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Relationship between internal accuracy and load-bearing capacity of minimally invasive lithium disilicate occlusal veneers

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Abstract: Purpose: To test whether internal accuracy affects the load-bearing capacity of 0.5-mm-thick occlusal veneers made out of milled or heat-pressed lithium disilicate (LS2). Materials and methods: Extracted human molars (N = 80) were divided into four groups (n = 20 each) depending on the bonding substrate (enamel [E] or dentin [D]) and the fabrication method (milling [CAD] or heat pressing [PRE]) for the occlusal LS2 veneers: (1) E-CAD, (2) D-CAD, (3) E-PRE, or (4) D-PRE. After restoration fabrication, the abutment teeth and the corresponding restorations were scanned and superimposed in order to measure the marginal and internal accuracy. After adhesive cementation, the specimens were thermomechanically aged and thereafter loaded until fracture. The load-bearing capacities (Fmax) were measured. Fmax and the marginal and internal accuracy between the groups were compared using Kruskal-Wallis test ($P < .05$) and pairwise group comparisons. In addition, the relationship between Fmax and the internal accuracy was analyzed using Spearman rank correlation. Results: Median Fmax values (and first and third quartiles) per group were as follows: 1,495 N (Q1: 932; Q3: 2'318) for E-CAD; 1,575 N (Q1: 1,314; Q3: 1,668) for E-PRE; 1,856 N (Q1: 1,555; Q3: 2,013) for D-CAD; and 1,877 N (Q1: 1,566; Q3: 2,131) for D-PRE. No statistical difference was found between the groups ($P = .0981$). Overall, the internal accuracy in the areas of the cusp ($P < .0007$) and fossa ($P < .0001$) showed significant differences. While no significant differences were detected in the marginal area ($P = .3518$), a significant correlation with a negative linear relationship was found between the 3D internal accuracy and the Fmax values ($P = .0007$). Conclusion: An increase in the internal accuracy raised the load-bearing capacity of minimally invasive LS2 occlusal veneers. In general, the restorations bonded to dentin in the occlusal regions showed a better accuracy compared to those bonded to enamel.

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Relationship between internal accuracy and load-bearing capacity of minimally invasive lithium disilicate occlusal veneers

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Key words: lithium disilicate ceramic, occlusal dental veneers, load-bearing capacity

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Abstract

Objectives: To test whether the internal accuracy affects the load-bearing capacity of 0.5 mm-thick occlusal veneers made out of milled or heat-pressed lithium disilicate (LS2).

Material and methods: Extracted human molars ($N = 80$) were divided into 4 groups ($n = 20$) depending on the bonding substrate (enamel or dentin) and the fabrication method (milling or heat-pressing) for the 0.5 mm thick occlusal lithium disilicate (LS2) veneers: milling, bonding to enamel (E-CAD) or dentin (D-CAD); fabricated by heat-pressing and bonded to enamel (E-PRE) or dentin (D-PRE). After restoration fabrication, the abutment teeth and the corresponding restorations were scanned and superimposed in order to measure the marginal and internal accuracy. After adhesive cementation, the specimens were thermo-mechanically aged and thereafter loaded until fracture. The load-bearing capacities ($F_{\max}$) were measured. $F_{\max}$ and the marginal and internal accuracy between the groups were compared using the Kruskal-Wallis test ($p < 0.05$) and pairwise group comparison. In addition, the relationship between $F_{\max}$ and the internal accuracy was analyzed using the Spearman rank correlation.

Results: Median $F_{\max}$ values (and first and third quartiles) were as follows per group: 1'495 N (Q1: 932; Q3: 2'318) for E-CAD, 1'575 N (Q1: 1'314; Q3: 1'668) for E-PRE, 1'856 N (Q1: 1'555; Q3: 2'013) for D-CAD and 1'877 N (Q1: 1'566; Q3: 2'131) for D-PRE. No statistical difference was found between the groups ($p = 0.0981$). Overall, the internal accuracy in the areas of the cusp ($p < 0.0007$) and fossa ($p < 0.0001$) showed significant differences. While no significant differences were detected in the marginal area ($p = 0.3518$), a significant correlation with a negative linear relationship was found between the 3D-internal accuracy and the $F_{\max}$ values ($p = 0.0007$).

