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Comparative assessment of the fracture resistance of endocrowns fabricated from three different CAD/CAM ceramic blocks

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Abstract

Objective: This study aimed to compare the fracture resistance of endocrowns fabricated from three different computer-aided design/computer-aided manufacturing (CAD/CAM) ceramic materials.

Methods: A maxillary left first molar of a typodont model was scanned using an intraoral scanner both before and after standardized endocrown preparation. The scan of the prepared tooth was used to fabricate thirty-six identical resin dies through three-dimensional printing. These dies were then assigned to three groups (n=12), each corresponding to a different CAD/CAM ceramic material: IPS e.max CAD, VITA Suprinity, and VITA Enamic. Endocrowns were digitally designed and milled for each group using a CAD/CAM system. They were then cemented onto the resin dies with dual-cure resin cement and subjected to 5000 thermal cycles. A compressive load was applied to each specimen at a 35° angle to the palatal cusp using a universal testing machine until fracture occurred. Fracture resistance values were recorded in Newtons, and failure modes were evaluated by a stereomicroscope. Statistical analysis was performed using the Kruskal-Wallis, Mann-Whitney U, and Bonferroni tests ($P<0.05$).

Results: A statistically significant difference was found in the fracture resistance among the three groups ($P=0.01$). The IPS e.max CAD group exhibited significantly higher fracture resistance compared to the VITA Enamic group ($P=0.01$). No statistically significant difference was observed in failure modes across the groups ($P>0.05$).

Conclusions: Endocrowns fabricated from IPS e.max CAD demonstrated the highest fracture resistance with no cases of catastrophic failure. VITA Suprinity endocrowns showed the second-highest fracture resistance, with only one case of catastrophic fracture.

Keywords: Computer-aided design, Dental porcelain, Dental prosthesis, Dental restoration failure, Fracture resistance, IPS e.max ceram

Introduction

Endocrown is a monolithic restoration composed of both a crown and an intraradicular cavity-retentive portion, designed primarily for endodontically treated posterior teeth. Compared to conventional full-coverage crowns, endocrowns demonstrate a lower incidence of catastrophic fractures. Catastrophic fractures are severe, irreparable failures that often extend below the gingiva. This advantage of endocrowns is attributed to their conservative design, which preserves a greater portion of the remaining tooth structure (1).

Endocrowns are indicated for teeth with sufficient pulp chamber volume. They are particularly suitable for cases involving short roots, atypical root morphology, or limited occlusogingival height, where conventional post-and-core techniques may be contraindicated (2). Clinical studies have reported favorable long-term outcomes for endocrowns fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) technologies (3). Notably, the reported rate of catastrophic fracture in endocrown restorations is relatively low, approximately 6%, highlighting their reliability in maintaining structural integrity under functional loads (4,5).

The choice of material is a critical factor influencing the longevity, mechanical performance, and clinical success of endocrowns. Various ceramic materials are available for CAD/CAM fabrication of endocrowns. One major category includes glass ceramics, which feature a glassy matrix reinforced by filler particles. While the glassy matrix enhances translucency and esthetics, the filler particles improve strength and durability. Based on filler content, glass ceramics are classified into high-glass and low-glass ceramics. High-glass ceramics offer superior translucency and esthetics but are mechanically weaker. Low-glass ceramics, such as lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS), contain a higher volume of reinforcing fillers and have greater strength (6).

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LDS ceramics are commonly fabricated via heat-pressing or CAD/CAM milling. They are composed of approximately 70% crystalline fillers, which are small, interlocking crystals. This structure contributes to their high flexural strength and excellent esthetic properties and ensures that their mechanical integrity remains unaffected throughout the milling process (7).

ZLS ceramics incorporate lithium metasilicate and tetragonal zirconia particles within a glassy matrix, offering a combination of high strength, esthetics, biocompatibility, and etchability (8,9).

Another class of CAD/CAM materials includes hybrid ceramics, such as polymer-infiltrated ceramic networks (PICNs). These materials combine ceramic and resin components to achieve a structure with improved strength and resilience. Due to the presence of resin, PICNs can be etched using hydrofluoric acid, allowing for adhesive bonding similar to low-glass ceramics (6,10). They also exert less wear on opposing natural teeth and are easier to repair and adjust intraorally, making them a practical choice for many clinical situations (11,12).

