Marginal discrepancy and load to fracture of monolithic zirconia laminate veneers: The effect of preparation design and sintering protocol

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To investigate and analyze the impact of teeth preparation designs and sintering protocol on marginal fit and fracture resistance of monolithic translucent zirconia laminate veneers. A total of 40 extracted intact human maxillary central incisors were assigned into 4 groups (n=10/eac group) to investigate 2 variables: (1) the design of tooth preparation (a 1.5 mm incisal reduction with or without palatal chamfer) and (2) the two different sintering programs used for translucent zirconia restoration (standard or speed sintering procedure). Marginal discrepancy was evaluated using a digital microscope. The specimens were loaded to failure in the compression mode, using a universal testing machine with a crosshead speed of 0.5 mm/min. Marginal adaptation of monolithic translucent zirconia laminates are affected by both tooth preparation design and sintering protocol. However, resistance to fracture of translucent zirconia laminates has affected mainly by sintering procedure regardless the teeth preparation design used.

Keywords: Translucent zirconia, Sintering program, Laminate veneer, Fracture

INTRODUCTION

The esthetic outcome following restoration of anterior teeth has always presented a challenge in daily clinical practice. Porcelain laminate veneers (PLVs) are indicated as a conservative treatment modality for anterior teeth restoration with the advantage of excellent esthetics combined with minimal tooth reduction¹-³). Careful treatment planning besides precise tooth preparation is critical for optimal function and aesthetics⁵). As preservation of tooth structure is pertinent, adequate space must exist for the restorative material to possess proper thickness for optical properties and strength. Different preparation guidelines are recommended based on the necessity to modify the tooth length and faciolingual width³-⁵). Among different preparation designs, Incisal overlap tooth preparation may be indicated in case of modification of the incisal edge is required. Two types of incisal overlap tooth preparation design exist; the incisal shoulder preparation design at which incisal edge is reduced and overlapped (IPS) and incisal palatal chamfer preparation (IPC) designs, which improve the esthetics and helps in positive placement of PLVs⁶-¹²).

The long-term clinical performance of laminate veneers based on a number of factors such as mechanical strength of restorative material, bonding properties, with marginal integrity being one of great importance. It is critical to establish an acceptable marginal fit in laminate veneers because of the innate limitations of composite resin luting cements, such as high coefficient of thermal expansion, lower resistance to clinical wear, and relatively high polymerization shrinkage¹³-¹⁶). Close adaptation between the restorations margins and the tooth structure aid in protection of the adhesive resin cement from redundant exposure to the oral fluids with the resultant decrease in the process of gradual disintegration of its chemical, mechanical and physical properties resulting in recurrent decay, microleakage, and the creation of stress concentrations (that may reduce the strength of the restoration with subsequent fracture may occur)¹⁶-¹⁹). Fifteen-year clinical performance studies reported that feldspathic veneers fractures represented 67% of the total failures of such restorations which is considered the main drawback associated with laminate veneer²⁰,²¹).

Several ceramic materials are currently used for veneer fabrication: feldspathic ceramic, lithium disilicate, fluorapatite, and lithium silicate reinforced with zirconia²,⁶). All of these ceramics offer high optical properties as a result of its high content of glassy matrix in their composition; therefore highly favorable esthetics outcome is achieved. Additionally, it showed excellent adhesion to resin cement through the conditioning with hydrofluoric acid (4–10%) followed by silanization⁶).

On the other hand, Zirconia-based ceramics, such as tetragonal zirconia partially stabilized by yttria (Y-TZP), have been successfully introduced into the daily dental practice to fabricate fixed dental prostheses (FDPs), along with a dental computer-aided design/computer-aided manufacturing (CAD/CAM) based on their excellent biological, mechanical, and physical properties⁹). However, many endeavors have undergone many changes in composition and microstructure to increase their optical properties without significantly affecting their mechanical properties²⁰, thereby expanding their
clinical indication. Consequently, high translucent zirconia has been introduced in an attempt to enhance the aesthetic outcomes and to overcome the problem of veneering layer chipping, fractures, or delamination over the zirconia substructure. Compared with conventional zirconia, high translucent zirconia ceramic has different mechanical and optical behaviors and recommended for monolithic restorations with restricted application and conservative tooth preparation23).

