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THE INFLUENCE OF MILLING SPEED ON THE INTERNAL FIT OF CERAMIC LAMINATE VENEERS: AN IN-VITRO STUDY

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ABSTRACT

Objective: This in-vitro study evaluated the internal fit of ultra-translucent zirconia and lithium disilicate laminate veneers using two milling protocols (normal and fast milling).

Materials and Methods: Forty-four laminate veneers were fabricated for a typodont central incisor veneer preparation . The samples were divided into four groups (n=11): **(Groups LN and LF)** - lithium disilicate glass ceramic normal milling and fast milling respectively; **(Groups ZN and ZF)** ultra-translucent zirconia normal and fast milling respectively . Digital impression was made using an intraoral scanner, and veneers were designed and fabricated using CAD/CAM software. Internal fit was evaluated using the triple scan technique, recorded in micrometers (µm) as root mean square (RMS) values.

Results: Ultra-translucent zirconia demonstrated significantly better internal fit (mean RMS: 229.7±15.5 µm) compared to lithium disilicate (mean RMS: 260.6±15.3 µm), regardless of the milling protocol used ($p<0.05$). No significant difference was found in RMS values between normal milling (245.7±22.5 µm) and fast milling (244.6±21.1 µm) when averaged across materials ($p>0.05$). Group ZF exhibited the best internal fit (227.8±14.4 µm) among all groups, while Group LF showed the poorest adaptation (261.5 ± 10.8 µm).

Conclusions: Ultra-translucent zirconia laminate veneers exhibited superior internal fit compared to lithium disilicate veneers. The milling protocol didn't affect the overall internal fit, therefore fast milling can be used without compromising adaptation. These findings support the use of ultra-translucent zirconia for laminate veneers, particularly when using fast milling protocols.

KEYWORDS: Laminate Veneers, Internal Fit, Lithium Disilicate, Ultra-Translucent Zirconia, Milling Protocols

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INTRODUCTION

Dental esthetics has become a primary concern for patients seeking oral rehabilitation, driving the continuous development of restorative materials that combine superior optical properties with adequate mechanical performance. Porcelain laminate veneers have gained widespread acceptance over the past three decades as a conservative treatment modality for anterior teeth with discoloration, malformation, or minor structural defects (Gresnigt et al., 2019). These minimally invasive restorations preserve tooth structure while providing excellent esthetic outcomes, making them a preferred choice for both clinicians and patients (Morimoto et al., 2016).

Traditionally, feldspathic porcelain was the material of choice for laminate veneers due to its superior translucency and lifelike appearance. However, its limited mechanical properties, particularly low flexural strength, restricted its application in certain clinical scenarios and compromised long-term durability (Aldafeeri et al., 2019). The introduction of lithium disilicate glass ceramics represented a significant advancement, offering improved mechanical properties (flexural strength of 350-400 MPa) while maintaining acceptable translucency (Zarone et al., 2019). This material has become the gold standard for CAD/CAM-fabricated laminate veneers, with IPS e.max CAD (Ivoclar Vivadent) being widely used in clinical practice.

The concurrent evolution of digital dentistry, particularly CAD/CAM technology, has revolutionized the fabrication process of ceramic restorations. This technology allows for standardized, predictable outcomes with reduced laboratory time and has expanded the range of materials available for restorative procedures (Miyazaki et al., 2009). With the advancement of milling technologies, manufacturers have introduced various milling protocols, including “normal” and “fast” milling options. The normal milling protocol represents the standard mode applicable to all materials and indications, whereas the fast-milling option accelerates the manufacturing process, potentially reducing chairside waiting time for patients (Hany & Taymour, 2019). However, the impact of these different milling speeds on the quality of restorations, particularly their adaptation, remains inadequately investigated.

More recently, ultra-translucent zirconia has emerged as a promising alternative material for esthetic restorations. Traditional zirconia (3Y-TZP) has been valued primarily for its exceptional mechanical properties, with flexural strength exceeding 1000 MPa and superior fracture resistance (Cho et al., 2020). However, its high opacity limited its use in the anterior region where esthetics is paramount. The development of ultra-translucent zirconia, through modifications in composition and microstructure, has addressed this limitation, making it a potential candidate for highly esthetic restorations such as laminate veneers (Zhang, 2014).

