ORIGINAL ARTICLE e-ISSN: 2349-0659 p-ISSN; 2350-0964

An *In Vitro* Evaluation of the Fracture Resistance of Computer-Aided Design/Computer-Aided Manufacturing Materials for Fixed Partial Dentures

Ajay Pandey[1], Rachna Kaushik[1]*, Lily Tiwari[2]

Abstract

Background: The mechanical durability of computer-aided design and computer-aided manufacturing (CAD/CAM) restorative materials is essential for the long-term performance of fixed partial dentures (FPDs). Differences in material composition and microstructure may influence their resistance to fracture under occlusal loading. **Aim:** The aim of the study is to evaluate and compare the fracture resistance of three CAD/CAM restorative materials used for three-unit FPDs under standardized *in vitro* conditions. **Materials and Methods:** The proposed experimental study comprised 30 standardized three-unit FPDs divided equally into three groups ($n = 10$): Group I, lithium disilicate glass-ceramic; Group II, zirconia-reinforced glass-ceramic; and Group III, resin-based CAD/CAM material. The restorations were designed for cementation onto standardized epoxy resin dies using resin cement. Fracture resistance was assessed using a universal testing machine at a crosshead speed of 1 mm/min, with maximum fracture load expressed in Newtons (N). The illustrative dataset was analyzed using one-way analysis of variance (ANOVA), followed by Tukey's *post hoc* test. Statistical significance was set at $P < 0.05$. **Results:** In the simulated dataset, Group II exhibited the highest mean fracture resistance (1312.60 ± 83.93 N), followed by Group I (1111.80 ± 82.27 N) and Group III (921.10 ± 75.41 N). One-way ANOVA identified a statistically significant difference among the groups ($F = 58.966$; $P < 0.001$). Tukey's *post hoc* analysis showed statistically significant differences between all three material pairs ($P < 0.001$). **Conclusion:** The illustrative analysis showed the highest mean fracture resistance for zirconia-reinforced glass-ceramic, followed by lithium disilicate glass-ceramic and resin-based CAD/CAM material.

Keywords: Computer-aided design/Computer-aided manufacturing, Fixed partial dentures, Fracture resistance, *In vitro* study, Lithium disilicate, Resin-based CAD/CAM materials, Zirconia-reinforced glass-ceramic

Asian Pac. J. Health Sci., (2026); DOI: 10.21276/apjhs.2026.13.4.35

Introduction

The replacement of missing teeth with fixed partial dentures (FPDs) remains an important treatment option in restorative dentistry. FPDs help restore masticatory efficiency, speech, esthetics, and occlusal function while maintaining the continuity of the dental arch. The long-term performance of these restorations depends on several factors, including material properties, prosthesis design, abutment support, and the ability to withstand repeated occlusal forces. Metal-ceramic restorations have traditionally been used because of their established clinical performance and mechanical reliability. However, growing demand for metal-free and esthetically pleasing restorations has encouraged the use of all-ceramic systems. Pjetursson *et al*. reported differences in the survival and complication rates of metal-ceramic and all-ceramic fixed dental prostheses, with framework fracture remaining an important concern for certain ceramic materials.[1] More recently, Saravi *et al*. reported favorable clinical survival rates for computer-aided design and computer-aided manufacturing (CAD/CAM) all-ceramic fixed dental prostheses, although mechanical complications, particularly ceramic chipping, continued to affect treatment outcomes.[2]

The introduction of CAD/CAM technology has changed the fabrication of fixed dental restorations by allowing digital designing and computer-controlled manufacturing. Compared with conventional techniques, digital workflows offer opportunities for improved standardization, efficient production, and reproducible restoration designs. CAD/CAM systems also permit the use of industrially manufactured restorative blocks with controlled material composition and processing conditions.

[1]Department of Dentistry, Government Medical College and Hospital, Bettiah, Bihar, India.

[2]Smile Saver, Bettiah, Bihar, India.

Corresponding Author: Dr. Ajay Prakash Pandey, Department of Dentistry, Government Medical College and Hospital, Bettiah, West Champaran, Bihar, India. E-mail: drajayprakashpandey@gmail.com

How to cite this article: Pandey A, Kaushik R, Tiwari L. An *In Vitro* Evaluation of the Fracture Resistance of Computer-Aided Design/Computer-Aided Manufacturing Materials for Fixed Partial Dentures. Asian Pac. J. Health Sci., 2026;13(4):178-184.

Source of support: Nil.

Conflicts of interest: None.

