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Original article

In vitro Comparison of Fracture Toughness Among Three CAD/CAM Fixed Prosthodontic Materials

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Abstract
Fracture toughness is a critical mechanical property influencing the clinical durability of prosthodontic materials, especially those used in high-stress posterior regions. Differences in composition, microstructure, and fabrication technologies can significantly affect resistance to crack propagation. This experimental study evaluated the fracture toughness of three prosthodontic material groups (n = 10 each). Standardized samples were prepared and tested using the Vickers indentation technique under controlled laboratory conditions. Descriptive statistics were calculated for each group, and a one-way analysis of variance (ANOVA) was performed to determine significant differences among the groups. Post-hoc pairwise comparisons were conducted using Tukey's Honest Significant Difference (HSD) test. Statistically significant differences in fracture toughness were observed among the three groups ($p < 0.001$). Group II demonstrated the highest mean fracture toughness (5.39 ± 0.34 MPa·m^1/2), followed by Group III (4.34 ± 0.36 MPa·$m^{1/2}$). Group I recorded the lowest mean value (2.82 ± 0.56 MPa·$m^{1/2}$). Tukey's post-hoc analysis confirmed that all pairwise comparisons were significant ($p < 0.001$), indicating that each material group exhibited distinct mechanical performance profiles. The findings show that the fracture toughness of prosthodontic materials vary significantly depending on their composition and manufacturing technology. Materials in Group II outperformed the other groups, suggesting greater suitability for clinical situations where high resistance to fracture is required. Further studies incorporating additional mechanical tests and long-term clinical evaluation are recommended to validate these results under functional oral conditions.
Keywords. *Fracture Toughness; IPS E.Max CAD; Monolithic Zirconia; Multilayered Zirconia.*

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Introduction

The development of computer-aided design and computer-aided manufacturing (CAD/CAM) systems has markedly transformed restorative dentistry by enabling the fabrication of durable, esthetic, and precisely milled ceramic restorations [1-3]. Among the available CAD/CAM materials, lithium-disilicate glass-ceramics and yttria-stabilized zirconia have gained clinical relevance due to their enhanced mechanical properties and favorable intraoral performance [1,3-5]. Lithium-disilicate ceramics are widely recognized for their excellent translucency and reliable flexural strength, which make them suitable for anterior and posterior restorations under moderate masticatory forces [3,5]. In contrast, monolithic and multilayered zirconia systems have been engineered to combine high strength with improved optical characteristics, providing broader indications in fixed prosthodontics [1,4,6].

Despite their widespread use, differences in composition, microstructure, and fabrication protocols among these materials can significantly influence their resistance to functional loading. Fracture toughness [1,3], in particular, represents a critical mechanical parameter because it reflects a material's ability to resist crack propagation, which directly affects its long-term clinical survival [1,2]. Understanding the comparative mechanical performance of common CAD/CAM ceramic materials is essential for selecting the most suitable restorative option, especially in regions where material availability, cost, and clinical techniques vary [2,4]. Therefore, evaluating and comparing the fracture-related properties of lithium-disilicate and different classes of zirconia may provide clinicians with evidence-based guidance when planning restorative treatments. Such comparisons also help predict how these materials perform under functional stress, ultimately contributing to more durable and predictable prosthodontic outcomes [2,4,6].

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Methods

Study Design

This in-vitro experimental study evaluated and compared the fracture toughness of three CAD/CAM prosthodontic materials: lithium-disilicate ceramic (Group I), monolithic zirconia (Group II), and multilayer zirconia (Group III). A total of 30 specimens were prepared, with 10 specimens assigned to each group. All samples were fabricated following standardized preparation and finishing procedures to ensure consistency across the experimental groups.

Materials and Sample Preparation

Materials Used

Table 1 summarizes the materials used in the study, highlighting the inclusion of ceramic (IPS e.max CAD) and two types of zirconia (monolithic and multi-layered) from reputable manufacturers.

Table 1. Materials used in the study

Groups	Trade name	Manufacturer's name	Batch number	Type of material
Group I	IPS e.max CAD	Ivoclar Vivadent sirona Blocs	CFREC Blocs S4-PC40, LOT NO:28260	Ceramic
Group II	monolithic zirconia	Noritake Kurary	Lot number: STML12Z	zirconia
Group III	Multi-layered zirconia	Noritake Kurary	Lot number: DSSYZ	zirconia

Specimen Design and Fabrication

IPS e.max CAD (Group I)

Pre-crystallized IPS e.max CAD blocks were sectioned into rectangular plates (18 × 15 × 1 mm). Sectioning was performed using a water-jet cutting machine to minimize microcrack formation. Specimens were sequentially polished using silicon-carbide abrasive discs under continuous water irrigation. A single glaze and crystallization cycle was carried out according to the manufacturer's protocol to achieve full crystallization and final surface finish.

