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RESEARCH ARTICLE

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Influence of ceramic thickness and dental substrate on the survival rate and failure load of non-retentive occlusal veneers after fatigue

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Ivoclar

Abstract

Objective: To investigate the effect of ceramic thickness and dental substrate (enamel vs. dentin/enamel) on the survival rate and failure load of non-retentive occlusal veneers.

Materials and Methods: Human maxillary molars ($n = 60$) were divided into five test-groups ($n = 12$). The groups (named DE-1.5, DE-1.0, DE-0.5, E-1.0, E-0.5) differed in their dental substrate (E = enamel, DE = dentin/enamel) and restoration thickness (standard: 1.5 mm, thin: 1.0 mm, ultrathin: 0.5 mm). All teeth were prepared for non-retentive monolithic lithium-disilicate occlusal veneers (IPS e.max Press, Ivoclar). Restorations were adhesively cemented (Syntac Classic/Variolink II, Ivoclar) and exposed to thermomechanical fatigue (1.2 million cycles, 1.6 Hz, 49 N/ 5–55°C). Single load to failure was performed using a universal testing-machine. A linear-regression model was applied, pairwise comparisons used the Student–Newman–Keuls method ($p < 0.05$).

Results: Three dentin-based occlusal veneers (one DE-1.0, two DE-0.5) revealed cracks after fatigue exposure, which corresponds to an overall-survival rate of 95%. Load to failure resulted in the following ranking: 2142 N(DE-0.5) > 2105 N(E-1.0) > 2075 N(E-0.5) > 1440 N(DE-1.5) > 1430 N(DE-1.0). Thin (E-1.0) and ultrathin enamel-based occlusal veneers (E-0.5) revealed high failure loads and surpassed the standard thickness dentin-based veneers (DE-1.5) significantly ($p = 0.044$, $p = 0.022$).

Conclusion: All tested monolithic lithium disilicate occlusal veneers obtained failure loads above physiological chewing forces. Thin and ultrathin enamel-based occlusal veneers outperformed the standard thick dentin-based occlusal veneers.

Clinical Significance: Minimally invasive enamel-based occlusal veneer restorations with non-retentive preparation design may serve as a conservative treatment option.

KEYWORDS

ceramic thickness, ceramics, dental bonding surface, fatigue, occlusal veneer

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1 | INTRODUCTION

With multiple restorative needs, fixed prosthodontics experienced a drastic paradigm shift within the last years. While the prevalence of caries has decreased,[1,2] erosive tooth wear has significantly increased over the last years and is nowadays considered to be the third most commonly observed oral condition after caries and periodontal disease.[3] The global erosion prevalence is specified between 20% and 45% for permanent teeth, with a difference in gender, age and global distribution.[4] When erosive tooth wear has progressed to a certain extent a full-mouth rehabilitation is often necessary.[5] Considering that these patients are generally rather young,[6] a conventional therapy, comprising elective root canal treatments and invasive full-coverage crown preparations with an average tooth structure removal of 67.5%–75.6%, should be avoided.[7] Hence, minimally invasive treatment concepts with defect-oriented preparation designs evolved.[8,9] Various techniques for full-mouth rehabilitations to reconstruct the vertical dimension of occlusion (VDO) have been described in literature.[10–12] Compared to resin composites, glass ceramic materials offer a higher abrasion resistance, biocompatibility and color stability[13] eventually resulting in higher survival rate and lower risk of fracture.[14] Lithium disilicate (LDS) glass ceramic has shown to be a reliable material for the fabrication of minimally invasive restorations in terms of esthetic, mechanical properties[15] and clinical long-term survival.[16,17] Based on these in-vitro and clinical data, the manufacturer reduced the minimum occlusal layer thickness for adhesively bonded IPS e.max restorations to 1 mm.[18] It has been recently reported that LDS complete and partial coverage posterior restorations presented high cumulative survival rates in a 16.9-year follow-up with no differences in survival between thickness of ≥1 or < than 1 mm.[19] With the great success of anterior veneers,[20] the concept of defect-oriented minimally invasive restorations was transferred as an occlusal veneer to the posterior area.[21] Clinical data on these treatment concepts are still scarce.[17,22,23] The few available clinical studies report high clinical success, but are limited to small-sized cohorts and the applied preparation designs showed high variation in restoration thicknesses (0.4–1.3 mm) and different marginal finishing lines.[17,23] Moreover, one clinical study on chairside-fabricated zirconia-reinforced lithium silicate ceramic partial crowns with reduced material thicknesses (0.5–0.74 and 0.75–1.00 mm) demonstrated that material thickness and position of the restoration (molars vs. premolars) are risk factors affecting the survival and success rate of such restorations.[22] All complete fracture failures occurred in restorations with reduced thickness (0.5–0.74 mm) and were placed on molars. Hence ceramic bulk fracture is still the most common complication of partial coverage restorations in clinical observation.[24] An array of factors such as mechanical properties of the restoration material, cementation protocol, applied occlusal load and cavity as well as restoration geometry affect these clinical fracture failures. Hence there is a need to systematically evaluate the failure mechanisms of ceramic systems in in vitro studies where key aspects such as preparation designs, restoration thickness and bonding substrate can be selectively analyzed under highly standardized conditions. A recent systematic review summarized current in vitro studies on ceramic occlusal veneers and pointed out the heterogeneity of preparation designs and evaluation methods.[25]