Received: 07/08/2026 **Revised:** 14/10/2026 **Accepted:** 22/10/2026

A wide range of materials is currently available, including zirconia, lithium disilicate glass-ceramics, resin-based composites, and hybrid ceramic materials. Each material has distinct mechanical and optical properties, making material selection an important consideration in fixed prosthodontics. Marchesi *et al*. described the clinical applications of contemporary CAD/CAM restorative materials and noted that successful material selection requires an understanding of their composition, mechanical behavior, and clinical indications.[3]

Among CAD/CAM materials, zirconia has received considerable attention because of its high flexural strength, fracture toughness, and resistance to crack propagation. These characteristics make it a suitable material for restorations exposed to substantial functional loading. Monolithic zirconia restorations also reduce the need for veneering porcelain, thereby avoiding some

©2026 The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

complications associated with veneer chipping. Nevertheless, the mechanical behavior of zirconia varies according to its crystalline composition, yttria content, and manufacturing conditions. Zhang *et al*. investigated the relationship between fracture resistance and translucency in zirconia and lithium disilicate ceramics and found that improvements in optical properties may involve changes in mechanical performance and sensitivity to defects.[4] Consequently, material selection should consider both esthetic requirements and the functional demands placed on the restoration.

Lithium disilicate glass-ceramic is another commonly used CAD/CAM material, valued for its translucency, esthetic appearance, and adhesive bonding potential. Its crystalline microstructure provides better mechanical properties than many conventional glass-ceramics, allowing its use in selected indirect restorations. However, its fracture resistance may be lower than that of zirconia, particularly in multi-unit prostheses exposed to higher stresses. Choi *et al*. compared the fracture resistance of three-unit fixed dental prostheses fabricated from monolithic lithium disilicate, monolithic zirconia, and lithium disilicate pressed onto zirconia. Their findings showed significantly greater fracture resistance for monolithic zirconia than for monolithic lithium disilicate under the experimental conditions.[5] These results demonstrate the importance of material composition when evaluating the mechanical performance of FPDs.

Resin-based CAD/CAM composites and hybrid ceramic materials have also been introduced as alternatives to conventional ceramics. These materials combine inorganic fillers or ceramic structures with a polymer-based phase, producing mechanical behavior that differs from that of fully ceramic restorations. Their comparatively lower elastic modulus may influence stress distribution and fracture patterns under loading. Zimmermann *et al*. evaluated three-unit fixed dental prostheses fabricated using different CAD/CAM materials and manufacturing methods. They observed significant differences in fracture loads among the materials tested, with zirconia recording the highest mean fracture load in their investigation.[6] El Zhawi *et al*. also examined the fatigue fracture behavior of polymer-infiltrated ceramic network restorations and reported favorable resistance to cyclic loading in monolithic crowns.[7] However, findings from single crowns cannot be directly applied to multi-unit FPDs because differences in span length and connector geometry can substantially affect stress distribution.

Apart from material composition, the fracture resistance of FPDs is affected by prosthesis geometry, particularly the dimensions and configuration of the connectors joining the retainers and pontic. These regions are vulnerable to stress concentration during occlusal loading and may serve as sites of fracture initiation. Kim *et al*. investigated the influence of connector designs on three-unit monolithic prostheses fabricated from four CAD/CAM materials. Their study found that both material type and connector geometry significantly affected fracture strength, with connector height playing an important role.[8] Therefore, a meaningful comparison of restorative materials requires standardization of prosthesis dimensions, connector cross-sectional areas, and loading conditions.

The oral environment presents additional challenges because fixed dental prostheses experience repeated chewing forces, temperature fluctuations, moisture exposure, and variations in the direction of applied loads. Over time, these conditions may contribute to fatigue damage and the development or propagation of microscopic cracks. Laboratory investigations commonly employ thermocycling, cyclic mechanical loading, and universal testing machines to assess material behavior under controlled conditions. Al-Haj Husain *et al*. compared the mechanical stability of CAD/CAM zirconia and glass-ceramic materials before and after simulated aging. Their findings showed that aging affected the flexural strength of the tested materials differently, with zirconia maintaining comparatively greater mechanical stability.[9] Although laboratory testing cannot reproduce every aspect of clinical function, it allows controlled comparisons of material performance and helps identify possible mechanisms of mechanical failure.

Despite advances in CAD/CAM restorative materials, selecting an appropriate material for FPDs remains challenging because fracture resistance is influenced by material composition, prosthesis design, fabrication procedures, and experimental conditions. Results obtained from isolated material specimens or single crowns may not accurately represent the behavior of multi-unit restorations. Furthermore, differences in aging protocols, cementation methods, abutment characteristics, and loading arrangements make direct comparisons between published studies difficult. Standardized *in vitro* evaluation of FPDs can therefore provide useful evidence regarding their relative mechanical performance and characteristic failure patterns.

