J Dent Mater Tech 2026; 15 (1): 41-48
DOI:

J Dent Mater Tech

Original Article Open Access

Edge chipping resistance of three hybrid ceramics compared to zirconia-reinforced lithium silicate

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Abstract

Objective: This study compared the edge chipping resistance of three hybrid ceramics, including two polymer-infiltrated ceramic networks (PICNs; VITA Enamic and Crystal Ultra), and one resin nanoceramic (Lava Ultimate), with a zirconia-reinforced lithium silicate (VITA Suprinity).

Methods: In this in vitro study, four restorative materials were prepared and tested (n=10 per group), as follows: 1: VITA Enamic, 2: Crystal Ultra, 3: Lava Ultimate, and 4: VITA Suprinity. Specimens were fabricated in dimensions of 10 × 10 × 2 mm, polished, and subjected to 5,000 thermocycles. Force was applied using a universal testing machine, with an indenter applied at distances of 0.1 to 0.8 mm from the specimen edge. Edge chipping resistance was calculated from the slope of the force-distance curves. Data were analyzed using ANOVA and Tukey's test, with significance set at $P<0.05$.

Results: The highest edge chipping resistance was observed in VITA Suprinity (201.03 N/mm), while Lava Ultimate exhibited the lowest (65.69 N/mm). A statistically significant difference was found in edge chipping resistance among the groups ($P=0.004$). Tukey's test revealed that the edge chipping resistance was significantly greater in VITA Suprinity than in all other groups ($P<0.05$). Additionally, VITA Enamic and Crystal Ultra showed significantly greater edge chipping resistance than Lava Ultimate ($P<0.05$).

Conclusions: Zirconia-reinforced lithium silicate showed superior edge chipping resistance among the tested materials, while resin nanoceramic showed the lowest. Hybrid ceramics, including resin nanoceramics and PICNs, should be used with caution in high-load areas, as their lower edge chipping resistance increases the risk of marginal failure.

Keywords: Ceramics, Computer-Aided Design, Dental restoration, Fracture strength, Hybrid ceramic, Zirconia

Introduction

The introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has evolved the dental field (1-3). A wide range of materials has been adapted for CAD/CAM fabrication, including acrylic resins, resin composites, ceramics, and, more recently, hybrid ceramics (4, 5). The increasing use of these materials has emphasized the importance of their mechanical and physical properties, such as strength, wear resistance, and machinability, which directly affect the clinical performance and longevity of dental restorations.

Ceramics offer favorable chemical stability, mechanical strength, optical properties, and biocompatibility. However, their brittle nature and potential to cause wear on opposing teeth are among their drawbacks (5, 6). Furthermore, direct repair of ceramic restorations after fracture is challenging (1).

To overcome the inherent brittleness and susceptibility to crack propagation of conventional glass-ceramics, modified materials such as zirconia-reinforced lithium silicate (ZLS) have been developed.

ZLS is a lithium silicate–based glass-ceramic that contains approximately 8–12 wt% zirconia particles. The addition of zirconia improves fracture resistance through a mechanism known as transformation toughening (7, 8). In this process, stress at the crack tip induces a phase transformation in zirconia particles, generating local compressive stresses. These compressive stresses oppose crack opening, slow crack propagation, and promote energy dissipation. In brittle glass-ceramics, such as lithium disilicate, failure typically occurs through catastrophic, uncontrolled crack propagation (6, 9). In contrast, ZLS exhibits higher

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Accepted: 11 February 2026. Submitted: 10 October 2025.

fracture toughness and improved resistance to crack growth, which is partly attributed to the transformation toughening effect of zirconia particles (10, 11).

Hybrid ceramics were developed to combine the strength and stability of conventional ceramics with the flexibility of resin-based composites, resulting in a more versatile restorative material. Hybrid ceramics have a unique dual-network microstructure that distinguishes them from conventional glass ceramics. The ceramic network provides rigidity and strength, while the polymer phase acts as a stress absorber, dissipating energy through microplastic deformation. The presence of a polymer phase in hybrid ceramics increases flexural strength while reducing elastic modulus and hardness.