Many preparation designs for posterior partial coverage restorations evolved from the recommendations applied for gold cast restorations with mechanical retention such as an isthmus, proximal boxes and additional circumferential shoulder preparations.[26,27] Today with the advancement of adhesive dentistry non-retentive preparation designs were developed. However the presented preparation designs on molars differ in occlusal reduction[13,28,29] with a range from 0.3 up to 1.0 mm or describe occlusal reductions of 1.5–2.0 mm[26,30] that exceed minimally invasive dentistry and are therefore of limited clinical relevance. Regarding preparation geometry no consensus exists, since some authors use preparation designs that are limited to an occlusal reduction[28,31] whereas others suggest different heights of circumferential preparation finishing lines[32] or bevel of the cusps.[33] Many studies even fail to present detailed description of the applied preparation design or amount of tooth structure removal.[25,34,35] The impact of enamel and dentin as a bonding substrate on the performance of occlusal veneers is discussed controversial in the present dental literature.[29,36] In vitro data for non-retentive occlusal ceramic veneers that evaluate the influence of different bonding substrates (enamel vs. dentin) on fracture failure are still sparse.[28,32,33,37] Hence there is a need for further investigations to provide evidence-based recommendations for the preparation design of occlusal veneers with a non-retentive geometry under clinical relevant conditions. Therefore, the aim of this in vitro study was to investigate how restoration thickness and dental substrate affect the failure load of molars restored with minimally invasive occlusal veneers with non-retentive preparation design after fatigue. The tested null-hypotheses were that (I) ceramic thickness (II) and dental substrate would not affect the failure load of posterior LDS occlusal veneer restorations.

2 | MATERIALS AND METHODS

2.1 | Specimen preparation

A total number of 60 extracted human maxillary molars were divided into five groups of 12 specimens each. The groups (named DE-1.5, DE-1.0, DE-0.5, E-1.0, and E-0.5) differed in dental substrate type (E = enamel, DE = dentin/enamel) and restoration thickness (standard:1.5 mm, thin:1.0 mm, ultrathin:0.5 mm). The group of standard layer thickness (DE-1.5) served as control. Third maxillary molars with an average dimension of 8.5 ± 0.8 mm mesiodistal and 10 ± 0.8 mm buccopalatal were selected and measured with a digital caliper (500–197-20 Mitutoyo, Kawasaki, Japan). All teeth were free of caries, cracks and fillings. The extracted teeth were cleaned and stored in a 0.1% thymol solution at room temperature. Subsequently, all teeth were embedded into an autopolymerizing resin (Technovit 4000; Heraeus Kulzer, Wernheim, Germany). For the purpose of standardization, all preparations were performed by one experienced prosthodontist. Occlusal reduction was performed and two diagonally set shallow notches (0.2 mm depth) were prepared to facilitate restoration positioning during adhesive cementation (Figure 1). The preparation was carried out with coarse-grained diamonds (nos. 806314158534

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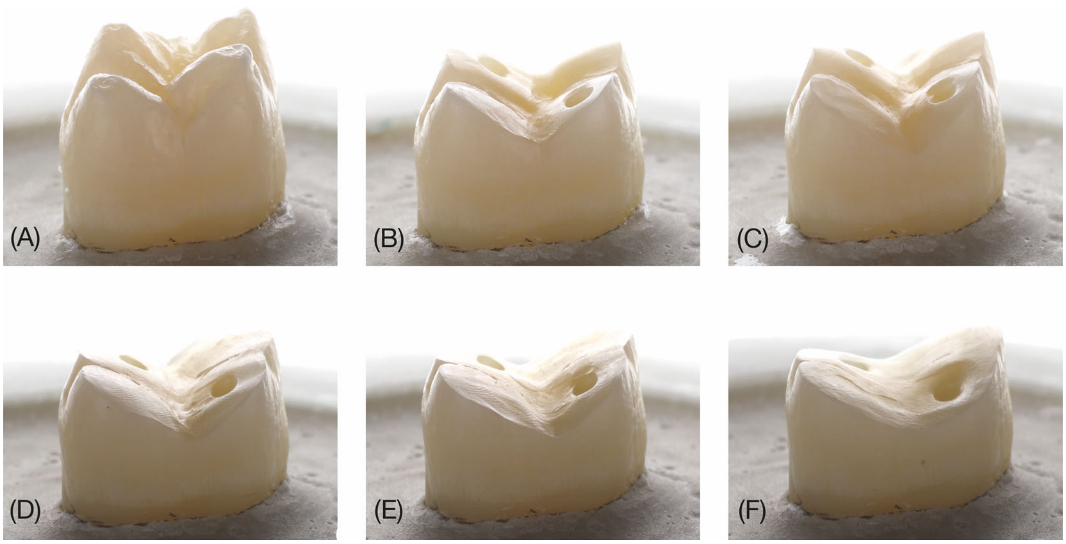

FIGURE 1 Non-retentive preparation design with diagonally placed round notches. The non-retentive preparation design is limited to occlusal reduction. (A) Without preparation (B) Enamel-based group E-0.5 ultrathin (C) Enamel-based group E-1.0 thin (D) Dentin-based group DE-0.5 ultrathin (E) Dentin-based group DE-1.0 thin (F) Dentin-based group DE-1.5 standard.

012 and 806314001534 014; Brasseler, Lemgo, Germany) and the surfaces were refined with fine-grained diamonds of congruent shape (nos. 806314158514 012 and 806314001514 012; Brasseler) under water cooling. A silicone impression (Twinduo, Picodent GmbH, Wipperfürth, Germany) was sectioned three times in buccolingual direction to verify and control tooth substance removal during the preparation.