The clinical success and longevity of ceramic restorations, including laminate veneers, are highly dependent on their marginal and internal adaptation (Kassis et al., 2023). Poor adaptation can lead to microleakage, secondary caries, cement dissolution, and ultimately restoration failure. For laminate veneers specifically, where margins are often placed in visible areas and restorations are typically thin, optimal adaptation is crucial for both esthetic outcomes and long-term success (Abdel-Nabi et al., 2020).

Various methods have been described in the literature to evaluate the adaptation of dental restorations, broadly categorized as destructive and non-destructive techniques. The triple-scan technique represents a non-invasive method that allows comprehensive assessment of both marginal and internal gaps without damaging the specimens (Basheer et al., 2017). It provides precise measurements for accurate crown fit assessments, reduces human error from manual measurements, and ensures consistent, reliable results. Additionally, it saves time compared to traditional replica techniques (Fayed et al 2025). This technique involves scanning the prepared tooth, the intaglio surface of the restoration, and the restoration seated on the tooth, followed by superimposition of the scans using specialized software to measure gap dimensions at multiple points (Fayed et al 2025).

While several studies have evaluated the adaptation of lithium disilicate laminate veneers, limited research has investigated ultra-translucent zirconia for this specific application. Furthermore, the potential influence of different milling protocols on the adaptation of these materials when fabricated as laminate veneers remains largely unexplored. Given the growing interest in both ultra-translucent zirconia as an esthetic material and faster manufacturing processes in digital dentistry, investigating these aspects becomes clinically relevant.

Therefore, this study aims to evaluate whether CAD/CAM ultra-translucent zirconia laminate veneers exhibit internal fit comparable to that of lithium disilicate glass ceramic veneers when fabricated using two different milling protocols (normal and fast milling). The findings will provide valuable insights for clinicians regarding material selection and processing parameters for minimally invasive anterior restorations.

MATERIALS AND METHODS

Study Design and Sample Size Calculation

This in vitro study was designed to evaluate and compare the internal fit of ultra-translucent zirconia and lithium disilicate glass ceramic laminate veneers using two different milling protocols. Sample size was calculated according to power analysis using internal fit (µm) as the primary outcome. Results from Rizk et al. (2023) showed that the mean value for the lithium disilicate group was 121.5 ± 49.1 µm, with an estimated mean difference of 39 µm between lithium disilicate and UTML zirconia groups. Using alpha (α) level of 5% and Beta (β) level of 20% (i.e., power = 80%), the minimum estimated sample size was 11 restorations per group with a total of 44 restorations. Sample size calculation was performed using PS program (Power and Sample Size Calculations Version 3).

Study Groups

The specimens were divided into four groups (n=11) according to the restorative material and milling protocol:

- **Group LN (Control)**: Lithium disilicate glass ceramic laminate veneers fabricated using normal milling speed
- **Group LF**: Lithium disilicate glass ceramic laminate veneers fabricated using fast milling speed
- **Group ZN**: Ultra-translucent zirconia laminate veneers fabricated using normal milling speed
- **Group ZF**: Ultra-translucent zirconia laminate veneers fabricated using fast milling speed

Tooth preparation.

A maxillary right central incisor acrylic tooth of a typodont model (NISSIN Dental Model, Koyota, Japan) was selected to be prepared and serve as a die. A silicon putty index was obtained using addition silicon material (PANASIL, Putty Soft Kettenbach dental-Germany) before reduction. A butt-joint incisal preparation design was chosen to reduce the incisal edge by 1 mm using a wheel stone grit green band (Frank, Germany). Labially depth grooves were obtained using 0.3 and 0.5 depth cutter diamond stones (Frank, Germany) in two planes. The required amount of preparation was done using tapered diamond stone with a round end and grit blue band (Frank, Germany) to obtain chamfer finish line 0.3-0.4mm thickness and 0.5mm supragingivally. Mesial and distal boundaries will be about 1 mm to mesio and distobuccal line angles, just before contact point. Finishing diamond stones were used to finish the tooth and the putty index section was used to ensure the required reduction. Then polishing of the preparation was done using polishing brush and paste **[Figure 1]**.