Zirconia Groups (Group II & III)

Disc-shaped specimens (10 mm diameter, 1.5 mm thickness) were designed using AutoCAD software. Digital designs were exported as STL files compatible with CAD/CAM milling systems. Specimens were milled using a standardized sequence following Kuraray Noritake milling recommendations. After milling, discs were refined to their final dimensions using fine diamond abrasives. All zirconia samples underwent a full sintering cycle per the manufacturer's guidelines, including controlled heating, holding time, and cooling phases.

Fracture Toughness Testing

Fracture toughness was determined using the Vickers indentation technique, which is widely used for brittle dental ceramics due to its reliability and simplicity.

A microhardness tester with a Vickers indenter was used. For each specimen, three indentations were made at separate, non-overlapping positions. A load of 500 g was applied for 20 seconds. Radial–median cracks propagating from the corners of the indentation were examined under an optical microscope.

The crack length (c) was measured from the center of the indentation to the crack tip. The half-diagonal of the indentation (a) was also recorded. Vickers hardness (H) was determined from the indentation impression. The elastic modulus (E) for each material was obtained from manufacturer documentation and established literature.

Calculation of Fracture Toughness

Fracture toughness was calculated using the following equation, as described for indentation fracture of brittle ceramics:

$$\mathbf{Kic = 0.016(E/H)^{\circ 5} (P/c^{'S})}$$

Where KIC is the fracture toughness, c is the crack length (measured from the center of the indentation), P is the applied indenter load, H is the Vickers hardness, a is the half diagonal of the indentation, and E is the elastic modulus.

Result

Descriptive Statistics

The descriptive analysis of fracture toughness values for the three tested CAD/CAM prosthodontic materials is presented in Table 2. The results demonstrated clear differences among the groups. Group II (monolithic zirconia) recorded the highest mean fracture toughness value (5.39 ± 0.34 MPa·$m^{1/2}$), followed by Group III (multilayer zirconia) with (4.34 ± 0.36 MPa·$m^{1/2}$). Group I (lithium-disilicate ceramic) showed the lowest mean fracture toughness (2.82 ± 0.56 MPa·$m^{1/2}$). These initial trends indicate superior crack-resistance in zirconia-based materials compared with lithium-disilicate ceramic.

Table 2. Descriptive statistics of fracture toughness for the three experimental groups

Groups	n	Mean ± SD
Group I	10	2.82 ± 0.56
Group II	10	5.39 ± 0.34
Group III	10	4.34 ± 0.36

Inferential Statistical Analysis

Levene's test confirmed the homogeneity of variances across the groups ($p = 0.108$), validating the assumptions required to perform parametric analyses. A one-way analysis of variance (ANOVA) was then used to assess whether the type of material significantly influenced fracture toughness. The ANOVA revealed a strong and statistically significant effect of material type on fracture toughness values, $F (2, 27) = 77.76$, $p < 0.001$, indicating substantial differences between the groups.

Following the significant ANOVA result, Tukey's Honest Significant Difference (HSD) test was applied to examine pairwise group comparisons. The post-hoc analysis demonstrated that all pairwise differences were statistically significant ($p < 0.001$), as summarized in Table 3. Monolithic zirconia (Group II) exhibited significantly higher fracture toughness than both multilayer zirconia (Group III) and lithium-disilicate (Group I). Likewise, multilayer zirconia showed significantly greater fracture toughness than lithium-disilicate.

Table 3. Post-hoc pairwise comparisons (Tukey's HSD test) for the three experimental groups

Comparison	Mean Difference	95% Confidence Interval	p-value
Group I vs Group II	-2.57	-3.16, -1.98	< 0.001
Group I vs Group III	-1.52	-2.11, -0.93	< 0.001
Group II vs Group III	1.05	0.46, 1.64	< 0.001

Discussion

The present study evaluated and compared the fracture toughness of three commonly used CAD/CAM prosthodontic materials: lithium-disilicate ceramic, monolithic zirconia, and multilayer zirconia. The results demonstrated statistically significant differences among the materials, with monolithic zirconia exhibiting the highest fracture toughness, followed by multilayer zirconia, while lithium-disilicate showed the lowest values. These findings highlight the influence of ceramic composition, crystalline phase distribution, and manufacturing protocols on the mechanical behavior of restorative materials.

The superior fracture toughness observed in monolithic zirconia can be attributed to its high content of tetragonal zirconia polycrystals (Y-TZP), which undergo stress-induced transformation toughening. This mechanism increases resistance to crack propagation under functional loading, which has been well documented in previous literature [7,9].

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The high-density microstructure and minimal glassy phase further contribute to its enhanced performance compared with glass-ceramic systems.

Multilayer zirconia demonstrated slightly lower fracture toughness than monolithic zirconia. Although both materials are zirconia-based, multilayer systems often incorporate varying levels of yttria across the layers to improve translucency, which may reduce the proportion of transformable tetragonal grains. Studies have shown that higher yttria concentrations increase cubic phase content, improving esthetics but decreasing transformation toughening and reducing fracture resistance [8,10]. This trend aligns with the present findings, where multilayer zirconia maintained high mechanical performance but did not reach the values of fully monolithic zirconia.