Considering the increasing variety of CAD/CAM ceramic materials and their material-specific mechanical properties, this study aimed to compare the fracture resistance of endocrowns fabricated from three different types of commonly used materials: IPS e.max CAD (LDS ceramic), VITA Suprinity (ZLS ceramic), and VITA Enamic (PICN ceramic). The null hypothesis was that there would be no significant difference in the fracture resistance among endocrowns fabricated from these three CAD/CAM ceramic blocks.

Materials and Methods

Study design

The protocol for this in vitro study was approved by the ethics committee of the Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1400.136). Based on a previous study by El-Damanhoury et al. (13), and assuming a significance level (α) of 0.05 and a statistical power of 80%, the minimum required sample size was calculated to be 12 specimens per group.

Sample preparation

An intraoral scanner (CEREC Omnicam; Sirona Dental System, Bensheim, Germany) was used to capture the original occlusal anatomy of a maxillary left first molar on a typodont (Nissin Dental Products Inc., Tokyo, Japan). The initial dimensions of the tooth were as follows: the vertical dimension of the crown was 7.5 mm, the mesiodistal width was 10.5 mm and the buccolingual width was 11.4 mm. The tooth was then prepared for a standard endocrown (14). Undercuts in the cavity were removed using a tapered diamond bur (G845KR; Edenta, Au St. Gallen, Switzerland). The internal axial walls were tapered between 11° and 22° to facilitate proper seating and retention of the restoration. Occlusal reduction was performed to 3 mm on the buccal and 5 mm on the lingual surfaces to ensure adequate material thickness. The preparation depth of the pulp chamber was 5 mm on the buccal side and 3 mm on the lingual side, maintaining symmetry with corresponding mesial and distal wall reductions. All finish lines were designed as butt joints to optimize marginal integrity and stress distribution. The prepared model was scanned to obtain a digital impression (Figure 1).

The scan of the prepared tooth was used to fabricate thirty-six identical resin dies (DentaModel; Asiga, Sydney, Australia) using DentalCAD software (version 3.2; Exocad GmbH, Darmstadt, Germany) and three-dimensional printing. Next, the 36 resin dies were assigned to three groups (n = 12), each designated for fabrication with a specific CAD/CAM ceramic block:

- IPS e.max CAD (lithium disilicate, LDS)
- VITA Suprinity (zirconia-reinforced lithium silicate, ZLS)
- VITA Enamic (polymer-infiltrated ceramic network, PICN).

Endocrown preparation

The endocrowns were digitally designed using CEREC Premium software (version 4.0; Dentsply Sirona, Bensheim, Germany) in Biogeneric Copy mode, which allows the restoration to replicate the original occlusal anatomy of the unprepared tooth. A uniform cement spacer of 60 µm was set for all endocrowns (15).

Once the digital design was finalized, each endocrown was milled from the corresponding CAD/CAM ceramic

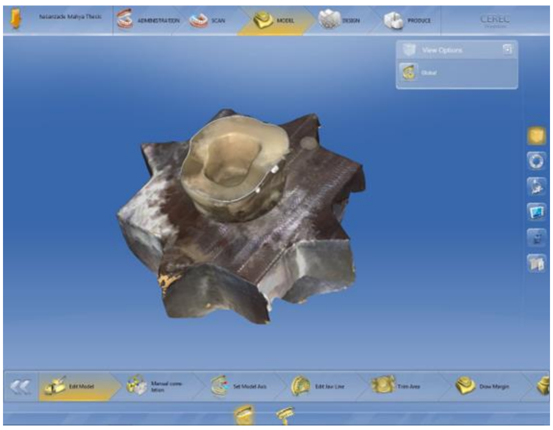

Figure 1. The occlusal view of a prepared typodont tooth captured by an oral scanner

