Alqalam Journal of Medical and Applied Sciences. 2025;8(4):2745-2749
https://doi.org/10.54361/ajmas.258493

Original article

In vitro Comparison of the Microhardness of Lithium Disilicate and Monolithic and Multilayered Fixed Prosthodontic Materials

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Abstract
Micro-hardness is a fundamental property of prosthodontic restorative materials, as it affects their resistance to surface deformation, wear, and long-term clinical performance. This study aimed to compare the Vickers micro-hardness of three widely used CAD/CAM materials: lithium disilicate, monolithic zirconia, and multilayered zirconia. A total of 30 specimens (N = 30) were fabricated, with 10 samples allocated to each material group. Lithium disilicate specimens were prepared as rectangular plates (18 × 15 × 1 mm), whereas zirconia specimens—both monolithic and multilayered—were fabricated as discs (10 mm in diameter and 1.5 mm in thickness) following standardized CAD/CAM milling and sintering protocols. Vickers micro-hardness testing was conducted using a digital micro-hardness tester under material-specific conditions: a load of 1 kg and a dwell time of 10 s for lithium disilicate, and a load of 500 g with a 20 s dwell time for zirconia. Statistical analysis was performed using one-way ANOVA followed by Tukey's post-hoc test, with the significance level set at $p < 0.05$. Significant differences in micro-hardness were identified among the three materials ($p < 0.001$). Monolithic zirconia demonstrated the highest mean hardness (680 ± 19 HV), followed by multilayered zirconia (623 ± 47 HV), while lithium disilicate exhibited the lowest values (553 ± 32 HV). Post-hoc analysis confirmed that all pairwise comparisons were statistically significant. The findings indicate that monolithic zirconia possesses superior micro-hardness compared to multilayered zirconia and lithium disilicate, supporting its suitability for high-stress clinical applications. Multilayered zirconia offers a balance between mechanical performance and esthetics, whereas lithium disilicate remains optimal for highly esthetic anterior restorations. These results provide clinicians with evidence-based guidance for selecting CAD/CAM materials in fixed prosthodontic rehabilitation.
Keywords. Micro-hardness, Vickers Hardness, CAD/CAM, Monolithic Zirconia, Multilayered Zirconia.

Introduction

Advances in CAD/CAM restorative materials have transformed prosthodontic practice by enabling a more precise balance between strength, aesthetics, and long-term durability. Among these materials, lithium disilicate glass-ceramics (e.g., IPS e.max CAD) remain highly valued for their excellent translucency, adhesive potential, and favorable mechanical behavior, especially in regions where esthetics are critical. However, its mechanical limitations under high stress have prompted interest in alternative materials [1]. On the other hand, yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) have become increasingly popular in monolithic form because of their superior strength and fracture resistance. Yet, traditional monolithic zirconia may lack the translucency found in glass-ceramics, which has led to the development of multilayered or gradient zirconia systems that aim to combine strength with improved optical properties. These gradient materials simulate natural tooth shading and can potentially offer a more favorable esthetic profile [2].

A critical property that influences the clinical performance of these restorative materials is surface micro-hardness, which reflects their resistance to surface deformation and wear. Micro-hardness also correlates with long-term behavior under occlusal loading and can indicate how a material will resist scratching or degradation over time [2]. Recent work has shown that polishing protocols and the yttria content in zirconia significantly affect its microstructure, phase composition, and micro-hardness. Furthermore, a direct comparison of monolithic and multilayered zirconia with lithium disilicate under a unified testing protocol is still needed to guide clinical selection [3].

Moreover, the interaction of restorative materials with bonding agents or cements is affected by their thickness and microstructure. For example, the polymerization efficiency of dual-cure resin cements under lithium disilicate or monolithic zirconia varies depending on the ceramic's thickness, which in turn impacts the cement's hardness and the overall clinical performance of the restoration [4,5]

Despite numerous studies comparing the mechanical behavior of lithium disilicate and various forms of zirconia, there remains a gap in the literature concerning a direct, standardized comparison of micro-hardness among lithium disilicate, monolithic zirconia, and gradient multilayered zirconia. Many existing studies differ in specimen dimensions, sintering protocols, surface treatments, or testing parameters, making comparisons difficult.

