Effect of Different CAD/CAM Fabrication Techniques on the Vertical Marginal Gap

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Abstract: The aim of this study was to evaluate the effect of two different CAD/CAM fixed partial denture fabrication techniques (Full anatomic technique and Framework then veneering by press on technique) on the vertical marginal gap before and after veneering and glazing. **Material and Methods:** Thirty zirconia 3-unit fixed dental prostheses were constructed on the specially fabricated stainless-steel dies simulating prepared mandibular second premolar tooth and mandibular second molar tooth to ensure the standardization of specimen shape and dimensions. The samples were classified into 2 equal groups, 15 each (n=15), according to the fabrication technique used. The vertical marginal fit was evaluated by using a scanning electron microscope at 150X magnification before and after veneering and glazing. Data were tabulated and statistically analyzed with three way ANOVA test followed by pair-wise Tukey's post-hoc tests. P values ≤0.05 are considered to be statistically significant in all tests. **Results:** The results showed that the fabrication technique had a statistically significant effect on the mean marginal fit of zirconia FPDs. **Conclusions:** Better marginal fit values were exhibited by the full anatomical fabrication technique.

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1. Introduction

Apart from the mechanical properties and aesthetics, the long-term clinical success of all-ceramic prosthodontics can be influenced by marginal fit. (1)

Marginal fit is one of the most important criteria for the long-term success of all-ceramic crowns. Great marginal discrepancies expose the luting material to the oral environment, thus leading to a more aggressive rate of cement dissolution, caused by oral fluids and chemo-mechanical forces. The cement seal becomes weak and permits the percolation of bacteria. Consequently, the longevity of the tooth could be compromised by caries and periodontitis. (2)

For the dual purpose of meeting patient expectations for good esthetic results and circumventing allergy concerns arising from contact with metallic frameworks, all-ceramic restorations have become both a necessary alternative as well as a preferred choice.(3)

The most popular approach for FPD framework fabrication is the lost wax technique. However, despite its simplicity, it involves several steps and materials that can introduce inevitable inaccuracies. To enhance the predictability of the fit of FPD frameworks, advanced milling technologies have been recently introduced. (4)

The Cerec system (Sirona Dental Systems, Bensheim, Germany) is a computer-assisted design/computer-assisted manufacturing (CAD/CAM) system designed for the fabrication of indirect restorations. 21The Cerec 3 system was introduced to the dental profession in 2000 and has several improvements over the Cerec 2 system. These improvements include: an enhanced intraoral optical camera able to reproduce finer detail and depth of scale and improved software capable of recording the preparation much faster. (5,6) Additionally, the Cerec 3 system allows more flexible and more true-to-detail grinding than the Cerec 2, which in turn should lead to a better fitting crown with improved occlusal morphology and design. (7,8)

The novel Cerec inLab allowed an easy, reliable and rapid fabrication for all-ceramic dental restorations with high mechanical strength and good biocompatibility. Cerec inLab was recently augmented by the new CEREC ML an inLab MC XL milling machines. Dentists and dental technicians who were on the threshold of introducing CAD (Computer Aided Dentistry) to their practice or laboratory could either obtain for a low-cost solution or for a system which offer an extended range of indications as well as enhanced reliability and ease of use. The Cerec in Lab milling machines were well-tried, accepted and proven, as they were not only faster and more precise, but also quieter and easier to use. [9]

The software was designed to be very user-friendly; the design of caps and frames had been greatly simplified. Without basic changes to the clinical process used for metal-ceramic, the smooth transition to the full-ceramic restorations was possible for the dentist. The distinct separation of Cerec units for the dentist and CerecinLab as laboratory machine made sense simply because of the high proportion of dental-technical steps. The new instrument could be seen as a further step toward the integration of CAD/CAM technology in the field of dentistry, of equal benefit to dentists, dental technicians and patients. [10]

Fabrication techniques of zirconia FPDs:

1. Zirconia single-coping or framework fabrication then veneering fabrication technique.
2. Full anatomical fabrication technique (Translucent zirconia).

