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Optical Properties of Monolithic Zirconia Crowns- In Vitro and In Vivo Evaluation

SUMMARY

Background/Aim: *The aim of this study was to compare the monolithic and layered zirconia crowns by their optical property of translucency, using in vitro and in vivo evaluation methods.* ***Material and Methods:*** *One upper incisor and one canine were prepared to receive 6 monolithic Lava Plus HT and 6 layered Lava crowns using the CAD/CAM technology. The translucency in the vitro evaluation, was determined using a digital photoradiometer to measure the light reflected by the crowns in two different conditions, natural and metal plated abutment tooth. A provisional complete prosthesis of an edentulous patient, with the abutment teeth mounted in their anatomical position, was used for the in vivo evaluation. The crowns were randomly placed and evaluated by two independent operators in the oral cavity conditions.* ***Results:*** *In vitro results showed that monolithic crowns were not significantly less translucent than layered ones in both incisor (p=0.098) and canine (p=0.340): contrast ratio 0.978 vs. 0.956 and 0.941 vs. 0.929, respectively (Student –t test; α=0.05). In vivo evaluation results showed that the difference in the luminance was not statistically significant between Lava Plus HT and layered Lava crowns according to Mann Whitney Test, p=0.089 (α=0.01).* ***Conclusions:*** *The difference in translucency between monolithic and layered zirconia crowns was not statistically significant both in vitro and in vivo evaluation. Monolithic zirconia had a good masking ability of the abutment tooth.*

Keywords: Monolithic Zirconia Crowns, CAD/CAM Technology, Optical Properties

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Introduction

The use of dental restorations that mimic the esthetic and mechanical properties of natural teeth has been a challenge through the years in dentistry. Many research and advancements have been done in the microstructure of the materials and the technology used for their fabrication. Based on their chemical composition and the presence of the specific attributes in their formulation, ceramic materials can be classified into three categories: glass-matrix ceramics, polycrystalline ceramics and resin-matrix ceramics[1].

Resin-matrix ceramics are a new category of restorative materials. They are hybrid dental ceramics with a dual structure, an organic matrix combined with ceramic fillers[2].

In the first category are included glassy matrix ceramics that have an incorporation of crystals in the glassy matrix. Feldspathic, leucite-reinforced glass ceramics and lithium disilicate glass ceramics, have good optical properties, an increased translucency, but lower mechanical properties compared with the other ceramic materials.

Polycrystalline ceramics have the higher mechanical properties of all ceramics in terms of flexure strength and fracture toughness. They have no glassy contents, but oxide metals densely packed. Alumina, zirconia toughened alumina, stabilized zirconia have crystalline

structure that contributes to their toughness but tend to have lower translucency and optical properties.

Zirconium dioxide has largely replaced alumina in clinics. Stabilised zirconia is an oxide ceramic used from the late of 90-s. Yttria-stabilised tetragonal zirconia polycrystals has become more prevalent along with advances in CAD/CAM technology[3]. Y-TZP is the strongest and toughest restorative material ever used in dentistry with a flexure strength of 900 to 1400 MPa modulus of elasticity of 210 GPa and fracture toughness of 10 MPa/m$^{1/2}$ [4]. Due to its superior mechanical properties Y-TZP is indicated for the milling of anterior and posterior copings and frameworks for fixed partial dentures and full ceramic restorations[5].

First generation of zirconia used in dentistry were zirconia copings veneered with feldspathic porcelain for esthetic reasons, because of the opacity of the zirconia frameworks[6]. Clinical research revealed that technical problems of the porcelain veneer such as chipping and delamination were very frequent[7]. To overcome these technical complications the monolithic zirconia crowns were introduced in the market. Full contour monolithic zirconia have a higher fracture resistance and clinical success rate than the bilayered ones[8]. This is due to increased zirconia thickness and lack of veneering porcelain.

When zirconia is employed to make full contour restoration, translucency still remains an issue since zirconia is the least translucent among dental ceramic[9]. Zirconia is monochromatic material, but it can be stained by infiltration, and the tendency is to use CAD/CAM polychromatic discs to imitate a tooth like appearance. Second generation zirconia materials have been manufactured with an increased translucency[10]. This zirconia ceramics with augmented translucency presented similar strength compared to conventional 3 mol% Y-TZP ceramics. Improvement in the translucency was due to the reduction of the alumina additive and sintering at higher temperature to eliminate porosity[11].