Hybrid ceramics are commonly classified into two main categories: polymer-infiltrated ceramic networks (PICNs) and resin nanoceramics (12). PICNs consist of a porous, interpenetrating ceramic network that is infiltrated by a polymer phase, forming a true dual-network structure. In contrast, resin nanoceramics are composed of a resin matrix reinforced with a high content of dispersed ceramic nanofillers and nanoclusters, without forming a continuous ceramic network (13-15).

PICNs, such as VITA Enamic and Crystal Ultra, exhibit mechanical behavior similar to that of natural tooth structure (16, 17). When the restoration edge in these materials is subjected to localized stress, the polymer matrix can absorb energy through microplastic deformation, which slows crack propagation and reduces the risk of sudden fracture and marginal chipping (14, 15, 18).

Resin nanoceramics, such as Lava Ultimate, rely primarily on their nanoparticle-reinforced resin matrix to distribute stresses and resist crack initiation. However, the resin phase may lead to increased viscoelastic deformation under load compared with more rigid ceramic-based materials (19).

Edge chipping resistance is a critical mechanical property of brittle dental restorative materials, reflecting their ability to withstand localized stresses at stress-concentrated areas, such as margins, marginal ridges, and cavosurface angles (20-23). It is defined as the force required to initiate a chip at a defined distance from a free edge, leading to localized material loss. Higher edge chipping resistance reduces the risk of marginal damage in thin-walled inlays, onlays, and endocrowns (20).

With the increasing use of hybrid ceramics in fixed restorations due to their favorable combination of ceramic and composite properties, it is important to evaluate their mechanical performance relative to conventional ceramics (10, 11). However, limited data are available to guide the selection of these newly introduced materials in clinical practice (5). Therefore, this study aimed to compare the edge chipping resistance of two PICNs (VITA Enamic and Crystal Ultra) and a resin nanoceramic (Lava Ultimate) with a zirconia-reinforced lithium silicate (VITA Suprinity).

Materials and methods

Study design

The protocol of this in vitro study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (Approval Code: IR.SBMU.DRC.REC.1402.091).

Grouping

In this study, four CAD/CAM restorative materials (n= 10) were fabricated to dimensions of 2 × 10 × 10 mm using a low-speed diamond blade (Accutom Struers, Germany) under continuous water irrigation. The materials were categorized as follows:

1. VITA Enamic: VITA Enamic (VITA Zahnfabrik, Bad Sackingen, Germany) is a type of PICN consisting of 86 wt% feldspar ceramic and 14 wt% cross-linked polymer.
2. Crystal Ultra (Digital Dental, Scottsdale, USA): Crystal Ultra is a type of PICN composed of appproximately 70% silicate glass ceramic phase and 30% cross-linked polymer matrix.
3. Lava Ultimate (3M ESPE, St. Paul, MN, USA): Lava Ultimate is a type of resin nanoceramic consisting of approximately 80 wt% nanoceramic and 20 wt% resin
4. VITA Suprinity (VITA Zahnfabrik, Bad Säckingen, Germany): VITA Suprinity is a zirconia-reinforced lithium silicate ceramic containing silicon dioxide (56–64%), lithium oxide (15–21%), zirconium dioxide (8–12%), and lanthanum oxide (0.1%).

Sample size calculation

The required sample size was calculated a priori using G*Power software (version 3.1.9.7; Heinrich Heine University Düsseldorf, Düsseldorf, Germany). A one-way analysis of variance (ANOVA) with four independent groups was used, with a significance level of α = 0.05 and a statistical power of 80%. Based on the expected effect size derived from a previous study (1), a total sample size of 40 specimens was required. Accordingly, 10 specimens were allocated to each group.

Sample preparation

Before any further processing, the VITA Suprinity specimens were sintered in a ceramic furnace (VITA Vacumat, VITA Zahnfabrik, Germany) for 8 minutes at 840°C, following the manufacturer’s instructions (2, 3, 5).

All specimens were polished in two steps using diamond paste and a polishing wheel. The first step employed a medium-grit pre-polisher (diamond particles 25–35 µm), followed by a fine-grit high-shine polisher (diamond particles 4–8 µm) (Clearfil Twist Dia, Kuraray, Japan). Polishing was performed according to the manufacturer’s instructions, applying light-to-medium pressure in a single, consistent direction (5).