2.2 | Fabrication of ceramic restorations

After preparation, impressions were made with trays for single impression (Miratray-Mini, Hager & Werken, Duisburg, Germany) using a silicone impression material (Affinis; Coltène/Whaledent AG, Altstätten, Switzerland). The impressions were poured with type 4 dental stone plaster (GC Fuji Rock EP; GC Europe N.V., Leuven, Belgium). All restorations were manufactured from a pressable lithium-disilicate glass–ceramic (IPS e.max Press; Ivoclar, Schaan, Liechtenstein) according to manufacturer's recommendations. During the fabrication process the layer thicknesses were carefully controlled. All restorations thicknesses were verified in wax and before cementation with a caliper (Kroeplin GmbH, Schlüchtern, Germany).

2.3 | Adhesive cementation of ceramic restorations

Prior to cementation the intaglio surfaces of the ceramic restorations were etched with 4.9% hydrofluoric acid (IPS Ceramic Etchant; Ivoclar) for 20 s, then thoroughly rinsed with air–water spray and air-dried. Afterwards, the restorations were silanized with a coupling agent (Monobond S; Ivoclar) for 60 s, dried again and a bonding agent was applied (Heliobond; Ivoclar). According to the Total etch procedure, the prepared teeth were pretreated with phosphoric acid at 37% (Total Etch; Ivoclar) for 30 s on enamel and 15 s on dentin, rinsed with water and gently air-dried.

Further pretreatment was carried out with the Syntac Classic System (Syntac Primer, Syntac Adhesive and Heliobond; Ivoclar) according to manufacturer's instructions. A dual-curing adhesive resin cement (Variolink II, Ivoclar) was applied to the inner surface of the restoration. Subsequently, the restoration was placed on the prepared tooth and seated with finger pressure. The prepared occlusal notches ensured a secured positioning and seating. Excess cement was carefully removed with foam pellets. The restoration margins were then covered with glycerin-gel (Liquid Strip; Ivoclar) and LED-light curing (Bluephase C8 with 800 mW/cm^2, Ivoclar) was conducted for 20 s from each surface.

2.4 | Fatigue test

All specimens were exposed to mouth-motion fatigue using a computer-controlled mastication-simulator (CS-4.8, SD Mechatronik, Feldkirchen-Westerham, Germany) with a load of 49 N at 1.6 Hz for 1.2 million cycles and simultaneous thermocycling (5–55°C, dwell time 60 s) simulating 5 years of clinical exposure.[38,39] Steatite spheres (Hoechst Ceram Tec, Wunsiedel, Germany) with a diameter of 6 mm were used as antagonists. Cyclic fatigue testing was performed horizontally by sliding the indenter 0.5 mm downwards the distopalatal cusp toward the central fissure.[40] During fatigue application, test specimens were examined regularly for cracks, fractures, or debonding.

2.5 | Load to failure

After fatigue testing, all restorations of each group underwent single load to failure (SLF) testing in a universal testing machine

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(Zwick Z010/TN2S, ZwickRoell GmbH & Co KG, Ulm, Germany). The load was applied axially until fracture occurred. A steel ball (6 mm diameter; crosshead speed 1.5 mm/min) was centered on the main fissure of each specimen in order to apply the load evenly to the cusps.[33] Failure loads were recorded with a computer software (testXpert II V7.1, ZwickRoell).

2.6 | Failure analysis

All specimens were visually evaluated for failure analysis using an optical microscope with a 5- and 10-fold magnification (Carl Zeiss AG, Jena, Germany). Failure modes were classified as follows: (I) Crack formation within the ceramic, (II) Cohesive fracture within the ceramic, intact tooth, (III) Fracture within ceramic and tooth structures, (IV) Serious/longitudinal ceramic and tooth fracture involving the root.

2.7 | Statistical analysis

For descriptive exploration of the data, boxplots were calculated and graphically displayed. A linear regression model with subsequent pairwise comparisons was applied to display correlations of layer thickness and dental substrate. Pairwise comparisons were corrected for multiple comparisons using the Student–Newman–Keuls method. The level of statistical significance was set at $p < 0.05$. Statistical analyses were performed using STATA 13.1 (StataCorp LP, College Station, TX, USA).

3 | RESULTS

3.1 | Fatigue exposure

All specimens showed superficial wear after fatigue exposure, located in the area between the mesio- and distobuccal cusps caused by the lateral sliding movements of the antagonist. Thermo-mechanical aging of 5 years[38] resulted in an overall-survival rate of 95%. No fractures were observed after fatigue in enamel-based specimens, but three dentin-based specimens (one of group DE-1.0 after 454,557 cycles, two of group DE-0.5 after 612,553 cycles and 852,964 cycles) revealed cracks after chewing simulation (Table 1 and Figure 2). These cracks only occurred in thin and ultrathin dentin-based restorations.

3.2 | Single load to failure

The results of the SLF test are listed in Table 2. Mean failure load values resulted in the following ranking: 2142 N (DE-0.5) > 2105 N (E-1.0) > 2075 N (E-0.5) > 1440 N (DE-1.5) > 1430 N (DE-1.0). Comparison of all five groups determined significant differences between all specimens ($p = 0.009$).

Subsequent pairwise comparisons revealed significantly higher failure load values of the groups E-1.0 and E-0.5 compared to the control group DE-1.5 (DE-1.5/E-1.0 $p = 0.044$; DE-1.5/E-0.5 $p = 0.022$; p-values corrected by Student–Newman–Keuls method).

Considering solely the ceramic thickness, no significant differences regarding failure loads could be observed ($p = 0.086$). The

TABLE 1 Survival rates after simulated fatigue exposure of 5 years.