Conclusions: An increase in the internal accuracy raised the load-bearing capacity of minimally invasive lithium disilicate occlusal veneers. In general, in the occlusal regions the restorations bonded to dentin showed a better accuracy compared to those bonded to enamel.

1. Introduction

For the treatment of a worn dentition, indirect minimally invasive restorative concepts can be indicated (1). Occlusal veneers are a suitable restorative treatment option for the posterior dentition for this indication. For these restorations, presently an enormous amount of different reconstructive materials are available on the market. They include resin-based materials, polymer-infiltrated ceramic network materials (PICN), reinforced ceramics or/and high-strength ceramics. Resin-based materials and PICN come along with a low hardness and brittleness compared to ceramic materials and thus may offer favourable properties when applied to reduced thicknesses (2). On the other hand, the high flexural strength and fracture toughness of reinforced glass ceramics or high strength ceramics could be in favour towards this application (3, 4). Lithium disilicate (LS2) – as a representative of the reinforced glass ceramics – shows favourable mechanical and bonding properties and can be used for the fabrication of these occlusal veneers (5-8). LS2 restorations can either be manufactured by heat-pressing or by CAD/CAM procedures – namely milling (9). The fabrication procedures itself has an impact on the internal accuracy of the restoration (10). The internal accuracy describes the distance between the inner surface of the restoration and the underlying tooth and thus determines the thickness of the cement layer. During fabrication, its dimension is determined by the thickness of the spacer. For pressed LS2 restorations - being manufactured with the conventional lost-wax and heat-press technique - the spacer-thickness is defined by a paint-on die spacer (11). In CAD/CAM technologies however, the spacer-thickness can be predefined during the design procedure of the restoration. This parameter has been addressed to influence the performance of all-ceramic restorations (12-14). The interface-zone between the restoration and the tooth has been accounted as the zone of crack initiation – especially in thin restorations (12). The initiated cracks can propagate towards the occlusal surface or the margin of the restoration and finally lead to catastrophic failure of the restoration (12). Thus, the mechanical stability of cemented restorations may depend on the dimensions of this zone and may decrease with increasing thickness. Besides that, the manufacturing-method of LS2 restorations can affect the mechanical resistance to fractures directly, (9) as pressed and CAD/CAM fabricated

restorations does not have the same physical properties (9). With regard to their fracture toughness, pressed restorations seem to perform superior compared to those which are CAD/CAM fabricated (9). To summarize, the selection of the material with the associated manufacturing procedure and the dimension of the spacer-thickness can have an influence on the resistance to fractures of restoration. Thus, the appropriate material selection is crucial when restoring worn teeth with ultra-thin occlusal veneers. However, little is known about the influence of these parameters on the mechanical performance of minimally invasive restorations in the load-bearing jaw regions. Furthermore, the substrate which is present for the bonding of the restoration plays a pivotal role. Therefore, the aim of the present study was to test whether the load-bearing capacity of ultra-thin occlusal veneers, made either out of pressed or milled LS2 ceramic, is influenced by their internal accuracy and the used bonding substrate. The hypothesis was that the load-bearing capacity decreases with increasing dimension of the interface zone in the occlusal area between the restoration and the tooth.

2. Material and Methods

2.1. Groups

The investigated groups (Table 1) differed in the tooth substrate on which the occlusal veneers were bonded (E: enamel or D: dentin) and in the manufacturing procedure of the lithium disilicate reinforced glass-ceramic (LS2) restorations (CAD: milling or PRE: heat-pressing). The following four groups (n = 20 per group) were assessed:

- (1) “E-CAD”: CAD/CAM fabricated LS2 occlusal veneer (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) bonded to enamel;
- (2) “E-PRE”: heat-pressed LS2 occlusal veneer (IPS e.max press; Ivoclar Vivadent) bonded to enamel;
- (3) “D-CAD”: CAD/CAM fabricated LS2 (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) bonded to dentin;
- (4) “D-PRE”: heat-pressed LS2 occlusal veneer (IPS e.max press; Ivoclar Vivadent) bonded to dentin.