Specimen dimensions were verified using a digital gauge (293 MDC-MX Lite, Mitutoyo, Tokyo, Japan), and any samples outside the specified range were replaced.

The specimens were then cleaned ultrasonically in distilled water and air-dried. Finally, they were stored at room temperature for 24 hours before testing to ensure standardized baseline conditions (24).

Thermocycling

To simulate clinical conditions, all specimens underwent thermocycling (5000 cycles between two water baths at 5°C and 55°C, with a dwell time of 30 seconds per bath).

Etching

Specimens in the VITA Suprinity group were etched with 9% hydrofluoric acid (BISCO Inc., Schaumburg, IL, USA) for 20 seconds, while specimens in the other groups were etched with 5% hydrofluoric acid for 60 seconds. All specimens were then thoroughly rinsed and treated with silane (BISCO Inc.).

One surface in each specimen was adhesively cemented to a composite resin substrate (Z350; 3M ESPE, USA) using a dual-cure resin cement (Multilink Automix; Ivoclar Vivadent, Schaan, Liechtenstein) (1).

This procedure was performed to provide standardized support during testing and to better simulate the clinical condition of a bonded ceramic restoration.

Edge chipping test

The edge chipping test was used to evaluate the resistance of the ceramic materials to localized fracture at the margin. The test was performed 24 hours after the thermal exposure. The specimens were placed on a custom-designed holder, which was mounted onto a universal testing machine (Instron 3367, Instron Corp., Norwood, MA, USA). Before loading, the intended indentation points were marked at horizontal distances of 0.1 to 0.8 mm from the specimen edge using a digital caliper (CD-6, Mitutoyo, Kanagawa, Japan). The test was performed at a crosshead speed of 0.1 mm/min using a sharp steel indenter with a conical tip having an included angle of 120° (Gilmore Diamond Tools, Inc) (Figure 1).

The load was applied until a chip formed at the edge. The maximum load (N) required to initiate chipping at each indentation distance was recorded. Indentations that resulted in incomplete chips or chips extending into the resin substrate were excluded from the analysis. A new indenter was used after every 20 indentations to minimize the effect of tip wear.

After testing, the actual distance between the indenter contact point and the specimen edge was verified using a calibrated stereomicroscope (Nikon SMZ1500, Nikon Corporation, Melville, NY, USA) to ensure measurement accuracy. The recorded chipping load and the corresponding edge distance were used to construct the force-distance relationship for each material. Edge chipping resistance, expressed as edge toughness (T_e), was calculated from the slope of the force–distance relationship and recorded in N/mm, based on the following equation:

$$F = T_e \times d$$

In this equation, F (N) represents the chipping force, d (mm) is the distance from the edge, and T_e (N/mm) denotes the edge toughness (1, 21-23). The values obtained from 10 specimens in each group were

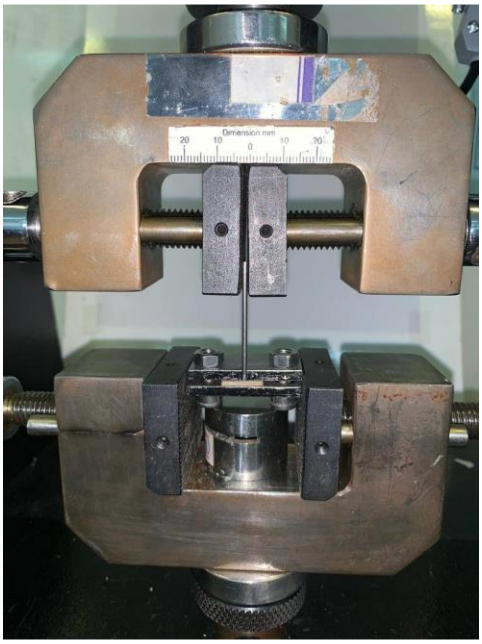

Figure 1. Edge chipping test assembly

averaged and reported as mean ± standard deviation (N/mm).

