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RESEARCH ARTICLE

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# Fracture load of CAD/CAM ultrathin occlusal veneers luted to enemel or dentin

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## Abstract

**Objectives:** To evaluate, in vitro, the fracture load of IPS e.max CAD occlusal veneers at thicknesses of either 0.3 or 0.6 mm luted to enamel or dentin.

**Materials and methods:** Fifty human molars were randomly distributed into five groups (n = 10): G1 - healthy teeth (control); G2-0.3-mm-thick veneers luted to enamel; G3-0.6-mm-thick veneers luted to enamel; G4-0.3-mm-thick veneers luted to dentin; and G5-0.6-mm-thick veneers luted to dentin. After the luting procedures, the specimens were immersed in distilled water at 37°C for 24 hours and then subjected to mechanical loading ($10^6$ cycles at 200 N load). The specimens were subjected to a fracture load test in a universal testing machine. Two-way ANOVA and Tukey's test ($\alpha$ = 0.05) were used to analyze data.

**Results:** Only the thickness factor was significant (*P* = .002). Values of fracture load followed by distinct letters represent significant differences (*P* < .05): G1 (3204 N ± 730)[ab]; G2 (3144 N ± 729)[ab]; G3 (2489 N ± 606)[b]; G4 (3591 N ± 776)[a]; and G5 (2770 N ± 598)[ab].

**Conclusion:** IPS e.max ultrathin occlusal veneers luted to enamel or dentin obtained fracture load comparable to that of the healthy tooth.

**Clinical significance:** IPS e.max CAD ultrathin occlusal veneers at 0.3 or 0.6-mm-thick seem to provide good perspectives in relation to the clinical use.

KEYWORDS

CAD/CAM, ceramic, dentin, enamel, fracture load, occlusal veneer

## 1 | INTRODUCTION

Premature loss of enamel, known as dental erosion, can be caused by the action of acidic beverages and foods, gastroesophageal reflux disease, medications, and bulimia nervosa.[1,2]

Teenagers and children may show clinical signs of dental erosion, which are characterized by noncarious lesions.[3,4] The treatment of these lesions presents a challenge.[5] Dental erosion occurs on the occlusal surfaces of molars and premolars, and its evolution takes place slowly. Thus, the clinical diagnosis of dental erosion is difficult in the early stages and is frequently identified when rehabilitation is necessary.[6]

Polymeric or ceramic materials have been used for the restorative treatment of erosive lesions. In young patients, rehabilitation should be as noninvasive as possible, preserving the healthy tooth structure.[7,8] Minimally invasive approaches preserve dental structure, maintain pulp vitality, and decrease postoperative dentine sensitivity.[9]

The ultrathin occlusal veneers made of lithium disilicate ceramic have provided the rehabilitation of posterior teeth, replacing traditional inlays, onlays, and full crowns.[10,11] This material presents higher fracture strength compared to feldspathic and leucite-reinforced ceramics.[12,13] In addition, lithium disilicate ceramic restorations can be obtained by CAD/CAM technology, providing an option for rehabilitating teeth with minimal or no preparation.[14]

Regarding fracture strength of occlusal veneers manufactured with IPS e.max CAD, different minimal occlusal thicknesses were evaluated, such as 1.5 mm or 0.6 mm,[15] 1.2 mm,[16] 0.8 mm,[17] 0.5 mm,[18] 0.7 mm, 0.5 mm or 0.3 mm,[19] 0,3 mm thickness.[20] The results of the studies showed that these ultrathin occlusal veneers seem to be a promising option for clinical use. However, it would be interesting more studies evaluating the strength of ultrathin occlusal veneers at the thickness limit, such as 0.3-mm-thick, aiming to restore the tooth with minimally invasive preparations.