2.2 Specimen preparation

80 extracted intact human molars were collected and embedded in a self-curing resin (Technovit 4071; Kulzer, Wasserburg, Germany) with the apical part facing downwards in an acrylic hollow cylinder (Figure 1). To simulate tooth wear caused by attrition, in 40 randomly selected specimens, the occlusal enamel was removed without extending into the dentin. For the other 40 specimens, defects with exposed dentin were prepared. For this purpose, the occlusal enamel was completely removed until only a border of enamel remained and the central part contained solely of dentin. In addition, in all 80 specimens, sharp edges were rounded off and if present, fissures were slightly opened with a diamond bur under water cooling. During the entire study procedures, the specimens were stored in a solution of 0.5 % chloramine T and distilled water.

2.3 Scanning procedures, restoration design and fabrication

Digital impressions of the prepared teeth were performed by means of an intraoral scanner (Cerec Omnicam; Software-Version 4.4, Sirona, Bensheim, Germany). Subsequently, the scans were transferred to a design software (InLab; Sirona) to design an occlusal restoration with a standardized thickness of 0.5 mm (range 0.3 - 0.7 mm) for each specimen.

The specimens of the groups E-CAD and D-CAD were directly milled out of pre-fabricated LS2 ceramic ingots (IPS e.max CAD; Ivoclar Vivadent) using a 5-axis milling machine (MC X5; Sirona).

For the specimens of the groups E-PRE and D-PRE, first, an acrylic polymer template (Vita CAD Waxx, Vita Zahnfabrik, Bad Säckingen, Germany) was produced by milling procedures (MC X5; Sirona). Consecutively, the template was used to produce heat-pressed LS2 restorations (IPS e.max Press; Ivoclar Vivadent) by applying the “lost-wax and press-technique”. Therefore, the template was vested (IPS PressVest Premium; Ivoclar Vivadent) and heated to complete dissolution. Thereafter, the LS2 ingot was heat pressed into the resulting space and carefully devested after cooling.

2.4 Evaluation of the marginal and internal adaption

To measure the internal adaption before cementing the restorations, an additional scanning procedure was performed. The three scans of the preparation, restoration, and the relationship between the two after setting were acquired with an intraoral scanner (3Shape Trios; 3Shape, Copenhagen, Denmark) and superimposition protocol was followed by triple-scan method introduced from several researches ([15-17](#)). The prepared teeth were scanned and the restorations were scanned with a reference structure on the occlusal surface. A third scan was taken in the occlusion mode with the restoration in place. Standard tessellation (STL) files were created and imported into a software for 3D analysis (Geomatic verify 64Bit, ver. 2015.2.0; 3D Systems, Rock Hill, SC, US). The alignment between the preparation and restoration was checked by matching the reference cubic structure with two cylinders at a right angle, which acted as the fiducial marker. This was conducted by the ‘N point align transform’, and ‘Best fit alignment’ command of the inspection software. The internal and the marginal adaptations were measured in the mesio-distal (MD) and the bucco-lingual (BL) cross-sections at different points:

2× margin MD, 2× margin BL, 2× cusp MD, 2× cusp BL, 1× fossa MD, 1× fossa BL (Figure 2). For further analysis, the measurements were pooled to margin (mean of measurements margin MD, margin BL), cusp (means of measurements cusp MD, cusp BL) and fossa (mean of measurements fossa MD, fossa BL). In addition, color maps of the 3-dimensionally (3D) assessed internal adaption were generated and the total surface between the inner surface of the restoration and the abutment tooth was measured. This 3D-internal adaption was further used for the correlation analysis to the load-bearing capacity.

