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The effect of immediate dentin sealing on fracture resistance and failure modes of resin composite onlay restorations

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Abstract

Aim: This study aimed to investigate the fracture resistance, failure modes, and reparability of molars restored with laboratory-processed resin composite (Ceramage, SHOFU Inc., Kyoto, Japan) onlays above or below the cemento-enamel junction (CEJ) in the presence or absence of immediate dentin sealing (IDS).

Methodology: Forty extracted sound human molars were selected and divided into four groups: 1) Below CEJ with IDS, 2) Below CEJ without IDS, 3) Above CEJ with IDS, and 4) Above CEJ without IDS. Standardized mesio-occlusal (MO) onlay preparations were made with the reduction of mesio-buccal and mesio-palatinal cusps. Butt-joint preparation was used in the proximal box area extending 1 mm below the CEJ (Groups 1 and 2) or 1 mm above the CEJ (Groups 3 and 4). In Groups 1 and 3, IDS was applied immediately after tooth preparation. After cementation (Variolink N, Ivoclar Vivadent AG, Schaan, Liechtenstein), the specimens were thermally aged (20000 cycles, 5-55 °C) and then subjected to load to failure (1 mm/min). The failure types and reparability of the onlays were recorded, and the data were analyzed using two-way ANOVA and Fisher's exact tests.

Results: The restorations in Group 4 showed the highest mean fracture strength compared to Group 1 (p=0.038), Group 2 (p=0.008), and Group 3 (p=0.019). The interaction between the level of proximal extension and the presence of IDS did not influence fracture mode or reparability (p>0.05).

Conclusion: No difference in the fracture strength of resin composite onlays below CEJ with or without IDS was found; however, not using IDS for resin composite onlays above CEJ appears to be preferable.

Keywords: Onlays, fracture strength, immediate dentin sealing, composite resin

Introduction

On small-to-moderate defects in load-bearing posterior areas, there is a consensus that direct resin composite restoration is the treatment of choice (1, 2). However, there is ongoing debate about the best treatment option for larger defects extending below the cemento-enamel junction (CEJ) and involving cusp replacement (2). Indirect restoration of these defects with partial coverage has gained popularity for its conservative approach compared to that of full crown restorations (3). With immediate dentin sealing (IDS) and direct composite build-ups to remove undercuts, even more conservative treatment can be achieved without sacrificing sound tooth tissue to maintain the tapered preparation design for partial indirect restorations (4, 5).

In this context, the practice of sealing dentin immediately following tooth preparation using a dentin bonding agent applied to the freshly cut dentin, known as immediate dentin sealing (IDS), was defined in the early 1990s (6). The application of IDS has benefits of enhanced adhesion, decreased bacterial leakage, and reduced post-operative sensitivity, improved bond strength of resin-based materials and ceramic restorations to dentin (7). Furthermore, IDS can be followed by the application of a thin layer of flowable resin composite (8, 9).

Based on the degree of substance loss, partial coverage restorations can be classified as inlays (no cusp involved), onlays (involvement of at least one cusp), or overlays (involvement of all cusps) (3). Among the numerous materials available for indirect partial restorations, ceramic and resin composite-based materials are the most widely used. Resin composites might be preferable for partial indirect restorations regarding the advantages such as ease of fabrication, repair, and less abrasive wear potential of the enamel antagonist compared to ceramics (10).

Although ceramics have better strength properties to resist compressive forces, they are more prone to fracture due to low tensile strength than resin composites (11). The main cause of failure of partial ceramic or resin composite indirect restorations was reported to be fracture (3, 6, 12). Previous in vitro studies demonstrated improved bond strength and fracture resistance for ceramic inlays with IDS (6, 13), whereas there was no difference for resin inlays with or without IDS (6).

In the literature, no study evaluating the effect of IDS on the fracture resistance of laboratory-processed indirect resin composite onlays with different level of proximal extensions (below/above the CEJ) was found.

Hence, the aim of this study was comparison of the fracture resistance, failure mode, and reparability of molars restored with laboratory-processed resin composite onlays extending below or above CEJ with or without IDS. The null hypothesis was that IDS had no beneficial effect on the fracture strength, failure mode, and reparability of the restorations extending below or above CEJ.