Group	Subgroup	Intact specimens after chewing simulation	Survival rate of groups	Survival rate of substrate	Overall survival rate
DE	DE-1.5	12/12	100%	Dentin-based 91.7% 33/36	95%
DE	DE-1.0	11/12 (crack after 454,557 cycles)	91.7%		
DE	DE-0.5	10/12 (cracks after 612,553 cycles and 852,964 cycles)	83.3%		
E	E-1.0	12/12	100%	Enamel-based 100% 24/24	
E	E-0.5	12/12	100%		

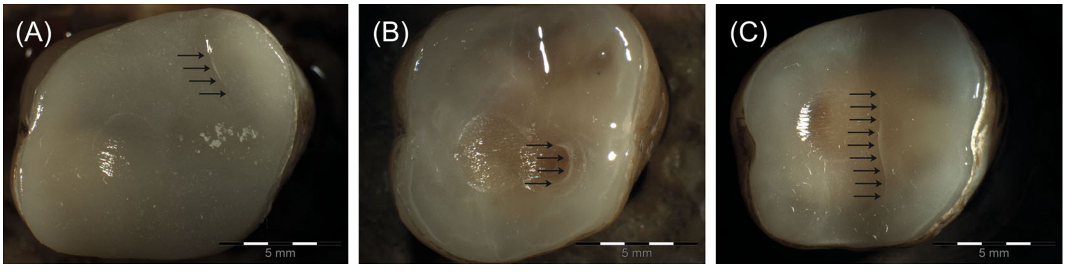

FIGURE 2 Occlusal veneer restorations after fatigue exposure showing superficial wear caused by the antagonists. The arrows mark the cracks. (A) DE-1.0 after 454,557 cycles, (B) DE-0.5 after 852,964 cycles, (C) DE-0.5 after 612,553 cycles.

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TABLE 2 Failure load results of all tested groups (N = Newton).

Group name	Min	1st Qu	Median	Mean	3rd Qu	Max	SD
DE-1.5	762	1100	1305	1440	1465	2770	565
DE-1.0	1010	1185	1405	1430	1645	1870	287
DE-0.5	1070	1725	1885	2142	2720	3480	787
E-1.0	1320	1530	2045	2105	2565	3160	627
E-0.5	1130	1215	1890	2075	2990	3310	879

Note: 1st Qu, 25% of data were below this value; 3rd Qu, 75% of data were below this value; Max, maximum; Median, 50% of data were below this value; Min, minimum; SD, Standard deviation.

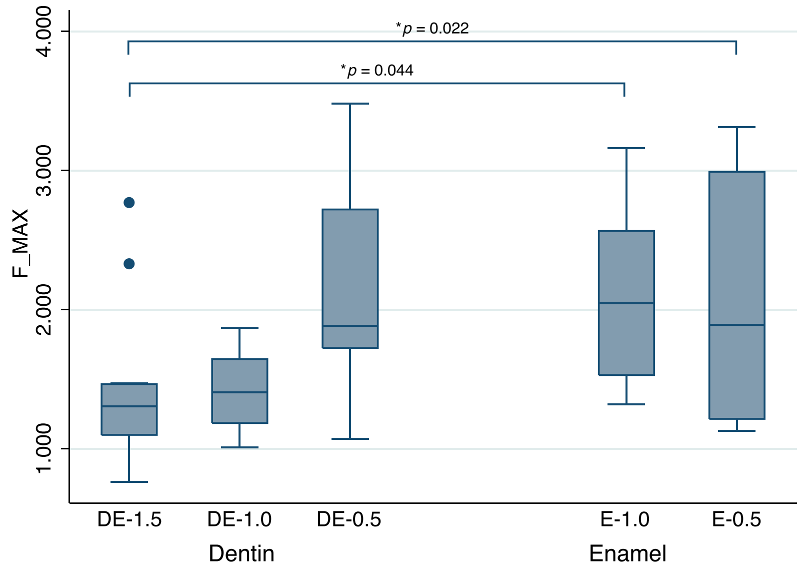

FIGURE 3 Failure load results (N) illustrated as boxplots for non-retentive occlusal veneer restorations. Groups were arranged according to bonding surface (enamel vs. dentin/enamel) at different ceramic thicknesses. Statistically significant differences ($p < 0.05$) are indicated by asterisks and solid lines.

TABLE 3 Failure mode description after SLF.

Group name	Failure mode (%) I	II	III	IV
DE-1.5	33.3	8.3	8.3	50.0
DE-1.0	66.7	16.7	16.7	0
DE-0.5	25.0	50.0	25.0	0
E-1.0	58.3	25.0	8.3	8.3
E-0.5	0	33.3	58.3	8.3
Overall	36.7	26.7	23.3	13.3

Note: Occurrence of failure modes for each group are given as percentage rate. I: Crack formation within the ceramic, II: Cohesive fracture within the ceramic, intact tooth, III: Fracture within ceramic and tooth structures, IV: Serious/longitudinal tooth fracture involving the root.

effect of the dental substrate solely was also not significant ($p = 0.126$). These results are graphically displayed in Figure 3.

3.3 | Failure analysis after SLF

Failure mode analysis after SLF testing is given in Table 3. Crack formation within the ceramic (Type I) was identified as the dominant failure mode for thin non-retentive occlusal veneers (DE-1.0, E-1.0). Dentin-based ultrathin occlusal veneers (DE-0.5) failed predominately because of cohesive fractures within the ceramic material with an intact tooth structure (Type II), while enamel-based ultrathin occlusal veneers (E-0.5) predominately exhibited fracture failures that involved the ceramic material and the underlaying tooth structure (Type III). The highest number of longitudinal fractures extending into the root (Type IV) occurred in the group with standard thickness (DE-1.5).