2.5 Cementation protocols

The cementation protocols varied within the two different tooth substrate groups (enamel or dentin) and followed the manufacturer's recommendations. The restorations were etched for 20 s with 5 % hydrofluoric acid (HF; Ivoclar Vivadent) before water-spraying and air-drying. A silane was applied for 60 s (Monobond Plus; Ivoclar Vivadent) and gently air-dried. Enamel and dentin were etched 30 s with 35 % phosphoric acid (Ultraetch; Ultradent, Utah, USA) and subsequently sprayed with water before gently air-drying. In the groups with exposed dentin, latter was additionally conditioned (Syntac Primer/Syntac Adhesive; Ivoclar Vivadent). Thereafter, a bonding agent was applied on the prepared teeth and on to the restorations (Heliobond; Ivoclar Vivadent) before gently air-dried.

After conditioning, the restorations were adhesively bonded to the prepared teeth, using a dual-curing resin cement (Variolink Esthetic; Ivoclar Vivadent). The excess cement was carefully removed before light-curing for 6 x 40 s was performed.

2.6 Aging procedures

Thermo-mechanical aging was applied to the specimens, using a custom-made chewing simulator ([18](#)). The aging parameters were set as follows: thermo-cycling with 5 – 50° C and a dwelling time of 120 s; chewing simulation with 1'200'000 cycles of 49 N force at 1.67 Hz loading frequency. A vertical indenter with a rounded tip of Ø 8 mm and made of corrosion-free steel, was used to load the specimens in axial direction to the occlusal plane.

2.7 Static loading

After ensuring the integrity of the specimens under a stereomicroscope (magnification 1.25×), the specimens were further tested in an universal testing machine (Zwick / Roell Z010; Zwick, Ulm, Germany). In order to test the static fracture load, an indenter hit the occlusal surface of the specimen in a perpendicular direction (crosshead speed 1 mm/min) until the specimen fractured. F_{initial} , being the force needed to form the first crack, while F_{max} is the ultimate force to completely fracture the restoration. On digital photographs and with loupes (magnification 2.5×) the types of failure were identified and scored into Score 0 = no visible fracture; Score 1 = cohesive fracture within the restoration; Score 2 = cohesive fracture of the restoration and of the cement layer; Score 3 = fracture of the restoration-cement-tooth complex.

2.8 Statistical analysis

The metric variables with mean, median, standard deviations, quartiles, minimum and maximum were described. Categorical variables were summarized by counts and proportions of the categories. The comparisons of the group medians of the metric variables were performed with nonparametric methods (Kruskal-Wallis test). Multiple comparisons of two groups are based on adjusted p-values, using Dwass-Steel-Fligner method (DSF). The proportions of the categorical parameters with the chi-squares test were compared (exact p-values derived). P-values < 0.05 were considered to be statistically significant in all tests.

3. Results

3.1 Fatigue *resistance*

All tested specimens survived the thermo-mechanical aging procedures without any fracture.

3.2 Load-bearing *capacity*

The median F_{initial} values and their first (Q1) and third (Q3) interquartile amounted for E-CAD 845 N (Q1: 600; Q3: 1'500), for E-PRE 700 N (Q1: 610; Q3: 1'050), for D-CAD 1'400 N (Q1: 900; Q3: 1'500) and for D-PRE 1'100 N (Q1: 900; Q3: 1'650) (Table 2, Figure 3). Comparing the groups under investigation, significant differences (KW: $p = 0.0248$) were only found between E-PRE and D-PRE ($p = 0.0169$).

The following median F_{max} values and their respective Q1 and Q3 were found: 1'495 N (Q1: 932; Q3: 2'318) for E-CAD, 1'575 N (Q1: 1'314; Q3: 1'668) for E-PRE, 1'856 N (Q1: 1'555; Q3: 2'013) for D-CAD and 1'877 N (Q1: 1'566; Q3: 2'131) for D-PRE (Table 2, Figure 4). No statistically significant differences were found comparing the tested groups (KW: $p = 0.0981$).

3.3 Failure *types*

The Chi-squares tests comparing the failure types of all groups (Table 3) showed no statistically significant differences ($p = 0.0715$).