Materials and Methods

The Principles of Helsinki Declaration were followed and ethical approval was obtained from Istanbul Medipol University Non-Interventional Clinical Trials Ethics Committee (Decision No: E-10840098-772.02-4580).

Freshly extracted (<6 months, conserved in water) sound human maxillary third molars were collected, tissue remnants or calculus residues were cleaned using scalers. The teeth with similar size, no lesions, restoration, or cracks were included in the study. The selected teeth (N=40) were embedded vertically in self-cure acrylic resin (Imicryl, Imicryl Dental, Konya, Türkiye) 1 mm below the CEJ using silicone molds and stored in distilled water at room temperature.

All specimens were then randomly divided into four groups (n=10): onlay below CEJ with IDS (Group 1), onlay below CEJ without IDS (Group 2), onlay above CEJ with IDS (Group 3), onlay above CEJ without IDS (Group 4). The study flow chart showing experimental sequence and allocation to groups is given in Table 1. All of the materials used in the study are listed in Table 2.

Table 1. Study flow chart showing experimental sequence and allocation to groups

Sound Human Molars (n=40)			
Onlay preparation below CEJ (n=20)		Onlay preparation above CEJ (n=20)	
Group 1 with IDS (n=10)	Group 2 without IDS (n=10)	Group 3 with IDS (n=10)	Group 4 without IDS (n=10)
Thermomechanical aging (n=40)			
Fracture test (n=40)			
Analysis (n=40)			

Preparation

Standardized mesio-occlusal (MO) onlay preparations were made (remaining dentin thickness: 2-3 mm in width, and depth of the cavity: 2 mm from the fissure) using shoulder diamond burs under water cooling. Mesio-buccal and mesio-palatinal cusps were reduced by 2 mm and beveled. Butt-joint preparation (width:1-1.5 mm) was used in the proximal box area extending 1 mm below the CEJ (Groups 1 and 2) or 1 mm above the CEJ (Groups 3 and 4). Interior walls diverge 6 to 10 degrees with rounded inside angles obtained by conical medium-grit diamond bur.

Immediate dentin sealing

In Groups 1 and 3, IDS was applied immediately after tooth preparation. A three-step adhesive system (Syntac, Ivoclar Vivadent AG, Schaan, Liechtenstein) was used (Table 1). The cavity was etched for 30 seconds for internal dentin surfaces with 37% phosphoric acid (Total

Etch-Ivoclar Vivadent AG), rinsed with water, and air-dried.

Thereafter, the primer and adhesive were applied in sequence using a microbrush for 15 and 10 seconds, respectively. Both the primer and the adhesive were air-dried for 5 seconds. Following that, the Heliobond Adhesive was applied for 10 seconds on all of the internal surfaces of the cavity and was photopolymerized with a LED light device (LED.B, Guilin Woodpecker Medical Instrument, Guilin, Guangxi, China) for 10 seconds after air-drying for 5 seconds. After this, a thin layer of flowable resin composite (Tetric-N Flow, Ivoclar Vivadent AG) was applied to cover the IDS layer and polymerized for 20 seconds. The IDS layer was further photopolymerized for 40 seconds using glycerin gel (Liquid Strip, Ivoclar Vivadent AG).

Table 2. The brands, types, batch numbers, manufacturers chemical compositions, and instructions for use of the primary materials utilized in this study

Material *(Type-Batch number)*	Manufacturer	Chemical Composition	Instructions for use
Syntac Primer *(Primer-Y22421)*	Ivoclar Vivadent AG, Schaan, Liechtenstein	TEGDMA, PEGDMA, maleic acid and acetone	15 sec application and drying
Syntac Adhesive *(Adhesive-Z00J9R)*	Ivoclar Vivadent AG, Schaan, Liechtenstein	PEGDMA, glutaraldehyde	10 sec application and drying
Heliobond ***(Adhesive-W1137)***	Ivoclar Vivadent AG, Schaan, Liechtenstein	Bis-GMA, TEGDMA, stabilizer and catalyst	Application, drying and 10 sec LED light curing (>500 mW/cm^2)
Tetric N-Flow *(Flowable resin composite-Y29756)*	Ivoclar Vivadent AG, Schaan, Liechtenstein	TEGDMA, barium glass, yterbium trifluoride, mixed oxide, stabilizer, catalyst and pigments	Application with 2 mm increments, 20 sec light curing for each increment
Ceramage *(Indirect resin composite-071934)*	SHOFU Inc., Kyoto, Japan	UDMA, zirconium silicate	300 sec light curing with Labolight LV-III
Monobond N *(Silane-Z0119K)*	Ivoclar Vivadent AG, Schaan, Liechtenstein	Alcohol solution of silane methacrylate, phosphoric acid and methacrylate and sulphide methacrylate	15 sec application and drying
Variolink-N *(Resin cement-YZ1259/YZ1263)*	Ivoclar Vivadent AG, Schaan, Liechtenstein	Bis-GMA, UDMA, TEGDMA, barium glass, ytterbium trifluoride, Ba-Al-fluorosilicate glass, mixed oxide, initiator, stabilizer and pigments	Mixing catalyst and base 1:1 ratio for 10 sec, 10 sec LED light curing for each millimeter of the restoration (>800 mW/cm^2)