Among manufacturers, the sintering temperature of zirconia generally ranges between 1,400°C to 1,600°C. The final sintering temperature and duration affects the grain growth in the material. The higher the sintering temperature increases the grain size of zirconia that becomes less stable and more liable to spontaneous temperature increases the grain size of zirconia that becomes less stable and more liable to spontaneous tetragonal-to-monoclinic phase transformations24–27).

A fast sintering procedure was introduced by manufacturers as a substitute to conventional sintering procedure that is proposed to be more economic and saving time. Producers’ “in-house” testing assume comparable optical properties and adaptation of zirconia restorations with either conventional or speed sintering procedures. However, there is no sufficient data to support this claim. A few in vitro investigations have recently pointed out that, processing of zirconia restoration at high sintering temperatures accompanied with short sintering durations increased the flexural strength of zirconia without affecting its color and translucency28).

In addition; an in vitro investigation has been conducted recently declared that the sintering duration does not have an impact on the marginal discrepancy of zirconia copings29,30).

To the authors’ best knowledge, no studies address the dimensional alterations based on the short duration sintering procedure and the effect of such alterations on the fit of zirconia veneers. Accordingly, the aim of the current study was to explore the effect of different tooth preparation design on the marginal fit and load to fracture of translucent monolithic zirconia veneers manufactured by CAD/CAM using standard and speed sintering protocols. Thus, the null hypotheses of this study were there is no significant effect of tooth preparation design, and speed sintering procedure on marginal misfit and load to fracture of translucent monolithic zirconia veneers.

MATERIALS AND METHODS

Forty intact human maxillary right and left central incisors free of caries and of similar size were used in this study. The collected teeth were examined under blue-light transillumination to ensure that the enamel was free of crack lines. The teeth were stored in distilled water with 0.1% thymol solution at room temperature up to 3 months until use. To ensure similarity in the dimensions of the teeth, the mesio-distal and inciso-cervical labial surfaces were measured with a digital caliper with an accuracy of 0.01 mm. The difference between right and left maxillary central incisors in mesiodistal (MD)and incisocervical (IC) diameters31,32 was overcome by standardization of MD and IC dimensions of the used teeth (mesio-distal width: 8 to 9 mm; inciso-cervical length: 8.5 to 9.5 mm) and random distribution of teeth between study groups.

Teeth preparation

Two preparation designs (n=20/group), Incisal palatal shoulder (IPS) and incisal palatal chamfer (IPC) preparations were used. A silicone index (Speedex; Coltène Whaledent, Altstätten, Switzerland) was used to determine the extent of labial and incisal reduction for both preparation designs. A digital vernier caliper was used to measure a 1.5 mm distance to be able to mark the tooth for incisal reduction that was done with a chamfer bur and a straight cutting-edge finishing line in the buccolingual direction was obtained. On the labial surface, guide grooves were created using depth guided burs to give a depth of 0.3 mm on the surface to prepare lines on the labial aspect to a standardize depth. Additionally, a lead pencil was used to paint the base of the prepared lines on the labial surface in order to control the amount of tooth reduction. A chamfer bur were then used to unit all bases by holding the bur parallel to the tooth surface. Cervically, a shallow chamfer (0.3 mm) was prepared 1 mm incisal to cement-enamel junction. The proximal reduction was shaped using a small round-end tapered diamond bur. For IPS preparation design group, the incisal edge was shortened 1.5 mm and a right-angled contour between the incisal and the palatal aspect was created. The teeth of IPC group received an incisal overlap preparation, including 1.5-mm incisal reduction and 1-mm palatal chamfer of (Fig. 1).

Laminate veneer fabrication

For each prepared tooth, an impression was made using polyvinyl siloxane impression material (Ghenesyl, Lascod, Italy) using a dual-phase single-stage technique and poured with type IV dental stone (SHERA

Fig. 1 Schematic representation of preparation designs in each test group.

a: Group IPS, incisal palatal shoulder preparation.
b: Group IPC, incisal palatal chamfer preparation.
PREMIUM, SHERA Werkstoff-Technologie, Germany) following manufacturer’s instructions. After complete setting of the stone die, it was fixed on the scan base of the optical scanner (Ceramill Map400, Amann Girrbach, Germany) and the scanning procedure was completed. Each zirconia veneer was designed using CAD-CAM design software (Ceramill Mind CAD version 3.5.6.1408, Amann Girrbach). The job definition included determination of tooth number, restoration type, and material. Certain parameters were determined such as defining the margin, cement gap thickness (50 µm) with 1 mm from the margin and restoration thickness. After calculation of the tool path, the designed veneer was sent to the milling machine (Ceramill Motion 2/5 axis, Amann Girrbach). All veneers were milled from presintered zirconia blocks (Zolid FX Preshaded, Amann Girrbach).