3.4 Marginal and internal *adaption*

The internal and the marginal adaption (Table 4) was measured in different cross-sections and at different locations: margin, cusp, fossa. In the area of the margin, medians and respective Q1 and Q3 values of 115 μm (Q1: 83; Q3: 167) were found for group E-CAD, 113 μm (Q1: 90; Q3: 137) for E-PRE, 107 μm (Q1: 86; Q3: 118) for D-CAD and 93 μm (Q1: 75; Q3: 120) for D-PRE. The medians in the area of the margins showed no significant differences between the groups (KW: $p = 0.3518$).

In the area of the cusp, the following medians and respective Q1 and Q3 were measured: 229 μm (Q1: 177; Q3: 285) for E-CAD, 239 μm (Q1: 205; Q3: 315) for E-PRE, 185 μm (Q1: 151; Q3: 211) for D-CAD and 145 μm (Q1: 105; Q3: 177) for D-PRE. Significant differences were found in this area (KW: 0.0007) between E-CAD and D-CAD (DSF: $p = 0.0495$), between E-CAD and D-PRE (DSF: $p = 0.0011$), between E-PRE and D-CAD (DSF: $p = 0.0013$) and between E-PRE and D-PRE (DSF: $p < 0.0001$).

The measurements in the area of the fossa revealed median and Q1/Q3 values of 560 μm (Q1: 451 Q3: 729) in E-CAD, 628 μm (Q1: 541; Q3: 796) for E-PRE, 264 μm (Q1: 225; Q3: 334) for D-CAD and 406 μm (Q1: 162; Q3: 580) for D-PRE. Significant differences were found also in the area of the fossa (KW: $p < 0.0001$) between E-CAD and D-CAD (DSF: $p < 0.0001$), between E-PRE and D-CAD (DSF: $p < 0.0001$) and between E-PRE and D-PRE (DSF: $p = 0.0046$).

The medians and Q1/Q3 values of the 3-dimensionally assessed internal adaption (color map) amounted of 196 μm (Q1: 159; Q3: 280) for E-CAD, 214 μm (Q1: 171; Q3: 248) for E-PRE, 186 μm (Q1: 149; Q3: 200) for D-CAD and 155 μm (Q1: 120; Q3: 187) for D-PRE. Comparing the medians of the color map measurements, significant differences were found (KW: $p = 0.0007$) between E-CAD and D-PRE (DSF: $p = 0.0172$), between E-PRE and D-CAD (DSF: $p = 0.0411$) and between E-PRE and D-PRE (DSF: $p = 0.0019$).

3.4 Correlation of internal adaption and load-bearing capacity

The measurement values of the internal adaption gathered by the color map measurements, were correlated to the F_{max} values for the load-bearing capacity by means of a Spearman correlation (Figure 5). A significant correlation with a negative linear relationship was found between these data ($p = 0.0019$). In other words, with the increasing distance between the restoration and the abutment tooth, the capacity to withstand loading forces also increased.

4. Discussion

In the present study it was disclosed that the proximity of ultra-thin restoration made of LS2 to the abutment tooth had a significant correlation to its capacity to withstand occlusal forces. In general, the restorations bonded to dentin showed a higher accuracy in the occlusal areas of the cusps and fossae compared to those bonded to enamel. Neither the fabrication method (milling / heat-pressing) nor the substrate for bonding (enamel / dentin) had an influence on the maximum load-bearing capacity of the occlusal veneers. The hypothesis that the load-bearing capacity decreases with increasing thickness of the interface zone was confirmed in this study. A significant correlation with a negative linear relationship was found between the load-bearing capacity and the internal adaption. To the knowledge of the authors, no previous study investigated this correlation.

No complications or failures in any of the tested groups occurred during the phase of artificial aging. Thus, all materials resisted the thermo-mechanical aging, which simulates dynamic loading forces under clinical conditions. The clinical conditions with temperature changes in the wet oral cavity and dynamic fatigue alterations were imitated by a chewing simulator. The used protocol of aging has been reported to simulate 5 years of clinical service ([19-21](#)).