The third generation of zirconia includes zirconia with a higher content of Y2O3 from 3 mol% to 5 mol% or more than 8mol%, the so called fully stabilized zirconia that has higher amounts of cubic phase particles. The biphasic tetragonal/ cubic zirconia is super and ultra translucent and this due to the cubic phase larger amounts but with significant lower mechanical properties. The flexure strength is 500 to 800 MPa, it is more like a dental alumina material because the strength decrease as the cubic content increase[12]. Cubic zirconia has no transformation toughening and are subject to low temperature degradation[13]. Lacking the feature that gives zirconia its toughness and resistance to fracture would be safe to indicate the use of fully stabilized zirconia for anterior fixed partial denture and in the posterior region for bridges that not exceed 3 units[14]. In terms of strength and fracture resistance, wear of antagonist enamel, high translucent monolithic zirconia is the material of choice compared to cubic zirconia and conventionally veneered zirconia even at a minimal thickness 0.5 -1mm[15]. Translucency is one of the main parameters in matching the appearance of the natural tooth and remains an issue. It is considered an important factor for material selection in controlling esthetics.

The purpose of our study was to evaluate the in vitro and in vivo translucency of high translucent monolithic zirconia crowns compared with conventionally layered zirconia crowns and how the translucency levels could affect the esthetic outcome of the restoration by varying the color of the abutment teeth. The null hypothesis was that there was no difference in the translucency of the monolithic and layered zirconia crowns changing the substrate of the abutment teeth.

Material and Methods

Two human teeth, a lateral incisor and a canine of the same quadrant were extracted for periodontal reasons, after the patient written consent that was informed and explained the aim of the study. The study was approved by the ethical committee of the University. Dental plaque, calculus and periodontal tissue were removed carefully using hand and ultrasonic instruments from the teeth, polished and stored in 0.2 % saturated thymol water solution. Each tooth was prepared following the 3M ESPE protocol for Lava All Ceramic crowns[16].

Six monolithic crowns per each tooth were replicated using Lava Plus CAD/CAM HT zirconia blocks. Then, six layered zirconia Lava 0.5 crowns were also replicated for each tooth, making standard Lava 0.5 zirconia copings and pressed on layering technique (IPS e.max Zirpress A2) as shown in Figure1. A total of 24 crowns having the same size and shape were obtained (Table 1).

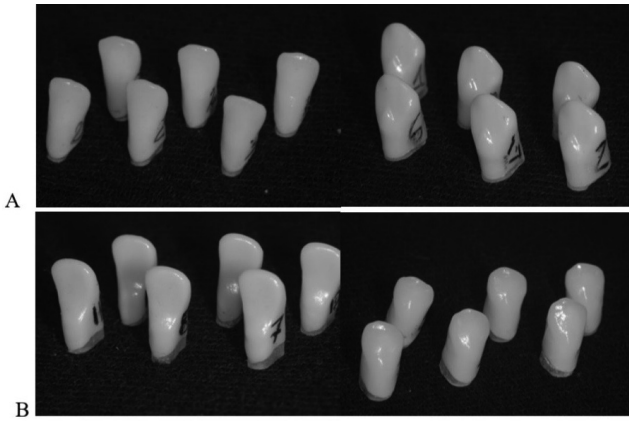

Figure 1. Monolithic Lava Plus HT crowns (A), Layered Lava crowns (B)

Table 1. The number of zirconia Monolithic HT and Layered Lava crowns used in the study

Crown	All ceramic system	
	Lava Plus monolithic zirconia HT	Lava 0.5 conventional layered zirconia
Incisive	6	6
Canine	6	6
N	12	12

In vitro methodology

The translucency of the restorations was determined by direct transmission of the crowns placed in a dark room, simulating a tooth being hit by D 65 external illuminated radiation. A band of light generated by a LED lamp was reflected by the crown buccal surface measured in a standartised area by the sensor of a digital photoradiometer (model HD 9221/S3; Delta Ohm Srl, Padua, Italy) with a spectrum range of 400 to 760 nm. Measurements of the quantity of light transmitted by the surfaces of the crowns were expressed in light units, Lux (lx).

The measurement system was verified before each test run in each of 6 crowns. First, a negative control test was performed and the instrument was evaluated for a zero light reading and for having a steady power supply. Then the translucency of each crown positioned on a firm base was measured, and the last figure turned up by the sensor before it was switched off, was selected. These measurements were repeated three times for each crowns put on the natural prepared tooth with try-in cement Variolink (Ivoclar Vivadent AG) color A2 (Figure 2).