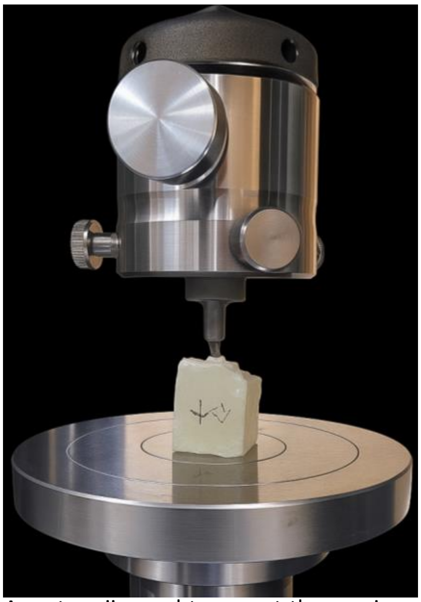

Figure 2. A custom jig used to mount the specimens in clear acrylic resin at a 35° angle relative to the long axis of the tooth

block using a CEREC MC XL milling machine (Dentsply Sirona). The milling process involved subtractive manufacturing under water cooling to prevent microcracks and overheating. The fabrication was performed according to the manufacturer-recommended parameters for each material.

Cementation procedure

All dies and endocrowns were cleaned in an ultrasonic bath (CD-4820; Codyson, Shenzhen, China) containing a water-alcohol solution. Etching was performed with 10% hydrofluoric acid (Condicionador De Porcelana; Angelus, Londrina, Brazil) for 20 seconds for the LDS and ZLS groups, and 60 seconds for the PICN group (16). Specimens were then rinsed for 20 seconds and air-dried. Silane (Silano; Angelus) was applied for 60 seconds and dried gently with air spray (17).

The resin dies were first mounted in silicone molds for stability. Each die was then sandblasted with 50 µm aluminum oxide particles at a pressure of 2.5 bar for 4 seconds to enhance surface roughness. After sandblasting, the dies were thoroughly rinsed with water and air-dried. For standardized cementation, a custom mold made of auto-polymerizing acrylic resin was used to ensure consistent positioning and pressure during the bonding process.

A dual-cure resin cement with self-adhesive and self-etching properties (Total C-RAM; ITENA, Paris, France) was applied to the internal surface of each endocrown. The restorations were seated on the dies using finger pressure for 30 seconds, followed by an initial light-curing (Bluephase; Ivoclar Vivadent, Schaan, Liechtenstein) at 1200 mW/cm² for 2 seconds. Excess cement was removed using foam pellets. Oxyguard (Panavia F 2.0; Kuraray Co., Tokyo, Japan) was applied for 3 minutes, after which specimens were light-cured for 20 seconds (18).

The specimens were immersed in distilled water at 37°C for one week. Subsequently, they underwent 5,000 thermal cycles between 5°C and 55°C, with a dwell time of 30 seconds and a transfer time of 5 seconds.

Fracture resistance testing

Each specimen was mounted in a custom-made jig at a 35° angle using transparent auto-polymerizing acrylic resin (Acropars, Marlic Co., Tehran, Iran), with the resin die embedded 2 mm below the cementoenamel junction. A universal testing machine (Z050; ZwickRoell, Ulm, Germany) applied a 2.5-kg load at a 35° angle relative to the long axis of the tooth on the palatal cusp slope of the endocrown (13) (Figure 2). The crosshead speed was set at 0.5 mm/min, and loading continued until failure. The fracture resistance was recorded in Newtons (N).

Failure mode analysis

Fractured specimens were examined under a stereomicroscope (Leitz DMB, Wetzlar, Germany) at 50× magnification, equipped with a digital camera (Redmi Note 9 Pro, 48MP; Xiaomi, Beijing, China). Failure modes were classified into four categories (19):

Type 1: Complete or partial debonding of the endocrown without fracture (favorable/repairable)

Type 2: Fracture of the endocrown without damage to the die (favorable/repairable) (Figure 3.a)