There are tree methods for fabrication of zirconia single-coping and framework. The first method is the manually controlled system or Manual-aided Design/Manual-aided Manufacturing (MAD/MAM) in which a coping or framework is manually fabricated in wax or composite, and then the pattern is placed into the pantographic machine. The copying arm of the machine traces the wax pattern while the cutting arm, which has a carbide cutter, mills a selected "green" or pre-sintered zirconia block. The final shape is 20% to 25% larger to account for shrinkage during the sintering step. The zirconia block has a density barcode label, so the copy mill machine can be adjusted properly to allow for shrinkage during the sintering phase. [11]

The second method is Computer-aided Design/Computer-aided Manufacturing (CAD/CAM) in which all-ceramic restorations are fabricated from an industrially prepared ceramic block. This technology promises highly accurate results. In order to produce milled restorations with an accurate fit, it is necessary to mechanically or optically scan the prepared tooth surface and convert the data into control signals for computer-assisted milling. [12]

The potential for CAD ⁄CAM to enhance accuracy is based on the omission of several fabrication steps such as waxing, investing and casting. However, with the advanced milling technologies, other steps are introduced to the fabrication process that may result in inaccuracies, namely scanning, software design, milling and material processing. [13]

The third metod is using Manufacturer-specific Closed System by scanning the tooth-prepared models, designing the single coping or framework using a particular company's construction software, and then electronically sending the information to the company's milling center. This is usually a closed system, which means the scan and design data can only be used at that particular manufacturer's milling center. [14]

Veneering Techniques of zirconia single coping and framerworks:

a. Layering technique:

The layering technique has been the principal method of applying veneering ceramics to the core material. With this technique, porcelain powder is mixed with modeling liquid, and the mixture is layered on the core using a brush. The layer is usually over built to compensate for condensation and firing shrinkage. Overall, this technique requires skill and multiple applications and firings. [15]

b. Overpressing technique (Press On):

Recently overpressed veneering porcelains have been developed. This technique also allows for quick and easy production compared to the conventional layering technique. Additionally, the shrinkage related problems as well as consequences of possible sintering procedures are eliminated. Although veneering porcelain demonstrates similar chemical compositions to those of the overpressed ones, the operator factor in the layered technique could be eliminated. Hence, it can be hypothesized that the overpressed veneering porcelain would result in similar or better fracture load results compared to the layering technique. [16]

With the pressing technique, a complete contour anatomical waxing is performed on a core, and subsequently a sprue is attached to the wax, and the wax-core complex invested. The wax is eliminated in an oven and ceramics are heat-pressed into the mold and to the core, thereby reproducing the anatomy created in the wax and allowing for the creation of the desired tooth anatomy. [49] Finally, glaze is applied on the crowns and fired in the ceramic furnace. [17]

In an effort towards entirely digitizing production, including the veneering process, CAD ⁄CAM technology can be employed to mill a resin replica of the veneering porcelain. The milled resin replicas serve as moulds for the press-over technology, in which the veneering ceramic pellets are heated and pressed into the investment mould directly over the framework. [18]

c. CADon technique:

A new hybrid structure of CAD/CAM porcelain crowns adhered to the CAD/CAM zirconia framework has been proposed. In this system, zirconia frameworks are digitized and porcelain crowns are also fabricated by the CAD/CAM process. Milled porcelain crowns are adhered to zirconia frameworks using adhesive resin cements and the final restoration is completed. Manipulation of the structure is reproducible and reliable without conventional manual porcelain work. Adhesive treatments reinforce the durability of porcelain. Even if porcelain chips, repairing it is easy using the preserved data.[19]

Full anatomical fabrication technique (Translucent Zirconia):

Exciting as the new developments in zirconia milling technology are, little attention has been paid to the optical behavior of the various zirconia core systems relative to core design to optimize esthetics.[20]

