

Surface treatments and thermocycling effects on the fracture resistance and marginal adaptation of veneering systems on yttrium stabilized tetragonal zirconia polycrystal: An In-vitro study

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ABSTRACT

Aim: Evaluating fracture resistance, marginal adaptation of two veneering systems (layering and pressing) over yttria stabilized tetragonal zirconium polycrystal copings with different surface treatments (sandblasting and hydrofluoric acid) and their susceptibility to thermocycling.

Methodology: Forty zirconia copings were manufactured using CAD/CAM and separated into two groups (n=20) depending on the veneering technique: layering and pressing. Every group was subsequently separated into four subgroups (n = 5) based on surface treatment. Marginal adaptation was measured at four reference points using a stereomicroscope with image analysis software before and after veneering. The crowns were exposed to thermocycling (1000 cycles at 5-55 °C). A universal testing equipment was used to determine fracture resistance by measuring maximum load and compressive strength.

Results: The average marginal difference after thermocycling was 94.87 µm for layered crowns as well as 96.64 µm for pressed crowns. Both groups showed a slight increase in marginal gap following thermocycling (8.28 µm and 11.94 µm, respectively), which was statistically insignificant (p>0.05). Fracture resistance was significantly higher in pressed crowns than layered crowns (p<0.05). Airborne-particle-abraded copings demonstrated the greatest compressive strength and maximum load values. Failure analysis revealed predominantly cohesive failures in pressed crowns, whereas layered crowns showed interfacial/adhesive failures.

Conclusion: Both veneering systems showed comparable marginal adaptation with minimal effect of thermocycling. However, pressed crowns exhibited significantly superior fracture resistance and more favorable failure modes compared to layered crowns.

Key words: Marginal integrity, surface treatment, fracture resistance, veneering techniques.

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INTRODUCTION

Fixed prosthodontics aims to restore lost function, comfort, and esthetics by providing permanent replacements for missing teeth without compromising oral or systemic health. Because of its strength, longevity, and consistent marginal integrity, PFM crowns have been regarded as the gold standard for decades.(1). However, shortcomings such as compromised esthetics, ceramic chipping, debonding, and biological complications have prompted the search for alternatives.

Because of its exceptional biocompatibility, optical qualities, and accuracy, all-ceramic restorations—especially those made using CAD/CAM systems—have grown in favor.(1,2). Ceramics are inherently brittle and their long-term success is influenced by fabrication technique, veneering method, and marginal adaptation. Zirconia-based restorations, in particular, combine high strength with improved esthetics. These materials are biocompatible, highly corrosive resistant with low thermal conductivity, has excellent aesthetics, high in hardness and has diminished plaque accumulation. With these above unique features, it remains as the most suitable material for aesthetics despite of disadvantages like brittleness and low fracture toughness. $ZrO_2Y_2O_3$, also known as "yttria stabilized zirconia" (YSZ), is an even stronger oxide that is utilized in dentistry when mixed with 3% yttria. Partially stabilized zirconia (PSZ) is created by sintering the oxide powder under pressure and heat. Tetragonal zirconium polycrystal (TZP) is created when the material shrinks and becomes much stronger after additional sintering. Although there are currently no long-term clinical trials for Y-TZP all-ceramic restorations, a number of short- and medium-term investigations have been carried out. The findings demonstrate that using Y-TZP as a coping material yields in excellent success rates for all-ceramic restorations. However, the most frequent issue was seen to be the veneering porcelain chipping or cracking. Several studies have investigated the cause of increased chipping or cracking of veneering porcelain over Y-TZP copings compared with metal copings. Research has shown that several surface treatments, such as airborne particle abrasion, heat treatment, liner porcelain usage, and core surface treatment with 9.5% hydrofluoric acid, have a substantial impact on the binding strength between Y-TZP coping and veneering porcelain. It is unclear; therefore, how various surface treatments affect the strength of the link between porcelain veneer and zirconia coping.