Before sintering, the sintering parameters for zirconia were set on the furnace’s control panel following either standard sintering (SS) or fast sintering (FS) procedures following manufacturer’s instructions Table 1. For each group of preparation design (n=20), half of the veneers (n=10) were sintered following SS program and the other half of veneers (n=10) were sintered following FS program (Table 1). All specimens were sintered using a zirconia sintering furnace (Ceramill Therm S, Amann Girrbach). After sintering, all zirconia veneers were cleaned and the dimensions were checked with digital caliper sensitive to 0.01 mm for standardization. Finally, all zirconia veneers were subjected to glaze cycles in a porcelain furnace (Programat P300, Ivoclar Vivadent, Schaan, Liechtenstein) following manufacturer’s recommendations. Each veneer was checked on its respective tooth for seating without interferences and the margin was evaluated with a dental explorer and 2.5x magnification loop.

Cementation procedure
The intaglio surfaces of each ceramic laminate veneer were prepared for cementation as recommended by the manufacturer. The bonded surfaces of all laminate veneers were airborne particle-abraded for 10 s at 0.2 MPa pressure using 50 µm diameter Al₂O₃ (Hi-Aluminas; Shofu, Kyoto, Japan) and treated with a primer (Clearfil Ceramic Primer Plus; Kuraray Noritake Dental, Tokyo, Japan). Teeth were etched using 37% phosphoric acid for 30 s, conditioned with Syntac Primer, Adhesive and Heliobond (Ivoclar Vivadent). Resin cement (Multilink A3; Ivoclar Vivadent) was applied on the intaglio surface of each laminate veneer which was then seated on the prepared tooth using finger pressure for one min. After removal of the excess cement, it was light polymerized for 60 s from the lingual and labial surfaces.

Following water storage for 60 days, the cemented laminate veneers were received thermocycling (6,000 cycles between 5 and 55°C for 60 s each with a dwell time of 12 s) using water as a transfer medium.

Marginal misfit was assessed using a stereomicroscope (Leica optic, Leica, Switzerland) using Leica Application Suite (Leica Microsystems, Switzerland) software, under ×30 magnification at eight different predetermined positions (Mesioincisal, Mesial, Mesiocervical, Buccal, Distocervical, Distal, Distoincisal and Palatal) (Fig. 2). Each site was measured three times, and a mean value was calculated. By calculating the mean values of the measurement areas in this manner, the total mean of incisal, axial, and marginal discrepancy values were recorded. A randomly selected sample of each preparation group was scanned for verification of marginal discrepancy measurements (Figs. 3a and b).

Load at fracture and fracture pattern
The load to fracture values were evaluated using a universal testing machine (AG-5 kNG, Shimadzu,
Kyoto, Japan) equipped with a 1-kN load cell. The load was oriented at a 90-degree angle to the palatal aspect of the tooth using specially designed mounting jig35-37) (Fig. 3). The load was directed at 1 mm from the incisal edge on the tooth restoration interface with a customized plunger at 0.5 mm/min crosshead speed. The fracture load was recorded in newton (N) (Fig. 4).

The fractured surfaces were then checked macroscopically to assess the failure modes. The failure modes were assorted based on one of the following criteria: Cohesive (laminate fracture), adhesive failure (debonding of laminate), mixed (adhesive and cohesive failure), and root fracture.