4 | DISCUSSION

All groups achieved failure loads beyond physiological chewing forces (50–250 N physiological, 500-900 N parafunctional[41]). The tested null-hypothesis was rejected as thin (E-1.0) and ultrathin enamel-based occlusal veneers (E-0.5) revealed higher failure loads and significantly surpassed the standard thick dentin-based veneers (DE-1.5). The significant better performance of enamel-based thin and ultrathin restorations (E-1.0 and E-0.5) could be attributed to the superior biomechanical properties of enamel in comparison to dentin-based restorations. The preservation of the dentin-enamel junction (DEJ) in enamel-based occlusal veneers provides the capacity to arrest cracks due to the shift in elastic modulus between both substrate structures (enamel to dentin)[42,43] and an increased retention of the resulting

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gradient structure compared to DE-1.5.[44] A decrease of elastic modulus from the enamel surface (E > 115 GPa) to the DEJ (E < 70 GPa) with resulting gradients up to a factor of two has been reported for human molars.[44,45] Furthermore, the preservation of tooth structure is one of the main reasons for the superiority of the enamel-based occlusal veneer groups, since the correlation of strength degradation with an increased loss of tooth structure is well known.[46] Any loss of tooth structure whether due to caries, erosions or extensive preparation designs leads to a weakening of the tooth-restoration-complex.[47] Therefore, fracture failures of extensively prepared teeth are commonly reported as catastrophic.[48] This assumption is in accordance with the finding that ultrathin enamel (E-0.5: 2075 N) but also dentin-based occlusal veneers (DE-0.5: 2142 N) achieved the highest failure load values within the present study. However, no significant difference was observed between both substrate groups with a thickness of 0.5 mm (E-0.5 and DE-0.5). Based on the hypothesis mentioned above (high mechanical properties due to the preservation of enamel, dentin and the DEJ), the high failure load values of both groups were likely the result of tooth substance preservation to an extent where restoration thickness and bond strength differences between enamel and dentin showed less impact to the loading scenario than human teeth's mechanical properties. Literature shows that the adhesive bond to enamel is superior compared to dentin,[32,49] especially when total-etch protocols are applied.[50] The bond strength of ceramic restorations luted to enamel is about 26 MPa regardless of manufacturer's luting protocol, while the bond strength to dentin can vary between 15 and 29 MPa depending on the adhesive system applied.[36] Hence preserving any enamel during preparation is essential to extend the lifetime of a restoration,[13] which is confirmed by the fact that no cracks occurred in the enamel-based groups (E-1.0 and E-0.5) during fatigue exposure. Overall, fatigue testing resulted in a cumulative 5-year in vitro survival rate of 95%.

After SLF testing, crack formation within the ceramic was identified as the dominant failure mode for thin and ultrathin non-retentive occlusal veneers. This is in accordance with a previous study, where this failure mode was also predominantly detected for thin (0.5/0.8 mm) IPS e.max CAD occlusal veneers.[51] Failures within the ceramic commonly lead to radial cracks, which emerge as a result of flexure of the brittle ceramic restoration over the less rigid tooth substance upon loading.[52] For standard thickness dentin-based veneers (DE-1.5) predominantly catastrophic fractures involving the root were observed. This could be attributed to the higher tooth substance removal and more extensive preparation design. A comparison of different onlay preparations with and without occlusal and proximal box preparation has shown that ceramic onlays without boxes revealed a significantly higher fracture resistance.[26] A recent study comparing different intraoral scanning systems also identified a simplified minimally invasive preparation design without isthmus reduction as most accurate since vertical walls and angles are more susceptible to misalignment errors.[53] This is in accordance with other investigations reporting that the accuracy is inversely proportional to the complexity of the preparation design.[54,55] Current minimally invasive designs include either additional circumferential round shoulder preparation[17] or are limited to an occlusal reduction.[28,31] A comparison of both preparation designs showed that the most conservative (solely anatomical occlusal reduction) non-retentive design revealed the highest fracture resistance.[26,56] Other studies applied a beveling of the cusps by extending finishing lines outside the occlusal plane.[33,36] Although beveled preparations were recommended previously due to improved aesthetics and enhanced adhesive cementation procedures,[57] a finite element analysis on beveled versus non-beveled occlusal veneers showed that beveled preparations presented notably higher tensile stresses in the ceramic and underlying substrates than the non-beveled groups.[58]

Previous studies investigated posterior occlusal LDS (IPS e.max CAD) veneers with different layer thicknesses of 0.3–1.5 mm using different chewing loads and different numbers of masticatory cycles.[25] A direct comparison is difficult, since the study design and methodological differences have a considerably high impact on failure load results.[28] Comparable failure load values of 2355 N for 0.5–0.8 mm[36] and 1631 N for 0.3–0.6 mm[33] thick enamel-based veneers were found in two previous in vitro studies investigating the survival rate of posterior occlusal LDS (IPS e.max CAD) veneers by using a thermo-mechanical fatigue protocol (thermocycling: 7500 cycles/5–55°, loading: 600.000 cycles, 2 Hz, 98 N) with a higher load but lower cycles compared to the present study. Failure loads of 1178 ± 588 N (0.5 mm) and 1530 ± 440 N (1 mm)[29] for enamel-based and 1191 ± 382 N (0.5 mm) and 1851 ± 631 N (1 mm)[37] for dentin-based occlusal LDS (IPS e.max Press) veneers were reported in studies using the same thermomechanical fatigue protocol and a similar preparation design as in the present study. However, the specimens of the aforementioned study revealed already cracks at 450 N.[37] In another in vitro study, all IPS e.max CAD veneers with a layer thickness of 0.3/0.5 mm tolerated cyclic loading of 1 million cycles at 100 N without any cracking, however, no single load to failure testing was applied.[13]

A clinical long-term study on minimally invasive LDS (IPS e.max Press) onlays with a defect specific layer thickness reported a 100% survival rate over up to 13 years of observation.[17] However, in contrast to the present study a shoulder preparation (1 mm) reduction was applied. A recent clinical short-term study[23] over 3 years compared a resin nano ceramic (Lava Ultimate) to LDS (IPS e.max CAD) and recorded a 100% survival rate for posterior non-retentive LDS occlusal veneers (0.4–1.3 mm thickness).

