glazed veneers obtained by hot-press technique keep their opacity values the same as the polished ones, excepting the ZLS glazed veneers obtained by CAD/CAM milling technique, which show a lower opacity compared to the polished samples. Celtra Duo HT glazed veneers exhibit the lowest opacity (median: 3.214±0.0015) among all tested groups.

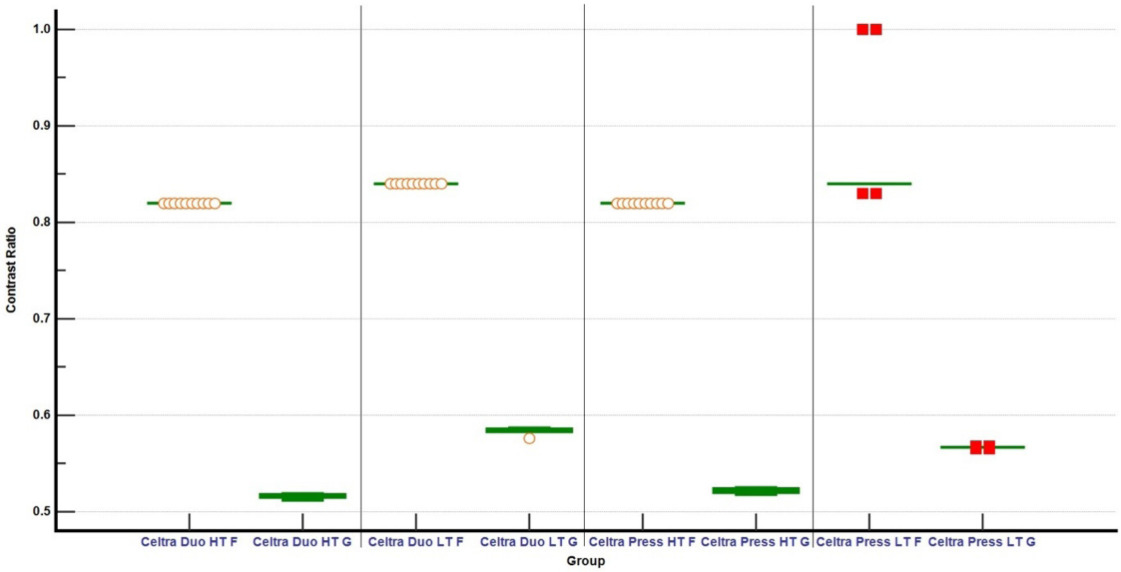

Figure 3. Variation of contrast ratio mean values as function of processing method and translucent degree used. “F” - polished veneers, “G” - glazed veneers.