Fig. (1) Laminate veneer preparation with a butt-joint incisal preparation design

Digital Impression and Restoration Design

The prepared typodont tooth was digitized using an intraoral scanner "Medit i500 intraoral scanner (Medit Corp., Seoul, Korea). The scanning procedure was performed according to the manufacturer's recommendations to obtain a high-quality digital impression. The scan data was imported into theimported into exo CAD dental CAD software (exocad GmbH, Darmstadt, Germany for designing the laminate veneers.

Using the CAD software, a standardized veneer design was created with a uniform thickness of 0.5 mm at the labial surface and 1.5 mm at the incisal edge. The cement spacer thickness was set at 50 µm for all specimens to standardize the designed internal gap. The same digital design file was used for fabricating all specimens to eliminate design variables from the study. **[Figure 2]**.

Fabrication of Laminate Veneers

Lithium Disilicate Glass Ceramic Veneers

For Groups LN and LF, lithium disilicate glass ceramic blocks (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) were used. The blocks were secured in the milling machine (inLab MC XL, Dentsply Sirona, York, PA, USA). **Group LN** specimens were milled using the normal milling protocol as recommended by the manufacturer with estimated time 25:26 minutes per unit , while **Group LF** specimens were milled using the fast milling protocol with estimated time 18:24 minutes per unit. Grinding porcedure was accomplished fully using diamond stones **[Figure 3]**

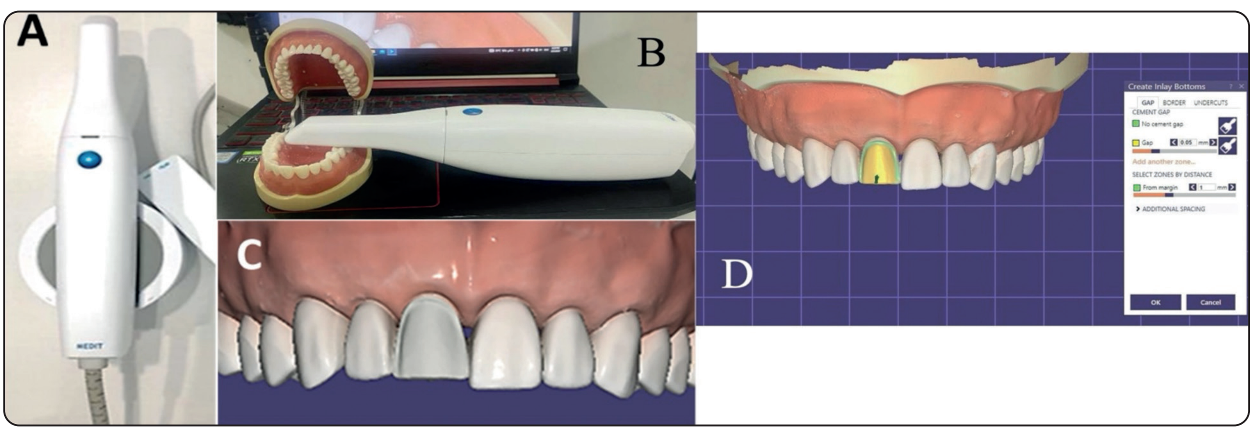

Fig. (2) (A) Medit i500, (B) Preparation Acquisition, (C) Virtual image of the typodont Model, (D) Cement Gap Space

Following the milling procedure, the lithium disilicate veneers were carefully removed from the blocks. The attachment sprue was removed using fine-grit diamond burs under water cooling. IPS e.max CAD Crystal/Glaze Paste (Ivoclar Vivadent, Schaan, Liechtenstein) was applied evenly on the blue stage. The specimens were then crystallized in a ceramic furnace (Programat P310, Ivoclar Vivadent, Schaan, Liechtenstein) according to the manufacturer's recommended crystallization program (850°C for 20-25 minutes).

Ultra-Translucent Zirconia Veneers

For Groups ZN and ZF, ultra-translucent zirconia discs (KATANA Zirconia UTML, Kuraray Noritake Dental Inc., Tokyo, Japan) were used. The discs were secured in the milling machine, and the same design file used for the lithium disilicate specimens was utilized. Group ZN specimens were milled using the normal milling protocol with estimated milling time 20:00 minutes per unit, while Group ZF specimens were milled using the fast milling protocol with estimated milling time 13:24 minutes per unit. Grinding porcedure was accomplished fully diamond coated burs. **[Figure 4]**

After milling, the zirconia veneers were carefully separated from the discs, and the attachment sprue was removed using fine-grit diamond burs. The specimens were sintered in a zirconia sintering furnace (inFire HTC speed, Dentsply Sirona, York, PA, USA) following the manufacturer's recommended sintering program (1550°C for 2 hours). Then , all zirconia veneers were glazed using a zirconia glaze "Apply CZR PRESS" (Kurary Nortike Dental Inc., Japan) and fired using glaze cycles in the porcelain furnace "Programat CS3".