By internal and external stain techniques, full-contour zirconia restorations can now be used. However, the clinical indication of full zirconia restorations is limited to posterior regions with little esthetic demand and excess wear of the opposing teeth has become a concern because of the high strength and hardness of zirconia. Nevertheless, with proper polishing protocol, opposing enamel attrition can be avoided. [21]

Sirona Dental Systems has expanded its material line by introducing inCoris TZI full-contour, translucent zirconia blocks. These blocks are indicated for full-contour crowns, bridges, and screw-retained implant crowns. Made of solid zirconia with no porcelain overlay, they are virtually chip-proof. [22]

The new zirconia restorations have a flexural strength of 950 MPa (+/- 50) and because the material is made with a monolithic composition, the absence of layered materials makes the new zirconia blocks extremely strong and durable. [22]

The precision of the zirconia-based restorations is dependent on various factors, like differences in manufacturing systems, individual characteristics of the prosthesis (e.g. span length, framework configuration), effect of veneering and influence of aging. As to soft-machined zirconia restorations, the precise numerical compensation required by such a system for the enlargement ratio of the model is a paramount factor, strictly dependent also on the composition and homogeneity of pre-sintered zirconia blanks that should be consistent and precise. [23]

A method for determining the marginal fit is to measure the marginal gap, i.e. the distance between the restoration margin and preparation margin. The methods and measurement units to determine the marginal gap of restorations are not validated. [24] Furthermore, the definition of marginal fit scatters widely.

Generally, the evaluation of the marginal discrepancy of crowns depends on several factors:

- Measurements of cemented or not-cemented crowns.
- Storage time and treatment (such as ageing procedures) after cementation.
- Kind of abutment used for measurements.
- Kind of microscope and enlargement factor used for measurements.
- Location and quantity of single measurements. [25]

As reported earlier, to achieve the desired strength and esthetic, a combination of a core substructure and veneering porcelain is required. However, there is an argument upon the effect of the veneering porcelain on the distortion of the restoration. Thus, a thorough understanding of the effect of the veneering porcelain on the marginal fit is essential. [26]

The null hypothesis of the current study postulated that there will be no influence of the fabrication technique on the vertical marginal fit of zirconia FPDs.

The aim of this study was to investigate the effect of two different CAD/CAM fixed partial denture fabrication techniques (Full anatomic technique and Framework then veneering by press on technique) on the vertical marginal gap before and after veneering and glazing.

2. Material and Methods

Specially fabricated stainless-steel dies simulating a prepared mandibular second premolar tooth and mandibular second molar tooth were with flat occlusal table, 1 mm thickness shoulder finish line, rounded internal line angle, degree of convergence 8° occlusally, preparation height 5 mm and cervical diameter of 8 mm for the premolar and 10 mm for the molar. Prepared dies were then fixed on a metal plate to prepare the master model for a three-unit bridge. [26] with mesiodistal width of the pontic of 11 mm. [27] (Figure 1)

Thirty zirconia 3-unit fixed dental prostheses were constructed on the master model. These were divided into 2 equal groups, 15 each (n=15), according to the fabrication technique used. Group I for full anatomical technique and group II for the framework then veneering technique.

For the full anatomical technique (Group I), a full anatomical FPDs was milled by Cerec inLab (Cere cinLab, Sirona, Dental Systems Gmbh FabrikstraBe, Bensheim) using Sirona inCoris TZI blocks, while the framework the veneering Technique (Group II), only framework was milled by Cerec inLab using Sirona inCoris ZI which was then veneered by press on technique. (Figure 2-4) For the purpose of standardization wax patterns were fabricated on the milled frameworks (Group II) by CAD/CAM. Scanning the master model with the framework and then scanning the master model with the full anatomical bridge. Then the wax pattern was designed using Zirkonzahn ExoCAD 5180 software and milled using M5 milling machine (M5 milling machine, Zirkonzahn GMBH), which was identically the same dimensions of the full anatomical bridge. (Figure 5,6) IPS e.max Ceram ZirLiner was applied and fired on the inCoris ZI frameworks to achieve a sound bond between the framework and the material pressed onto it. Then the wax patterns were sprued, invested and the press on was done using IPS zirpress ingots according to the manufacturer instructions.