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test confirmed normal distribution of the data ($P > 0.05$), allowing for parametric analysis. One-way ANOVA was used to compare mean edge chipping resistance among groups, followed by Tukey's post hoc test for pairwise comparisons. The significance level was set at $\alpha = 0.05$.

Results

Figure 2 illustrates the relationship between the applied force and edge distance across the study groups. Overall, higher forces were required to produce edge chipping as the distance from the edge increased.

Table 1 presents the mean edge chipping resistance of the tested materials (Figure 2). VITA Suprinity showed the highest mean edge chipping resistance (201.03 ± 124.88 N/mm), whereas Lava Ultimate showed the lowest value (65.69 ± 39.78 N/mm). VITA Enamic and Crystal Ultra showed intermediate values of 95.10 ± 41.99 N/mm and 88.88 ± 37.49 N/mm, respectively.

ANOVA indicated that edge chipping resistance varied significantly among the study groups ($P = 0.004$; Table 1). Tukey's post hoc test revealed that VITA Suprinity exhibited significantly higher resistance than all other groups ($P < 0.05$). Additionally, both VITA Enamic and Crystal Ultra showed significantly higher edge chipping resistance than Lava Ultimate ($P < 0.05$), whereas no significant difference was observed between VITA Enamic and Crystal Ultra ($P > 0.05$; Table 1).

Discussion

This in vitro study evaluated the edge chipping resistance of four recently introduced ceramic materials after thermocycling. The findings revealed that the mean edge chipping resistance ranked as follows: VITA Suprinity > VITA Enamic > Crystal Ultra > Lava Ultimate.

VITA Suprinity exhibited significantly higher resistance than all other groups. Additionally, both VITA Enamic and Crystal Ultra showed significantly greater edge chipping resistance compared to Lava Ultimate.

In the present study, VITA Suprinity, a zirconia-reinforced lithium silicate, exhibited the highest edge

