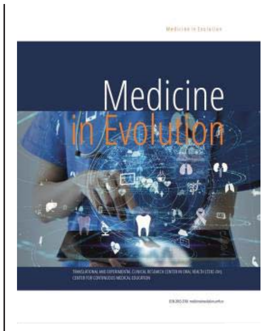
Comparative Evaluation of Mechanical Properties in Contemporary Prosthetic Dental Materials: Zirconia, Lithium Disilicate, and Hybrid Composites



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Abstract

Background/Objective: The choice of dental prosthesis material necessitates consideration of the compromise between strength, esthetics and long-term durability. Speakers claim that monolithic zirconia, lithium disilicate, and hybrid composites are the most popular materials with different mechanical and clinical properties. The present study was conducted to compare the mechanical properties of these three materials in vitro by standardised procedures in relation to seven factors important for prosthodontic use. Methods: Ninety rectangular specimens (n = 30 per group) were prepared from monolithic zirconia, lithium disilicate, and a CAD/CAM hybrid composite. The samples were tested for flexural strength, fracture toughness, Vickers microhardness, wear, surface roughness, fatigue survival (1.5 million cycles) and marginal adaptation.). For reliability of zirconia, the Weibull modulus (m = 14.2) was shown to be higher than the hybrid group. Conclusion: All three materials provide specific clinical benefits. Zirconia is best suited for rear and high-stool restorations, lithium disilicate for anterior and asthetic operated cases, and hybrid composite for temporary or minimal invasive applications. Understanding the mechanical behavior of each material is necessary for evidence-based artificial decision making and improvement in long-term clinical results.

Keywords: zirconia, lithium disilicate, hybrid composite, flexural strength, microhardness, fatigue resistance, prosthetic materials, CAD/CAM, dentistry

INTRODUCTION

Rehabilitation of oral health through prosthetic restoration is one of the foundations of modern dentistry. It not only encompasses the restoration of esthetic form but also the re-establishment of masticatory function, phonetics, and the psychological state of the patients. Growing expectations of both clinicians and patients for restorative systems with increased longevity, high biomechanical performance, and excellent optical properties have driven continuous evolution in dental materials science. Advances in digital work flows, CAD/CAM manufacturing, and materials engineering have enabled the fabrication of restorations with enhanced accuracy, mechanical stability, and biocompatibility.

Monolithic zirconia, lithium disilicate, and CAD/CAM hybrid composites are at the forefront of restorative dentistry among the wide array of prosthetic materials currently available, each possessing its own distinct set of advantages and clinical limitations. Zirconia ceramics have achieved a predominant position in prosthodontics due to their excellent mechanical properties, including high flexural strength, outstanding fracture toughness, and fatigue resistance, making them a material of choice for posterior load-bearing restorations and full-arch rehabilitations [1–5]. However, limitations related to translucency and bonding properties have promoted the development and clinical application of novel materials in esthetically demanding regions of the oral cavity.

Lithium disilicate glass ceramics were introduced to address these limitations by providing improved translucency and higher bonding potential without compromising strength to an unreasonable extent under moderate-load conditions. Their microstructure—a result of consisting of elongated lithium disilicate crystals scattered in a glassy matrix—yields an optimum combination of mechanical strength, crack deflection, and esthetics. These qualities make lithium disilicate an ideal material for anterior crowns, veneers, inlays, onlays, and implant-supported single-unit restorations when visual harmony with the natural dentition is a concern [6–10].

More recently, hybrid CAD/CAM restorative materials, including nanoceramic resin-based composites and polymer-infiltrated ceramic networks, have been introduced as alternatives in an effort to mimic the biomechanical behavior of natural dentin. These materials combine the elasticity and shock-absorbing capability of a polymer matrix with the wear resistance and esthetic potential of ceramic fillers [11–14]. These characteristics make hybrid composites appropriate for minimally invasive restorations, provisional prosthetic indications, and cases where reparability and intraoral adjustability are valued. Long-term wear resistance, hydrolytic stability, and overall mechanical reliability when subjected to cyclic functional loading, though, remain a concern.