Glaze firing of both groups was conducted with IPS e.max Ceram Glaze Spray which was applied in an evenly covering layer on the FPDs in the usual manner.

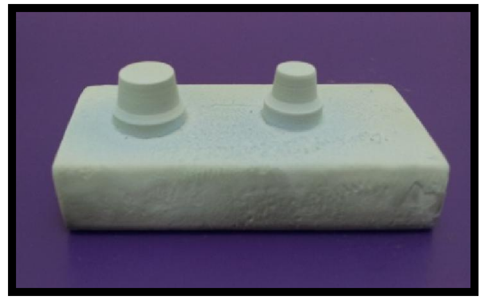
All tested FPDs were individually seated on the stainless steel master model and were held in place using a specially designed and fabricated holding device (Figure 7) and were examined for vertical marginal fit by scanning electron microscope [(29,30)] (JEOL, JXA-840 AElectron Probe Microanalyzer, Japan) at magnification 150 X. Digital images were captured at six measuring locations along the cervical circumference for each retainer [(31,32)] mesiobuccul, midbuccal, distobuccal, mesiolingual midlingual and distolingual.

The measurements were done on an IBM compatible personal computer (PC). After that the software, which was used for image analysis was calibrated and the vertical gap distance was measured for each shot. A measurement at each point was repeated five times. Then the data obtained were collected, tabulated and subjected to statistical analysis. (Figure 8)

For Group I, the vertical marginal fit was measured two times; before and after glazing. While for Group II, the vertical marginal fit was measured three times; before veneering by press on, after veneering by press on veneering and finally after glazing.

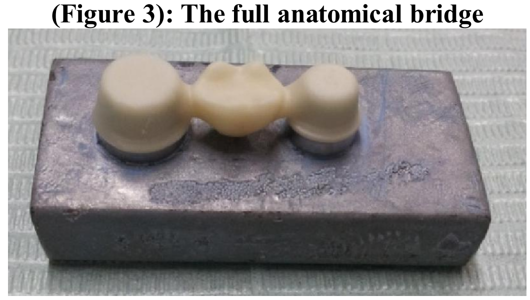
Data analysis was performed using three factorial analysis of variance ANOVA test followed by pair-wise Tukey's post-hoc tests. Statistical analysis was performed using Aasistat 7.6 statistics software for Windows. P values ≤0.05 are considered to be statistically significant in all tests.

(Figure 1): The master model

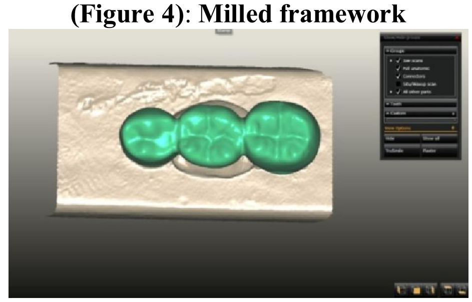


(Figure 2): The model sprayed with Cerec propellant powder.

(Figure 3): The full anatomical bridge



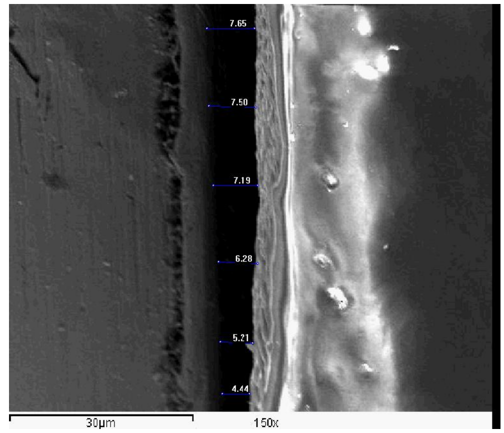
(Figure 4): Milled framework



(Figure 5): Wax pattern designed and milled using CAD/CAM

(Figure 6): The wax pattern on the framework.