Fabrication of the indirect restorations

A putty material (Zetaplus, Zhermack SpA, Badia Polesine, Italy) and a low-viscosity condensation silicone material (Oranwash L, Zhermack SpA) were used for the double impression technique. Thereafter, provisional resin restorations were placed (Clip, VOCO GmbH, Cuxhaven, Germany), and the specimens were stored in distilled water at room temperature for three weeks. Prior to placement, glycerin gel was applied on the IDS to prevent interaction between the IDS and the provisional restorative material. One experienced certified dental technician fabricated all the onlay restorations using a laboratory-processed resin composite material (Ceramage, SHOFU Inc., Kyoto, Japan). For the final polymerization of the onlays, a laboratory polymerization device (GC Labolight LV-III, GC Corporation, Tokyo, Japan) was used for 5 minutes.

Adhesive cementation

The permanent restorations were bonded after three weeks. After removing the provisional restoration, the fitting of the onlay restoration was checked. In the case of inadequate marginal fitting, impression-making and fabrication of the restoration were repeated.

A silan coupling agent (Monobond N, Ivoclar Vivadent AG) was applied on the internal surfaces of the restorations and left to dry for 60 seconds. The cavity was cleaned, etched for 30 seconds for enamel margins and 15 seconds for internal surfaces with 37% phosphoric acid rinsed with water, and air-dried. The three-step etch, and rinse system used for the IDS was also used to condition the internal surfaces of the cavity prior to the cementation procedure. The adhesives were not photopolymerized before restoration placement, to avoid inadequate fitting. Dual-polymerized resin cement (Variolink N, Ivoclar Vivadent AG) was used for cementation. The restorations were cemented with light pressure, and the excessive material was removed with a probe. The restorations were photopolymerized for 40 seconds from the buccal, lingual, and occlusal sides, using glycerin gel for final polymerization. Once the restorations were bonded, the margins, the residual excess cement, and occlusion were checked. Necessary adjustments were made using fine-grit diamond burs under water cooling and polishing discs (Sof-Lex 3M ESPE, Seefeld, Germany).

Thermocycle aging and fracture test

All groups were thermocycled for a total of 20000 cycles between 5°C and 55°C with a dwell time of 30 seconds and a transferring time of 10 seconds in a thermocycling machine (SD Mechatronik Thermocycler, Feldkirchen-Westerham, Germany) to age the restorations.

After the thermocycling process was completed, the specimens were placed in the universal testing machine (Autograph AGS-X, Shimadzu, Tokyo, Japan) and loaded with a 3 mm steel ball, perpendicular to the occlusal surface, at a crosshead speed of 1 mm: min. The maximum force (N) leading to fracture was recorded.

Fracture analysis

All specimens observed using a stereomicroscope (Nikon SMZ800, Tokyo, Japan) and classified as follows: Type 1: cohesive fracture of the restoration; Type 2: adhesive fracture of the restoration; Type 3: adhesive-cohesive fracture of the restoration; Type 4: fracture of the restoration/tooth complex above the CEJ; Type 5: fracture of the restoration/tooth complex below the CEJ (14).

Failure types were also classified according to their reparability. Type 1, 2, 3 and 4 were defined as reparable, whereas Type 5 as irreparable failure.

Statistical analysis

Analyses were performed by using SPSS software (IBM SPSS Statistics version 23.0, IBM Inc., Armonk, NY, USA).