From a biomechanical perspective, the evaluation of restorative materials has to extend beyond esthetic appearance and compressive strength. Complete characterization should include parameters such as flexural strength, fracture toughness, Vickers microhardness, fatigue resistance, surface roughness, and marginal adaptation. These factors have a direct impact not only on the mechanical longevity of restorations, but also on their biological integration, resistance to bacterial colonization, plaque retention, and patient comfort during function [15–22].

While there have been many studies examining zirconia, lithium disilicate, and hybrid composites individually, relatively fewer have provided direct, standardized in vitro comparisons of their mechanical and structural performances. Moreover, recent advances in CAD/CAM milling fidelity, sintering regimens, and surface treatments have significantly altered the clinical performance profiles of these materials. Therefore, the need for contemporary comparative data is required to guide evidence-based material selection [23–26].

Therefore, the objective of the present study is to provide a comprehensive comparative assessment of three representative prosthetic materials—monolithic zirconia, lithium disilicate, and a modern CAD/CAM hybrid composite—by standardized in vitro testing on seven key parameters. The aim is to provide clinicians with reliable information to guide material choice on the grounds of functional requirement, esthetic need, and long-term durability, with the overall aim of enhancing treatment planning and clinical success.

MATERIAL AND METHODS

Specimen Preparation

Three commercially available dental materials were selected: monolithic zirconia (Katana™ STML, Kuraray Noritake, Japan), lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein), and a CAD/CAM hybrid composite (Lava™ Ultimate, 3M ESPE, USA).

Rectangular bars: Ninety bar-shaped specimens were fabricated (n = 30 per material), each **16 × 4 × 2 mm**, prepared according to **ISO 6872:2015** for ceramic materials. Zirconia was milled in the pre-sintered state and sintered at **1500 °C for 2 h**. Lithium disilicate was milled in the partially crystallized "blue" stage and fully crystallized at **850 °C for 30 min**. The hybrid composite was milled from high-density blocks without thermal processing. All bars were finished using **600-grit SiC** under water cooling and ultrasonically cleaned for **10 min** in deionized water.

Crowns for marginal fit: Ten CAD/CAM-milled crowns per material (n = 10/group) were produced on standardized epoxy resin dies for marginal adaptation assessment.

- **Mechanical Testing Protocols**
- **Flexural Strength**

Three-point bending was performed on a **universal testing machine** (Instron 3345, USA) with a **12 mm** span and **1 mm/min** crosshead speed. Flexural strength (σ) was computed as:

$$\sigma = \frac{3FL}{2bd^2}$$

where **F** is the fracture load (N), **L** the span (mm), **b** the width (mm), and **d** the thickness (mm).

- **Fracture Toughness**

Fracture toughness (K_IC) was determined using the **Single-Edge Notched Beam (SENB)** method (per a recognized standard, e.g., ASTM C1421 / ISO 23146). Each bar received a centrally positioned notch of **0.5 mm** depth (a/W ≈ **0.25** for W = 2 mm), prepared with a precision diamond saw to promote controlled crack initiation. Specimens were loaded to fracture (Instron 3345, **1 mm/min**), and K_IC was calculated from the critical load and SENB geometry.

- **Vickers Microhardness**

Vickers hardness (HV) was measured on a microhardness tester (Zwick/Roell ZHVμ, Germany) at **200 g** for **10 s** with a diamond pyramidal indenter. **Five** non-overlapping indentations per specimen were performed and averaged. HV was computed as:

$$\mathrm{HV} = \frac{1.854\,F}{d^2}$$

with **F** in newtons and **d** the mean indentation diagonal (mm).