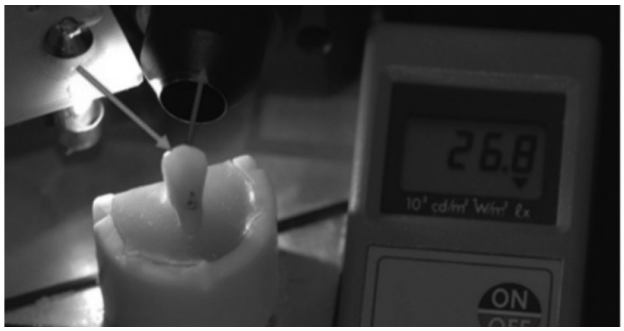

Figure 2. In vitro measurements of the crowns placed on the natural abutment tooth

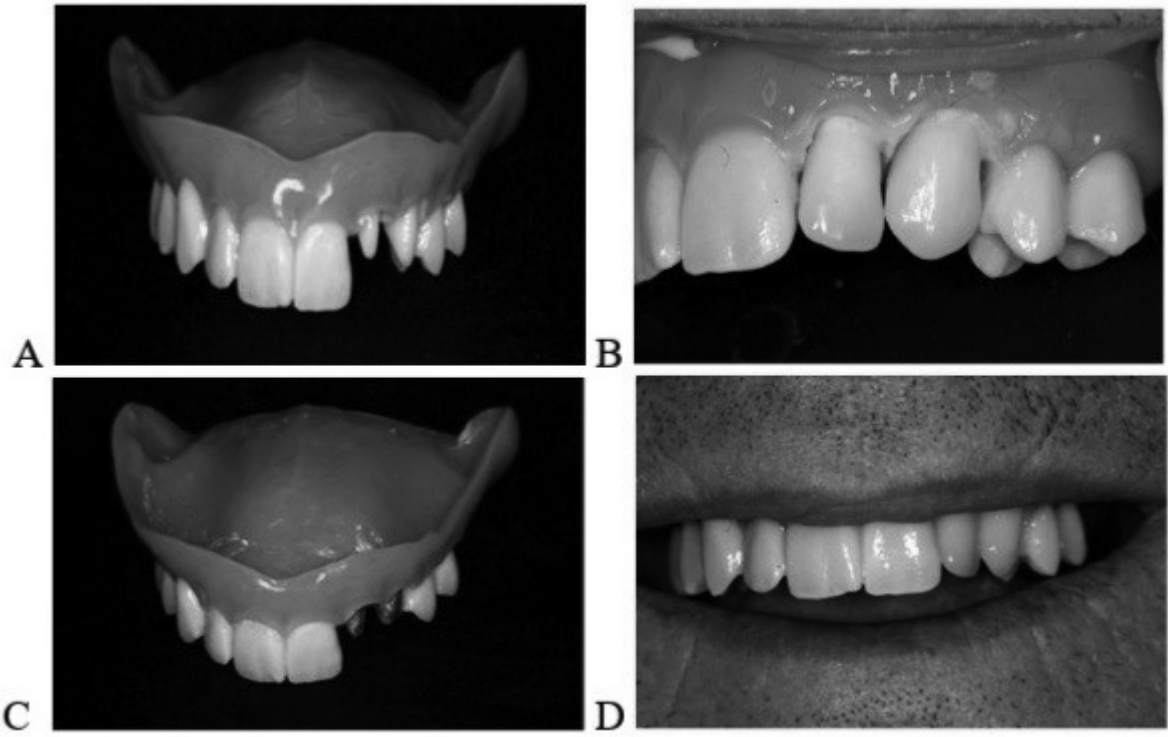

Figure 3. Provisional complete prostheses with the abutment teeth mounted in their anatomical position (A), Clinical evaluation of the crowns (B), Abutment teeth simulating metal core mounted in the provisional complete prostheses (C), Clinical evaluation of the crowns (D)

Each of the crowns underwent the same translucency analyses after the natural teeth were dyed with dye spacer silver YETI Dental (Yeti Dentalprodukte, GmbH Engen/Germany), simulating a metal core, resulting in a total of 144 measurements. To convert the data obtained into quantitative measurements of translucency it was made the ratio between the light reflectance of each specimen over a dark background and the reflectance on a white background. The contrast ratio obtained gave the luminous reflectance of each crown applied on the metal plated abutment (M lux) and on the natural abutment (D lux). The ratio for each crown. CR =M lux/ D lux ranges from 0 to 1 and the tendency toward unity means a lower translucency. The mean of the luminous reflectance of

each crown on the metal plated abutment was divided by the mean of the luminous reflectance on the natural abutment to give the mean contrast ratio. The in vitro data were statistically analyzed using the Student's *t* test for paired and unpaired data and a p value of < 0.05 was considered statistically significant.