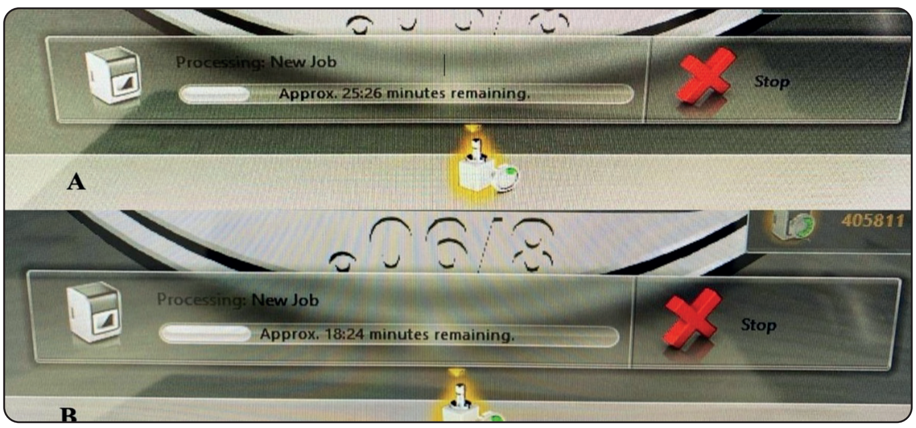

Fig. (3) Estimated milling time: (A) group Ln (25:26 mins/unit), (B) group Lf (18:24 mins/unit)

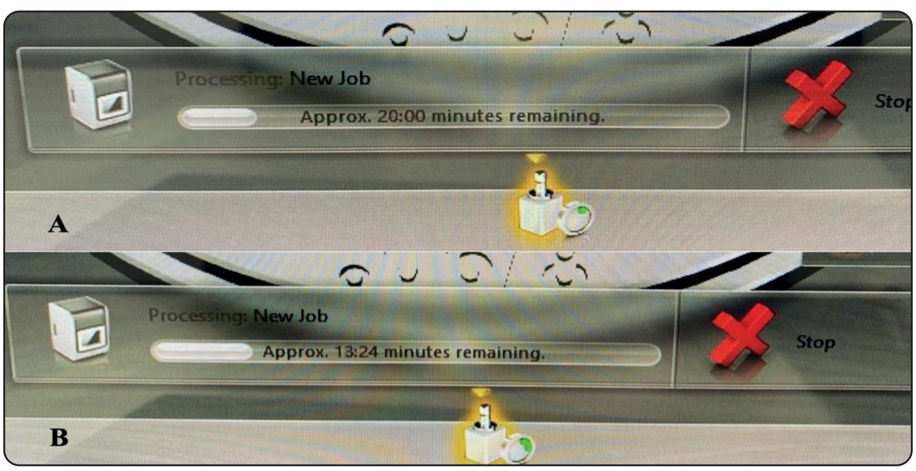

Fig. (4) Estimated milling time: (A) group Zn (20:00 mins/unit), (B) group Zf (13:24 mins/unit)

All specimens were inspected under 2.5× magnification to verify their integrity and absence of visible defects before evaluation. Each specimen was numbered and stored in individual labeled containers.