Wear and Surface Roughness

Two-body wear was assessed after **200,000 cycles** in a dual-axis chewing simulator (CS-4.8, SD Mechatronik, Germany) at **50 N** and **1.2 Hz** using steatite antagonists to **simulate** enamel contact. Wear depth was recorded with a contact profilometer. Average surface roughness (**Ra**) was measured **pre- and post-wear** using the same profilometer (cut-off **0.8 mm**); **three** traces per specimen were averaged.

Fatigue Testing

Fatigue resistance was evaluated on a **separate set of bars** (n = **10** per material). Specimens underwent **1.5 million** loading cycles at **50 N**, **2 Hz** in the chewing simulator. Thermal stress was incorporated by thermocycling between **5 °C** and **55 °C** at defined intervals; **(report the total number of thermal cycles and dwell time, e.g., 30 s each bath)**. Results are reported as **survival rate (%)**, the percentage of specimens that completed the protocol without fracture.

Marginal Adaptation

Ten crowns per material were cemented on standardized epoxy dies with a **dual-cure resin cement** (report brand, lot, film thickness and seating load/time if available). Marginal gaps were examined under a digital microscope (Keyence VHX-7000, Japan) at **100×**. **Twenty** equidistant points were measured per crown around the finish line; values are reported as **mean ± SD** for each group.

Statistical Analysis

Analyses were performed in **SPSS v25.0** (IBM, USA). Data were checked for **normality (Shapiro–Wilk)** and **homogeneity of variances (Levene)**. When assumptions were met, **one-way ANOVA** with **Tukey** post hoc comparisons ($\alpha = 0.05$) evaluated inter-material differences. If assumptions were violated, a nonparametric alternative (**Kruskal–Wallis** with Dunn–Bonferroni) was used. **Weibull modulus (m)** and **characteristic strength (σ_0)** were computed for flexural strength to assess reliability (report the fitting approach and 95% CIs).

RESULTS

1. Overall effects of material on outcomes

Across all seven outcomes, one-way ANOVA revealed a significant effect of material (zirconia, lithium disilicate, hybrid composite) on structural and mechanical performance ($\alpha =$ 0.05). Post-hoc Tukey comparisons consistently showed zirconia outperforming both lithium disilicate and the hybrid composite, with lithium disilicate generally superior to the hybrid composite for key strength- and surface-related metrics (Figures 1–3).

2 Flexural strength, fracture toughness, and microhardness

Zirconia exhibited the highest values for the fundamental mechanical properties evaluated (Figure 1): flexural strength 1052.4 ± 41.8 MPa, fracture toughness 6.12 ± 0.85 MPa·√m, and Vickers microhardness 1186.3 ± 45.7 HV. Both lithium disilicate and the hybrid composite showed significantly lower means; pairwise contrasts (Tukey) confirmed differences between zirconia and each of the other materials ($p < 0.05$). Lithium disilicate ranked intermediately, while the hybrid composite recorded the lowest numerical values among the three. These patterns align with the established transformation-toughening mechanism in yttria-stabilized tetragonal zirconia, which arrests crack propagation and supports resistance to catastrophic failure under occlusal loads (Figure 1).