Shapiro-Wilk test was used to test the normal distribution of the fracture strength data, and Levene's test was used for the homogeneity of variances. Since the data were normally distributed ($p>0.05$) and variances were homogeneous ($p>0.05$), a two-way ANOVA was used to evaluate the influence of two independent variables on the fracture strength.

These variables were defined as the level of proximal extensions (below/above CEJ) and the presence of IDS (with/without). Multiple pairwise comparisons were analyzed with the Tukey HSD test to find out the mean difference between specific pairs of groups. The failure type and reparability data were analyzed using Fisher's exact test. The overall significance level of the study was evaluated at $p<0.05$.

Results

The mean fracture loads according to groups are presented in Table 3. Only the level of proximal extension significantly affected the results [$F(1.36)=4.937$, $p=0.033$]. The onlays with the proximal box above CEJ were stronger than below CEJ. Moreover, the interaction effect was statistically significant [$F(1.36)=6.796$, $p=0.013$], showing that the interaction between the level of proximal extension and the presence of IDS had an influence on fracture resistance. According to Post hoc test results, there was a statistically significant difference in fracture strength between Group 4 and Group 1 ($p=0.038$), Group 2 ($p=0.008$), Group 3 ($p=0.019$). Restorations above CEJ and without IDS (Group 4) showed the highest mean fracture strength compared to Group 1, 2 and 3. According to the results of Fisher's exact test, the effect of level of proximal extension on fracture mode (Fig. 1) and reparability (Fig. 2) was not significant ($p>0.05$). Moreover, the interaction between the level of proximal extension and presence of IDS did not influence fracture mode and reparability ($p>0.05$). Representative photos of failure types are given Figure 3.

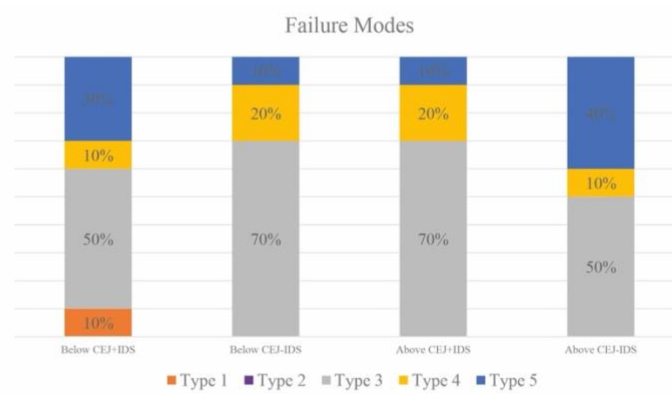

Figure 1. Frequencies of failure modes after fracture test. Type 1: fracture of the restoration without displacement (cohesive failure); Type 2: debonding of the restoration without fracture (adhesive failure); Type 3: fracture of the restoration with displacement (adhesive-cohesive failure); Type 4: fracture of the restoration/tooth complex above the CEJ; Type 5: fracture of the restoration/tooth complex below the CEJ

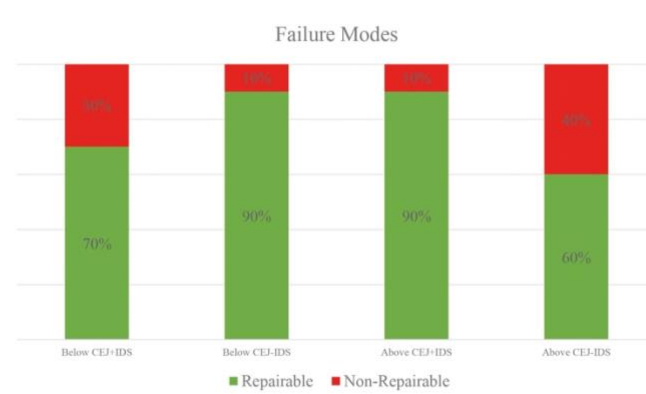

Figure 2. Frequencies of reparability: reparable and non-reparable failures

Table 3. Fracture strength results of experimental groups with minimum, maximum, and 95% confidence interval