Currently, zirconia is being explored for minimally invasive restorations.[52,59] Yet, it should be considered, that only a few studies are available and clinical long-term data for the application of zirconia occlusal veneers are still missing.

One limitation of this study is the in vitro test set-up itself, as clinical conditions can only be simulated to a certain extent. Depending on the individual anatomical cusp angle of the clinical crown and tooth substance removal, the angulation of the prepared cusps varied between the groups. This needs to be considered, since previous studies reported that the failure frequency increased with a steep cusp inclination (i.e., decreased cusp angle) compared to medium or flat cusp angles.[60,61] Therefore, the inclination of the preparation angle may have influenced the results. Moreover, since extracted human

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molars were used, standardization of teeth due to age and size differences is limited.[62] Morphological variations among the extracted teeth might have further resulted in variations of failure load values and in a relatively high standard deviation.

Layer thickness of enamel-based occlusal veneers was reduced to 0.5 mm; manufacturer's recommendations should be considered. Further clinical long-term studies are necessary to confirm the present results in vivo.

5 | CONCLUSION

All tested monolithic lithium disilicate non-retentive occlusal veneers withstood failure loads above physiological chewing forces. Thin (1.0 mm) and ultrathin (0.5 mm) enamel-based occlusal veneers outperformed the standard thick dentin-based occlusal veneer restorations and may serve as a tooth substance preserving treatment option.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Fleming E, Afful J. Prevalence of total and untreated dental caries among youth: United States, 2015-2016. *NCHS Data Brief*. 2018;307:1-8.
2. Frencken J. Caries epidemiology and its challenges. *Monogr Oral Sci*. 2018;27:11-23.
3. Bartlett D, Dattani S, Mills I, et al. Monitoring erosive toothwear: BEWE, a simple tool to protect patients and the profession. *Br Dent J*. 2019;226(12):930-932.
4. Schlueter N, Luka B. Erosive tooth wear – a review on global prevalence and on its prevalence in risk groups. *Br Dent J*. 2018;224(5):364-370.
5. Carvalho TS, Colon P, Ganss C, et al. Consensus report of the European Federation of Conservative Dentistry: erosive tooth wear – diagnosis and management. *Clin Oral Investig*. 2015;19(7):1557-1561.
6. Wazani BE, Dodd MN, Milosevic A. The signs and symptoms of tooth wear in a referred group of patients. *Br Dent J*. 2012;213(6):E10.
7. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. *Int J Periodontics Restorative Dent*. 2002;22(3):241-249.
8. Fradeani M, Barducci G, Bacherini L. Esthetic rehabilitation of a worn dentition with a minimally invasive prosthetic procedure (MIPP). *Int J Esthet Dent*. 2016;11(1):16-35.
9. Araujo E, Perdigao J. Anterior veneer restorations – an evidence-based minimal-intervention perspective. *J Adhes Dent*. 2021;23(2):91-110.
10. Goldstein G, Goodacre C, MacGregor K. Occlusal vertical dimension: best evidence consensus Statement. *J Prosthodont*. 2021;30(S1):12-19.
11. Oudkerk J, Eldafrawy M, Bekaert S, Grenade C, Vanheusden A, Mainjot A. The one-step no-prep approach for full-mouth rehabilitation of worn dentition using PICN CAD-CAM restorations: 2-yr results of a prospective clinical study. *J Dent*. 2020;92:103245.
12. Mainjot AKJ, Charavet C. Orthodontic-assisted one step- no prep technique: a straightforward and minimally-invasive approach for localized tooth wear treatment using polymer-infiltrated ceramic network CAD-CAM prostheses. *J Esthet Restor Dent*. 2020;32(7):645-661.
13. Heck K, Paterno H, Lederer A, Litzenburger F, Hickel R, Kunzelmann KH. Fatigue resistance of ultrathin CAD/CAM ceramic and nanoceramic composite occlusal veneers. *Dent Mater*. 2019;35(10):1370-1377.
14. Liu M, Gai K, Chen J, Jiang L. Comparison of failure and complication risks of porcelain laminate and indirect resin veneer restorations: a meta-analysis. *Int J Prosthodont*. 2019;32(1):59-65.
15. Zhang Y, Vardhaman S, Rodrigues CS, Lawn BR. A critical review of dental lithia-based glass-ceramics. *J Dent Res*. 2023;220345221142755:245-253.
16. Aslan YU, Uludamar A, Ozkan Y. Clinical performance of pressable glass-ceramic veneers after 5, 10, 15, and 20 years: a retrospective case series study. *J Esthet Restor Dent*. 2019;31(5):415-422.
17. Edelhoff D, Erdelt KJ, Stawarczyk B, Liebermann A. Pressable lithium disilicate ceramic versus CAD/CAM resin composite restorations in patients with moderate to severe tooth wear: clinical observations up to 13 years. *J Esthet Restor Dent*. 2023;35(1):116-128.
18. Ivoclar. IPS e.max Press. Monolithic Solutions. Gebrauchsinformation. Accessed: February 18, 2023. https://www.ivoclar.com/de_DE/downloadcenter/#search-text=IPS%20e-max%20Press%20Monolithic%20Solutions&details=12365
19. Malament KA, Margvelashvili-Malament M, Natto ZS, Thompson V, Rekow D, Att W. Comparison of 16.9-year survival of pressed acid etched e.max lithium disilicate glass-ceramic complete and partial coverage restorations in posterior teeth: performance and outcomes as a function of tooth position, age, sex, and thickness of ceramic material. *J Prosthet Dent*. 2021;126(4):533-545.
20. Vailati F, Gruetter L, Belser UC. Adhesively restored anterior maxillary dentitions affected by severe erosion: up to 6-year results of a prospective clinical study. *Eur J Esthet Dent*. 2013;8(4):506-530.
21. Vogl V, Hiller KA, Buchalla W, Federlin M, Schmalz G. Controlled, prospective, randomized, clinical split-mouth evaluation of partial ceramic crowns luted with a new, universal adhesive system/resin cement: results after 18 months. *Clin Oral Investig*. 2016;20(9):2481-2492.
22. Rinke S, Zuck T, Hausdorfer T, Leha A, Wassmann T, Ziebolz D. Prospective clinical evaluation of chairside-fabricated zirconia-reinforced lithium silicate ceramic partial crowns-5-year results. *Clin Oral Investig*. 2022;26(2):1593-1603.
23. Schlichting LH, Resende TH, Reis KR, Raybolt Dos Santos A, Correa IC, Magne P. Ultrathin CAD-CAM glass ceramic and composite resin occlusal veneers for the treatment of severe dental erosion: an up to 3-year randomized clinical trial. *J Prosthet Dent*. 2022;128:158.e1-158.e12.
24. Morimoto S, Rebello de Sampaio FB, Braga MM, Sesma N, Ozcan M. Survival rate of resin and ceramic inlays, Onlays, and overlays: a systematic review and meta-analysis. *J Dent Res*. 2016;95(9):985-994.
25. Sirous S, Navadeh A, Ebrahimgol S, Atri F. Effect of preparation design on marginal adaptation and fracture strength of ceramic occlusal veneers: a systematic review. *Clin Exp Dent Res*. 2022;8(6):1391-1403.
26. Falahchai M, Babaee Hemmati Y, Neshandar Asli H, Rezaei E. Effect of tooth preparation design on fracture resistance of zirconia-reinforced lithium silicate overlays. *J Prosthodont*. 2020;29(7):617-622.