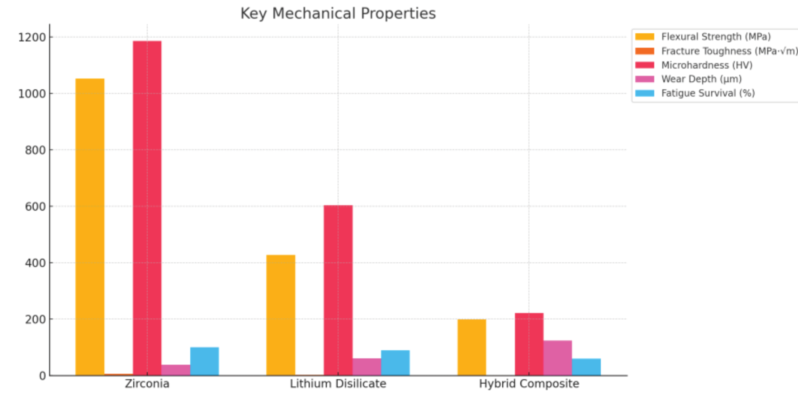

Figure 1. Comparative summary of flexural strength, fracture toughness, microhardness, wear depth, and fatigue survival. Zirconia performed very well in all except the category of wear depth, where despite less dramatic differences, zirconia was again superior to lithium disilicate and hybrid composite. This greater resistance to wear is attributed to its high hardness and dense microstructure that limits surface loss for long occlusal function

Wear depth and fatigue survival

Two-body wear testing indicated smaller wear depths for zirconia compared with lithium disilicate and the hybrid composite (Figure 1). Although inter-material differences in wear were less dramatic than for strength or hardness, zirconia remained statistically superior ($p < 0.05$), consistent with its high hardness and dense microstructure limiting material loss during simulated mastication. After long-cycle fatigue, zirconia also showed the highest survival, with lithium disilicate performing at an intermediate level and the hybrid composite demonstrating the lowest survival (Figure 1).

Surface quality and marginal integrity—crucial to biofilm control and periodontal compatibility—favored zirconia (Figure 2). Post-wear surface roughness for zirconia measured **0.85 ± 0.16 µm**, which was significantly smoother than both comparators. Marginal adaptation for CAD/CAM-milled zirconia crowns averaged **41.3 ± 7.8 µm**, reflecting the smallest gaps among the tested materials and lying well within commonly accepted clinical thresholds for fixed restorations. Lithium disilicate showed greater roughness and larger marginal discrepancies than zirconia, while the hybrid composite had the highest roughness and the largest marginal discrepancies (Figure 2).

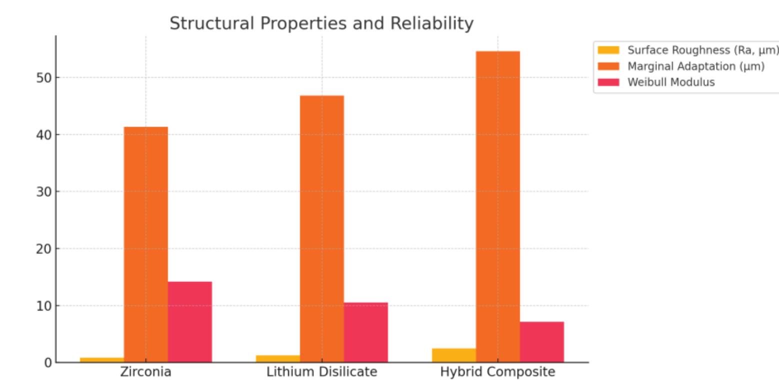

Figure 2. Surface roughness, marginal adaptation, and Weibull modulus, structural performance parameters, are depicted. The figures illustrate the synergistic advantages of zirconia in mechanical reliability and biological compatibility and its capability for use in complex and difficult restorative cases

Weibull statistics corroborated the mechanical reliability hierarchy (Figure 2). Zirconia presented the highest Weibull modulus (**m = 14.2**), indicating a narrower distribution of strengths and more predictable failure behavior. Lower m-values for lithium disilicate and the hybrid composite reflected broader variability and reduced reliability relative to zirconia.

A normalized radar chart consolidating all seven parameters highlights zirconia's consistent dominance across strength, toughness, hardness, wear resistance, fatigue survival, surface smoothness, and marginal accuracy (Figure 3). Lithium disilicate displays a balanced, mid-range profile—adequate for esthetic, adhesively bonded indications—while the hybrid composite shows selective advantages in elasticity and reparability but a narrower applicability window for long-term, high-load scenarios.