Therefore, this in-vitro comparative study was designed to evaluate and compare the Vickers micro-hardness of three common CAD/CAM restorative materials — IPS e.max CAD (lithium disilicate), monolithic Y-TZP

***Received**: 26-09-2025 - **Accepted**: 25-11-2025 - **Published**: 02-12-2025* https://doi.org/10.54361/ajmas.258493

zirconia, and gradient (multilayer) Y-TZP zirconia — under a unified protocol for sample fabrication, surface treatment, and hardness testing. This approach aims to provide clinicians and researchers with clearer, directly comparable data to inform material selection in different prosthodontic applications.

Materials and Methods

Study Design

This in-vitro comparative study evaluated the micro-hardness of three commonly used CAD/CAM prosthodontic restorative materials. A total of thirty specimens (N = 30) were fabricated and allocated into three groups (n = 10 per group):

Group I: Lithium disilicate glass-ceramic (IPS e.max CAD; Ivoclar Vivadent).

Group II: Monolithic yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) (Noritake KATANA™; Kuraray Noritake Dental).

Group III: Gradient multilayered Y-TZP zirconia (Noritake KATANA™ Multi-Layer; Kuraray Noritake Dental).

All materials were processed following manufacturer-recommended protocols, and all testing procedures were standardized to ensure comparability among groups.

Specimen Design and Fabrication

IPS e.max CAD (Group I)

Rectangular plate-shaped specimens were prepared using IPS e.max CAD blocks. Each block was sectioned into standardized dimensions of 18 × 15 × 1 mm. Sectioning was performed using a water-jet cutting machine to minimize microcrack formation. Surfaces were polished sequentially using abrasive discs under constant pressure. A single glazing and crystallization cycle was completed according to the manufacturer's instructions to achieve the final microstructure and surface finish.

Zirconia Groups (Groups II & III)

Disc-shaped specimens were fabricated for both monolithic and multilayered zirconia. Specimens were digitally designed using AutoCAD software with dimensions of 10 mm in diameter and 1.5 mm thickness. Designs were exported in STL format and transferred to the CAD/CAM milling unit. All milling procedures were performed using a standardized sequence based on the manufacturer's guidelines. Following milling, specimens were sectioned if necessary and finished to the intended final dimensions. All zirconia specimens underwent a full sintering cycle recommended by Kuraray Noritake to achieve complete densification.

Micro-Hardness Testing

Micro-hardness testing was conducted under standardized conditions to ensure comparability across all groups, with the applied load adjusted according to the specific properties of each material. A Vickers diamond indenter was employed for all measurements. For zirconia specimens (Groups II and III), a load of 500 g was applied with a dwell time of 20 seconds, whereas lithium disilicate specimens (Group I) were tested under a load of 1 kg with a dwell time of 10 seconds. Each specimen was subjected to three indentations, with a minimum spacing of 0.5 mm between indentations to prevent overlapping deformation zones and ensure accuracy of measurement.

The Vickers micro-hardness value (HV) was calculated using the standard formula:

$$HV = 1.854\ P/d^2$$

Where P is the applied load (in kgf), and d is the average diagonal length of the indentation (in mm). This formula was applied uniformly to all specimens to obtain the micro-hardness values for statistical comparison.

Statistical Analysis

All statistical analyses were performed using standard analytical procedures. The dataset was first evaluated for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. After confirming that the data satisfied the assumptions for parametric testing, a one-way analysis of variance (ANOVA) was conducted to assess the differences in micro-hardness among the three material groups. When a statistically significant result was detected, Tukey's post-hoc multiple comparison test was applied to determine pairwise differences between groups. A significance level of $p < 0.05$ was adopted for all analyses.