Evaluation of Internal Fit using Triple Scan Technique

The internal fit of the laminate veneers was evaluated using the triple scan technique. This non-destructive method involved three scanning procedures:

1. Scanning of the prepared tooth
2. Scanning of the intaglio surface of each veneer
3. Scanning of each veneer seated on the prepared tooth

The master die was embedded in an epoxy resin cylinder and consequently seated in a putty platform with a marking on the labial aspect to be easily detected upon scanning. All scans were performed using an intraoral scanner (Primescan, Dentsply Sirona, Germany) [Figure 5]

The three scans were imported into specialized evaluation software (Geomagic Control X, 3D Systems, Rock Hill, SC, USA). The software aligned the scans and generated color-coded maps representing the gap dimensions between the veneer and the prepared tooth surface. Gap measurements were recorded at 50 predetermined points distributed across the entire internal surface including the incisal, middle, and cervical thirds of the veneer. [Figure 6]

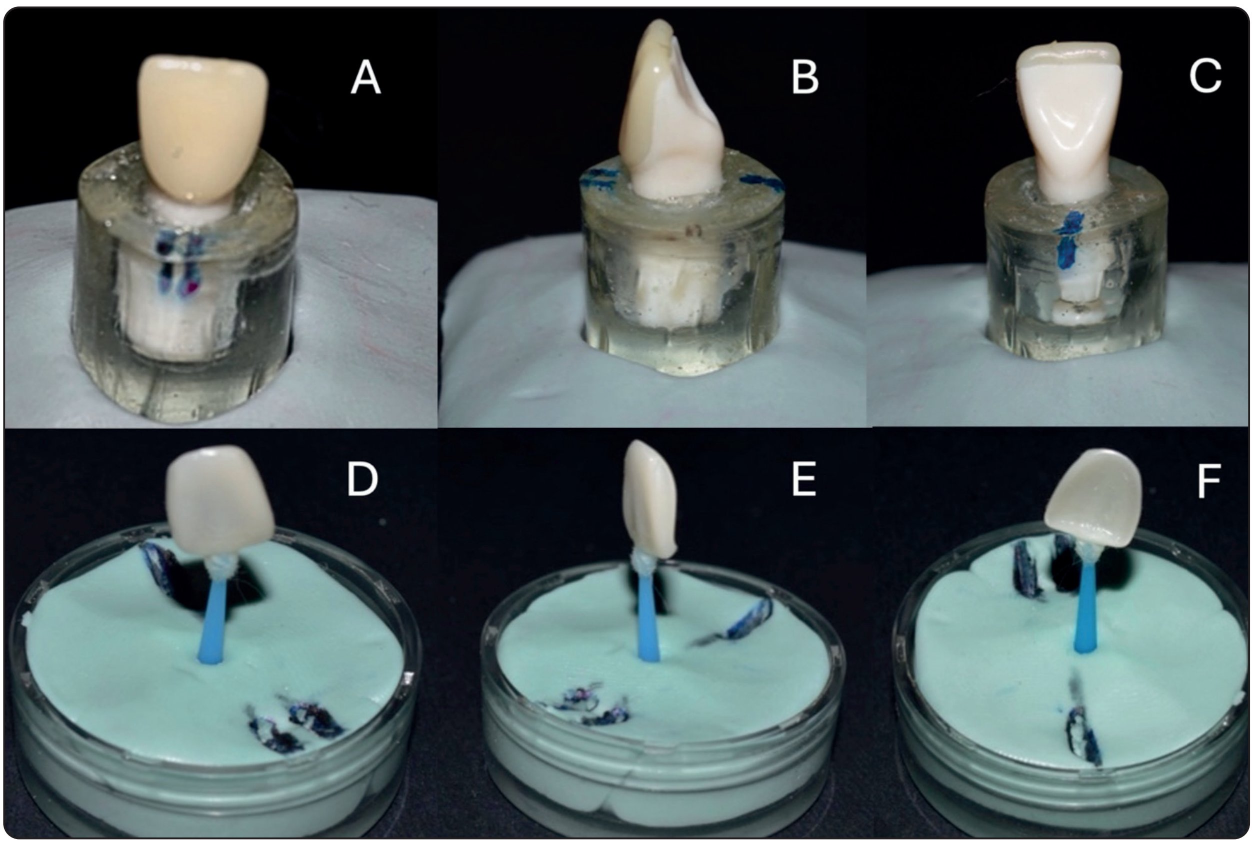

Fig. (5) **A,B and C:** Master die embeded in epoxy resin and seated in putty platform with laminate veneers stabilized to the prepration (Labial, Proximal nd palatal views) and consequently scanned **D,E and F:** laminate veneers stand alone embedded in a putty platform to be scanned alone