(Figure 7): The bridge held on the master model using specially fabricated design

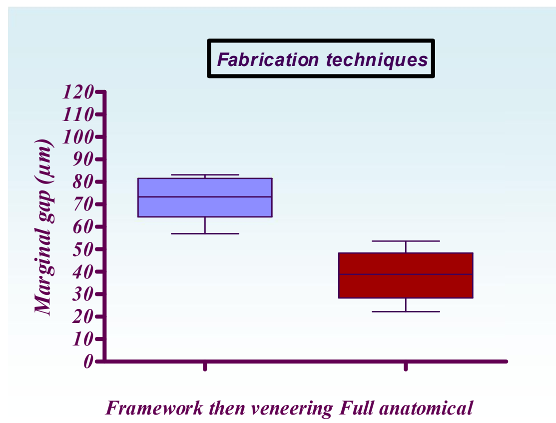


(Figure 8): Measuring the vertical marginal gap by scanning electron microscope.

3. Results:

For simplicity and convenient of statistical comparisons, the mean recorded from the molar and the premolar were averaged to get one single value which was used in the statistical analysis. [27,33,34]

It was found that Framework then veneering group (II) recorded statistically significant (P<0.05) higher marginal gap mean value (73.37±8.4 µm) than Full anatomical group (I) which recorded gap mean value (38.72±8.2 µm). (Figure 9) (Table 1) It was found that after veneering by press on the marginal gap mean value (52.3±15.8µm) was higher than before veneering by press on (38.49±13.19µm). (Figure 10) (Table 2) Although it was statistically non-significant (p>0.05). It was found that after glazing the marginal gap mean value (57.64 ± 4.9 µm) was higher than before glazing (53.44 ± 6.7µm). Yet it was statistically non-significant (p>0.05). (Figure 11) (Table 3).



(Figure 9): Box plot of marginal gap mean values as function of fabrication techniques.

(Table 1): Comparison between marginal gap results (Mean values± SDs) as function of fabrication techniques

Variable	Mean± SD			Tukey'srank	Statistics (P value)
Fabrication techniques	Full anatomical (I)	38.72±8.2	B	<0.0001*	<0.0001*
	Framework then veneering (II)	73.37±8.4	A		

Different letter in the same column indicating statistically significant difference (p < 0.05)
*; significant (p < 0.05); ns; non-significant (p>0.05)

(Table 2): Comparison between total marginal gap results (Mean values± SDs) as function of veneering by press on.

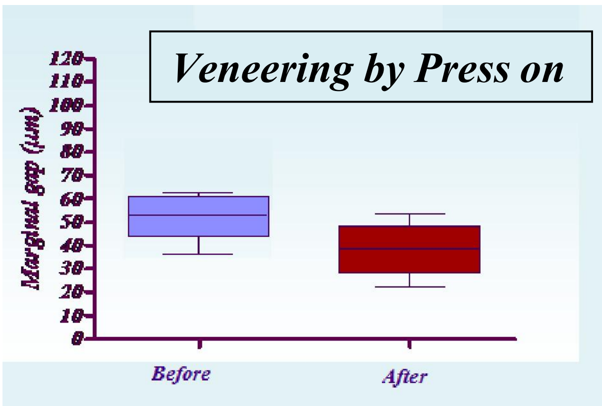
Variables		**Mean± SD**	**Tukey's rank**	**Statistics (p value)**
Veneering (Press on)	**Before**	38.49±13.19	A	0.2486ns
	After	52.3±15.8	A	

Different letter in the same column indicating statistically significant difference (p < 0.05; *; significant (p < 0.05); ns; non-significant (p>0.05)