The present *in vitro* study aims to evaluate and compare the fracture resistance of selected CAD/CAM materials used for FPDs under standardized laboratory conditions**.** The investigation is intended to assess differences in fracture load and, where applicable, modes of failure among the tested materials. The findings may contribute to a better understanding of their mechanical behavior and assist clinicians in selecting suitable restorative materials, while recognizing that laboratory fracture resistance alone cannot establish long-term clinical success.

Materials and Methods

The present study is designed as a comparative *in vitro* experimental investigation to evaluate the fracture resistance of three commercially available categories of CAD/CAM restorative materials used for three-unit FPDs. The study has been proposed by the Department of Dentistry, Government Medical College and Hospital, Bettiah, West Champaran, Bihar, India.

The principal objective is to compare the maximum load required to produce fracture in standardized three-unit FPDs fabricated from different CAD/CAM materials. Material type will serve as the independent variable, whereas the fracture load, expressed in Newtons (N), will be the primary outcome variable.

All specimens will be evaluated under controlled laboratory conditions to permit comparison of their mechanical performance. Standardization of prosthesis design, supporting dies, cementation procedures, and mechanical testing conditions will be maintained to minimize potential sources of experimental variation.

Sample Size and Experimental Grouping

A total of 30 standardized three-unit FPD specimens will be included in the investigation. The specimens will be divided into three experimental groups according to the CAD/CAM restorative material, with 10 specimens allocated to each group ($n = 10$).
The proposed groups are as follows:

- Group I (n = 10): Three-unit FPDs fabricated from lithium disilicate glass-ceramic
- Group II (n = 10): Three-unit FPDs fabricated from zirconia-reinforced glass-ceramic
- Group III (n = 10): Three-unit FPDs fabricated from the resin-based CAD/CAM restorative material identified in the study synopsis. The precise material classification requires confirmation because the synopsis describes this group using the terms "resin bonded ceramic and resin composite."

Each completed three-unit FPD will constitute one independent experimental unit. The total sample size is based on the proposed study protocol. The sample size rationale and its adequacy for identifying clinically meaningful differences will require further statistical justification.

Preparation of Standardized Abutment Dies

Standardized epoxy resin dies replicating prepared abutment teeth will be used to support the FPDs during cementation and fracture resistance testing.

The dies will reproduce the geometry of prepared teeth intended to receive a three-unit fixed prosthesis. Consistent abutment preparation characteristics will be maintained across the experimental groups to reduce the influence of supporting geometry on fracture resistance.

The prepared abutment configuration and interabutment distance will remain consistent for all specimens. The dimensions of the abutments, preparation finish lines, axial convergence, and pontic space must be recorded in the final experimental protocol.

The use of standardized epoxy resin dies is intended to provide a reproducible supporting arrangement and reduce variation associated with natural tooth anatomy.

CAD/CAM Design and Fabrication of FPDs

Thirty-three-unit FPDs will be fabricated using CAD/CAM technology according to their respective material groups.

The restorations will be designed using a standardized digital prosthesis configuration. The external contours, retainer dimensions, pontic morphology, and connector geometry will be maintained as consistently as the selected materials and their manufacturing requirements permit.

Following digital design, the FPDs will be manufactured from the corresponding CAD/CAM restorative materials using the appropriate computer-aided manufacturing procedures.

Any material-specific post-processing procedures, such as crystallization, finishing, or polishing, will be carried out according to the validated requirements of the selected restorative system. These procedures must be described individually for each material in the final manuscript.

All specimens will be inspected before cementation to identify visible manufacturing defects, incomplete margins, or structural irregularities that could affect fracture resistance.

Cementation of FPDs

Following fabrication, each FPD will be positioned on its corresponding standardized epoxy resin abutment dies.

Resin cement will be used for the cementation of all restorations. Cement will be applied, and the FPDs will be seated on the prepared dies in a controlled manner to ensure consistent adaptation and support.

The resin cement will subsequently be polymerized. The cementation procedure will be completed using the manufacturer's recommended protocol for the selected luting material.

The cement formulation, surface treatment procedures, seating force, polymerization method, and duration of curing will be documented in the final manuscript.

Following cementation, the restorations will be inspected to confirm appropriate seating and the absence of visible defects before fracture resistance testing.

Evaluation of Fracture Resistance

Fracture resistance will be evaluated using a universal testing machine equipped with a suitable loading assembly.

Each cemented FPD specimen will be secured in the testing apparatus using its corresponding epoxy resin support. The specimens will be subjected to mechanical loading under standardized laboratory conditions.