Marginal discrepancies may lead to plaque accumulation, secondary caries, periodontal breakdown, and restoration failure, making marginal integrity a critical factor for clinical longevity.(3,4) To improve the bonding between zirconia copings and veneering ceramics, various surface treatments such as sandblasting and hydrofluoric acid etching have been investigated.(5) Veneering can be achieved either by conventional layering or by pressing, with each technique influencing the restoration's strength, fit, and failure mode.(6,7) Additionally, thermocycling is widely used to simulate the oral environment and evaluate the aging resistance of restorative materials.

The purpose of this in vitro investigation was to assess the fracture resistance and marginal adaptation of zirconia copings veneered using layering and pressing methods., with and without surface treatments, and to assess their performance after thermocycling.

Null-Hypothesis

There would be no significant difference in marginal adaptation, fracture resistance, or failure modes between layered and pressed veneering systems on yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) copings, irrespective of surface treatment or thermocycling.

Aim:

The purpose of this study was to:

1. Examine the marginal adaptation of zirconia copings created by CAD/CAM before and after veneering (layered and pressed) and following thermocycling.
2. Assess the impact of surface treatments, such as sandblasting and hydrofluoric acid on the fracture resistance of layered and pressed crowns.
3. Assess the Thermocycling's impact on fracture resistance and failure modes of veneered crowns.

Methodology

This in vitro investigation assessed the fracture resistance and marginal adaptability of zirconia copings veneered by layering and pressing techniques, with or without surface treatments, before and after thermocycling.

Specimen Preparation

A mandibular first molar (#46) on a typodont model (Nissin) was prepared for all-ceramic crowns. Tooth preparation (Figure-1) comprised 4 mm axial height, 1 mm axial reduction, and 1.5 mm occlusal reduction 10° total occlusal convergence, and a 1 mm radial shoulder.

All line angles were rounded and finished with fine-grit diamond burs.(1)



Fig no1: Prepared molar on Typodont

Master Die Fabrication

A laser scanner was used to scan the prepared tooth (Imetric, Delcam, Switzerland)(7) (Figure -2). A wax pattern was digitally generated and cast in cobalt-chromium (Co-Cr) to obtain the master die. The die was rescanned to design zirconia copings (thickness 0.7 mm, 1 mm at the margin, 60 µm die spacer) using CAD software (DentCAD) (Figure -3). Forty copings were milled from presintered zirconia discs (Nexx ZRT, Sagemax) using a 5-axis milling machine (Roland DWX-50) and sintered at 1530–1580 °C to achieve final dimensions and translucency.(7)



Fig no 2: Laser scanned image



Fig no 3: Scanned master die

Grouping of Specimens

The 40 copings were divided into two main groups (n=20 each):

- Group L: Layered veneering
- Group P: Pressed veneering

Four subgroups were made from each group (n=5) based on surface treatment: control, sandblasting, hydrofluoric acid, or combined treatment.(5)

Surface Treatments

- Sandblasting: 110 µm Al₂O₃, 0.4 MPa, 10 mm distance, 1 min.(Figure-4)
- Hydrofluoric Acid: 48% HF for 30 min at room temperature, followed by rinsing.

After being ultrasonically cleaned for ten minutes in acetone and distilled water, treated copings were allowed to air dry. (Figure-5)



Fig no 4: Sandblasting the coping



Fig no 5 : HF acid application

Veneering Procedures

Layering Technique: IPS Emax Ceram (Ivoclar Vivadent) was used to veneer twenty copings. Enamel was placed after sequentially applying dentin (A2) and firing it in a Programat P200 porcelain furnace that had been calibrated (Figure 6). Crown outlines were standardized using a silicone index.



Fig no 6: Layering – dentin application

Pressed Technique: For the best bonding, zirliner (IPS e.max Ceram) was applied to the coping. Copings were scanned, wax patterns milled, sprued, invested, burnout processed (34→967°C), and IPS ZirPress ingots pressed at 700°C under controlled pressure (Figure-7). Specimens were divested, cleaned, and finished. Fifteen crowns from each group were subjected to thermocycling.