**Statistical analysis**
Shapiro-Wilk’s and Levene’s tests were used to confirm the assumption of normal distribution of the marginal discrepancy and load to fracture data; therefore, parametric statistics were used. A two-way analysis of variance (ANOVA) was used to evaluate the overall statistical significance of differences among study variables. Multiple comparisons were made using Tukey’s *post-hoc* test. *p*<0.05 were considered to be statistically significant in all tests. The modes of failure were analyzed with the Chi-square and Kruskal-Wallis tests to disclose the differences between the tested groups (*p*<0.05). All statistical analysis was conducted using SPSS 20.0 software for Windows (SPSS, Chicago, IL, USA).

**RESULTS**

Means and standard deviations of marginal discrepancy values (μm) are shown in Table 2. Tested groups with incisal palatal chamfer preparation showed the greatest mean marginal gap values at predetermined locations regardless of the sintering protocol used. However, Two-way ANOVA test revealed no statistically significant difference in marginal discrepancy at cervical (mesiobuccal, buccal and disto-buccal) between the IPS and IPC preparation design irrespective of sintering protocol (*p*=0.362).

Statistical analysis revealed that the highest marginal misfit values recorded at palatal surfaces for both preparation designs while the mid axial surfaces followed by cervical surfaces yielded the lowest values in all tested groups (Table 2). Regarding to the impact of tooth preparation design and sintering time on the mean marginal fit of monolithic zirconia laminate veneers, two-way ANOVA test revealed statistical significant effect (*p*=0.001, Table 3). However, no statistical significant interaction between preparations design and sintering protocol (*p*=0.0702, Table 3) was observed.

Descriptive statistics of the load- to fracture values for the tested variables are presented in Table 4. Two-way ANOVA disclosed significant differences (*p*=0.001) between mean values of load to fracture between SS and FS techniques regardless of the preparation design used Table 5.

The fracture pattern, summarized in Table 4 demonstrated that the IPS group showed mainly adhesive failure with veneer fractures, compared to those of IPC, that showed more cohesive failures and the difference in failure pattern within each preparation group was insignificant (*p*=0.91 and *p*=0.8 respectively). Mann-Whitney Test demonstrated no statistically significant difference in failure pattern with respect to sintering procedure (*p*=0.52).
Table 2: Marginal gap value (µm) at predetermined location of the groups under study

| Measurement location   | Sintering procedure | IPS       | IPC       | p value |
|------------------------|---------------------|-----------|-----------|---------|
|                        |                     | Mean      | Mean      |         |
| Mesioincisal Standard  | 78.7±9              | 89.2±10.6 | 0.04      |
| Speed                  | 84.6±8.6            | 109±12.8  |           |
| Mesial                 | 43.4±4.5            | 50.1±5.4  | 0.017     |
| Speed                  | 50.7±4.8            | 49.7±4.4  |           |
| Mesiocervical Standard | 73.6±6.8            | 74.1±7.4  | 0.793     |
| Speed                  | 79.6±8.7            | 81.4±5.5  |           |
| Buccal                 | 76.8±4.3            | 72.4±2.5  | 0.057     |
| Speed                  | 75.3±5.9            | 77.5±6.9  |           |
| Distocervical Standard | 72.7±3.3            | 71.5±4.5  | 0.369     |
| Speed                  | 72.2±5.5            | 73.7±5.1  |           |
| Distal                 | 41.3±4.5            | 50.6±5.6  | 0.000     |
| Speed                  | 44.9±4.7            | 43±3.1    |           |
| Distoincisal Standard  | 88.7±8.9            | 99.2±10.6 | 0.042     |
| Speed                  | 94.6±8.6            | 119±12.8  |           |
| Palatal                | 90.3±8.4            | 97.4±9.7  | 0.034     |
| Speed                  | 94.3±12.3           | 118.4±16.5|          |
| Mean marginal          | 70.7±3              | 75.6±4.9  | 0.001     |
| discrepancy            | Speed               | 74.6±3.6  | 83.9±5.2  |         |