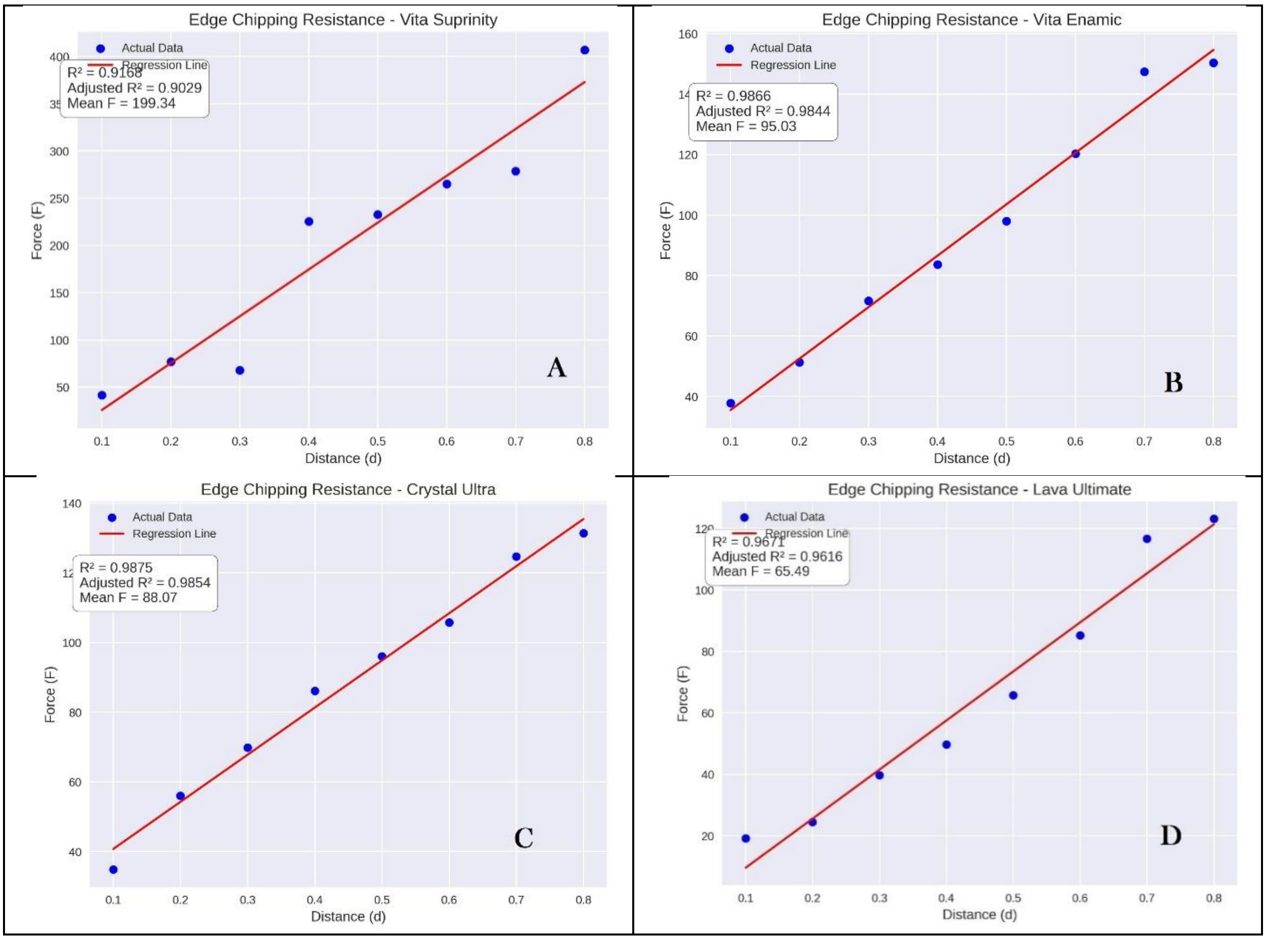

Figure 2. Chipping force versus edge distance. A) VITA Suprinity, B) VITA Enamic, C) Crystal Ultra, and D) Lava Ultimate

Table 1. Mean and standard deviation (SD) of edge chipping resistance among tested materials

Type of ceramic	Brand	Edge chipping resistance
		Mean ± SD*
polymer-infiltrated ceramic networks (PICNs)	Crystal Ultra	88.88 ± 37.49b
polymer-infiltrated ceramic networks (PICNs)	VITA Enamic	95.10 ± 41.99b
Resin nanoceramic	Lava Ultimate	65.69 ± 39.78a
Zirconia-reinforced lithium silicate	VITA Suprinity	201.03 ± 124.88c
P-value	0.004	

* Different superscript letters indicate statistically significant differences between groups at $P<0.05$.

chipping resistance, which was significantly greater than both the PICN groups and the resin nanoceramic group.

This may be attributed to its unique microstructure, which contains approximately 10% zirconia nanoparticles dispersed within a lithium silicate glassy matrix, resulting in higher fracture toughness (5, 22, 23). This improvement enhances resistance to crack propagation from surface flaws, a critical factor for long-term clinical performance (25, 26).

The outcomes of this study are consistent with those of Chen et al. (25) who reported that zirconia-reinforced lithium silicate ceramics outperform lithium disilicate in edge stability and crack resistance, likely due to their optimized crystalline phase. Similarly, Song et al. (10) evaluated the edge chipping resistance of CAD/CAM ceramics before and after thermo-mechanical aging and found that zirconia-reinforced lithium silicate maintained superior mechanical integrity compared to resin nanoceramics under simulated intraoral conditions. Other studies suggest that the inclusion of zirconia particles into the lithium silicate ceramics enhances fracture toughness by acting as crack deflectors (9, 25-27).

In the present study, PICNs (VITA Enamic and Crystal Ultra) required lower forces to initiate edge chipping compared with the zirconia-reinforced lithium silicate ceramic (VITA Suprinity). It is worth noting that while PICNs offer superior machinability and elastic behavior compared to traditional glass ceramics, their edge chipping resistance remains lower than that of more brittle ceramics. This behavior may be attributed to their dual-network microstructure, in which a rigid ceramic network is interpenetrated by a ductile polymer phase, influencing both crack initiation and propagation.