Depending on the severity of dental erosion, mineral loss may be restricted to the enamel, or it may advance and expose the dentin.[21] Regarding the substrate, the studies evaluated ultrathin occlusal veneers made of IPS e.max CAD luted to enamel,[18] or dentin.[15,16,17] Since the different variables applied in the studies can influence the results, it is important to evaluate the fracture load of IPS e.max CAD ultrathin occlusal veneers luted to enamel or dentin under the same methodology. However, few studies have evaluated this ceramic bonded to different substrates.[19,20]

Therefore, the aim of this in vitro study was to assess the fracture load of IPS e.max CAD occlusal veneers at thicknesses of either 0.3 or 0.6 mm luted to enamel or dentin. The hypotheses of the study were that both (a) the occlusal veneers' thickness and (b) the substrate would influence the fracture load of the restorations.

## 2 | MATERIALS AND METHODS

This research was approved by a local ethics committee (CAEE 55675416.7.0000.5336). Fifty human third molars, extracted for therapeutic reasons and free of caries, restorations, cracks or fractures, were selected after measurement of the mesiodistal and buccal-palatal dimensions with a digital caliper (500-197-20 Mitutoyo, Kawasaki, Japan). It was allowed a variation of 0.5 mm for each measurement with the aim to standardize the teeth's dimensions. The teeth were cleaned, disinfected in 0.5% chloramine T solution for 24 hours, and immersed in distilled water at 4°C. The teeth were randomly distributed among five different groups (n = 10): G1) healthy teeth (control); G2) 0.3-mm-thick occlusal veneers made of IPS e.max CAD luted to enamel; G3) 0.6-mm-thick occlusal veneers luted to enamel; G4) 0.3-mm-thick occlusal veneers luted to dentin; and G5) 0.6- mm-thick occlusal veneers luted to dentin.

The root portion of each tooth was covered by a layer of Universal Tray Adhesive (Zhermack, Rovigo, Italy), followed by a layer of Express vinyl polysiloxane (3M, St. Paul, Minnesota) in the regular viscosity. In the sequence, the teeth had their roots vertically embedded in plastic matrix filled with self-curing acrylic resin up to 2 mm from the enamel-cement junction, and then immersed in distilled water at 4°C. The preparations on dentin or enamel were standardized as follow: (a) Preparation on dentin: tooth preparation followed the method described by Magne et al.[16] The occlusal dentin was exposed using a 4138 diamond bur (KG Sorensen, Cotia, SP, Brazil) operating at high speed under air-water spray. The lingual and buccal margins were maintained approximately 5.0 mm from the cementoenamel junction and 2.3 to 2.6 mm above the central groove. The inclination of the cusps was maintained. Diamond burs 4138F and 4138FF (KG Sorensen, Cotia, SP, Brazil) performed the finished preparation (Figure 1A); (b) Preparation on enamel: the preparation was only within enamel with a reduction of about 0.5 mm using a 2135 diamond bur (KG Sorensen, Cotia, SP, Brazil) at high speed under air-water spray. Diamond burs 2135F and 2135FF (KG Sorensen, Cotia, SP, Brazil) performed the finished preparation. The inclination of the cusps was maintained (Figure 1B).

The reflective titanium (VITA Zahnfabrik, Bad Säckingen, Germany) was sprayed on the tooth preparation. After, the tooth preparation was scanned with an optical 3D intraoral camera (Cerec software, version 4.0.2, Sirona Dental Systems GmbH, Bensheim, Germany). A three-dimensional virtual representation was obtained, and a standardized occlusal form of a right second lower molar was the shape of the CAD/CAM occlusal veneers. The software defined the thickness of the occlusal veneers (0.3 or 0.6 mm), and the virtual die spacer was set at 50 μm. Twenty occlusal veneers made of IPS e.max CAD with a 0.3-mm-thick and 20 occlusal veneers with a 0.6-mm-thick were fabricated. After milling, the occlusal veneers were crystallized in the Programat P300 ceramic furnace (Ivoclar Vivadent, Schaan, Liechtenstein) for 30 minutes at a final temperature of 850°C in a vacuum. In the sequence, the occlusal veneers were polished with the Diagloss rubber tips (Edenta, Au, Switzerland), and then glazed at 770°C.