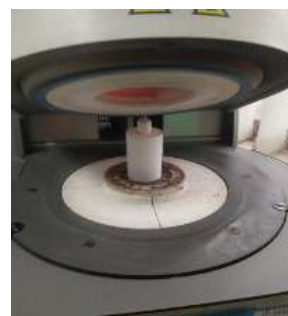


Fig no 7: Investment ready for pressing

Thermocycling

Thirty specimens (15 layered, 15 pressed) underwent 1000 thermocycles (5°C ↔ 55°C, dwell 30 s, dry 5 s) using a WILITECH thermocycler (Figure-8) to simulate oral conditions.(7) Marginal gaps were measured post-thermocycling.



Fig no 8: samples loaded for thermocycling

Marginal Adaptation Measurement

A stereomicroscope (Labomed) equipped with a camera (Progress C3) and image analysis software (Progress 14 Plus) was used to assess marginal fit at four reference positions (AB, BC, CD, and DA). The largest gap of each reference point was recorded, (Figure-9) and the mean of four points represented the marginal gap per specimen. Measurements were performed pre-veneering, post-veneering, and post-thermocycling.(8)

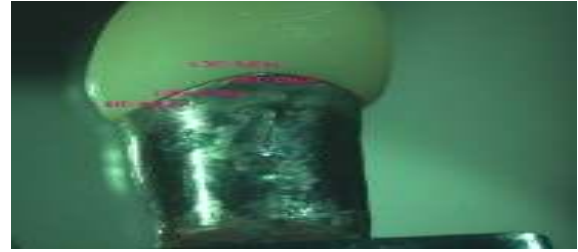


Fig no 9: Marginal gap measurements

Fracture Resistance Testing

A universal testing machine (Shimadzu/Instron 8801, 50 kN capacity) was used to compressively stress the specimens at a crosshead speed of 0.5 mm/min.(9) A ball-ended plunger applied load centrally on the crown. Fracture was identified by a sharp sound and sudden drop in load. Maximum load (N) and compressive strength (MPa) were recorded. Failure modes were visually classified as cohesive, adhesive, or mixed.

Statistical Analysis

Microsoft Excel was used to enter the data, while SPSS was used for analysis. The mean and standard deviation, two descriptive statistics, were computed. For two-group comparisons, independent sample t-tests were employed; for subgroup comparisons, non-parametric tests (Mann–Whitney U, Kruskal–Wallis) were employed. The threshold for significance was fixed at $p < 0.05$.

Table 1: Materials, Surface Treatments, and Processing Parameters

Parameter	Group Material	Details / Settings	Manufacturer / Equipment
Zirconia Copings	Pre sintered	Thickness: 0.7 mm (1 mm at margin), Die spacer: 60 μ m	Nexx ZRT, Sagemax
CAD/CAM Design	-	CAD design from digital scan of master die	DentCAD, Delcam
Milling	Zirconia disc	5-axis milling, X/Y/Z rotation, $\pm 20^\circ$ tilt, air blower + vacuum system	Roland DWX-50
Sintering	Zirconia copings	1530–1580 $^\circ$ C, heat rate 4–10 $^\circ$ C/min, hold 2 h, cool 7 $^\circ$ C/min	Sintering furnace
Surface Treatments	Sandblasting	110 μ m Al_2O_3 , 0.4 MPa, 10 mm distance, 1 min	-
	Hydrofluoric Acid	48% HF, 30 min, room temp, rinse 1 min	-
Layered Veneering	IPS e.max Ceram	Dentin A2 + enamel, incremental layering, silicone index standardization	Ivoclar Vivadent, Programat P200
Pressed Veneering	IPS ZirPress	Zirliner applied 0.1 mm, wax pattern milled, sprued & invested, burnout 34 \rightarrow 967 $^\circ$ C, pressing at 700 $^\circ$ C	Ivoclar Vivadent, Pressing furnace
Thermocycling	All groups	1000 cycles, 5 $^\circ$ C \leftrightarrow 55 $^\circ$ C, dwell 30 s, dry 5 s	Wiltech Thermocycler, Germany

Parameter	Group Material	Details / Settings	Manufacturer / Equipment
Marginal Fit Measurement	All groups	4 reference points (AB, BC, CD, DA), stereomicroscope 3× magnification	Labomed + Progress C3 camera + Progress 14 Plus software
Fracture Resistance Testing	All groups	Compressive load at 0.5 mm/min, ball-ended plunger, max load (N) and compressive strength (MPa) recorded	Shimadzu / Instron 8801, 50 kN

RESULTS

1. Sample Distribution

A total of 40 samples were included, equally divided between Group L (Layering, n=20) and Group P (Pressing, n=20). The distribution was equal across categories (50% each) (Table 1, Figure 1).