The universal testing machine will operate at a constant crosshead speed of 1 mm/min, as specified in the study protocol.

Loading will continue until fracture or structural failure of the restoration occurs. The maximum load recorded at the point of failure will be considered the fracture resistance of the specimen.

Fracture load values will be recorded in Newtons (N) using the testing machine's data acquisition system.

To maintain comparability, the load application site, orientation of the loading assembly, and specimen-support arrangement must remain consistent across the experimental groups. These parameters, together with the loading-tip geometry, must be specified in the completed laboratory protocol.

Assessment of Fracture Load

The principal outcome of the study will be the maximum fracture load sustained by each three-unit FPD before structural failure.

For each specimen, the peak load obtained from the universal testing machine will be recorded in Newtons. Individual measurements will be grouped according to the restorative material.

The fracture resistance values will be used to determine differences in mechanical performance among the three CAD/CAM material groups.

Where fracture patterns have been systematically documented during testing, the location and characteristics of structural failure may be reported as supplementary outcomes. Such analysis will be included only if supported by recorded observations and an appropriate classification method.

Data Collection and Statistical Analysis

The fracture load recorded for each specimen will be entered into a structured database for statistical analysis.

The experimental data will be analyzed using IBM Statistical Package for the Social Sciences Statistics software (IBM Corp., Armonk, NY, USA; version to be specified).

Descriptive statistics will be calculated for the three material groups. Continuous fracture load data will be summarized using the mean and standard deviation, together with the minimum and maximum observed values.

Differences in mean fracture resistance among the three groups will be evaluated using one-way analysis of variance (ANOVA), provided the relevant statistical assumptions are satisfied.

Where the overall ANOVA indicates a statistically significant difference, Tukey's honestly significant difference (HSD) *post hoc* test will be used for pairwise comparisons between the material groups.

All statistical tests will be performed using a two-sided significance level of 0.05. A *P*-value below 0.05 will be considered statistically significant.

Research Oversight

The proposed study has been reviewed and endorsed by the Departmental Research Committee of the Department of Dentistry, Government Medical College and Hospital, Bettiah.

The departmental endorsement recommends the study for further institutional review and approval in accordance with applicable institutional requirements. The final manuscript will report the institutional ethics determination or approval details, as appropriate, after confirmation from the relevant committee.

Results

The illustrative dataset comprised 30 three-unit FPDs, distributed equally among three CAD/CAM restorative material groups. Group I included lithium disilicate glass-ceramic, Group II included zirconia-reinforced glass-ceramic, and Group III included a resin-based CAD/CAM material (Table 1). Each group contained 10 specimens (33.3%), providing equal sample sizes for the comparative analysis.

For this worked example, specimen fracture loads were assigned to demonstrate how the results of the universal testing machine could be analyzed. The illustrative values ranged from 796 N to 1,453 N across the three groups. Group II had the highest individual fracture load, whereas Group III had the lowest (Table 2).

Descriptive analysis of the simulated measurements showed differences in mean fracture resistance among the three CAD/CAM materials. Group II exhibited the highest mean fracture load (1,312.60 ± 83.93 N), followed by Group I (1,111.80 ± 82.27 N). Group III recorded the lowest mean fracture load (921.10 ± 75.41 N) (Table 3).

Group II also had the highest maximum fracture load (1,453 N), whereas the lowest minimum load was recorded in Group III (796 N). The standard deviations were relatively similar across groups, indicating broadly comparable absolute dispersion within the illustrative dataset.

The Shapiro–Wilk test was applied to assess the distribution of illustrative fracture-load values within each group. No statistically significant departure from normality was detected in Group I ($P = 0.976$), Group II ($P = 0.970$), or Group III ($P = 0.883$).

Levene's test based on group medians also yielded a non-significant result ($P = 0.977$), providing no evidence of unequal variances in the simulated dataset. These findings, together with inspection of the group distributions, supported the use of conventional one-way ANOVA for the illustrative comparison (Table 4).

One-way ANOVA identified a statistically significant difference in the simulated mean fracture loads among the three material groups ($F = 58.966$; $P < 0.001$) (Table 5).

The between-group sum of squares was 766,531.27, compared with a within-group sum of squares of 175,494.90. The calculated eta-squared effect size was 0.814, corresponding to approximately 81.4% of the variance in the simulated fracture-load dataset being associated with group membership.

Tukey's HSD *post hoc* test was used to identify the pairs of material groups responsible for the overall difference in the simulated ANOVA.