Results

The one-way ANOVA demonstrated a statistically significant difference in the mean Vickers micro-hardness values among the three tested materials $F [2 -27] = 33.78$, $p < 0.001$), indicating that material type had a significant effect on surface hardness.

Descriptive statistics for each group are presented in (Table 1). Group II (monolithic zirconia) exhibited the highest micro-hardness value (M = 680, SD = 19), followed by Group III (multilayered zirconia) (M = 623, SD = 47). Group I (lithium disilicate CAD/CAM) demonstrated the lowest mean micro-hardness value (M = 553, SD = 32).

Table 1. Mean Vickers Micro-Hardness (HV) Values of the Tested Materials

Received: 26-09-2025 - **Accepted**: 25-11-2025 - **Published**: 02-12-2025 https://doi.org/10.54361/ajmas.258493

Group	Material	Mean Hardness (HV)	Standard Deviation	N	T
I	Lithium Disilicate	553	± 32	10	53
II	Monolithic Zirconia	680	± 19	10	45
III	Multilayered Zirconia	623	± 47	10	101

Post-Hoc Analysis

Tukey's HSD post-hoc analysis revealed statistically significant pairwise differences among all three tested groups. Monolithic zirconia (Group II) exhibited significantly higher micro-hardness compared to lithium disilicate (Group I) ($p < 0.001$), and it also demonstrated significantly greater hardness than multilayered zirconia (Group III) ($p < 0.001$). In addition, multilayered zirconia (Group III) showed significantly higher values than lithium disilicate (Group I) ($p < 0.001$). These differences confirm that each material group displayed distinct hardness characteristics, with monolithic zirconia consistently outperforming the other two. The comparative results are illustrated in Figure 1, which provides a visual representation of the statistical differences among the groups.

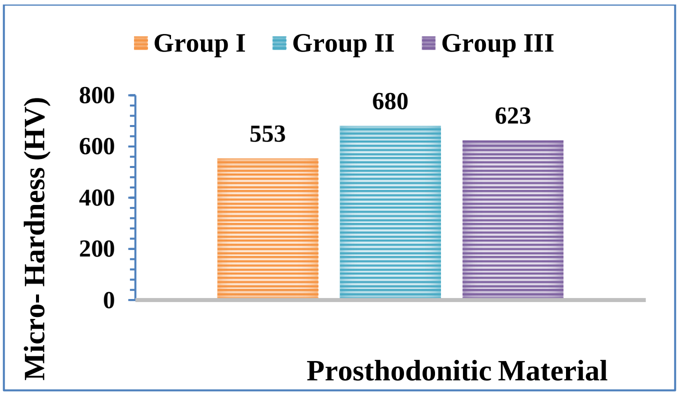

Figure 1: - Line graph showing One-way ANOVA comparison of micro-hardness Surface Test (VH) of the tested prosthodontic

These findings confirm that monolithic zirconia exhibits the greatest resistance to surface deformation, followed by multilayered zirconia, while lithium disilicate demonstrated the lowest micro-hardness values.

Discussion

The present study demonstrated statistically significant differences in Vickers micro-hardness among the three tested prosthodontic materials, with monolithic zirconia exhibiting the highest hardness values, followed by multilayered zirconia, while lithium disilicate showed the lowest measurements. The superior performance of monolithic zirconia aligns with the findings of Labetić et al. (2024) [6], who reported that the homogenous and fully polycrystalline structure of monolithic zirconia enhances its mechanical resistance and minimizes surface deformation under load. Similarly, Güntekin and Kızılırmak (2025)[7] confirmed that the absence of internal gradients or esthetic layers provides monolithic zirconia with a more uniform grain distribution, which directly contributes to its higher hardness and wear resistance.