2. Marginal Fit (Table -2)

Pre-veneering

The mean marginal gap prior to veneering was $85.67 \pm 9.75 \mu\text{m}$ in Group L and $84.21 \pm 10.54 \mu\text{m}$ in Group P (mean difference 1.46, 95% CI -5.03 to 7.96, $P = 0.651$), indicating no significant difference between groups.

Post-Layering/Pressing

After veneering, Group P exhibited a higher marginal fit ($95.74 \pm 6.79 \mu\text{m}$) than Group L ($91.91 \pm 5.67 \mu\text{m}$), but Table -2 : Marginal Fit (μm) Across Stages

Stage	Group L Mean \pm SD	Group P Mean \pm SD	Mean Difference (95% CI)	P value	Notes
Pre-veneering	85.67 ± 9.75	84.21 ± 10.54	1.46 (-5.03, 7.96)	0.651	No significant difference
Post Layering/Pressing	91.91 ± 5.67	95.74 ± 6.79	-3.83 (-7.83, 0.175)	0.06	Not significant
Change after veneering	6.24 ± 11.49	11.53 ± 11.61	-5.29 (-12.69, 2.10)	0.155	Not significant
Change after thermocycling	8.28 ± 12.37	11.94 ± 12.18	-3.65 (-11.52, 4.19)	0.12	Not significant

Sub Group Analysis: Median values across subgroups (Aa1–Aa4, Ba1–Ba4) showed no statistically significant differences (Mann-Whitney U and Kruskal-Wallis tests, $P > 0.05$)

Fracture Resistance (Table -3)

Maximum Load:

Table-3: Fracture Resistance:

the difference was not statistically significant (mean difference -3.83, 95% CI -7.83 to 0.175, $P = 0.06$).

Change after veneering

The mean improvement in marginal fit was $6.24 \pm 11.49 \mu\text{m}$ in Group L and $11.53 \pm 11.61 \mu\text{m}$ in Group P, which was not statistically significant ($P = 0.155$).

After Thermocycling

Following 1000 thermocycles, marginal gaps were $8.28 \pm 12.37 \mu\text{m}$ (Group L) and $11.94 \pm 12.18 \mu\text{m}$ (Group P) ($P = 0.12$), indicating no significant difference.

Sub Group Analysis

Sub Group Analysis (n=5 each) showed no significant differences in median marginal gaps before veneering, after veneering, or after thermocycling between subgroups of Group L and B .

Group P demonstrated significantly higher mean maximum load ($2329.82 \pm 662.62 \text{ N}$) compared to Group L ($1735.51 \pm 347.12 \text{ N}$; $P < 0.001$) .

Compressive Strength:

Group P also exhibited higher mean compressive strength ($36.54 \pm 10.34 \text{ MPa}$) than Group L ($27.17 \pm 5.38 \text{ MPa}$; $P < 0.001$).

Parameter	Group L Mean ± SD	Group P Mean ± SD	Mean Difference (95% CI)	P value	Notes
Maximum Load (N)	1735.51 ± 347.12	2329.82 ± 662.62	-594.31 (-932.92, -255.69)	<0.001	Pressing group significantly higher
Compressive Strength (MPa)	27.17 ± 5.38	36.54 ± 10.34	-9.37 (-14.65, -4.09)	<0.001	Pressing group significantly higher

Sub Group Analysis: Subgroups within Pressing group consistently had higher maximum load and compressive strength than corresponding Layering subgroups ($P < 0.05$ for most comparisons).

Sub Group Analysis

Within Group L and B, subgroups showed significant differences in both maximum load and compressive strength. For example, in Group L, Aa1 had the highest maximum load (2158.68 N) and compressive strength (33.73 MPa), whereas Aa3 and Aa4 had the lowest values. Similarly, in Group P, Ba1 had the highest fracture resistance (maximum load 3067.12 N, compressive strength 47.92 MPa).