Group II had a significantly higher mean fracture load than Group I, with a mean difference of 200.80 N ($P < 0.001$). Group I had a significantly higher mean load than Group III, with a difference of 190.70 N ($P < 0.001$). The largest mean difference was between Group II and Group III (391.50 N; $P < 0.001$) (Table 6).

All pairwise differences are significant in the simulated dataset. Confidence intervals are simultaneous Tukey-adjusted 95% confidence intervals.

Discussion

The fracture resistance of CAD/CAM restorative materials is an important factor in determining their mechanical suitability for FPDs, particularly when restorations are exposed to substantial occlusal forces. In the illustrative analysis, significant differences in fracture resistance were observed among the three CAD/CAM material groups. Zirconia-reinforced glass-ceramic exhibited the highest mean fracture load (1312.60 ± 83.93 N), followed by lithium disilicate glass-ceramic (1111.80 ± 82.27 N) and the resin-based CAD/CAM material (921.10 ± 75.41 N). One-way ANOVA showed a statistically significant difference among the groups ($F = 58.966$, $P < 0.001$), and Tukey's *post hoc* comparisons identified significant differences between all three material pairs. The calculated eta-squared value of 0.814 represented a substantial proportion of explained variation within the simulated dataset. These differences provide a useful basis for examining how restorative material composition may influence the load-bearing behavior of multi-unit prostheses.

The higher fracture resistance assigned to the zirconia-reinforced glass-ceramic group may be considered in relation to the microstructural characteristics of zirconia-containing glass-ceramics. When the material is a zirconia-reinforced lithium silicate ceramic, its mechanical behavior is influenced by the crystalline phases, glass matrix, and manufacturing conditions. Elsaka and Elnaghy[10] compared the mechanical properties of zirconia-reinforced lithium silicate glass-ceramic (VITA Suprinity) and lithium disilicate glass-ceramic (IPS e.max CAD). They reported significantly higher fracture toughness and flexural strength for the zirconia-reinforced lithium silicate material. The investigators also observed differences in microstructure and Weibull strength characteristics. These findings provide a possible explanation for the higher fracture-load values assigned to the zirconia-reinforced group in the illustrative analysis. However, flexural strength measured using standardized test bars cannot be directly equated with the fracture resistance of a complete three-unit FPD.

Comparable findings were reported by Schwindling *et al*.,[11] who evaluated the fracture resistance of glazed, full-contour zirconia-reinforced lithium silicate, lithium disilicate, and feldspathic ceramic crowns. Before aging, the mean fracture loads of zirconia-reinforced lithium silicate and lithium disilicate crowns were 725 N and 701 N, respectively, without a statistically significant difference. Following thermomechanical aging, zirconia-reinforced lithium silicate crowns showed significantly greater fracture resistance than the other tested ceramics. The authors concluded that zirconia-reinforced lithium silicate

maintained favorable resistance to fracture after simulated aging. Although their investigation involved single anterior crowns rather than three-unit FPDs, the findings provide useful information regarding the response of different glass-ceramic microstructures to mechanical loading and aging.

Nevertheless, the available literature does not consistently establish superior fracture resistance for zirconia-reinforced lithium silicate compared with lithium disilicate. Kashkari *et al*.[12] investigated monolithic zirconia, lithium disilicate, and zirconia-reinforced lithium silicate CAD/CAM crowns following cyclic loading under wet conditions. They reported significantly different fracture loads among the materials, with zirconia exhibiting the highest values, followed by lithium disilicate and zirconia-reinforced lithium silicate. This contrasting result shows that the mechanical ranking of restorative materials may change according to the specific product, restoration geometry, processing technique, and loading conditions. Therefore, the higher simulated fracture resistance of Group II should not be interpreted as proof that every zirconia-reinforced glass-ceramic material is mechanically superior to lithium disilicate.

Lithium disilicate glass-ceramic occupied an intermediate position in the illustrative comparison, with a mean fracture load of 1111.80 ± 82.27 N. Its fracture resistance was lower than that of zirconia-reinforced glass-ceramic but higher than that of the resin-based material. Lithium disilicate ceramics contain an interlocking crystalline structure within a glassy matrix, which contributes to their mechanical properties while permitting favorable optical characteristics. Their performance in fixed prosthodontics has been examined in several laboratory investigations. Tinschert *et al*.[13] compared the fracture resistance of three-unit FPDs fabricated using lithium disilicate-, alumina-, and zirconia-based core ceramics. They reported significant differences among the ceramic systems, with the highest failure loads associated with the high-strength zirconia material and lower loads recorded for some glass-ceramic systems. These findings establish that material composition can strongly influence the load-bearing capacity of complete multi-unit restorations. However, zirconia-based polycrystalline ceramics should not be confused with zirconia-reinforced lithium silicate glass-ceramics, because the two material classes have different compositions and mechanical behavior.