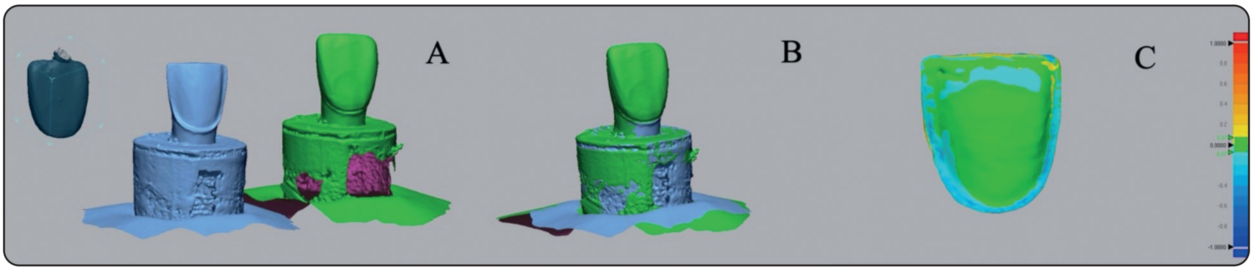

Fig. (6) A. Geomagic control X interface showing the three STL files before alignment B. STL files after "best fit alignment" C. The color map representing internal fit of the veneer. The green color represents areas of fit between the die and veneer while the blue color represents gap between the die and the internal laminate surface

For each specimen, the following measurements were recorded:

- Root mean square (RMS) values (μm)
- Positive average deviations (+AVG) (μm)
- Negative average deviations (-AVG) (μm)

Statistical Analysis

Statistical analysis was performed with SPSS 27®, Graph Pad Prism® and Microsoft Excel 2016. All data were explored for normality by using Shapiro Wilk and Kolmogorov Normality test which revealed that all data originated from normal data distribution. Accordingly, Comparison between groups was performed by One Wau ANOVA test followed by Tukey's Post Hoc test for multiple comparisons and presented as means and standard deviation (SD) values. The significance level was set at $p<0.05$ within all tests.

RESULTS

Internal fit assessment:

Comparison between groups regarding internal fit demonstrated that there was a significant difference between them as $P < 0.0001$ (table 1 and figure 7)

In the pairwise comparison of internal fit values, a statistically significant difference was observed between several groups. The internal fit difference between LF and ZF was 23.101 μm with a P-value of 0.009, and between LF and Zn it was 20.575 μm with a P-value of 0.024, indicating significant differences in both cases. Similarly, LN vs ZF showed a significant difference of 24.324 μm ($P = 0.005$), and LN vs Zn presented a difference of 21.799 μm ($P = 0.015$). In contrast, no statistically significant differences were found between LF and LN (-1.224 μm, $P = 0.998$) and between ZF and Zn (-2.525 μm, $P = 0.984$). These findings suggest that while ZF and Zn groups differed significantly from LF and LN, they did not differ significantly from each other, and neither did LF and LN. (table 2, figure 8).

TABLE (1) Comparison between different groups regarding Internal Fit (μm):

	Mean	Standard Deviation	P Value
LF	253.85 a	12.97	<0.0001*
LN	255.07 a	20.21	
ZF	230.75 b	21.75	
ZN	233.28 b	25.10	

Significant difference as P ≤ 0.05.

Means with different superscript letters were significantly different as P ≤ 0.05

TABLE (2) Pairwise Comparison between different groups regarding Internal Fit (μm):

Pairwise comparison	Mean Difference	Std. Error	95% Confidence Interval		P value.
			Lower Bound	Upper Bound	
LF Vs LN	-1.224	7.028	-19.763	17.316	0.998
LF Vs ZF	23.101	7.028	4.561	41.640	0.009*
LF Vs Zn	20.575	7.028	2.036	39.115	0.024*
LN Vs ZF	24.324	7.028	5.785	42.864	0.005*
LN Vs Zn	21.799	7.028	3.259	40.338	0.015*
ZF Vs Zn	-2.525	7.028	-21.065	16.014	0.984

Significant difference as P ≤ 0.05.