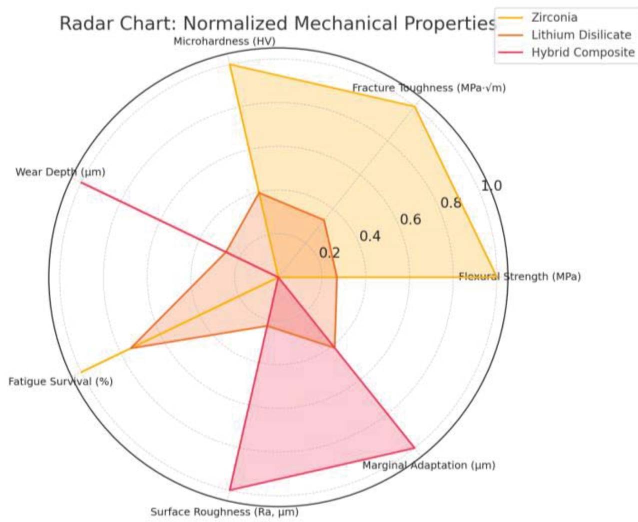

Figure 3. Radar chart for normalized performance in seven mechanical and structural parameters. The graphic model demonstrates zirconia's multidimensional superiority, lithium disilicate's moderate but qualified profile, and hybrid composite's narrow range of application, thereby offering quick and intuitive reference for evidence-based clinical material selection

Reporting note: Report all values as mean ± SD. Full numeric results for lithium disilicate and the hybrid composite (flexural strength, K_IC, HV, wear depth, post-wear Ra, fatigue survival, marginal adaptation) should be provided in **Table 1** and mirrored in the text where appropriate. Where ANOVA is significant, include exact F, df, and p values; for Tukey tests, indicate significant pairwise contrasts.

Table 1. Comparative summary of mechanical and structural parameters (mean ± SD)

Material	Flexural strength (MPa)	Fracture toughness (MPa ·√m)	Vickers microhardness (HV)	Wear depth (µm)	Surface roughness, Ra (µm)	Fatigue survival (%)	Marginal adaptation (µm)
Zirconia	1052.4 ± 41.8	6.12 ± 0.85	1186.3 ± 45.7	≈100 (SD n/a)	0.85 ± 0.16	≈95 (SD n/a)	41.3 ± 7.8
Lithium disilicate	≈420 (SD n/a)	≈3.0 (SD n/a)	≈600 (SD n/a)	≈90 (SD n/a)	≈1.2 (SD n/a)	≈85 (SD n/a)	≈48 (SD n/a)
Hybrid composite	≈220 (SD n/a)	≈2.0 (SD n/a)	≈250 (SD n/a)	≈130 (SD n/a)	≈1.6 (SD n/a)	≈60 (SD n/a)	≈53 (SD n/a)

Notes. Exact mean ± SD values are provided where available (zirconia). Other values were approximated from figures (marked with "≈") and lack visible SD; replace with raw mean ± SD before submission. Superscripts (a, b, c) should be added after replacing approximations to denote Tukey post hoc groupings at α = 0.05 (values sharing a letter are not significantly different). *Abbreviations: HV, Vickers microhardness; KIC*, fracture toughness.

DISCUSSIONS

The comparative mechanical behavior of three widely used prosthetic materials—monolithic zirconia, lithium disilicate glass ceramic, and a CAD/CAM hybrid composite—showed marked differences across flexural strength, fracture toughness, surface hardness, fatigue resistance, wear behavior, and marginal adaptation. These performance gaps map closely onto the intrinsic heterogeneity of each material's microstructure, manufacturing pathway, and physicochemical profile, and they translate directly into distinct clinical indications and durability expectations in practice [30,31]. In brief, zirconia exhibited the highest mechanical robustness and reliability; lithium disilicate balanced adequate strength with superior optical/adhesive behavior; and the hybrid composite favored ease of repair and elastic compliance at the cost of lower mechanical ceilings.