Hampe et al. (11) reported that although hybrid ceramics may exhibit fracture resistance within the range of physiological occlusal forces, their edge chipping resistance is generally comparable to or slightly lower than that of glass ceramics. These findings suggest that, while hybrid ceramics can reduce catastrophic fractures by dissipating elastic energy, careful attention to margin design, surface finishing, and adhesive protocols is crucial to minimize edge-related chipping in clinical restorations (15, 17).

VITA Enamic is produced through the infiltration of a pre-sintered ceramic network with monomer, and contains 86 wt% feldspar ceramic (4). It has been claimed that the polymer phase in this type of PICN reduces brittle fracture compared to pure ceramics (14, 15, 18). Moreover, some studies have demonstrated that VITA Enamic can be strong enough to be used in ultra-thin restorations (11, 28).

Crystal Ultra is a recently introduced PICN containing approximately 70% silica-based ceramic fillers, combining the advantages of both ceramics and resin composites (2, 3, 5). In the present study, VITA Enamic showed slightly higher edge chipping resistance than crystal ultra, but the difference was not statistically significant. Although both VITA Enamic and Crystal Ultra are categorized as PICNs, they have minor differences in the silica percentage and chemical composition, which could explain their slightly different behavior in terms of edge chipping resistance.

In this study, Lava Ultimate showed the lowest edge chipping resistance among the tested materials. Lava Ultimate is a resin nanoceramic composed of approximately 80 wt% nanoceramic fillers embedded in a 20 wt% resin matrix (3, 5). Unlike PICN materials, it does not contain an interconnected ceramic network.

Therefore, its lower edge chipping resistance in the present study may be related to its resin matrix and dispersed filler structure, which may provide less resistance to localized edge stresses under the conditions of this test.

Previous studies have also reported low edge chipping resistance for resin nanoceramics (9, 25, 26). Song et al. (10) demonstrated low edge chipping and flexural strength for resin nanoceramics. Argyrou et al. (1) compared resin nanoceramics with other CAD/CAM materials, such as feldspathic and leucite-reinforced glass ceramics, and reported that while edge chipping toughness is higher in resin nanoceramics than in some CAD/CAM materials, these materials remain prone to edge crack initiation under functional loads. This behavior reflects the polymer-rich matrix's role in dissipating stress, although its chipping resistance remains lower than that of more brittle ceramics.

These findings suggest that, although hybrid ceramics offer favorable esthetics and reparability, they should be used with caution in high-stress areas. Clinicians should also consider conservative tooth preparation, proper finishing and polishing, and appropriate margin design to reduce the risk of edge-related failures (10, 29).

There are some limitations in this study, as the in vitro design could not fully replicate the oral environment. The edge chipping test protocol also had some limitations, including difficulties in precisely standardizing specimen geometry. Although dimensional variations were kept below 0.1 mm, slight deviations in edge perpendicularity may still have been present. Additionally, identifying the exact contact point of the indenter and its distance from the edge had an estimated error of about 10 µm. Therefore, further studies are needed to confirm these in vitro findings and to better assess the clinical performance of different ceramic materials under oral conditions.

Conclusions

Under the conditions used in this study:

1. Zirconia-reinforced lithium silicate (VITA Suprinity) exhibited significantly higher edge chipping resistance than all other tested ceramics.
2. The edge chipping resistance in the resin nanoceramic material (Lava Ultimate) was significantly lower than that of other groups.
3. Among the PICNs, Crystal Ultra showed lower edge chipping resistance compared to VITA Enamic, but the difference was small and not statistically significant.
4. Based on the current findings, hybrid ceramics, including resin nanoceramics and PICNs, should be used with caution in high-load areas, as their lower edge chipping resistance may increase the risk of marginal failure.

Author contributions

E.B. contributed to the study's conceptualization, supervision, validation, and manuscript revision. M.M. contributed to data curation, methodology, and preparation of the manuscript. M.N. contributed to data analysis and interpretation and revised the manuscript. All authors reviewed and approved the final version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

Not applicable.

Ethical considerations

The protocol of this in vitro study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (Approval Code: IR.SBMU.DRC.REC.1402.091).

Funding

None

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