Further evidence concerning material-dependent performance was provided by Beuer *et al*.,[14] who evaluated the load-bearing capacity of three-unit FPDs fabricated from glass-infiltrated alumina, glass-infiltrated alumina strengthened with zirconia, and yttria-stabilized polycrystalline zirconia. The polycrystalline zirconia group demonstrated significantly higher fracture loads than the other materials. Their investigation also included thermal and mechanical aging procedures, which did not significantly affect the fracture loads under the tested conditions. Although the materials used in that study differ from those described in the present protocol, the results support the importance of identifying the exact ceramic system rather than assuming that all zirconia-containing materials have equivalent mechanical performance.

The resin-based CAD/CAM material demonstrated the lowest mean fracture resistance in the illustrative dataset (921.10 ± 75.41 N). A potential explanation is the difference in the structure and mechanical behavior of resin-containing restorative materials compared with predominantly ceramic materials. Resin-based CAD/CAM restorations typically contain an organic polymer phase combined with inorganic fillers or ceramic components. Their

Table 1: Distribution of specimens according to CAD/CAM restorative material

Experimental group	*CAD/CAM material*	*Number (n)*	*Percentage*
Group I	Lithium disilicate glass-ceramic	10	33.3
Group II	Zirconia-reinforced glass-ceramic	10	33.3
Group III	Resin-based CAD/CAM material	10	33.3
Total		30	100.0

CAD/CAM: Computer-aided design/Computer-aided manufacturing

Table 2: Illustrative individual fracture resistance measurements of the three CAD/CAM material groups (N)

Specimen number	*Group I*	*Group II*	*Group III*
1	1,128	1,327	844
2	984	1,206	993
3	1,213	1,394	938
4	1,057	1,349	796
5	1,168	1,186	972
6	1,093	1,453	876
7	1,241	1,281	1,032
8	1,017	1,367	918
9	1,139	1,248	861
10	1,078	1,315	981

Table 3: Descriptive statistical analysis of fracture resistance in the three CAD/CAM material groups

Parameter	*Group I*	*Group II*	*Group III*
Sample size (*n*)	10	10	10
Mean fracture load (*n*)	1,111.80	1,312.60	921.10
Standard deviation (*n*)	82.27	83.93	75.41
Median (*n*)	1,110.50	1,321.00	928.00
Minimum (*n*)	984	1,186	796
Maximum (*n*)	1,241	1,453	1,032
95% CI lower limit (*n*)	1,052.9	1,252.6	867.2
95% CI upper limit (*n*)	1,170.7	1,372.6	975.0

CAD/CAM: Computer-aided design/Computer-aided manufacturing, CI: Confidence interval

Table 4: Tests of normality and homogeneity of variance for the simulated fracture resistance measurements

Statistical test	*Group*	*Test statistic*	*P-value*
Shapiro–Wilk	Group I	0.982	0.976
Shapiro–Wilk	Group II	0.981	0.970
Shapiro–Wilk	Group III	0.969	0.883
Levene's test	All three groups	0.023	0.977

Table 5: One-way ANOVA comparing fracture resistance among the three CAD/CAM restorative material groups

Source of variation	*Sum of squares*	*df*	*Mean square*	*F statistic*	*P-value*
Between groups	766,531.27	2	383,265.63	58.966	<0.001
Within groups	175,494.90	27	6,499.81	—	—
Total	942,026.17	29	—	—	—

ANOVA: Analysis of variance, CAD/CAM: Computer-aided design/Computer-aided manufacturing

Table 6: Tukey's *post hoc* pairwise comparison of fracture resistance among the three CAD/CAM material groups

Pairwise comparison	*Mean difference (n)*	*95% confidence interval (n)*	*Adjusted P-value*
Group I–Group II	−200.80	−290.20–−111.40	<0.001
Group I–Group III	190.70	101.30 to 280.10	<0.001
Group II–Group III	391.50	302.10 to 480.90	<0.001

mechanical performance depends on filler concentration, filler distribution, polymer composition, manufacturing procedures, and the quality of bonding between the material phases. Awada and Nathanson[15] evaluated the mechanical properties of several resin-ceramic CAD/CAM restorative materials and identified differences in flexural strength, flexural modulus, and resilience among the tested products. These findings show that resin-based CAD/CAM materials do not constitute a mechanically uniform category and should be evaluated individually.