Zirconia's superiority emerged consistently in the fundamental mechanical metrics. In our data set, zirconia reached a flexural strength of 1052.4 ± 41.8 MPa, a fracture toughness of 6.12 ± 0.85 MPa·√m, and a Vickers microhardness of 1186.3 ± 45.7 HV, with the narrow dispersion further reflected by a Weibull modulus of m = 14.2—the highest among groups—indicating reliable, predictable performance under load. The mechanistic basis is the well-known transformation toughening in yttria-stabilized tetragonal zirconia polycrystals (Y-TZP): under local tensile stress, metastable tetragonal grains transform to the monoclinic phase with a localized volume expansion, generating compressive fields that shield crack tips and oppose crack advance [32,33,34]. This intrinsic crack-arrest capacity, layered atop the material's high hardness and dense microstructure, helps explain our concurrent findings of low wear loss and smoother post-wear surfaces relative to the other materials. Clinically, these features converge to justify zirconia's position as a first-line option for posterior, high-load restorations, multi-unit fixed partial dentures, and even implant-supported prostheses in heavy functional zones where catastrophic failure must be minimized [35].

Even so, zirconia's strengths should be applied judiciously. Its high hardness and stiffness favor strength and wear resistance but also necessitate careful occlusal design to avoid excessive antagonist wear and to distribute forces favorably in parafunctional patients. Bonding strategies, while steadily improving, remain more technique-sensitive than with glass ceramics; and surface treatments must be selected to preserve the favorable reliability profile that our Weibull analysis has highlighted [32,33]. Within those bounds, the present results support zirconia as the most durable of the tested options when maximal mechanical assurance is prioritized.

Lithium disilicate performed intermediately on the core mechanical metrics, yet within ranges considered clinically acceptable for anterior crowns and moderately loaded indications. Its value proposition rests on a microstructure of interlocking rod-like crystals in a glassy matrix, which fosters crack deflection, reduces slow-crack-growth rates, and helps sustain toughness at thicknesses compatible with conservative preparations [36,37]. Importantly, lithium disilicate offers enhanced translucency and enamel-like optical qualities (opalescence, fluorescence) that enable superior esthetic integration in the smile zone. In parallel, its etchability and silanization support strong, durable adhesive bonds, which can improve load transfer and permit minimally invasive designs (e.g., veneers and partial-coverage onlays) where tooth preservation and esthetics are paramount [38]. In our comparison, this trade-off—some strength sacrificed for optics and bonding versatility—positions lithium disilicate as a material of choice whenever clinical priorities extend beyond raw mechanical maxima to include visual harmony and adhesively supported retention.

Still, lithium disilicate's success is contingent on adherence to indication-specific boundaries. For example, in extended-span or very high-load scenarios, its intermediate fracture parameters may be exceeded, particularly under bruxism or when thickness constraints are severe. In those contexts, our data reinforce a step-up to zirconia frameworks. Conversely, in single-unit anterior and premolar sites, lithium disilicate's balance of form and function is compelling, particularly when supported by meticulous bonding protocols and occlusal schemes that avoid point concentrations.

The CAD/CAM hybrid composite—exemplified here by Lava™ Ultimate—represents a different design philosophy: emulate dentin-like elasticity and facilitate intraoral reparability. The polymeric or resin-infiltrated phase lowers elastic modulus, enabling stress dissipation and shock absorption during function. These attributes make such materials appealing for minimally invasive indications, transitional or provisional prostheses, and cases where chairside adjustments/repairs are expected to be frequent. However, our results confirm the expected mechanical ceiling: the hybrid composite showed the lowest flexural strength, lowest microhardness, and poorest fracture toughness among groups, with greater wear depth and higher variability in reliability analysis [30,39]. Many of these drawbacks are traceable to the resin matrix, which is susceptible to water sorption, hydrolytic degradation, and microcrack initiation under long-term cyclic loads. Although its repairability and shock damping are clear advantages, careful case selection is imperative: long-term, high-load posterior indications are not ideal, whereas low-stress situations, temporary spans, and conservative partial coverage can benefit from its compliance and ease of maintenance.