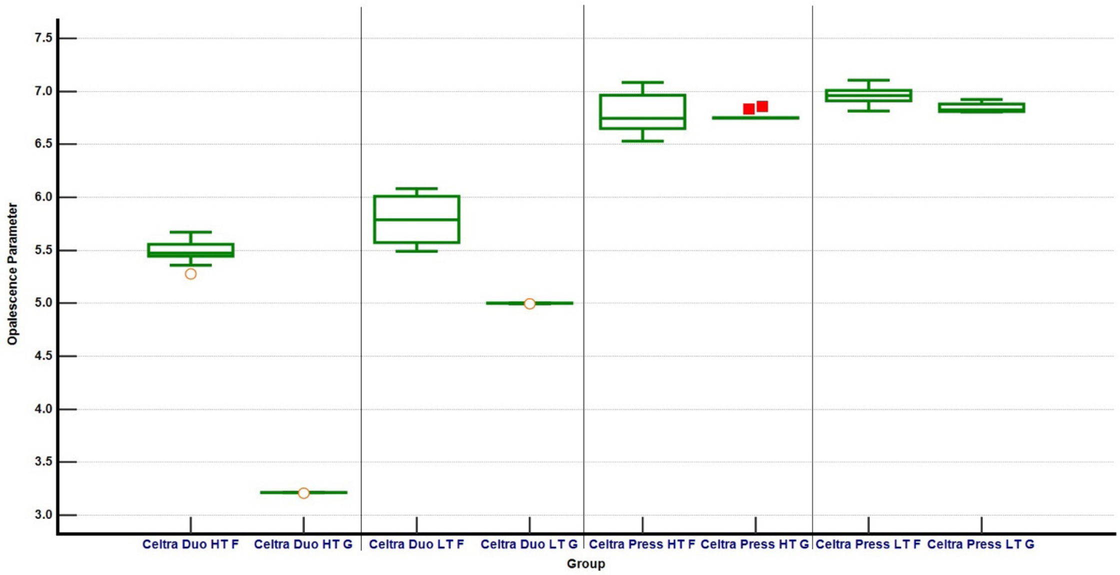

Figure 4. Variation of opalescence mean values as function of processing method and translucent degree used. “F” - polished veneers, “G” - glazed veneers.

Discussion

In dentistry, the patient's satisfaction is mainly linked with the optical properties of the final restoration. In aesthetic rehabilitation, the translucency and opalescence of restorative veneers are critical factors alongside with their color. In this context, the microstructure of a zirconia-reinforced lithium silicate (ZLS) which consist of a combination of a brittle ceramics matrix enriched with high strength ceramic particles, may be a material with excellent optical properties.However, some factors such as processing techniques, could affect the optical properties of the desirable restorations. Thus, the purpose of this study was to assess the optical parameters of a ZLS dental material as a function of processing method (hot-pressing and CAD/CAM milling) chosen for the preparation of the final prosthetic restorations.

The null hypothesis that the processing techniques would not affect the optical properties of the monolithic glass-ceramics dental materials, was rejected, as there was a statistically significant influence regarding the optical parameters of ZLS prosthetic restoration, fabricated through both hot-pressed and CAD/CAM milled techniques. When we compared the two polished groups with the same category of translucency (Celtra Duo LT and Celtra Press LT), the results showed that Celtra Duo LT group (veneers obtained from CAD/CAM milled ceramic blocks) had a lower translucency than the Celtra Press LT group (pellets obtained through hot-pressing technique). Once glazed, translucency values increased for all tested groups. The translucency of a restoration is an important parameter due to the fact that the restorations color and final appearance may be affected by it, which is also an essential component in achieving a natural look [50]. Translucency is the property of the material to enable light to pass through it, and a translucent object allows light to pass through with minimal light absorption or reflection. The most common method to quantitatively assess the translucency of a dental material is spectrophotometry [51], but little by little it is replaced by spectroradiometry, which is a more accurate method [52]. Considering the complete visible spectrum, two approaches exists for measuring translucency: the calculation of the translucency parameter (TP), which is a standard approach for assessing translucency and the contrast ratio (CR), which indicates the reflectance of a certain material with a specific thickness [53]. However, both parameters put clinicians into a difficult position when they compare research studies [37,54]. In addition, contrast ratio is an indirect method of measuring translucency that relies on light reflection rather than transmission; it is therefore suitable for materials with a high percentage of translucency (> 50%) [34,47,53,55,56].

TP and CR have both been used to assess the dental material translucency. Our results are similar with the results reported by other research studies [15,47,53]. In addition, our study confirms the fact that the zirconia content of ZLS has a negative effect on the translucency level. It was stated that a higher zirconia content (12%) increases the mechanical strength of ZLS material, but it affects their optical behavior [57]. In our case Celtra Duo LT has 12 % zirconia content (polished samples TP mean value: 17.75±0.18; glazed samples TP median: 18.52±0.1)) and Celtra Press LT has 9.3 .% zirconia content (polished samples TP mean value: 18.22±0.09; glazed samples TP median: 19.2±0.08). Unquestionably, ZLS aesthetic performance is one of its greatest strengths, as the material is highly valued for its optical properties, such as its translucency. Some in vitro studies reported ZLS ceramics high translucency [25,46,58,59].