Lawson *et al*.[16] further investigated the strength, elastic modulus, hardness, and wear behavior of CAD/CAM materials, including lithium disilicate, zirconia-reinforced lithium silicate, resin composites, and a polymer-infiltrated ceramic material. The study identified substantial variation in mechanical properties among the different restorative systems. These observations are relevant to the interpretation of the illustrative Group III findings. Materials containing a polymer phase may undergo greater elastic deformation than highly rigid ceramics, but lower elastic modulus does not necessarily imply inferior clinical performance. Deformation behavior, fracture toughness, fatigue resistance, wear properties, and adhesive bonding may influence restoration longevity in different ways. Consequently, the lower simulated fracture load of the resin-based group should not be used to exclude all resin-containing CAD/CAM materials from fixed prosthodontic applications without considering their individual properties and approved indications.

Apart from material composition, restoration geometry is an important determinant of fracture resistance. Three-unit FPDs contain connectors between the retainers and pontic, where tensile stresses may become concentrated during loading. Connector dimensions, particularly the occlusogingival height, may substantially influence the mechanical performance of ceramic restorations. Bataineh *et al*.[17] used finite element analysis to investigate the fatigue resistance of three-unit CAD/CAM ceramic FPDs fabricated from zirconia and lithium disilicate, including the influence of connector size. Their investigation demonstrated the importance of structural design when considering the mechanical performance of multi-unit restorations. These observations are relevant because differences in connector geometry may affect measured fracture loads independently of the material itself. Standardizing the dimensions of the experimental prostheses is therefore essential for obtaining meaningful comparisons.

The experimental method used to determine fracture resistance also requires careful consideration. In the proposed protocol, the FPDs are cemented onto standardized epoxy resin dies and loaded using a universal testing machine at a crosshead speed of 1 mm/min until fracture. This approach offers controlled testing conditions and permits comparison of maximum failure loads. Nevertheless, static loading until fracture does not reproduce the complex mechanical environment experienced during mastication. Kelly[18] discussed the limitations of conventional load-to-failure testing and recommended clinically relevant approaches that reproduce important fracture mechanisms observed in ceramic restorations. The load application site, support conditions, cementation system, and specimen geometry may all influence the measured fracture load and the manner in which failure occurs.

In the oral environment, fixed restorations are subjected to repeated mechanical loading in the presence of saliva, temperature changes, and variable occlusal contacts. These conditions may initiate microscopic damage that gradually progresses through fatigue-related crack propagation. Garoushi *et al*.[19] evaluated the fracture behavior of CAD/CAM ceramic crowns fabricated from lithium disilicate and zirconia-reinforced lithium silicate before and after cyclic fatigue aging. The authors reported a reduction in load-bearing capacity following aging and observed better mechanical performance for lithium disilicate than zirconia-reinforced lithium silicate after fatigue loading. Their findings demonstrate that the relative mechanical performance of restorative materials under repeated loading may differ from results obtained under a single static fracture test. Consequently, the illustrative differences in fracture resistance cannot be regarded as evidence of long-term clinical durability.

Several limitations must be considered when interpreting this experimental design. First, each group contains only ten specimens, which may limit the precision of the estimated mean fracture loads and reduce the ability to detect smaller differences. Second, epoxy resin dies provide a standardized supporting arrangement but do not fully reproduce the structural and biomechanical characteristics of natural teeth, the periodontal ligament, or surrounding tissues. Third, the available synopsis does not specify the exact commercial products, connector dimensions, loading-tip configuration, or detailed cementation procedures. These factors must be documented because they can influence fracture resistance. Fourth, cyclic fatigue loading and thermocycling cannot be assumed to have been performed unless they are confirmed in the laboratory records. Finally, no experimentally observed failure-mode classification or fractographic examination is available. Accordingly, the present analysis cannot establish where fractures originated or whether failure occurred through cohesive fracture, interfacial separation, or other mechanisms.

From a clinical perspective, selecting a CAD/CAM material for FPD fabrication requires consideration of several properties rather than fracture resistance alone. Mechanical strength must be assessed alongside translucency, esthetic requirements, restoration thickness, connector dimensions, bonding characteristics, antagonist wear, and manufacturer-supported clinical indications. A material capable of withstanding a higher single fracture load may not necessarily provide superior long-term performance under repetitive functional loading. Similarly, a lower fracture load does not automatically indicate clinical unsuitability when the material is intended for different restorative conditions or loading demands.

Overall, the illustrative comparison presents a statistically significant ranking of fracture resistance, with the zirconia-reinforced glass-ceramic group showing the highest mean load, followed by lithium disilicate glass-ceramic and the resin-based CAD/CAM group. The published literature confirms that substantial differences can occur among CAD/CAM restorative materials, although the direction and magnitude of these differences depend on their composition, fabrication procedures, restoration design, and testing conditions. Validation using the actual experimental measurements, together with clearly documented

material specifications and failure characteristics, is necessary before drawing definitive conclusions about the relative fracture resistance of the three tested materials.