The materials used for the luting procedure are shown in Table 1. Following the manufacturer's instructions, the occlusal veneers were etched with 5% hydrofluoric acid for 20 seconds, then rinsed off with forceful water spray for 30 seconds, and ultrasonically cleaned with isopropyl alcohol for 5 minutes.[22] The silane Monobond-N was applied and dried gently for 5 seconds. The phosphoric acid at 37% was applied on enamel for 30 seconds and on dentin for 15 seconds, rinsed for 30 seconds and dried with cotton buds. The adhesive system ExciTE F DSC was applied on the etched enamel and dentin, and dried gently for 5 seconds. The resin cement Variolink N was applied to the inner surface of the occlusal veneer, which was immediately placed on the preparation, followed by a 1-kg-load using a metallic device. After removing excess cement, each face of the occlusal veneer was photopolymerized for 60 seconds with a Bluephase N curing unit (Ivoclar Vivadent, Schaan, Liechtenstein) in high power mode. The light intensity was monitored with a radiometer (SDI, Bayswater, Vic, Australia).

The specimens were immersed in distilled water at 37°C for 24 hours, and then subjected to mechanical loading (ER-11000, Erios, São Paulo, SP, Brazil). The pistons of the machine were always in contact mode on the occlusal surface of the restorations. A load of 200 N and a frequency of 1 Hz was applied on the restorations for $10^6$ cycles in distilled water at 37°C. After this aging protocol, it was observed the occurrence of cracks, chips, fractures, or luting failures on the restorations with a 10X loupe (Olympus, Tokyo, Japan). The

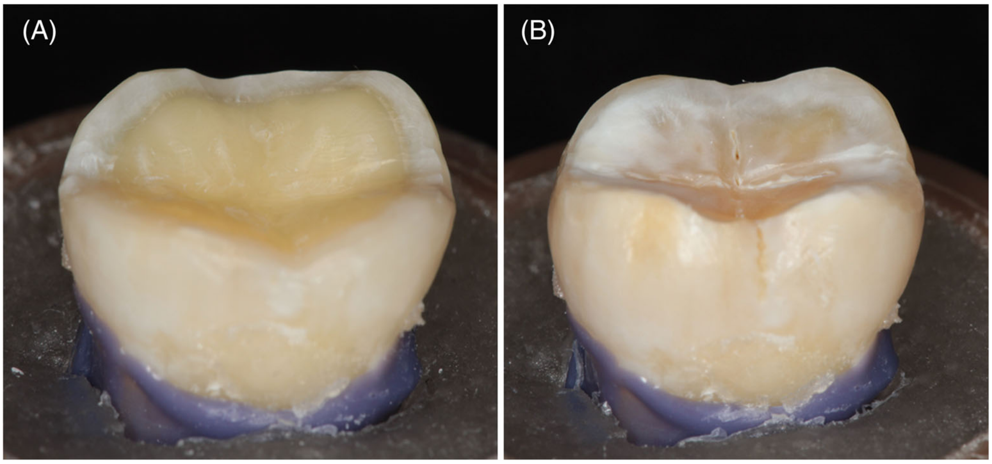


**FIGURE 1** Preparations of the teeth: A, Preparation on dentin; B, Preparation on enamel

**TABLE 1** Materials used in the study, compositions, and manufacturers

| Materials | Composition | Manufacturer |
|---|---|---|
| IPS e.max CAD | SiO2 Li2O, K2O, MgO, Al2O3, P2O5 e outros óxidos | Ivoclar Vivadent, Schaan, Liechtenstein |
| Condac 37% phosphoric acid | Phosphoric acid 37%, thickener, dye, and deionized water | FGM, Joinville, SC, Brazil |
| Condac Porcelain | Hydrofluoric acid 5%, water, thickener, surfactant, dye | FGM, Joinville, SC, Brazil |
| Monobond N | Silane methacrylate alcohol solution, phosphoric acid methacrylate and sulfide methacrylate | Ivoclar Vivadent, Schaan, Liechtenstein |
| ExciTE DSC | HEMA, dimethacrylate, acrylate initiators, stabilizers and potassium fluoride, alcoholic solution. The ExciTE F DSC applicator is coated with primers | Ivoclar Vivadent, Schaan, Liechtenstein |
| Variolink N | BisGMA, urethane dimethacrylate and triethylene glycol dimethacrylate, barium glass, ytterbium trifluoride, aluminum and barium fluorsilicate glass and mixed spheroidal oxides, initiators, stabilizers and pigments | Ivoclar Vivadent, Schaan, Liechtenstein |

occlusal veneers were classified as follow: (a) success (no changes); (b) failure (cracks, chips, or fractures); or (c) survival (failure that did not compromise the restoration's use).[23]