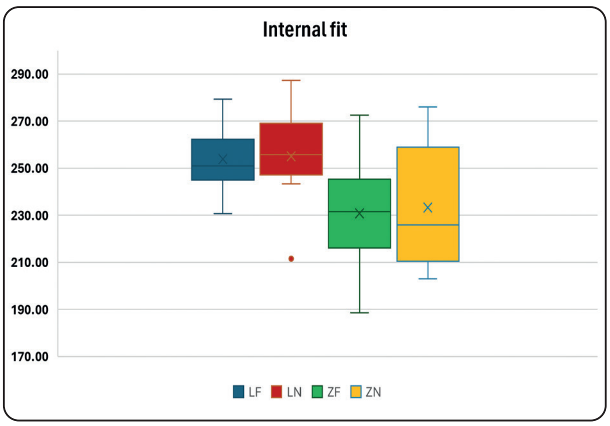

Fig. (7): Boxplot representing internal fit in all groups.

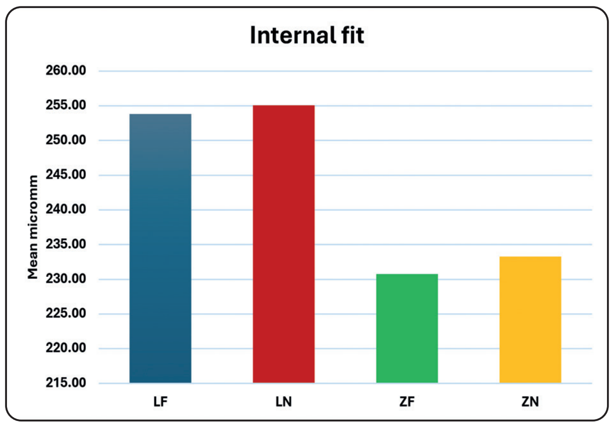

Fig. (8): Bar chart represents comparison between groups regarding internal fit.

Effect of Material Type on Internal Fit

Regardless of the milling protocol used, the mean RMS values for lithium disilicate and ultra-translucent zirconia were 260.6 ± 15.3 µm and 229.7±15.5 µm, respectively. The data indicated that ultra-translucent zirconia laminate veneers demonstrated significantly better internal fit (lower RMS values) compared to lithium disilicate laminate veneers (p<0.05).

Effect of Milling Protocol on Internal Fit

When comparing the effect of milling protocols regardless of material type, the mean RMS values for normal milling and fast milling were 245.7±22.5µm and 244.6±21.1µm, respectively. Statistical analysis revealed no significant difference in the RMS values between the two milling protocols (p>0.05).

However, significant differences were observed in the positive average deviation (+AVG) between normal milling (119.4 ± 25.8 µm) and fast milling (85.4 ± 24.2 µm), indicating that fast milling resulted in less positive deviation (p < 0.05).

Interaction Between Material Type and Milling Protocol

Two-way ANOVA revealed a significant interaction between material type and milling protocol for the RMS values (p<0.05). While the milling protocol had minimal effect on the internal fit of lithium disilicate veneers (Group LN: 259.8±18.7µm vs. Group LF: 261.5±10.8µm), there was a notable difference in the internal fit of ultra-translucent zirconia veneers between normal and fast milling protocols (Group ZN: 231.6 ± 16.3 µm vs. Group ZF: 227.8±14.4 µm).

The data revealed that Group ZF (Ultra-translucent zirconia with fast milling) exhibited the lowest mean RMS value (227.8±14.4 µm) among all groups, indicating the best internal fit. In contrast, Group LF (Lithium disilicate with fast milling) showed the highest mean RMS value (261.5±10.8µm), suggesting the poorest internal fit among the tested groups.

DISCUSSION

This in vitro study evaluated the internal fit of ultra-translucent zirconia and lithium disilicate glass ceramic laminate veneers fabricated using two different milling protocols. The findings provide valuable insights into the relationship between material selection, manufacturing parameters, and restoration adaptation.

The methodology employed was designed to provide a comprehensive assessment of internal fit while controlling for variables. The standardized typodont preparation, triple scan technique for evaluation (Fayed et al 2025), and adequate sample size ensured reliable and clinically relevant results. Digital impression techniques have been shown to provide highly accurate transfers of the preparation to CAD software (Kirsten et al., 2020).

Our results demonstrated that ultra-translucent zirconia laminate veneers exhibited significantly better internal fit compared to lithium disilicate, regardless of the milling protocol used. The mean RMS values for ultra-translucent zirconia (229.7±15.5µm) were notably lower than those for lithium disilicate (260.6±15.3 µm), indicating superior adaptation of the zirconia material. This finding aligns with recent research by Rizk et al. (2023), who reported better adaptation values for ultra-translucent multilayer zirconia compared to lithium disilicate when used for laminate veneers.