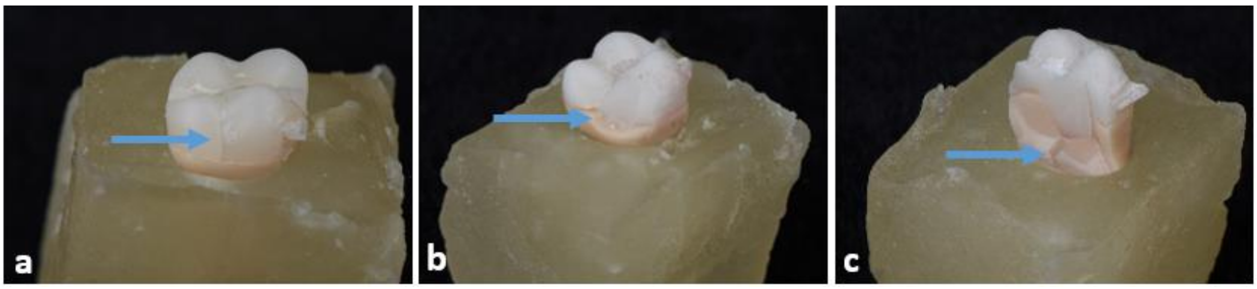

Figure 3. (a) Fracture of the endocrown without involving the die, (b) Fracture of the endocrown/die assembly above the CEJ, (c) Fracture of the endocrown/die assembly below the CEJ

Table 1. Mean and standard deviation (SD) of fracture resistance (N) of endocrowns fabricated from three ceramic blocks

Groups	Mean ± SD	Minimum-maximum
IPS e.max CAD (LDS)	2677 ± 887.2 [a]	(767.0 - 4386.3)
VITA Suprinity (ZLS)	2011 ± 706.3 [ab]	(1055.8 - 3457.3)
VITA Enamic (PICN)	1632 ± 523.0 [b]	(770.0 - 2107.8)
P-value	0.01	

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

Type 3: Fracture of the endocrown and die above the cementoenamel junction (favorable/repairable) (Figure 3.b)

Type 4 (Catastrophic fracture): Fracture of the endocrown and die below the cementoenamel junction (unfavorable/irreparable) (Figure 3.c).

Statistical analysis

Statistical analysis was conducted using SPSS software (version 25, IBM Corp., Armonk, NY, USA). The Kruskal-Wallis and Mann-Whitney U tests, with Bonferroni correction, were used to compare the fracture resistance and failure modes among the three ceramic groups. The significance level was set at $P<0.05$.

Results

Table 1 presents the mean fracture resistance values for endocrowns fabricated from three different types of ceramic blocks. The Kruskal-Wallis test revealed a statistically significant difference in fracture resistance among the three groups ($P = 0.01$).

Pairwise comparisons using the Mann-Whitney U test with Bonferroni adjustment indicated that the LDS group exhibited a significantly higher mean fracture resistance compared to the PICN group ($P=0.01$). However, no statistically significant differences were found between the LDS and ZLS groups ($P=0.13$), or between the PICN and ZLS groups ($P=0.91$).

Figure 4 illustrates the distribution of failure modes across the three groups. No irreparable fractures were observed in the LDS group, whereas four and one irreparable fractures occurred in the PICN and ZLS groups, respectively. Moreover, no type 1 failure (debonding without fracture) was observed in any groups. The differences in the frequency of failure modes were not statistically significant among the groups ($P=0.15$).

Discussion

This study evaluated the axial fracture resistance of endocrowns fabricated from three different CAD/CAM materials: lithium disilicate ceramic (LDS, IPS e.max CAD), zirconia-reinforced lithium silicate ceramic (ZLS, VITA Suprinity), and polymer-infiltrated ceramic network (PICN, VITA Enamic). The results of the present study showed a significant difference in fracture resistance among the groups, leading to the rejection of the null hypothesis.

In this study, axial loading was applied, which represents the predominant functional force. Axial resistance simulates vertical masticatory forces during normal function, while lateral resistance mimics