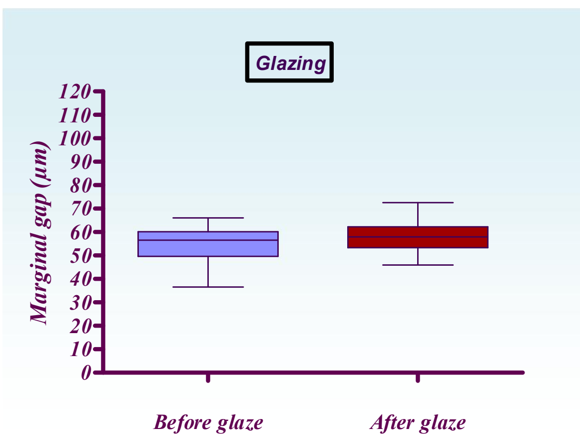
(Table 3): Comparison between total marginal gap results (Mean values± SDs) as function of glazing

Variables		Mean± SD	Tukey'srank	Statistics (p value)
Glazing	Before	53.44 ± 6.7	A	0.0636ns
	After	57.64 ± 4.9	A	

Different letter in the same column indicating statistically significant difference ($p < 0.05$; *; significant ($p < 0.05$); ns; non-significant ($p>0.05$)



(Figure 10): **Box plot of marginal gap mean values as function of veneering by press on.**



(Figure 11): Box plot of total marginal gap mean values as function of glazing.

4. Discussion:

The present research was directed towards the evaluation of the vertical marginal fit of zirconia 3-unit posterior bridges fabricated by CAD/CAM, by full anatomical technique or framework then veneering by press on technique.

In this study, machined stainless-steel dies were used in substitution to natural teeth. **Beschnidt & Strub** [25] report that natural teeth present great variation considering the age, individual structures and time of storage, making the standardization of the pillars difficult.

The framework thickness was adjusted for 0.5 mm axially and 0.7 mm occlusally. As almost all manufacturers agree in considering 0.5 mm the minimum thickness, in order to prevent framework deformation. [35,36]

The vertical marginal gap measurement was selected as the most frequently used to quantify the accuracy of fit of a restoration [37, 38], as this discrepancy, if undetected prior to crown cementation, will result in a vertical crown/tooth interface with wider zones of exposed luting agent. While horizontal discrepancies result in a crown or tooth structure step defect that may affect cleansability and plaque retention. In addition, the investigation did not assess the internal fit of the copings; however, this assessment would require cross-sectioning the crowns, which would limit the marginal gap measurement to only a certain number of sites.

Testing procedure of the vertical marginal adaptation was performed without cementation. This is another point of relevance that concerns to the cementing of the bridges. Some authors measure the marginal fit with cementation [39,40], because they believe that the most important inadaptability is the one that occurs in vivo, when the crowns are already cemented. In our study, as well as in many other studies [37,41-44], this was not accomplished. **Tinschertet al** [41] affirmed that when we cement the crowns, we lose the precision of the primary adaptation, allowing the influence of the cement type, viscosity and cementation techniques to be a variable in the outcome results. Some authors approved that on comparing crowns construction techniques and modifications that will influence in the precision of primary adaptation as the type of finish lines; the cementation should not be used. [37,42-44]

Also, when measuring the marginal gap after cementation, the same number of teeth or steel dies as that of restoration sample is needed because of the control of variables. On the other hand, only one tooth or steel die is needed if the measurement is done without a luting agent. [45]

A specially fabricated holding device was used to hold the bridges on the master model during measurement. **Wanserski et al** [46] fabricated a specimen positioning device to allow fixation of the specimen in consistent, reproducible manner. This was used by some investigators with some modifications [42,44,47], while others remained using finger pressure. [25,33,41,48,49]

Scanning Electron Microscope using a fixed magnification of 150X was used in this study to measure the marginal adaptation. It was ascertained by earlier studies that SEM is the most reliable and realistic method to quantitatively measure the marginal fit of indirect restorations.[29,30] However, there have been earlier investigations, which employed digital microscopes [42,44], stereomicroscopes [50] to analyze the marginal fit of CAD/CAM fabricated crowns.

Tinschertetal [41] reported mean marginal discrepancies of between 61 µm and 74 µm for ZrO2 ceramic FDP frameworks. **Reich et al** [51] reported a median marginal discrepancy of 65 µm for 3-unit ZrO2 ceramic FDP frameworks.