**TABLE 2** Fracture load mean (N) between the occlusal veneer thicknesses

| Thickness (mm) | Fracture load mean (N) |
|---|---|
| 0.3 | 3368[b] |
| 0.6 | 2629[a] |

*Note:* Different letters represent different means according to Tukey's test ($\alpha$ = 0.05).

Universal testing machine (EMIC-DL2000, São José dos Pinhais, PR, Brazil), with a 6-mm diameter steel sphere, at a cross-head speed of 1.0 mm/min, was used to perform the fracture load test. The specimens were vertically loaded on the center of the occlusal surface until fracture occurred. The maximum load was recorded in Newtons (N). The types of fractures were visually assessed. The specimens were classified as follow: (a) reparable (fracture at the occlusal veneer or fracture that involved all or part of the cusp); (b) irreparable (the tooth was divided into two parts at the pulp chamber floor).

Fracture load outcomes were normally distributed according to Kolmogorov-Smirnov normality test. Two-way ANOVA (occlusal veneer thickness × substrate) followed by Tukey's post hoc test analyzed the fracture load values among the experimental groups. One-way ANOVA followed by Tukey's post hoc test compared the fracture load of the healthy teeth with the experimental groups. Statistical significance was set at .05. The IBM SPSS statistics 10.0 statistical package was used to carry out the statistical analyses.

## 3 | RESULTS

Chips, cracks, or fractures were not observed in any specimen after mechanical loading. One G4 sample was excluded from the statistical analysis due to failure during the fracture load testing.

Two-way ANOVA showed that the substrate factor was not significant ($P$ = .104), the thickness factor was significant ($P$ = .002), and the interaction between the factors ($P$ = .705) was not significant.

The 0.3-mm-thick occlusal veneers (3368 N) obtained significantly higher fracture load than 0.6-mm-thick occlusal veneers (Table 2).

G4 (3591 N) (0.3-mm-thick occlusal veneers luted to dentin) obtained the highest fracture load, and G3 (2489 N) (0.6-mm-thick occlusal veneers luted to enamel) had the smallest fracture load, with a significant difference between these values. G4 and G3 did not differ significantly from the other groups (Table 3).

The failures were 100% irreparable for G1 (healthy teeth). Reparable fractures were predominant in G2 (Figure 2A), and irreparable fractures were predominant in G3 (Figure 2B). Groups G4 and G5 showed a more uniform distribution between the two types of fractures (Table 4).

## 4 | DISCUSSION

The manufacturer of IPS e.max CAD recommends a minimal thickness of 1.5 mm for occlusal veneers. In an earlier study using the same methodology as the present study, a thickness of 0.6 mm luted to dentin showed high values of fracture load.[15] Aiming to reduce wear on the dental structure, the present study extrapolated the manufacturer's indications and tested smaller thicknesses for the occlusal region.

The 0.3-mm-thick occlusal veneers obtained higher fracture load than 0.6-mm-thick occlusal veneers. Thus, the first hypothesis was not rejected. This finding was surprising, showing that even with a constant load of fracture, an ultrathin thickness of 0.3 mm obtained high strength. Therefore, the higher thickness was not a determinant of fracture load values when comparing the thicknesses of 0.6 and 0.3 mm. This finding may be related to adhesive luting.