The improved adaptation of zirconia can be attributed to several factors. Recent advances in zirconia materials have focused on increasing yttrium content, modifying grain size, and reducing impurities to create ultra-translucent zirconia with enhanced properties (Ghanem et al., 2024). The specific formulation of KATANA Zirconia UTML contains approximately 70% cubic phase and 30% tetragonal phase, which differs significantly from conventional zirconia materials (Cesar et al., 2024). Additionally, the different manufacturing processes—crystallization firing for lithium disilicate versus sintering with 25% shrinkage for zirconia—may explain part of the observed differences in internal fit (Turkyilmaz et al., 2021).

Our study found no significant difference in overall RMS values between normal milling (245.7 ± 22.5 µm) and fast milling (244.6 ± 21.1 µm) protocols when averaged across both materials. This contradicts the common assumption that faster milling might compromise precision due to reduced milling time and increased vibration (Hany & Taymour, 2019). The normal and fast milling protocols examined represent standardized options with time differences of approximately 7 minutes per unit for lithium disilicate and 6.5 minutes for zirconia. Modern CAD/CAM milling systems appear to maintain precision even with accelerated processing times (Lebon et al., 2016).

While overall internal fit was similar between milling protocols, significant differences were observed in the positive average deviation (+AVG) between normal milling (119.4 ± 25.8 µm) and fast milling (85.4 ± 24.2 µm). This suggests that while overall fit remained consistent, the distribution of gaps differed between protocols.

Our study revealed a significant interaction between material type and milling protocol for internal fit values. For lithium disilicate, changing from normal to fast milling had minimal impact on internal fit. In contrast, for ultra-translucent zirconia, fast milling resulted in slightly better internal fit, though this difference was not statistically significant. This differential response may relate to the inherent properties of the materials, particularly their machinability characteristics (Al-Aali et al., 2021).

The bur-material interaction during milling is complex, influenced by material hardness, brittleness, thermal properties, and milling parameters (Kirsch et al., 2017). The improved fit observed with zirconia under fast milling could be attributed to reduced wear of milling burs during the shorter process. With zirconia being harder, extended milling time might lead to progressive bur wear, potentially affecting precision (Tapie et al., 2015).

The findings of this study have several important clinical implications. Ultra-translucent zirconia appears to be a viable alternative to lithium disilicate for laminate veneers, offering better internal fit and higher flexural strength while maintaining excellent esthetics (Zhang & Lawn, 2018). Fast milling protocols did not compromise internal fit, supporting their clinical efficiency in reducing chairside treatment time. CAD/CAM milled restorations consistently demonstrate high-quality outcomes with long-term survival rates exceeding 90% at 10 years (Beuer et al., 2008).

Although the observed internal gap values (227.8-261.5 µm) exceed the theoretically ideal cement space of 50-100 µm (Kassis et al., 2023), they align with previous findings for CAD/CAM-fabricated laminate veneers (Basheer et al., 2017) and remain within clinically reasonable parameters (Khmaj et al., 2021). Recent clinical trials have confirmed that high-translucency zirconia performs comparably to lithium disilicate in esthetic outcomes (Fawakhiri et al., 2023), further supporting its use in the anterior region.

Limitations of this in vitro study include the use of a standardized typodont tooth, evaluation of a single preparation design, and testing with only one CAD/CAM system. Future research should examine the correlation between internal fit and other clinical outcomes, including retention, fracture resistance, and long-term esthetic stability of ultra-translucent zirconia laminate veneers (de Araújo-Júnior et al., 2022).

CONCLUSION

Within the limitations of this in vitro study,

1. Ultra-translucent zirconia laminate veneers demonstrated significantly better internal fit compared to lithium disilicate glass ceramic laminate veneers, regardless of the milling protocol used.
2. The milling protocol (normal vs. fast) did not significantly affect the overall internal fit of either material, suggesting that fast milling can be utilized without compromising adaptation.
3. Ultra-translucent zirconia with fast milling exhibited the best internal fit, suggesting that this combination may be optimal for fabricating laminate veneers with superior adaptation.

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