Intergroup Subgroup Comparison

Direct comparison between matching subgroups in Layering vs Pressing (Aa vs Ba) showed that Pressing groups consistently had higher fracture resistance.

4. Summary of Key Findings

- Marginal fit did not differ significantly between Layering and Pressing groups at any stage (pre-veneering, post-veneering, or after thermocycling).
- Pressed crowns (Group P) had significantly higher fracture resistance than layered crowns (Group L), both in maximum load and compressive strength.
- Sub Group Analysis confirmed consistent trends of higher mechanical strength in Pressing groups.

DISCUSSION

Advancements in dental technology and high-strength ceramics have made all-ceramic restorations a viable option for long-span fixed partial dentures, particularly with CAD/CAM systems.(1,2) CAD/CAM offers simplicity, reduced manufacturing time, and operator efficiency, but potential inaccuracies in scanning, software design, milling, and material shrinkage can affect marginal fit and, consequently, restoration longevity.(2,7) The main criteria of this study were marginal fit, fracture resistance, and aesthetics, all of which are critical to the clinical success of all-ceramic restorations.(4)

A single Co-Cr master die with the elastic moduli was 210 GPa which is higher than human dentin with elastic

moduli of 14 GPa was used for standardized preparation, with zirconia copings milled at 0.7 mm thickness and 60 μm virtual die spacer.(7)The use of a metal die ensured consistent measurements and eliminated wear seen with natural teeth. Marginal fit was evaluated at three stages—pre-veneering, post-veneering (layering vs. pressing), and post-thermocycling—using a stereomicroscope with image analysis software. Measurements were taken at four standardized points on each side, and the largest marginal gap in each region was recorded.(8)

Marginal Fit

The distance between the restoration's margin and the finish line is known as the marginal gap. Thorough inspection, exploratory probing, radiographic examination, cross sectional view, direct view of the crown on a die, impression replica technique, and clinical assessment are some of the techniques used to confirm marginal fit(9). The marginal gap before and after veneering as well as after thermocycling was assessed in the current study utilizing a direct microscopic view under a stereomicroscope and image analysis software (Progress 14 Plus). Direct viewing is a non-destructive and a relatively simple method. Prior to veneering, mean marginal gaps were 85.67 μm for Group L (layering) and 84.21 μm for Group P (pressing), with no significant difference. After veneering, marginal gaps increased slightly (91.91 μm for layering, 95.74 μm for pressing), but the difference remained statistically insignificant.(10) Pressing produced slightly higher gaps than layering, likely due to thermal expansion differences, contraction of porcelain during sintering, or firing cycles. Thermocycling caused a further minor increase (94.87 μm for layering, 96.64 μm for pressing), also statistically insignificant.(11) All marginal gaps were, on average, less than 120 μm , which is the clinically acceptable criterion.

According to McLean et al.'s analysis of the marginal fit of 1000 fixed restorations over a five-year period, it is challenging to identify marginal gaps smaller than 80 μm in clinical settings. Christensen reported that range of clinically acceptable subgingival marginal openings was

from 34 μ m to 119 μ m and the acceptable supragingival margin range was from 2 to 51 μ m. Mc Lean and Fraunhofer stated that a marginal opening of 120 μ m should be the limit of clinical acceptability. Lofstrom and Barakat observed marginal discrepancy values of 7 to 65 μ m after microscopically assessing the marginal gap of clinically well-fitting crowns. The mean marginal gaps of multilayer zirconia crowns, zirconia copings, and whole zirconia crowns were compared by Saraswathi et al. The mean marginal gap of full zirconia crowns was 101.9 μ m, 110.41 μ m for zirconia copings and 118.97 μ m for layered zirconia crowns with no statistically significant difference between them and they stated that this could be attributed to the dimensional stability of zirconia copings sintered at 15000 centigrade temperature which has been later veneered with a porcelain at temperature of 9300 centigrade. Additionally, Komine et al. assessed and compared the marginal fit of crowns (mean value of 69 μ m) and zirconia copings (mean of 61 μ m), concluding that there was no discernible difference before and after veneering. The marginal fit of zirconia CAD/CAM crowns with various finish line configurations was examined by Mahroo et al. before and after porcelain firings. Deep chamfer had a mean marginal gap of 49.2 and 68.2 μ m, whereas rounded shoulder had a mean marginal gap of 35.2 μ m and 63.06 μ m before and after porcelain firing, respectively, with veneering having a statistically significant impact on the marginal fit.