17088240, 2024, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/jerd.13103 by Univ of Sao Paulo - Brazil, Wiley Online Library on [25/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

27. Gomes de Carvalho AB, de Andrade GS, Mendes Tribst JP, et al. Mechanical behavior of different restorative materials and Onlay preparation designs in endodontically treated molars. *Materials*. 2021;14(8):1923.
28. Valenzuela EBS, Andrade JP, da Cunha P, Bittencourt HR, Spohr AM. Fracture load of CAD/CAM ultrathin occlusal veneers luted to enamel or dentin. *J Esthet Restor Dent*. 2021;33(3):516-521.
29. Ioannidis A, Muehlemann S, Ozcan M, Husler J, Hammerle CHF, Benic GI. Ultra-thin occlusal veneers bonded to enamel and made of ceramic or hybrid materials exhibit load-bearing capacities not different from conventional restorations. *J Mech Behav Biomed Mater*. 2019;90:433-440.
30. Al-Zordk W, Saudi A, Abdelkader A, Taher M, Ghazy M. Fracture resistance and failure mode of mandibular molar restored by occlusal veneer: effect of material type and dental bonding surface. *Materials*. 2021;14(21):6476.
31. Noronha MDS, Carvalho MA, Do AQ, et al. Effect of thickness and CAD-CAM material on fatigue resistance of endodontically treated molars restored with occlusal veneers. *J Prosthodont*. 2023;32(2):e19-e29.
32. Clausen JO, Abou Tara M, Kern M. Dynamic fatigue and fracture resistance of non-retentive all-ceramic full-coverage molar restorations. Influence of ceramic material and preparation design. *Dent Mater*. 2010;26(6):533-538.
33. Krummel A, Garling A, Sasse M, Kern M. Influence of bonding surface and bonding methods on the fracture resistance and survival rate of full-coverage occlusal veneers made from lithium disilicate ceramic after cyclic loading. *Dent Mater*. 2019;35(10):1351-1359.
34. Zumstein K, Fiscalini L, Al-Haj Husain N, Evci E, Özcan M, Ioannidis A. Load-bearing capacity of pressable lithium disilicates applied as ultra-thin occlusal veneers on molars. *J Mech Behav Biomed Mater*. 2022;136:105520.
35. Mueller B, Pilecco RO, Valandro LF, Ruschel VC, Pereira GKR, Bernardon JK. Effect of immediate dentin sealing on load-bearing capacity under accelerated fatigue of thin occlusal veneers made of CAD-CAM glass-ceramic and resin composite material. *Dent Mater*. 2023;39(4):372-382.
36. Sasse M, Krummel A, Klosa K, Kern M. Influence of restoration thickness and dental bonding surface on the fracture resistance of full-coverage occlusal veneers made from lithium disilicate ceramic. *Dent Mater*. 2015;31(8):907-915.
37. Maeder M, Pasic P, Ender A, Ozcan M, Benic GI, Ioannidis A. Load-bearing capacities of ultra-thin occlusal veneers bonded to dentin. *J Mech Behav Biomed Mater*. 2019;95:165-171.
38. Kern M, Strub JR, Lu XY. Wear of composite resin veneering materials in a dual-axis chewing simulator. *J Oral Rehabil*. 1999;26(5):372-378.
39. DeLong R, Sakaguchi RL, Douglas WH, Pintado MR. The wear of dental amalgam in an artificial mouth: a clinical correlation. *Dent Mater*. 1985;1(6):238-242.
40. Kordass B, Amlang A, Hugger A, Behrendt C, Ruge S. Number and localization of occlusal contact areas on natural posterior teeth without dental findings – evaluations of the regional baseline study (SHIP-1) with the Greifswald digital analyzing system (GEDAS). *Int J Comput Dent*. 2022;25(1):47-56.
41. Ferrario VF, Sforza C, Zanotti G, Tartaglia GM. Maximal bite forces in healthy young adults as predicted by surface electromyography. *J Dent*. 2004;32(6):451-457.
42. Imbeni V, Kruzic JJ, Marshall GW, Marshall SJ, Ritchie RO. The dentin-enamel junction and the fracture of human teeth. *Nat Mater*. 2005;4(3):229-232.
43. Bechtle S, Fett T, Rizzi G, Habelitz S, Klocke A, Schneider GA. Crack arrest within teeth at the dentinoenamel junction caused by elastic modulus mismatch. *Biomaterials*. 2010;31(14):4238-4247.