For assessing translucency, the material's thickness is crucial, as translucency decreases when thickness increases [60]. To replicate the clinical setting, the specimen's thickness in the present study was set at 0.8 mm. It was stated that the TP mean value of a 1-mm slice of normal human dental enamel and dentin, according to previous research, is 18.7 in the incisal area and 16.6 in the cervical area [61]. According to our study, polished Celtra Press LT (TP mean value 18.22±0.09) is the material with the closest translucency value to genuine tooth enamel, although the other studied materials also have translucency values relatively close to those of natural teeth.

Different levels of translucency were seen in the systems that present LT and HT alternatives, most likely as a result of the formation of crystals [15]. In this study, when comparing the translucency between the polished groups of veneers made by the CAD/CAM milling method, Celtra Duo HT and Celtra Duo LT respectively, a greater difference was observed between the two. On the other hand, when comparing the translucency between the polished groups of veneers made by the hot-pressing technique, the difference in translucency between Celtra Press HT and Celtra Press LT groups was not as significant. The link between TP and CR is strong: as TP is decreasing, CR is increasing. This association was also demonstrated in other studies [45,55].

Dental ceramics have an optical property known as opalescence, which represents the degree of blueness in the light spectrum that is reflected by the material. This quality is brought on by the scattering effect of visible light, which has wavelengths that are either shorter than or equivalent to the particle size of the material being examined [34]. Opalescence is a characteristic of the enamel of normal teeth; hence, considering the growing need for aesthetic restorations, dental restorative materials should be able to replicate the opalescence of genuine tooth enamel, which was reported to be between 19.8 and 27.63 [62,63]. Opalescence is essential for aesthetics because a ceramic with insufficient opalescence cannot replicate the life-like appearance of a natural tooth [64].

If the OP value is less than 4, there is no opalescence, if the OP value is between 4 and 9 then the opalescence may be noticed; nevertheless, it is barely perceptible to the human eye [49]. In the present study, the highest OP was obtained in the case of polished Celtra Press LT group, followed by glazed Celtra Press LT group. The lowest OP was obtained in the case of glazed Celtra Duo HT group. Based on the outcomes obtained in this study, no parameter influences the opalescence of the materials, recorded between 3.21 and 6.97. Our results agree with other previous studies, which reported values of 2.5–13.3 for monolithic ceramic restorations [33]. Heffernan et al. stated that glazing influences the color and translucency of ceramic materials, hence lowering the contrast ratio [65].

One of the limitations of the current study was that only one brand of zirconia-reinforced lithium silicate material was tested. Since translucency of dental ceramics depends on the crystalline structure, number of pigments, grain size, porosity and so on, zirconia-reinforced lithium material provided from various manufacturers has different formulations and chemical compositions, rendering different physical and optical properties between these materials. Thus, the outcomes of the current study cannot be generalized to other brands of zirconia materials. Moreover, the translucency outcomes cannot be related to the clinical situation since the underlying structure effect was not taken into consideration. Another limitation was the thickness of the material since the final thickness of monolithic zirconia tends to affect its color. Although, according to the literature, a thickness of 0.9 is acceptable to achieve aesthetics [66], different thicknesses should be evaluated in further studies.

Although ZLS can be considered a highly promising ceramic material, further *in vitro* and *in vivo* studies are needed to define accurately the optical properties and adequate processing technique for preparation of fixed dental prosthesis, as well as the clinical indications and their long-term performance.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- there are variations regarding the optical properties of dental restorations manufactured from the same kind of dental material but employing different processing techniques.
- translucency and opalescence parameters seem to be mostly dependent on the processing technique of zirconia-reinforced lithium silicate.
- it may be stated that, in comparison with the other groups that were evaluated, the Celtra Press HT dental material emerges as the one that has translucence and opacity values that mimic the best those of real teeth.

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