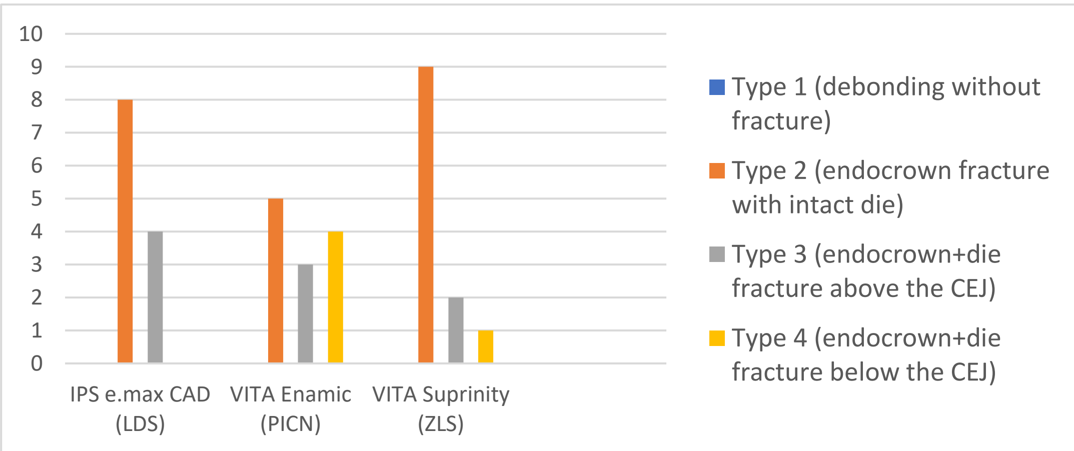

Figure 4. The frequency of failure types in the study groups

parafunctional or off-axis forces such as bruxism or lateral excursions. It should be noted that the results of the present study may underestimate clinical failure potential under multidirectional stress.

In the present study, LDS endocrowns (IPS e.max CAD) exhibited the highest mean fracture resistance (2677 ± 887.2 N), significantly outperforming PICN (VITA Enamic: 1632 ± 523.0). The fracture resistance value of LDS endocrowns was also greater than ZLS (VITA Suprinity: 2011 ± 706.3), but the difference was not statistically significant. This result aligns with numerous studies reporting superior mechanical properties and fracture resistance of LDS compared to ZLS and PICN ceramics (13,20–23).

However, absolute fracture resistance values vary across studies. For example, Sağlam et al. (24) reported a much lower fracture resistance for LDS endocrowns (IPS e.max CAD; 714.83 N), which falls below the average maximum molar chewing force (~850 N) (20). In contrast, the present study's LDS group exceeded this threshold considerably. Taha et al. (23) also reported lower fracture resistance values for LDS endocrown under axial load (1478.9 N) compared to the present study. Acar et al. (20) evaluated both axial and lateral fracture resistance values for LDS endocrowns (IPS e.max CAD; 1913 N and 690 N, respectively), highlighting the drop in strength under non-axial loading.

Variations in reported values among the studies can be attributed to differences in the study design. The high fracture resistance observed in this study may be due to the use of three-dimensional printed resin dies. These dies, with mechanical properties comparable to dentin, were used to standardize the test substrate across specimens. The resin's homogeneous structure likely caused stronger bonding with resin cement compared to natural dentin. Rocca et al. (25) and Nakamura et al. (26) similarly used composite dies, reporting enhanced interfacial strength. This improved bond interface may reduce microcrack initiation and propagation, ultimately increasing fracture resistance.

Nevertheless, some studies (23,27) have reported higher fracture resistance values than those observed in the present study, even when using natural teeth as the substrate. For instance, El Ghoul et al. (27) reported the highest axial fracture resistance for LDS endocrowns at 2914 N, which slightly surpasses the value found in the present study. This discrepancy may be attributed to more favorable stress distribution resulting from the improved alignment of the applied load with the tooth's long axis or a more optimized preparation design of endocrowns in the study of El Ghoul et al. (27) . Proper force alignment with the long axis minimizes stress concentrations at critical interfaces and helps delay crack initiation and propagation, thereby increasing overall fracture resistance.

Another contributing factor to the lower fracture resistance values reported in some studies may be the application of cyclic loading, which was not included in the current investigation. For example, Taha et al. (23) applied cyclic loading to simulate the fatigue effect of repeated mastication over time. This type of mechanical aging introduces microcracks and gradually weakens the adhesive interface between the restoration and the tooth structure or die material. As a result, cyclic loading can significantly reduce the overall fracture resistance by mimicking the cumulative stresses experienced under functional conditions. In contrast, the present study only applied static loading, which does not replicate the fatigue-related degradation that occurs clinically.