The hypothesis of the present study was set due to the fact that the cement layer between the restoration and the tooth is contemplated to be responsible for the crack initiation ([12](#), [22](#)) and, therefore, the thickness of this zone may influence the load-bearing capacity of ceramic restorations. The thickness of the interface normally depends upon the fabrication method for LS2 ([23](#), [24](#)). The internal discrepancies of CAD/CAM fabricated LS2 restorations are known to be significantly higher than in heat-pressed ones ([23](#), [24](#)). This has also been shown in a clinical study comparing digital and conventional workflows ([25](#)). In terms of the internal adaption, this previous study showed that LS2 crowns which were fabricated by heat-pressing revealed a higher accuracy than CAD-milled LS2 restorations ([25](#)). Accordingly, another clinical study showed a higher accuracy of conventionally fabricated frameworks compared to CAD/CAM fabricated ones ([26](#)). This fact can be attributed to the

shortcomings of CAD/CAM technologies within the milling process. Narrow configurations of the inner surface cannot be accurately milled by rotating instruments. In this context it has to be mentioned that in the present investigation the wax-templates for heat-pressing were milled. For the above-mentioned reason, the drawbacks of CAD/CAM fabrication affected the internal discrepancy and consequently, the stability of the heat-pressed restorations. The present findings without differences in the internal adaption between the milled and the heat-pressed restorations reflect these thoughts. Probably on the same grounds, the here revealed results of the internal adaption differed for the restorations fabricated for the enamel compared to the restorations fabricated for the dentin specimens. In the areas of the cusps and the fossae, which reflects the internal adaption, a significantly higher accuracy was found for the dentin specimens. For methodological motives, the occlusal relief of the enamel and of the dentin specimens evidently differed. In order to mimic defects reaching into the dentinal areas, the occlusal relief of the dentin specimens were flat. In contrast, the relief of the enamel specimens were much more pronounced and thus showed more small configurations of the inner surface which might have caused inaccuracy during the milling process.

Typically, if LS2 restorations are bonded to enamel, they reveal a higher fracture resistance compared to the ones bonded to dentinal substrate (27). A previous study showed median fracture resistances of 4'173 N on enamel, whereas the values amounted to 3'840 N on dentin (27). This was not the case in the present investigation with F_{initial} and F_{max} values tending to be higher in the groups in where the restorations were cemented onto dentin. Two previous studies with very similar study conditions tested heat-pressed LS2 restorations bonded to enamel (6) and dentin (7). Similarly to the present investigation, in both studies occlusal veneers of 0.5 mm thickness were thermo-mechanically aged and consecutively loaded until fracture (6, 7). The revealed F_{max} values reached median load-bearing capacities of 1'692 (enamel) and 1'165 N (dentin) (6, 7). In contrast to the present investigation, the measurements of the previous studies followed the expected order by having a higher load-bearing capacity measured on enamel than on dentin. Comparing the fracture toughness of the LS2 fabricated by heat-pressing or milling, heat-pressed restorations seem to perform superior compared to those who are CAD/CAM fabricated (9). Although the chemical composition of these two materials is very

similar, LS2 for CAD/CAM fabrication has a larger glassy matrix and smaller crystals compared to the material being used for heat-pressing (9). The differences in the mechanical performance can be attributed to these distinctions. In the present study however, no differences between the fabrication methods were found regarding their load-bearing capacity. In contrast to the measurements of the mechanical performance of a dental material itself, here a complex of tooth-cement-restoration was tested on their mechanical behavior. One can assume that the adhesion between the restoration and the abutment tooth is capable of compensating for the individual inferior mechanical properties of the weaker material. In this context it can be imagined that the morphology of the restoration in connection with the adhesion to the tooth surface may change the classical ranking of the materials regarding their mechanical properties, as shown also in other studies (6, 7). Furthermore, as already mentioned above, the higher accuracy of the dentin-bonded restorations might be attributed to the relief differences between enamel and dentin specimens. As found in the present study, the load-bearing capacity depends on this parameter. Presumably, dentin- and enamel-bonded specimens with identical occlusal configurations would follow more the 'classic hierarchy' with enamel-bonded restorations showing a higher load-bearing capacity than dentin-bonded restorations.