The luting protocol of IPS e.max CAD occlusal veneers was standardized for all groups. On the preparation surface, it was applied the ExciTE F/DSC adhesive system in the etch-and-rinse technique on enamel and dentin, as the manufacturer recommends this technique. A recent study showed that the application of a self-etching adhesive system on enamel reduced the survival rate of IPS e.max CAD ultrathin occlusal veneers.[24] On the inner surface of the veneers, 5% hydrofluoric acid was applied for 20 seconds. To completely eliminate the debris following etching, all specimens were immersed in an ultrasonic bath containing isopropyl alcohol for 5 minutes.[22] In the sequence, the primer Monobond N, which contains silane, was applied. Silane application after the hydrofluoric acid-etching enhances the chemical bond between materials containing silicon, such as IPS e.max CAD, and the adhesive material used for luting.[25,26] In addition, silane increases the material's surface wettability, favoring higher contact between the adhesive and the restoration.[27] The resin cement was the Variolink N recommended by the manufacturer. Therefore, adhesive luting promotes the formation of a single unit among the tooth, luting agent and restoration. Thus, the occlusal forces applied on the restored tooth are dissipated through the tooth structure, periodontal ligament, and alveolar bone,[9,28] preventing the forces from being concentrated in the internal region of the restoration, which would lead to fracture,[29] regardless of thickness. This finding is confirmed by the types of fractures observed in the study.

**TABLE 3** Fracture load mean (N) and SD in the different groups

| Group | n | Mean (N) | SD |
|---|---|---|---|
| G1-control - healthy teeth | 10 | 3204$^{ab}$ | 730 |
| G2-0.3 mm - enamel | 10 | 3144$^{ab}$ | 729 |
| G3-0.6 mm - enamel | 10 | 2489$^{b}$ | 606 |
| G4-0.3 mm - dentin | 9 | 3591$^{a}$ | 776 |
| G5-0.6 mm - dentin | 10 | 2770$^{ab}$ | 598 |

*Note:* Different letters represent different means according to Tukey's test ($\alpha$ = 0.05).

**TABLE 4** Failure analyses of the different groups

| Group | Reparable fracture | Irreparable fracture |
|---|---|---|
| G1-control - healthy teeth | 0 | 10 |
| G2-0.3 mm - enamel | 7 | 3 |
| G3-0.6 mm - enamel | 3 | 7 |
| G4-0.3 mm - dentin | 5 | 4 |
| G5-0.6 mm - dentin | 6 | 4 |

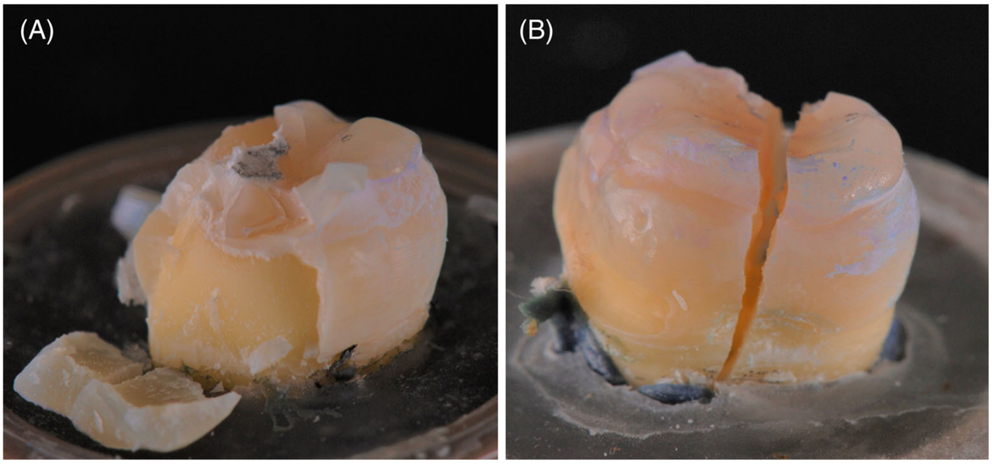


**FIGURE 2** Types of failures: A, Repairable fracture; B, Irreparable fracture

Although repairable fractures were more frequent, these fractures were not concentrated only on the occlusal veneer. The load dissipated through the tooth, resulting in cusp fracture or longitudinal fracture of the tooth.