Fracture Resistance

Mechanical testing revealed significantly higher fracture resistance in the pressing group compared to layering.(12) Mean maximum load was 2329.82 N for pressing and 1735.51 N for layering ($p < 0.001$), while mean compressive strength was 36.54 MPa and 27.17 MPa, respectively ($p < 0.001$). Subgroup Analysis indicated that airborne-particle-abraded copings showed the highest fracture resistance. Failure modes differed: pressing predominantly resulted in cohesive failures, whereas layering showed more adhesive or interfacial failures, likely due to differences in veneer-core bonding.(13) The micro tensile bond strength of manually layered zirconia and CAD veneered zirconia restorations was studied by Aboushelib NM et al.(11) The two groups' micro tensile bond strengths did not differ statistically significantly. While manual layering revealed veneer ceramic delamination, the CAD veneered group displayed a coherent fracture. They concluded that CAD veneering is a dependable technique for zirconia restorations.

This present study demonstrated that sandblasting the zirconia core resulted in significantly higher compressive strength and maximum load values than the hydrofluoric acid treated Group and the control group. Surface treatment with airborne particle abrasion can expand the veneering ceramic's contact area, reducing the likelihood of failure. Airborne particle abrasion enhanced surface roughness and contact surface area, which may reduce the percentage of interfacial failure of zirconia and veneering ceramic, according to studies made using a scanning electron microscope.(14) According to the findings, veneering ceramic bond strength may be increased more effectively by airborne particle abrasion than by HF acid treatment. The relationship between zirconia surface roughness and veneering ceramics' shear bond strength was documented by Zavod Za et al. They evaluated the surface morphology and roughness of Y-TZP ceramic material after grinding as well as sand blasting in relation to shear bond strength and concluded that there is a positive relation between the shear bond strength and surface roughness. Dan Liu et al conducted a study to compare the effect of three different surface treatments in enhancing the bonding potential of zirconia to veneer ceramic.(15) They concluded that both sand blasting and laser irradiation increased porcelain, zirconia bond strength. Kirmali O. et al. assessed the impact of various surface treatments on the shear bond strength (SBS) of pre-sintered zirconia to veneer ceramic, including sandblasting, liner application, and various laser irradiations. According to SEM pictures, the topography of the yttrium-stabilized tetragonal zirconia (Y-TZP) ceramic is considerably altered by surface treatments. The null hypothesis was partially rejected.

Limitations

- All specimens were made and examined under optimal in vitro settings, which might not accurately reflect clinical situations.
- Only marginal gaps were measured; internal gaps were not assessed due to the need for cementation and sectioning.
- Although a single Co-Cr die provided standardization, natural teeth would better simulate clinical conditions

CONCLUSION

Within this study's limitations:

- Marginal gaps increased after veneering and thermocycling, but changes were statistically insignificant.

- Pressing yielded slightly higher marginal gaps than layering; all values remained within the clinically acceptable range (<120 µm).
- Fracture resistance, assessed by maximum load and compressive strength, was significantly higher for pressing than layering.
- Airborne-particle-abraded copings demonstrated the highest fracture resistance.
- Failure modes differed: pressing favored cohesive failure, while layering favored adhesive or interfacial failure.

Clinical Significance

The present study highlights the influence of veneering technique and surface treatment on the mechanical performance of zirconia-based restorations. Pressed veneering systems demonstrated superior fracture resistance and more favorable cohesive failure patterns compared to layered restorations, while maintaining clinically acceptable marginal adaptation even after thermocycling. Airborne-particle abrasion improved the fracture resistance of veneered zirconia crowns, suggesting its potential clinical advantage in enhancing long-term restoration durability. These findings may assist clinicians in selecting veneering techniques and surface treatments for improving the longevity and predictability of zirconia restorations.

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