In this study, the 'triple-scan method' was used to measure the internal adaptation of restorations (15-17). This protocol is a three-dimensional approach to assess the gap between abutment and restoration with three scans: abutment, restoration and restoration on top of the abutment. The three scans were obtained by an intraoral scanner. The accuracy of these scanners has been reported in previous studies (28-31). Their collective evidence is that there may be deviations in the full-arch scan depending on the performance of the scanner system. However, they show a clinically acceptable accuracy in single tooth and quadrant arch scans (31). Here very small objects were scanned, presumably 1.5 to 2 times smaller than the optical window of the intraoral scanner. This reduces the distortion which is a result of the stitching process of multiple three-dimensional scans. Regarding the distortion of the scan, a desktop scanner would have been advantageous. However, undercuts of restorations can be acquired with a higher reliability by means of an intraoral scanner. Usually, scanning of the outer and inner surface of a restoration have to be performed in two scans when a desktop scanner is used. The matching process of these two scans would include a further source for

error. Furthermore, no powder application was needed by the used intraoral scanner, while desktop scanners usually require the application of a powder which might influence the measurements. The here used method to determine the accuracy, allows an unlimited number of cross-sections and eliminates manual sources of errors that can appear in the classical replica technique (32). An acceptable validity of the measurement method employed in this study has been shown (17).

In clinical cases, the surface of severe erosive or abrasive tooth wear usually leads to the presence of sclerotic dentin. There are structural differences between sclerotic dentin and the freshly cut dentin which was used in the present study. The in vitro simulation of identical sclerotic dentin in a study set-up however, is very difficult or impossible to simulate. Nevertheless, for the above-mentioned structural differences, in this present where we could not simulate the sclerotic dentin, the results could reflect only adhesion to freshly cut dentin. However, interestingly enough clinical evidence suggests an acceptable performance over 3.5 years in terms of bonding quality after amalgam replacement (33), which may be more critical than expected than bonding to eroded dentin. Furthermore, in the presence of tooth wear, the margins enclose enamel which adds to the durability of adhesion on erosive/sclerotic dentin.

5. Conclusions

This study revealed a significant correlation of the internal adaption to the load-bearing capacity. An increase in the internal accuracy raised the load-bearing capacity of minimally invasive 0.5 mm-thick occlusal veneers made of lithium disilicate reinforced glass-ceramic. In general, the restorations bonded to dentin showed a higher accuracy in the areas of the cusps and fossae compared to those bonded to enamel. In addition, enamel- and dentin-bonded specimens did not differ regarding their load-bearing capacity.

Conflict of Interest

[REDACTED]

[REDACTED]

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Tables

Table 1 – Groups with the given substrate for bonding, the fabrication procedures and the used restorative materials with their respective chemical composition.

Group	Substrate for bonding	Fabrication procedure	Restorative material
E-CAD	Enamel	CAD/CAM milling	Lithium disilicate ceramic (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein): SiO ₂ (57 - 80 wt%), Li ₂ O (11 - 19 wt%), K ₂ O (0 - 13 wt%), P ₂ O ₅ (0 - 11 wt%), ZrO ₂ (0 - 8 wt%), ZnO (0 - 8 wt%), AlO ₃ (0 - 5 wt%), MgO (0 - 8 wt%)
E-PRE		Heat-pressing	Lithium disilicate ceramic (IPS e.max Press; Ivoclar Vivadent): SiO ₂ (57 - 80 wt%), Li ₂ O (11 - 19 wt%), K ₂ O (0 - 13 wt%), P ₂ O ₅ (0 - 11 wt%), ZrO ₂ (0 - 8 wt%), ZnO (0 - 8 wt%), other oxides (0 - 10 wt%), coloring oxides (0 - 8 wt%)
D-CAD	Dentin	CAD/CAM milling	Lithium disilicate ceramic (IPS e.max CAD; Ivoclar Vivadent, Schaan, Liechtenstein)
D-PRE		Heat-pressing	Lithium disilicate ceramic (IPS e.max Press; Ivoclar Vivadent):

Table 2 – The forces required to crack the material (F_{initial}) and the load-bearing capacity (F_{max}) in Newton for all groups under investigation with mean, standard deviation (SD), first quartile (Q1), median, third quartile (Q3), minimum (min) and maximum (max).