In vivo methodology

The clinical evaluation of the crowns was performed by two different operators. A complete provisional prosthesis was constructed with the abutment teeth mounted in their anatomical position to the same edentulous patient (Figure 3/A). The crowns were placed in a random manner on the natural abutment with experimental cement Variolink (Ivoclar Vivadent) color A2 and two independent operators were invited to evaluate the luminance values of the crowns with the counterparts artificial teeth of the complete prostheses (color A2). The difference in luminance were evaluated asking the two operators if the crowns have a minor or a major value of luminance according to the visual scale VES where the complete difference was expressed with 0% and the total similarity was expressed with 100% (Figure 3/B). The same evaluations were repeated with the crowns placed on the metal core (Figure 3/C,D). The comparison of in vivo luminance values for each crown placed on different substrates were statistically analyzed using Mann Whitney rank sum test, and a p value < 0.01 was considered statistically significant.

Results

The mean data of the luminous reflectance obtained for each crown on natural abutment and metal plated abutment are shown in Table 2. The monolithic Lava Plus and layered zirconia Lava crowns reflected more light when they were placed on the natural abutment than on metal plated abutment and this difference indicated that translucency of the crowns was affected by the change of the core. Incisive Layered Lava crowns were significantly more translucent ($p= 0.001$) when the abutment substrate was changed from natural to metal plated. Monolithic zirconia crowns reflected lower light when changing the substrate from natural to metal plated but this difference was not statistically significant. The light reflected when the canine abutment was turned to dark by metal plated, was statistically significant for all layered Lava crowns and monolithic Lava Plus zirconia crowns. All measurements showed low values of SD, suggesting a high standardization level. CR values used to compare the translucency of each conventionally layered zirconia Lava and monolithic zirconia Lava Plus HT as shown in the following graph (Figure 4).

Table 2. The reflected light of monolithic and layered zirconia Lava crowns

Natural abutment tooth	Mean and SD reflected light (lux)	
	Monolithic Zirconia Lava Plus	Layered Zirconia Lava 0.5
Incisor	25.53±0.77	25.73±0.47
Canine	28.32±0.24	29.57±0.38
Metal-colored abutment tooth	Mean and SD reflected light (lux)	
	Monolithic Zirconia Lava Plus	Layered Zirconia Lava 0.5
Incisor	24.97±0.59	24.62±0.63
Canine	26.65±0.23	27.48±0.49

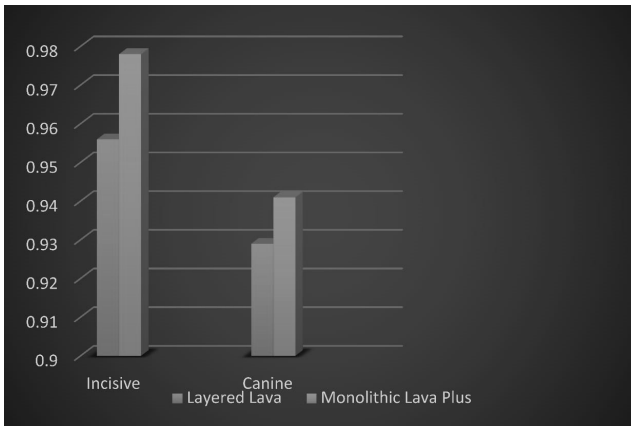

Figure 4. Contract Ratio for layered zirconia Lava and Lava Plus monolithic crowns

Contrast ratio values for monolithic zirconia Lava Plus were 0.941 and 0.929 for layered Lava crowns when the abutment tooth was the canine. The contrast ratio of the incisive crowns was 0.978 for monolithic zirconia Lava Plus and 0.956 for layered zirconia Lava. All the specimens tend to have low translucency as the ratio for each crown go toward unity. Layered Lava crowns tend to be slightly more translucent than monolithic Zirconia Lava Plus but this translucency is not statistically significant, in both incisor ($p=0.098$) and canine ($p=0.340$), according to Student's t test for paired and unpaired data, $\alpha=0.05$. The luminance values of monolithic Lava Plus and layered Lava crowns obtained during the clinical evaluation by two different operators statistically analyzed with Mann Whitney Test (Figure 5).