In contrast, multilayered zirconia, although still significantly harder than lithium disilicate, demonstrated reduced hardness compared to the monolithic form. This trend supports the observations of Alfahed and Alayad (2023)[8,9], who explained that multilayered zirconia incorporates translucency-enhancing layers with higher yttria content (4Y–5Y), resulting in larger grains and lower tetragonal-to-monoclinic transformation potential—factors that collectively decrease hardness. Additionally, Alrabiah (2025)[10,11] indicated that gradient interfaces in multilayer zirconia may function as stress concentration sites, affecting micro-indentation behavior and lowering hardness values when compared to homogeneous monolithic structures.

Lithium disilicate presented the lowest hardness among the tested groups, consistent with the reports of Mavriqi et al. (2022)[12], who attributed this to its dual-phase glass-ceramic microstructure, containing a substantial glassy matrix that is inherently more susceptible to indentation than the densely packed grains of zirconia. Likewise, [13] found that although lithium disilicate offers excellent translucency and bonding advantages, its mechanical properties remain inferior to zirconia-based materials, especially in terms of hardness and resistance to occlusal wear.

Despite broad agreement in the literature, some authors present conflicting viewpoints. For example, Mohammed and Hussein (2025)[14,15] suggested that certain high-translucency zirconia compositions may approach or even fall below the hardness values of lithium disilicate under corrosive or aged conditions,

Received: 26-09-2025 - **Accepted**: 25-11-2025 - **Published**: 02-12-2025

challenging the assumption that zirconia consistently outperforms glass-ceramics in hardness. Additionally, Riyam and Al-Azzawi (2024)[16,17] reported that surface finishing, glazing materials, and polishing protocols can significantly alter zirconia hardness, implying that differences between monolithic and multilayered zirconia may become less pronounced depending on the clinical finishing technique.

The overall agreement among most researchers supports the current study's findings: monolithic zirconia remains the hardest material due to its homogeneous structure; multilayered zirconia balances mechanical strength with enhanced esthetics at the cost of a slight reduction in hardness; and lithium disilicate continues to excel esthetically but exhibits lower surface hardness. These results reinforce the importance of selecting restorative materials based on a balance between esthetic demands and functional load requirements.

Limitations

Although we used a standardized fabrication and testing protocol, the in vitro nature of this study does not fully replicate oral conditions. Factors such as cyclic fatigue, thermal aging, and intraoral pH may further influence hardness in vivo. We tested only one brand/type per material group. Different manufacturers' zirconia or lithium disilicate with varying compositions (yttria content, grain size) may yield different hardness values. The study did not investigate aging effects (e.g., thermocycling, low-temperature degradation) or surface degradation over time, which could affect long-term hardness.

Conclusion

Within the limitations of this in-vitro study, the findings demonstrated clear and statistically significant differences in micro-hardness among the three tested prosthodontic CAD/CAM materials. Monolithic zirconia exhibited the highest hardness values, reflecting its homogeneous polycrystalline structure and superior resistance to surface deformation. Multilayered zirconia showed intermediate hardness, suggesting that the incorporation of esthetic gradient layers slightly compromises mechanical performance while maintaining clinically acceptable strength. Lithium disilicate displayed the lowest hardness, consistent with its glass-ceramic microstructure and esthetic-focused composition. These results highlight the importance of material selection in clinical decision-making. Monolithic and multilayered zirconia may be preferable in high-stress posterior regions where resistance to wear and deformation is essential, whereas lithium disilicate remains suitable for anterior restorations where esthetics and bonding ability are prioritized. Further studies incorporating aging, chewing simulation, and surface treatment variables are recommended to provide a more comprehensive understanding of the long-term clinical behavior of these materials.

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Received*: 26-09-2025 -* ***Accepted****: 25-11-2025 -* ***Published****: 02-12-2025*

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Received*: 26-09-2025 -* ***Accepted****: 25-11-2025 -* ***Published****: 02-12-2025*