Group		Mean $\pm$ SD	Q1	Median	Q3	Range min to max
E-CAD	F_{initial}	992 $\pm$ 623	600	845	1500	50 to 2300
	F_{max}	1555 $\pm$ 759	932	1495	2318	176 to 2494
E-PRE	F_{initial}	837 $\pm$ 372	610	700	1050	300 to 1700
	F_{max}	1562 $\pm$ 310	1314	1575	1668	1009 to 2286
D-CAD	F_{initial}	1180 $\pm$ 454	900	1400	1500	400 to 1700
	F_{max}	1800 $\pm$ 442	1555	1856	2013	480 to 2490
D-PRE	F_{initial}	1215 $\pm$ 457	900	1100	1650	300 to 1900
	F_{max}	1861 $\pm$ 364	1566	1877	2131	1139 to 2446

Table 3 – The marginal and internal adaption in μm for all groups under investigation with mean, standard deviation (SD), first quartile (Q1), median, third quartile (Q3), minimum (min) and maximum (max) at the different locations “margin”, “cusp”, “fossa”, as well as the 3D-adaption measurements (“color map”). Significant differences were detected in the area of the cusp (dashed line), fossa (dotted line) color map (continuous line).

Group	Location	Mean $\pm$ SD	Q1	Median	Q3	Range min to max	Significances
E-CAD	Margin	127 $\pm$ 57	83	115	167	50 to 281	
	Cusp	127 $\pm$ 57	177	229	285	142 to 441	
	Fossa	635 $\pm$ 270	451	560	729	351 to 1448	
	Color map	216 $\pm$ 67	159	196	280	147 to 375	
E-PRE	Margin	115 $\pm$ 40	90	113	137	55 to 192	
	Cusp	258 $\pm$ 67	205	239	315	177 to 404	
	Fossa	663 $\pm$ 155	541	628	796	370 to 973	
	Color map	212 $\pm$ 38	171	214	248	150 to 264	
D-CAD	Margin	109 $\pm$ 29	86	107	118	72 to 181	
	Cusp	180 $\pm$ 38	151	185	211	120 to 252	
	Fossa	287 $\pm$ 106	225	264	334	95 to 539	
	Color map	176 $\pm$ 34	149	186	200	114 to 232	
D-PRE	Margin	99 $\pm$ 36	75	93	120	49 to 188	
	Cusp	145 $\pm$ 55	105	145	177	47 to 261	
	Fossa	397 $\pm$ 228	162	406	580	66 to 798	
	Color map	156 $\pm$ 42	120	155	187	82 to 238	

— — — — — Cusp

..... Fossa

————— Color map

Table 4 – Failure types with percentage of no visible fracture (score 0), cohesive fracture within the restoration (score 1), cohesive fracture of the restoration and of the cement layer (score 2) and fracture of the restoration-cement-tooth complex (score 3).

Group	Score 0 [%]	Score 1 [%]	Score 2 [%]	Score 3 [%]
E-CAD	5	15	75	5
E-PRE	5	0	95	0
D-CAD	0	0	100	0
D-PRE	5	0	95	0

Figures

Figure 1 – Schematic drawing of the embedded specimen with the preparations within enamel (E-CAD and E-PRE) or with exposed dentin (D-CAD and D-PRE). The restorations consisted of 0.5 mm thick occlusal veneers made out of lithium disilicate with different fabrication techniques (E-CAD and D-CAD: milling; E-PRE and D-PRE: heat-pressing).

Figure 2 – Cross section for the measurement of the marginal and internal adaption. In mesio-distal (M-D) and disto-lingual (D-L) direction the measurements areas were at the margins, the cusps and the fossae.

Figure 3 – Box-plots with the F_{initial} values.

Figure 4 – Box-plots with the $F_{\max}$ values.

Figure 5 – Fit plot for $F_{\max}$ and the internal adaption (color map) of all groups pooled.

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