The difference in luminance values is proportional to the translucency of each crown, monolithic and layered one placed on the different substrates. Changing the substrate from natural abutment tooth to metal plated one, all Lava crowns, monolithic and layered ones have a minor value of luminance with their counter parts teeth of the complete denture. The difference was not statistically significant according to Man Whitney rank sum test, $p=0.089$. The comparison of in vivo luminance for each crown, monolithic Lava Plus and layered zirconia

Lava, for both incisive and canine abutment teeth is shown in the following graph (Figure 6). According to the clinical evaluation made by two operators, there was no statistically significant difference in the luminance between all Lava and Lava Plus HT crowns, where placed on the canine and incisive natural abutment or metal plated one, p=0.734.

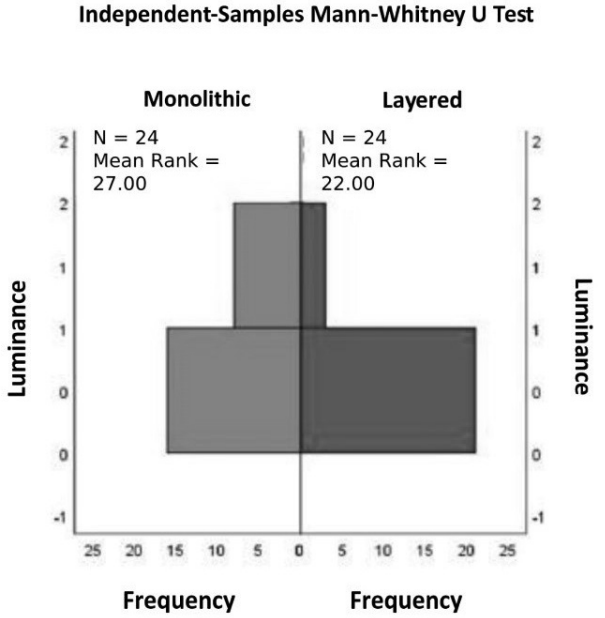

Figure 5. In vivo luminance values of monolithic and traditional Lava crowns

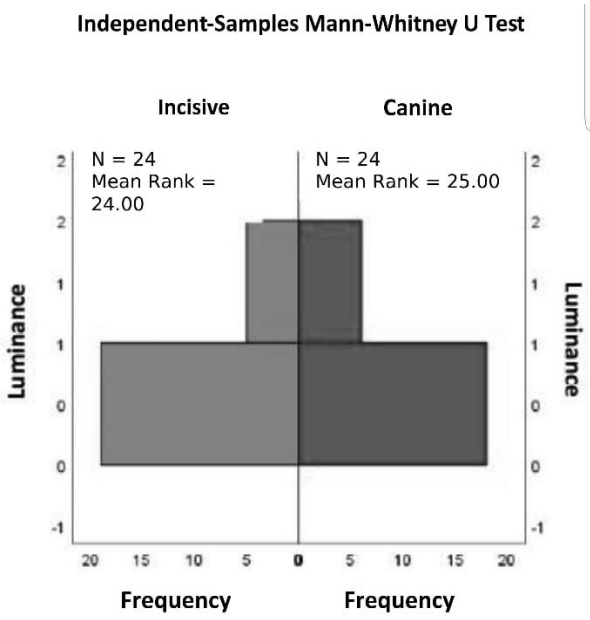

Figure 6. In vivo luminance values on different abutment teeth

Discussion

Translucency has been defined as the light transmission through a material resulting in a combination of absorption, reflection and refraction producing light scattering. If the most of the light is diffusely transmitted, the material will appear translucent.

Translucency can be measured according to different equations using different instruments. There are three methods used in the literature on this purpose, light transmittance, translucency parameter (TP) and contrast ratio (CR) as the most common parameters used[17,18]. Light transmittance includes direct transmission where the light that pass through a ceramic restoration is measured[19] the total transmission where the light that reach the restoration and the light scattered are measured.

Translucency parameter is achieved from the color difference of a specimen on a white and black background. TP is obtained through CIE-Lab formulation. It varies from 0 to 100 and is used in different studies in measuring the translucency of a restoration[20,21].