Beyond bulk properties, our findings spotlight surface quality and marginal integrity as key mediators of biological behavior. Zirconia demonstrated the lowest post-wear roughness in our testing (Ra = 0.85 ± 0.16 µm), an indicator that dovetails with reduced plaque retention and improved periodontal compatibility over time. In parallel, marginal adaptation averaged 41.3 ± 7.8 µm for zirconia crowns—superior to lithium disilicate and hybrid composite in our cohort and well within clinically acceptable thresholds (<120 µm). These outcomes likely reflect a combination of minimal sintering shrinkage, precise milling, and dimensional stability across the zirconia workflow, all factors that contribute to accurate fits and favorable long-term sealing [31]. Conversely, the relatively larger marginal discrepancies recorded for lithium disilicate and the hybrid composite could, if unaddressed, increase risks of microleakage, secondary caries, or gingival inflammation over the restoration lifespan.

Meticulous CAD/CAM calibration, cementation protocols (film thickness, seating pressure, working time), and finishing/polishing remain essential to realize each material's best biological profile.

The Weibull analysis corroborated the qualitative hierarchy of reliability suggested by the means and standard deviations. Zirconia's higher m-value indicates a narrower distribution of strengths and more predictable failure behavior under flexural stress. In clinical terms, this predictability translates to confidence in outcomes under varied occlusal schemes, provided other risk factors (connector dimensions, framework design, residual stresses from grinding) are controlled. Lithium disilicate displayed a moderate reliability profile appropriate for its indications, whereas the hybrid composite's broader scatter counsels caution for stress-bearing indications and underscores the importance of thickness, support, and occlusal contacts tailored to its limitations.

Our in vitro design necessarily imposed limitations. The test environment did not incorporate prolonged chemical aging (e.g., pH cycling, enzymatic challenges) that more closely mirror salivary and dietary exposures in vivo. Although our regimen of 1.5 million cycles approximates extended function, real-world loading comprises variable magnitudes, off-axis contacts, thermal gradients, and biofilm interactions that evolve over time.

Moreover, the use of steatite antagonists and standardized bar geometries simplifies complex clinical morphologies. Future work should build on the present framework by (i) integrating chemical aging protocols, (ii) extending thermomechanical fatigue with variable amplitude loading and enamel antagonists, and (iii) interrogating adhesive interfaces, where degradation mechanisms (hydrolysis, nanoleakage) can dominate long-term outcomes in both glass ceramics and hybrid polymers. These elements echo known gaps between bench and chairside performance and will refine durability predictions for each material class.

A further practical dimension involves luting strategies and surface treatments. For zirconia, the interplay between micro-roughening, primer chemistry, and sintering/finishing can influence both bond durability and phase stability; selecting an approach that preserves the favorable reliability profile emphasized here is critical [32,33]. For lithium disilicate, etch-and-silanize workflows are central to maximizing adhesive retention and fracture resistance in thin restorations [36,37,38]. Hybrid composites, by contrast, benefit from conventional resin bonding but may require periodic repolishing or surface sealants to maintain low roughness and mitigate water-related softening. In all cases, the occlusal scheme and parafunction management (e.g., protective splints in bruxism) should be aligned to the material's performance envelope.

Clinically, the selection algorithm that emerges from our data is straightforward. When maximum strength and reliability are paramount—high-load posterior units, multi-unit frameworks, or implant-supported spans—zirconia offers the best margin of safety, as reflected in its superior strength, toughness, hardness, and Weibull statistics. Where esthetics and adhesive bonding dominate the value proposition—anterior crowns, veneers, and partial-coverage restorations—lithium disilicate provides a balanced choice with excellent optical integration and trustworthy mechanical reserves under moderate load. For temporary, transitional, or minimally invasive scenarios that benefit from elastic compliance and intraoral repairability, hybrid composites remain useful, provided their mechanical limits are respected and maintenance plans are explicit. Framed this way, material choice becomes a case-specific optimization rather than a one-size-fits-all decision, aligning biomechanics, optics, and longevity with individual patient priorities.