In the present study, ZLS endocrowns (VITA Suprinity) showed intermediate fracture resistance (2011 ± 706.3 N), which was nonsignificantly lower than that of the LDS. This could be attributed to the lower etchability and bond strength of ZLS compared to LDS. Many studies have reported that LDS has a higher crystalline content and etches more effectively, promoting micromechanical retention (10,18,21). El Ghoul et al. (27) found a statistically significant difference between LDS and ZLS (2914 N vs. 2279 N under axial loading). Although this trend aligns with the current study's ranking, no significant difference was found in this study among the ZLS and LDS groups.

PICN endocrowns (VITA Enamic) exhibited the lowest fracture resistance (1632 ± 523.0 N) in the current study, significantly lower than that of the LDS. This is consistent with Acar et al. (20), who also found PICN to yield the lowest resistance (1406 N). In contrast, Taha et al. (23) reported no statistically significant difference between PICN (1241 N) and LDS (1478 N), which may reflect the influence of factors such as internal adaptation, loading protocol, or sample variability. The inherently lower stiffness and brittleness of PICN may contribute to its reduced bond strength, although its shock-absorbing ability has been suggested to prevent catastrophic failure under dynamic conditions (23).

Despite material differences, all groups in this study demonstrated mean fracture resistance values exceeding the average maximum occlusal force in molars, suggesting that these endocrowns are potentially suitable for clinical use in posterior restorations. However, clinical decisions should consider both fracture strength and failure mode.

Failure mode analysis is clinically relevant, as it determines the reparability of fractured restorations. Restorations that fail in a repairable manner (above the cementoenamel junction) allow retreatment without compromising the remaining tooth structure. In contrast, catastrophic or irreparable fractures below the CEJ often necessitate tooth extraction (28,29). In the present study, all LDS endocrowns failed in a repairable manner, while four irreparable fractures occurred in the PICN group and one in the ZLS group. No debonding without fracture (Type I failure) was observed in any groups. The variation observed in the type of failure was not statistically significant among the groups.

The present findings align with those of Sağlam et al. (22), who also observed no Type I failures (debonding without restoration fracture). In contrast, Acar et al. (20) reported that 48% of failures were due to debonding. This discrepancy highlights the significant influence of bonding protocols and the direction of load application on failure modes. Additionally, Acar et al. utilized a shallower pulp chamber preparation (2 mm in depth) compared to the 3–5 mm depth used in the present study. The reduced cavity depth may have limited the mechanical interlocking and retention of the endocrown, thereby increasing the likelihood of debonding in their study. Although variability exists, most studies (20,22,24) have reported no significant differences in failure modes among the tested materials, which is in line with the present results. In most cases, fractures were predominantly repairable (20,22,24).

The use of standardized resin dies enhanced the internal validity of our findings by controlling variability in substrate properties. However, this in vitro study has some limitations. Cyclic loading, which mimics long-term functional stresses and is known to degrade resin cement bonds (23,27), was not performed due to equipment constraints. Furthermore, the use of resin instead of natural dentin may overestimate the clinical performance of endocrown restorations. Therefore, clinical studies with natural teeth and long-term follow-ups are needed to validate these findings.

Conclusions

Within the limitations of this in vitro study:

1. Lithium disilicate (LDS; IPS e.max CAD) demonstrated the highest fracture resistance, significantly outperforming the polymer-infiltrated ceramic network (PICN; VITA Enamic).
2. Zirconia-reinforced lithium silicate (ZLS; VITA Suprinity) ranked second, with no statistically significant difference from either LDS or PICN.
3. All three materials showed fracture resistance values exceeding the average masticatory forces in the molar region, indicating their potential clinical suitability for endocrown restorations.
4. Failure modes were predominantly repairable across all groups, with no significant differences observed between the materials.

Acknowledgments

None to report.

Conflict of interest

All authors declare that they have no conflict of interest.

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Ethical approval

The study was ethically approved by the ethics committee of the Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1400.136).

Author contributions

M.An. and M.Al. contributed to the research design, implementation, and analysis; N.Y. contributed to the research implementation, interpretation, and writing of the manuscript, and N.K. contributed to the research supervision and writing of the manuscript. All authors read and approved the final manuscript.

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