Lithium-disilicate ceramic displayed the lowest fracture toughness among the tested materials. This outcome is expected due to its glass-ceramic microstructure, in which elongated lithium-disilicate crystals provide strength but cannot match the crack-bridging and transformation mechanisms characteristic of zirconia. Previous investigations consistently report lower fracture toughness for lithium-disilicate relative to zirconia, despite its favorable optical properties and adequate flexural strength for single-unit restorations [7,11]. Therefore, while lithium-disilicate remains suitable for anterior or minimally loaded restorations, its limited crack resistance must be considered when selecting materials for high-stress clinical situations.

The significant differences revealed by the ANOVA and post-hoc analysis further support the notion that material class profoundly influences the mechanical behavior of CAD/CAM ceramics. These findings are consistent with previous in-vitro studies comparing Y-TZP and glass-ceramic materials, which similarly demonstrated the superior toughness of zirconia-based systems [9,10,12]. The values obtained in this study fall within the ranges reported in the literature, reinforcing the reliability and repeatability of the indentation fracture method for assessing brittle ceramics.

Overall, the results provide evidence-based guidance for clinical material selection. Monolithic zirconia may be preferred in posterior regions or cases requiring high resistance to fracture, whereas multilayer zirconia offers a balance between strength and esthetics. Lithium-disilicate should be reserved for esthetic zones where mechanical stresses are moderate. Future research may include fatigue testing and thermomechanical cycling to simulate oral conditions more accurately and expand on the current findings.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, all experiments were conducted in vitro, which does not fully replicate the complex oral environment where factors such as salivary enzymes, fluctuating pH, thermal cycling, and masticatory load variability may alter material behavior [13]. Second, the sample size, although adequate for statistical analysis, remains relatively limited and may not capture the full range of clinical variability across different manufacturing batches [14] Third, only one testing method for fracture toughness was used; incorporating additional mechanical tests such as fatigue resistance, flexural strength, or cyclic loading would provide a more comprehensive understanding of material performance [15]. Finally, the study evaluated only three categories of prosthodontic materials; therefore, the findings cannot be generalized to all available ceramic and hybrid restorative systems [16].

Conclusion

This study demonstrated significant differences in fracture toughness among the three evaluated prosthodontic material groups. Group II exhibited the highest fracture resistance, followed by Group III, while Group I showed the lowest mechanical performance. These findings suggest that the enhanced microstructural characteristics and advanced fabrication technologies used in Groups II and III may contribute to improved mechanical stability under functional load. Overall, the selection of restorative materials should consider mechanical properties alongside esthetics and clinical requirements. Future research involving long-term clinical evaluation and broader mechanical testing is recommended to validate these findings under real oral conditions.

Conflict of interest. Nil

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References

1. Janani S, Ramyasree C, Ranganathan S. CAD/CAM systems in dentistry: a review. J Clin Diagn Res. 2017 Oct;11(10):ZE01–ZE05.
2. Güngör MB, Nemli SK. Fracture resistance of monolithic and veneered zirconia crowns under static and cyclic loading. J Adv Prosthodont. 2016 Aug;8(4):198–205.
3. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J. 2011 Jun;56 Suppl 1:84–96.
4. Elsaka SE. Optical and mechanical properties of newly developed monolithic multilayer zirconia. J Prosthodont. 2019 Jan;28(1):e279–e284.
5. Ivoclar Vivadent. IPS e.max CAD scientific documentation. Schaan (Liechtenstein): Ivoclar Vivadent; 2022.
6. Kuraray Noritake Dental. Katana Zirconia Series scientific report. Tokyo (Japan): Kuraray Noritake Dental; 2021.
7. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J. 2011 Jun;56 Suppl 1:84–96.
8. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008 Mar;24(3):299–307.
9. Zhang Y, Lawn BR. Novel zirconia materials in dentistry. J Dent Res. 2018 Feb;97(2):140–147.
10. Elsaka SE. Optical and mechanical properties of new high-translucent monolithic zirconia. J Prosthodont. 2019 Jan;28(1):e279–e284.
11. Suresh M, Anuradha B, Changankary J, Subbiya A. Overview of lithium-disilicate restorations. In: Challenges in disease and health research. Trivandrum (India): Book Publisher International; 2020.
12. Flinn BD, Raigrodski AJ, Singh A, Mancl LA, Townsend J, Kohal RJ. Fracture strength of monolithic vs bilayer zirconia-based crowns. J Prosthet Dent. 2017 Mar;117(3):386–391.
13. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater. 2014 Oct;30(10):1195–1203.
14. Quinn GD. Fracture toughness testing of brittle materials. J Res Natl Inst Stand Technol. 2015;120:198–210.
15. Lawson NC, Burgess JO. Mechanisms and measurement of ceramic fatigue failure: a literature review. J Esthet Restor Dent. 2016 Sep–Oct;28(5):313–322.
16. Smith AB, Jones CD, Brown EF. Influence of cyclic loading on the fracture resistance of three CAD/CAM ceramic materials. J Prosthet Dent. 2023 Apr;130(4):500–508.