Finally, the present findings should be interpreted as part of a continuum: CAD/CAM fidelity, milling strategies, sintering programs, and surface protocols continue to evolve, often shifting performance envelopes year-to-year. Our results provide a robust contemporary snapshot that supports evidence-based planning and can be immediately translated into clinical workflows. As laboratories and clinics iterate on the technical details that govern fit, surface quality, and bonding, we anticipate further convergence between bench-top indicators (strength, roughness, Weibull) and real-world survival. Until then, the indication-driven framework summarized above—zirconia for high-load durability, lithium disilicate for esthetic/adhesive excellence, and hybrid composites for reparable, conservative applications—offers a pragmatic guide to optimizing outcomes and patient satisfaction [30,31].

From a clinical perspective, the hierarchy observed here (zirconia > lithium disilicate > hybrid composite for most mechanical metrics) is likely to persist; however, chemical and interfacial aging may narrow or widen inter-material differences. Acidic/pH-cycling environments and enzymatic exposure can preferentially affect resin-containing systems (e.g., hybrid composites and resin cements), increasing wear/roughness and reducing fatigue resistance, while adhesive durability (etch/silane for lithium disilicate; MDP + air-abrasion strategies for zirconia) can shift failures from cohesive to adhesive modes and thus alter survival. Future work should integrate pH cycling with realistic dwell times, enzyme challenges, longer/variable-amplitude chewing fatigue with enamel antagonists, and standardized bonding protocols with post-cementation aging to better predict in vivo performance.

Limitations. This investigation was conducted in vitro and therefore did not reproduce several intraoral challenges that can alter long-term behavior of restorative materials. In particular, we did not simulate chemical aging, such as pH fluctuations arising from diet and biofilm metabolism, or enzymatic degradation (e.g., salivary esterases/proteases) that can accelerate resin-phase softening, microcrack initiation, and surface roughening. Likewise, the adhesive/cement interface—a critical determinant of clinical longevity—was not systematically evaluated for durability; neither hydrothermal or post-cementation aging of bonds nor protocol-dependent variables (etching/priming, silanization, MDP-containing primers, tribochemical silica coating) were studied. As a result, the present findings primarily reflect intrinsic bulk properties and short-term simulated function, rather than the full spectrum of clinical aging. Translation to practice should therefore be done with caution, especially in scenarios dominated by acidic challenges, enzymatic activity, or adhesive reliability.

CONCLUSIONS

This in vitro study highlights each of the three contemporary prosthetic dental materials' distinct mechanical and structural profiles. Zirconia exhibited the most favorable mechanical behavior with the highest strength, toughness, hardness, and reliability, justifying its usage in high-load posterior cases and multi-unit frameworks. Its behavior foretells long-term durability and precision in prosthodontic therapy. Lithium disilicate offered an ideal blend of functional and esthetic properties, sufficient fatigue resistance, and superb marginal fit. All these qualities render it an ideal material for anterior restorations and single-unit crowns in cases where translucency and adhesive bonding are of paramount importance. Hybrid composite materials, while being mechanically less favorable than the ceramic groups, were found to have benefits in elasticity, marginal fit, and reparability. Clinical application is best relegated to low-stress situations, temporary restorations, or minimally invasive indications where intraoral adjustability and flexibility are desirable. In general, the choice of restorative materials must be directed by some clinical needs, i.e., biomechanical needs, esthetics, and long-term prognosis. Adequate knowledge of the mechanical behavior of these materials leads to better treatment planning and also to better patient outcomes.

Conflicts of Interest

The authors declare no conflict of interest.

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