Regarding the effect of fabrication technique of FPDs on the vertical marginal fit, it was found that that **Group II; Framework then veneering** recorded statistically significant ($P<0.05$) **higher** marginal gap mean value (73.37 ± 8.4 µm) than **Group I; Full anatomical** which recorded gap mean value (38.72 ± 8.2 µm).

Regarding the effect of veneering of the frameworks by press on (Group I) on the vertical marginal fit, it was found that **after press on** the marginal gap mean value (52.3 ± 15.8µm) was higher than **before** (38.49 ± 13.19µm). Yet it was statistically non-significant ($p>0.05$).

Regarding the effect of glazing on the vertical marginal fit, it was found that **after glazing** the marginal gap mean value (57.64 ± 4.9 µm) was higher than **before glazing** (53.44 ± 6.7µm). Yet it was statistically non-significant ($p>0.05$).

The results of this study are in agreement with **Quintas et al** [52] who stated that the ceramic manufacturing technique appeared to be the most important factor tested for the definitive vertical discrepancy of all-ceramic copings. And also approved by **Wael A et al** [33] who reported that the marginal adaptation of different zirconia 3-unit fixed dental prostheses at different fabrication stages and after artificial aging is influenced by manufacturing technique.

Also the previous results were approved by **Balkaya et al** [47] **and Pak et al** [45] who reported that the addition of porcelain caused a distortion to the copings' margins, where glazing had no such effect. Also this was approved by **Dittmer et al** [53] who reported that the veneering process had a significant influence on the marginal fit of pre-sintered zirconia 4 unit FDPs.

Marc P D et al [54] reported that stresses and distortions, occurring due to the veneering process, may influence the marginal and internal fit and therefore the clinical success of dental restorations.

Sattar J. A. and Adel F. I. [55] reported that the porcelain firing and the glaze firing cycles affected the marginal gap. **Hamza et al** [56] reported that the CAD/CAM technique, ceramic type, and their interaction had a statistically significant effect on the mean marginal fit.

The increase in the marginal gap in veneered frameworks after the press on and glazing cycle may be a result of porcelain contamination on the inner surfaces of frameworks, and reduction in the resilience of the framework material and rigidity of the porcelain. [57]

Also the difference in thermal expansion coefficient (TEC) of the veneering ceramic and the framework material leads to pressure tension during cooling at room temperature which leads to enhancement in bonding strength between the two materials might affect the marginal fitness. [58]

On contrary to our results **Vigolo et al** [59] reported that porcelain firing cycles and the glaze cycles did not affect the marginal fit of the LAVA TM, Everest and Procera systems used.

There were some limitations in this study. Despite vertical marginal fit were measurable through this experimental design, internal fit were not, since cementation and sectioning of specimens are required for such measurement. The specimens were also not submitted to an aging process which simulates oral conditions. [60]

Further investigations are needed to measure both the marginal and internal fits and to evaluate the influence of the aging process on the margin distortion. [60] Also further studies are needed to evaluate the influence of the scanning process and the milling process on the accuracy of a CAD/CAM restoration as well as the influence of cementation technique on the marginal and internal fits of zirconia restorations. [61]

From previous results and discussion, the null hypothesis of this study was rejected regarding that the technique of fabrication assumed to have an influence on the vertical marginal fit zirconia FPDs.

5. Conclusions

Under the limitations of this study, several conclusions could be detected:

1. The two tested groups had clinically acceptable vertical marginal fit which is within the recorded levels of the suggested acceptability for vertical marginal fit, which leads to clinical success.
2. Superior vertical marginal fit was exhibited by full anatomical technique.
3. Inferior vertical marginal fit was exhibited after glazing than before glazing but it was non-significant.

6. Recommendations

Regarding to minimum marginal discrepancy, using the full anatomical technique is recommended.

Further investigations are needed to measure both the marginal and internal fit of zirconia FPDs.

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