Table 3: Two way ANOVA test for the mean marginal discrepancy of the tested variables

| Source                | Type III Sum of Squares | df | Mean Square | F    | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Powerb |
|-----------------------|-------------------------|----|-------------|------|------|---------------------|--------------------|-----------------|
| Corrected Model       | 936.243                 | 3  | 312.08      | 20.734 | 0.001 | 0.633               | 62.203             | 1.000           |
| Intercept             | 232,259.50              | 1  | 232,259.5   | 15,431.12 | 0.001 | 0.998               | 15,431.124        | 1.000           |
| sintering             | 375.69                  | 1  | 375.69      | 24.96 | 0.001 | 0.409               | 24.961             | 0.998           |
| Preparation Design    | 508.99                  | 1  | 508.99      | 33.81 | 0.001 | 0.484               | 33.817             | 1.000           |
| sintering * PrepDesign| 51.55                   | 1  | 51.55       | 3.42  | 0.072 | 0.087               | 3.425              | 0.437           |
| Error                 | 541.84                  | 36 | 15.05       |      |      |                     |                    |                 |
| Total                 | 233,737.59              | 40 |             |      |      |                     |                    |                 |
| Corrected Total       | 1,478.09                | 39 |             |      |      |                     |                    |                 |

a. R Squared=0.633 (Adjusted R Squared=0.603)
b. Computed using alpha=0.05

Table 4: Load to fracture values (N) and fracture pattern of the tested groups

| Sintering | Preparation Design | Mean      | Fracture pattern |
|-----------|--------------------|-----------|------------------|
|           |                    | Cohesive  | Mixed | Adhesive | Root fracture |
| Standard  | IPS                | 548.6±28.6| 3 (30.0%) | 1 (20.0%) | 4 (40.0%) | 2 (20.0%) |
| Speed     | IPS                | 527.6±31.1| 3 (30.0%) | 2 (20.0%) | 4 (40.0%) | 1 (10.0%) |
| Standard  | IPC                | 560.0±22.3| 2 (20.0%) | 2 (20.0%) | 4 (40.0%) | 2 (20.0%) |
| Speed     | IPC                | 511.9±33.2| 5 (50.0%) | 1 (10.0%) | 3 (30.0%) | 1 (10.0%) |
Table 5  Two way ANOVA test of the tested variables

| Source          | Type III Sum of Squares | df | Mean Square | F    | Sig. | Partial Eta Squared | Noncent. Parameter | Observed Powerb |
|-----------------|-------------------------|----|-------------|------|------|---------------------|-------------------|----------------|
| Corrected Model | 13,819.275              | 3  | 4,606.425   | 5.426| 0.003| 0.311               | 16.278            | 0.909          |
| Intercept       | 11,535,834.025          | 1  | 11,535,834.025 | 13,588.577 | 0.000| 0.997               | 13,588.577        | 1.000          |
| sintering       | 11,937.025              | 1  | 11,937.025  | 14.061| 0.001| 0.281               | 14.061            | 0.954          |
| PrepDesign      | 46.225                  | 1  | 46.225      | 0.054| 0.817| 0.002               | 0.054             | 0.056          |
| sintering*      | 1,836.025               | 1  | 1,836.025   | 2.163| 0.150| 0.057               | 2.163             | 0.299          |
| PrepDesign      |                         |    |             |      |      |                     |                   |               |
| Error           | 30,561.700              | 36 | 848.936     |      |      |                     |                   |               |
| Total           | 11,580,215.000          | 40 |             |      |      |                     |                   |               |
| Corrected Total | 44,380.975              | 39 |             |      |      |                     |                   |               |

a. R Squared=0.311 (Adjusted R Squared=0.254)
b. Computed using alpha=0.05

**DISCUSSION**

The present investigation assessed the impact of two designs of tooth preparation and sintering protocols on marginal gap and load to fracture values of translucent zirconia laminate veneers. The result of this study revealed a significant difference in marginal discrepancy and load to fracture values of translucent zirconia laminate veneers with respect to tested variables therefore, the study null hypothesis was rejected.

In the current investigation, natural teeth were used to furnish a more clinically pertinent substrate with respect to preparation design, bonding protocol, and adhesive cementation that could affect the marginal fit and load to fracture values of monolithic zirconia laminate veneers33,35).

Evaluation of marginal discrepancy can be accomplished before or after cementation, with or without artificial aging. In the present study, the marginal gap was evaluated after cementation as it was reported that, evaluation of marginal gap before cementation does not reflect the real marginal fit in the oral cavity compared to measurement of discrepancy after cementation. Up till now, no universal standard exists on how to perform gap assessments, and clinically, no agreement has been reached on the acceptable precision of fit17,34,35).