Conclusion

The present *in vitro* study was designed to compare the fracture resistance of three CAD/CAM restorative materials used for three-unit FPDs. In the illustrative analysis, zirconia-reinforced glass-ceramic exhibited the highest mean fracture resistance (1312.60 ± 83.93 N), followed by lithium disilicate glass-ceramic (1111.80 ± 82.27 N) and resin-based CAD/CAM material (921.10 ± 75.41 N). Statistically significant differences were observed among the three groups ($P < 0.001$), with all pairwise comparisons showing significant differences. These findings are consistent with the possibility that differences in material composition and microstructure influence the mechanical behavior of CAD/CAM FPDs.

References

1. Pjetursson BE, Sailer I, Makarov NA, Zwahlen M, Thoma DS. All-ceramic or metal-ceramic tooth-supported fixed dental prostheses (FDPs)? A systematic review of the survival and complication rates. Part II: Multiple-unit FDPs. Dent Mater 2015;31:624-39.
2. Saravi B, Vollmer A, Hartmann M, Lang G, Kohal RJ, Boeker M, *et al*. Clinical performance of CAD/CAM all-ceramic tooth-supported fixed dental prostheses: A systematic review and meta-analysis. Materials (Basel) 2021;14:2672.
3. Marchesi G, Camurri Piloni A, Nicolin V, Turco G, Di Lenarda R. Chairside CAD/CAM materials: Current trends of clinical uses. Biology (Basel) 2021;10:1170.
4. Zhang F, Reveron H, Spies BC, Van Meerbeek B, Chevalier J. Trade-off between fracture resistance and translucency of zirconia and lithium-disilicate glass ceramics for monolithic restorations. Acta Biomater 2019;91:24-34.
5. Choi JW, Kim SY, Bae JH, Bae EB, Huh JB. *In vitro* study of the fracture resistance of monolithic lithium disilicate, monolithic zirconia, and lithium disilicate pressed on zirconia for three-unit fixed dental prostheses. J Adv Prosthodont 2017;9:244-51.
6. Zimmermann M, Ender A, Attin T, Mehl A. Fracture load of three-unit full-contour fixed dental prostheses fabricated with subtractive and additive CAD/CAM technology. Clin Oral Investig 2020;24:1035-42.
7. El Zhawi H, Kaizer MR, Chughtai A, Moraes RR, Zhang Y. Polymer infiltrated ceramic network structures for resistance to fatigue fracture and wear. Dent Mater 2016;32:1352-61.
8. Kim YJ, Ko KH, Park CJ, Cho LR, Huh YH. Connector design effects on the in vitro fracture resistance of 3-unit monolithic prostheses produced from 4 CAD-CAM materials. J Prosthet Dent 2022;128:1319.e1-10.
9. Al-Haj Husain N, Dürr T, Özcan M, Brägger U, Joda T. Mechanical stability of dental CAD-CAM restoration materials made of monolithic zirconia, lithium disilicate, and lithium disilicate-strengthened aluminosilicate glass-ceramic with and without fatigue conditions. J Prosthet Dent 2022;128:73-8.
10. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. Dent Mater 2016;32:908-14.
11. Schwindling FS, Rues S, Schmitter M. Fracture resistance of glazed, full-contour ZLS incisor crowns. J Prosthodont Res 2017;61:344-9.
12. Kashkari A, Yilmaz B, Brantley WA, Schricker SR, Johnston WM. Fracture analysis of monolithic CAD-CAM crowns. J EsthetRestor Dent 2019;31:346-52.
13. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: A laboratory study. Int J Prosthodont 2001;14:231-8.
14. Beuer F, Steff B, Naumann M, Sorensen JA. Load-bearing capacity of all-ceramic three-unit fixed partial dentures with different computer-aided design (CAD)/computer-aided manufacturing (CAM) fabricated framework materials. Eur J Oral Sci 2008;116:381-6.
15. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015;114:587-93.
16. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater 2016;32:e275-83.
17. Bataineh K, Al Janaideh M, Abu-Naba'a LA. Fatigue resistance of 3-unit CAD-CAM ceramic fixed partial dentures: An FEA study. J Prosthodont 2022;31:806-14.
18. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent 1999;81:652-61.
19. Garoushi S, Säilynoja E, Vallittu PK, Lassila L. Fracture-behavior of CAD/CAM ceramic crowns before and after cyclic fatigue aging. Int J Prosthodont 2023;36:649.