In the contrast ratio method the measurements are taken from the reflectance of a specimen over a black and white background. It ranges from 0 to 1 where 0 represents total transparency and 1 total opacity of a material. CR and light transmittance are two methods that could be either luminous or spectral[22,23].

In the current study we have conducted an in vitro evaluation of translucency of monolithic and layered zirconia crowns with CR parameter and the results are easily to compare with the most recent literature.

In the vitro evaluation of the translucency, in the present study, monolithic crowns being considered superior in strength exhibited slightly less but not a statistically different translucency than layered crowns.

This was not in accordance with the study of Vichi *et al*.[24] where augmented translucency TPZ showed higher translucency and similar flexure strength than traditional TPZ. These were due to the difference in the instrumentation used to make the measurements, the specimen used were discs and not crowns as in our study and differed in their strengthening components.

Another study that evaluated the translucency of monolithic HT with layered specimens but with different colors was the study of Matsuzaki *et al.* [25]. The results were in concordance with the present study. Monolithic high translucency zirconia specimens showed slightly lower translucency parameter values than layered zirconia of 0.5 mm core. Translucency of monolithic HT specimens decreased in dark colors and this was influenced by adding Fe_2O_3 but this was an object of the present paper.

In the study of Tuncel *et al*.[26] were evaluated monolithic specimens compared with frameworks without veneering porcelain. They used the same method, CR evaluation as in our study. The monolithic zirconia was

shown significantly more opaque than colored and non-colored zirconia framework of 0.5 mm thickness. These results were not consistent with the results of our paper because the grain size influenced the translucency of the specimens. Monolithic zirconia group used was 361 nm differently from our study where Lava Plus monolithic zirconia has an average grain size of 250 nm [4]. In our study the bilayered restorations were veneered with lithium disilicate pressed on zirconia core of 0.5 mm, showing similar results with Kim HJ *et al*.[27]. This study reported decreased translucency as increased zirconia core thickness.

Monolithic crowns are not veneered with esthetic porcelain like conventionally layered ones, however according to Antonson *et al*.[28] the thickness of the ceramic rather than esthetic properties are more contributory factors in the transmission of light. Another factor contributing in the translucency of the zirconia crowns is the more complex procedure in the fabrication of layered than monolithic crowns. The increased number of firings influence significantly in the translucency of all ceramic systems[29].

Both groups of Lava and Lava Plus HT showed low translucency values but these values were not statistically significant. Monolithic Plus Lava HT crowns exhibited a higher masking ability of the abutment tooth, but the translucency was affected by different substrates used. These results were in concordance with the paper of Dai *et al*.[30] where the masking ability of Lava Plus HT depended on the type of substrate, thickness of the zirconia specimen and the type of the cement used.

The in vitro evaluation results were clinically cross examined with the luminance values of the same crowns by two different independent operators. There is a lack of evidence in the literature about clinical relevance of the same in vitro results in the in vivo conditions. In this study we tried to evaluate the difference in the translucency, that human eye can perceive, between Lava and Lava Plus HT crowns put in the oral cavity conditions. The translucency of a crown is proportional to its luminance values and in the present study was a blind evaluation by two independent skilled operators. There was not found a significant difference in the translucency among monolithic and layered crowns in the clinical evaluation. Changing the substrate resulted in a good masking ability of all the crowns, layered and monolithic ones. The different core was not perceived by the two independent operators in differences in the luminance of all zirconia Lava crowns. There are few in vivo studies[31] where the measurements of the translucency are instrumental using different devices and this is a limitation of our study.

There are different intrinsic and extrinsic factors that influence light transmission contributing to the translucency and opacity of zirconia restorations[32]. Losses in the intensity of the incident light is due to the TZP crystals birefringence with different refractive index, particle and grain size, density, pores and impurities, sintering temperature, the use of different dopants.

Light transmission is affected too by the dental background, luting agent and the thickness of the restorations. Strong point to mention in the current study was the measurement of the translucency of the crowns in the in vitro and in vivo conditions, simulating the appropriate clinical conditions of the oral cavity. Changing the substrate indicates how the translucency is affected by different dental background.

Conclusions

Monolithic Lava Plus HT crowns were less translucent than layered Lava crowns, but this was not statistically significant, both in vitro and in clinical evaluation. Monolithic Lava Plus HT zirconia crowns showed a good masking ability and they do not affect the esthetic outcome of the restoration when changing the substrate of the abutment tooth.

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