The IPS e.max CAD presents a flexural strength of 360 MPa and an elastic modulus of 95 GPa.[30] The elastic modulus of the material and substrate, as well as the flexural strength of the material, are factors that influence the strength of the tooth/restoration set.[31] In the present study, the occlusal veneers were luted on different substrates: (a) on enamel and (b) on dentin and enamel margins. These differences in preparation have clinical relevance, since enamel adhesion is more predictable, and restorations with dentin margins compromise restoration longevity.[32] Studies emphasize that ceramics with an elastic modulus that approaches the substrate present better stress distribution as well as better load-bearing capacity.[33] In addition, a similar elastic modulus between the substrate and restorative material favors the strength of the tooth restoration set.[34] The greater the elastic modulus of the substrate, the greater the force needed to cause a fracture in the restoration.[31] Despite the difference in the elastic modulus of enamel (80 GPa) and dentin (19 GPa),[35] in the present study, luting on enamel or on dentin of the IPS e.max CAD ultrathin occlusal veneers did not significantly influence the fracture load values. Thus, the second hypothesis was rejected. This finding does not corroborate the few studies that evaluated ultrathin ceramic restorations luted to enamel or dentin under the same methodology.[19,20,36] Piemjai et al[36] reported that the fracture load of restorations luted to enamel was greater than that of those luted to dentin. Sasse et al[19] showed that ultrathin restorations (0.3-0.6 mm) luted to dentin obtained higher fracture load than that of those luted to enamel only. Krummel et al[20] also obtained higher fracture resistance for the restorations luted to dentin with the selective enamel-etching technique on the surrounding enamel. The different results may be related to the methodological differences between studies, such as the occlusal veneer preparation, the thickness of the restorations, the type of mechanical loading, and the adhesive luting protocols.

Regardless of the substrate on which the ultrathin occlusal veneers were luted, the fracture load values were higher than the masticatory forces recorded in patients. These bite force values reached 922 N (in forced bite tests) and 1120 N in bruxism patients.[37] Furthermore, there was no significant difference in fracture load between the healthy teeth group and the experimental groups. It is an important result, because even with a 0.3-mm-thick in the occlusal region, the restored teeth obtained fracture load similar to the healthy teeth.

All specimens were subjected to $10^6$ cycles of mechanical loading with a loading force of 200 N. This cycling regime simulated around 4 years of natural function, as 250 000 cycles correlate to 1 year of average mastication.[37,38] After this mechanical cycling, no failures, such as cracks or fractures, were observed in any restorations, providing positive results. However, mechanical loading corresponds to an axial load that is applied by a pneumatic piston in the central occlusal region of the restoration, not corresponding to the clinical reality in which forces are applied in different directions.

Structural defects in ceramics and their inability to deform plastically contribute to the strength of the ceramic materials.[39] The IPS e.max CAD is a lithium disilicate ceramic, and restorations with this material are made by CAD/CAM technology. The structure of this ceramic is more homogeneous, with fewer defects in its structure, giving greater strength to the material. This characteristic is important and must have contributed to the high fracture load values of the ultrathin occlusal veneers since a more homogeneous material is subject to less internal stress, allowing a higher fracture load of the material compared to that of less homogenous materials.[30] Another factor to be considered is the preparation's form that respected the natural anatomy of the tooth, allowing a better distribution of stress[40] at the time of the fracture load test.

The results of this study must be interpreted with cautions since in vitro experiments do not reproduce the masticatory biomechanics, the oral environment or its complexity.[23] The constant axial load applied by a steel sphere on the occlusal surfaces of the specimens during the fracture load test do not correspond to the clinical reality, being a limitation of the study. However, the results of this mechanical test are important to compare the fracture load between different techniques of restoration as well as to compare the restored teeth with healthy teeth. Importantly, the minimum thicknesses in the restoration recommended by the manufacturer must be respected. Nonetheless, ultrathin occlusal veneers are indicated in cases in which the remaining dental structure must be preserved or in cases in which there is limited interocclusal space due to the wear of the teeth. In this context, the results obtained in this study seem to provide good perspectives in relation to the clinical use of these restorations.

## 5 | CONCLUSION

The IPS e.max CAD occlusal veneers at thicknesses of either 0.3 or 0.6 mm luted to enamel or dentin obtained fracture loads comparable to that of healthy teeth.

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