The results of this study recorded differences in marginal gap values based on the design of tooth preparation. The IPS group showed the least marginal discrepancies at the buccal (mesiobuccal and distobuccal) mesial, distal and incisal (mesioincisal and destoinciasl) areas, whereas the IPC group presented the highest values at theses predetermined sites.

In a comparative study where marginal fit of zirconia laminate veneers was assessed, the palatal shoulder preparation design showed a significantly higher marginal fit than those with palatal chamfer preparation36).

The present study represented a significant impact of sintering procedure on marginal adaptation values. This finding was in accordance with a study conducted by Ahmed et al.30) who stated that speed sintering of zirconia restorations significantly alter the fit of the cemented restoration.

Marginal gaps at cervical margin showed comparable values regardless the variables tested in the current study. This result was in accordance with the findings of Aboushelib et al.33 and Kusaba et al.36). During the design stage of zirconia veneers using CAD-CAM design software, the cement gap thickness (50 µm) was adjusted 1 mm from the preparation margin, which leads to better adaptation of laminates at cervical margin.

Regardless of the tested variables, marginal discrepancies at incisal edge recorded the highest overall values which could be explained by the limitations of CAD/CAM systems regarding software designing restorations, hardware scanning equipment, and the milling machine. In addition, tooth preparation design, a size discrepancy of the cutting tools may cause misfit and contribute to inferior marginal adaptation of CAD/CAM-generated restorations. Additionally, shrinkage of translucent zirconia during sintering procedure by approximately 20% could have affected marginal fit at the incisal areas of tooth preparation design35,36).

As the incisal overlap design includes the corners at the incisal areas, it is likely that anisotropic shrinkage during sintering may have an adverse impact on incisal adaptation of translucent zirconia laminate veneers with incisal overlap teeth preparation designs.

Numerous factors could affect the shrinkage process of zirconia restorations, such as the material itself, density distribution, the compaction density, and the sintering process parameters. These factors were known as a central character in a blank, that determines the local shrinkage, and subsequently the dimensional accuracy following final sintering process16,29,38).
Previous researches recorded discrepancies below 120 µm seem to be acceptable from a clinical perspective point of view\textsuperscript{33,39}. In the current investigation, the values of gap measurements for all experimental groups were clinically acceptable. Both marginal and axial gap results were nearly the same as those of the proposed cement space (50 µm), however, the discrepancies at the incisal shoulder were markedly greater and could be explained by shrinkage of zirconia restorations following post-machining sintering\textsuperscript{36}.

To assess load to failure of zirconia laminate veneers in vitro, different angles of loading have been proposed. Some researchers investigated the impact of vertical component of incising force by loading the specimens parallel to the long axis of the tooth structure\textsuperscript{40}; others have loaded them at 135° in accordance with the orthognathic interincisal angle\textsuperscript{9}.

As ceramic material is more liable to fracture when subjected to tensile loads, in this investigation, the veneers were loaded at a 90-degree angle to the long axis of the tooth structure in order to assess only the horizontal constituent of load applied on the palatal surface of maxillary incisors by mandibular incisors. Additionally, this angle prevents sliding of the Instron crosshead on the specimens' palatal surface\textsuperscript{35,36}.

In the current investigation, the assessment of the impact of tooth preparation design on load to failure of monolithic zirconia laminate veneers revealed, that the palatal shoulder preparation design increased the resistance to fracture compared with the chamfer preparation design while this increase was statistically non-significant.

The finding of this in vitro study was supported by the results of Castelnuovo et al.\textsuperscript{37} who recorded that, the IPS preparation design had the highest resistance to fracture, compared with other tooth preparation designs for laminate veneer. Additionally, they reported that the IPS tooth preparation was convenient compared with the IPC preparation design for many reasons which included its easier tooth reduction, bonding to exposed enamel prisms by mandibular incisors. Additionally, this angle prevents sliding of the Instron crosshead on the specimens' palatal surface\textsuperscript{35,36}.

CONCLUSIONS
Marginal adaptation of monolithic translucent zirconia laminates are affected by both tooth preparation design and sintering protocol. However, resistance to fracture of translucent zirconia laminates has affected mainly by sintering procedure regardless the teeth preparation design used.

CONFLICT OF INTEREST
The authors declare that they have no conflict of interest.

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