44. Barani A, Bush MB, Lawn BR. Effect of property gradients on enamel fracture in human molar teeth. *J Mech Behav Biomed Mater*. 2012;15:121-130.
45. Cuy JL, Mann AB, Livi KJ, Teaford MF, Weihs TP. Nanoindentation mapping of the mechanical properties of human molar tooth enamel. *Arch Oral Biol*. 2002;47(4):281-291.
46. St-Georges AJ, Sturdevant JR, Swift EJ Jr, Thompson JY. Fracture resistance of prepared teeth restored with bonded inlay restorations. *J Prosthet Dent*. 2003;89(6):551-557.
47. Guess PC, Schultheis S, Wolkewitz M, Zhang Y, Strub JR. Influence of preparation design and ceramic thicknesses on fracture resistance and failure modes of premolar partial coverage restorations. *J Prosthet Dent*. 2013;110(4):264-273.
48. Stokes AN, Hood JA. Impact fracture patterns of intact and restored human maxillary central incisors. *Int J Prosthodont*. 1988;1(2):208-210.
49. Piemjai M, Arksornnukit M. Compressive fracture resistance of porcelain laminates bonded to enamel or dentin with four adhesive systems. *J Prosthodont*. 2007;16(6):457-464.
50. Al-Akhali M, Kern M, Elsayed A, Samran A, Chaar MS. Influence of thermomechanical fatigue on the fracture strength of CAD-CAM-fabricated occlusal veneers. *J Prosthet Dent*. 2019;121(4):644-650.
51. Al-Akhali M, Chaar MS, Elsayed A, Samran A, Kern M. Fracture resistance of ceramic and polymer-based occlusal veneer restorations. *J Mech Behav Biomed Mater*. 2017;74:245-250.
52. Zamzam H, Olivares A, Fok A. Load capacity of occlusal veneers of different restorative CAD/CAM materials under lateral static loading. *J Mech Behav Biomed Mater*. 2021;115:104290.
53. de Andrade GS, Luz JN, Tribst JPM, et al. Impact of different complete coverage onlay preparation designs and the intraoral scanner on the accuracy of digital scans. *J Prosthet Dent*. 2022;S0022-3913(22)00278-5.
54. Zimmermann M, Ender A, Mehl A. Local accuracy of actual intraoral scanning systems for single-tooth preparations in vitro. *J Am Dent Assoc*. 2020;151(2):127-135.
55. Schmidt A, Benedickt CR, Schlenz MA, Rehmann P, Wostmann B. Accuracy of four different intraoral scanners according to different preparation geometries. *Int J Prosthodont*. 2021;34(6):756-762.
56. Schroeder G, Rosch P, Kunzelmann KH. Influence of the preparation design on the survival probability of occlusal veneers. *Dent Mater*. 2022;38(4):646-654.
57. Veneziani M. Posterior indirect adhesive restorations: updated indications and the morphology driven preparation technique. *Int J Esthet Dent*. 2017;12(2):204-230.
58. Aliaga J, Caro RS, Hermoza M. Stress distribution in occlusal veneers with different finishing lines when applying vertical and tangential forces. *ODOVTOS-Int J Dental Sc*. 2022;24(3 (September–December)):103-114. 296, 307.
59. Gupta S, Abdulmajeed A, Donovan T, Boushell L, Bencharit S, Sulaiman TA. Monolithic zirconia partial coverage restorations: an In vitro mastication simulation study. *J Prosthodont*. 2021;30(1):76-82.
60. Preis V, Dowerk T, Behr M, Kolbeck C, Rosentritt M. Influence of cusp inclination and curvature on the in vitro failure and fracture resistance of veneered zirconia crowns. *Clin Oral Investig*. 2014;18(3):891-900.
61. Shahmoradi M, Wan B, Zhang Z, Wilson T, Swain M, Li Q. Monolithic crowns fracture analysis: the effect of material properties, cusp angle and crown thickness. *Dent Mater*. 2020;36(8):1038-1051.
62. Fernandez-Estevan L, Millan-Martinez D, Fons-Font A, Agustin-Panadero R, Roman-Rodriguez JL. Methodology in specimen fabrication for in vitro dental studies: standardization of extracted tooth preparation. *J Clin Exp Dent*. 2017;9(7):e897-e900.

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