Group	N	Mean ± SD	95% Confidence Interval Lower bound	95% Confidence Interval Upper bound	Minimum	Maximum
Below CEJ with IDS	10	1793.57 ± 324.97	1561.09	2026.04	1198.90	2208.87
Below CEJ without IDS	10	1669.70 ± 392.46	1388.95	1950.46	1147.27	2245.12
Above CEJ with IDS	10	1737.44 ± 451.35	1414.56	2060.32	1098.14	2458.32
Above CEJ without IDS	10	2373.5 ± 622.27	1928.70	2819.00	1492.86	3315.22

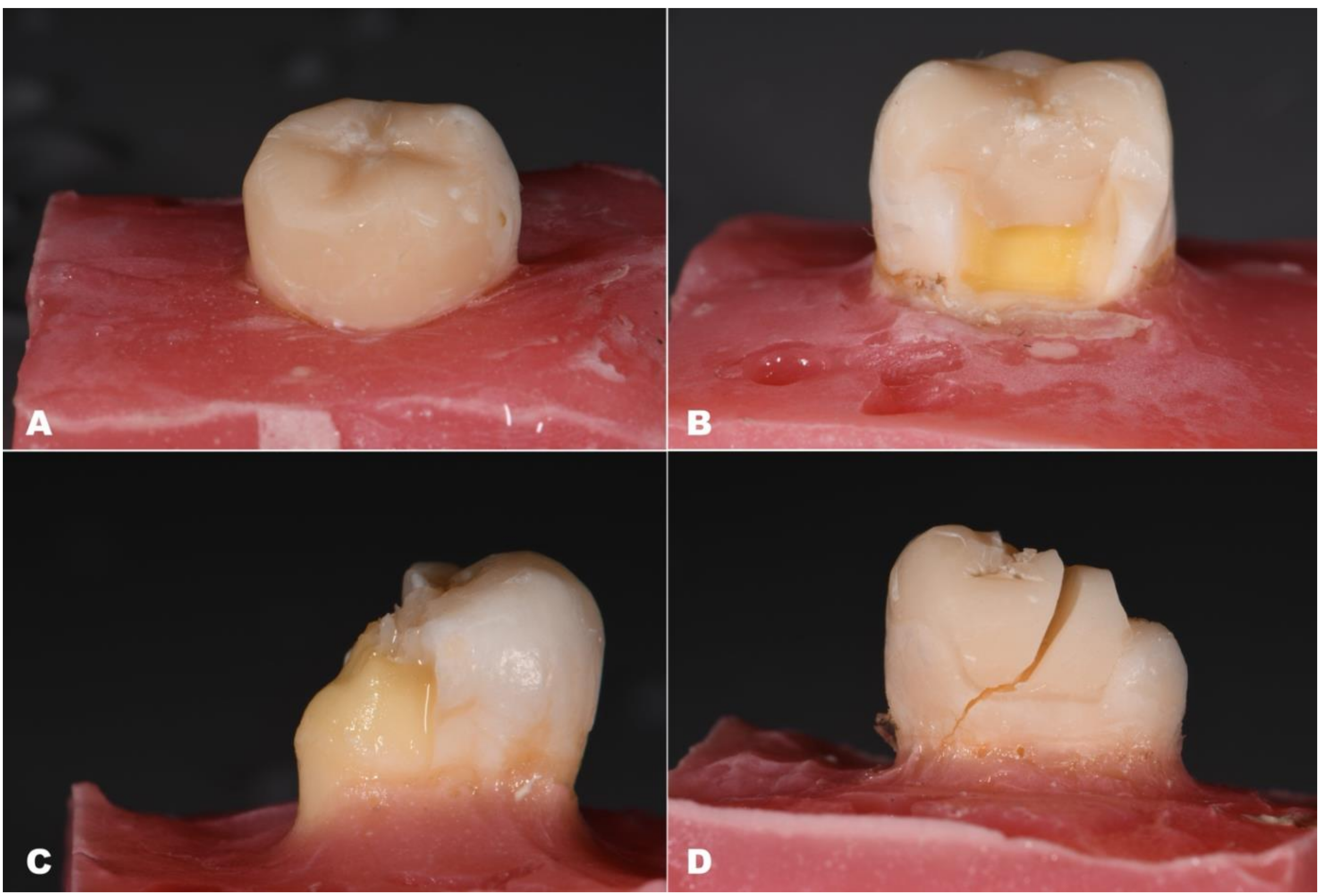

Figure 3. Representative photos of fracture (A) Type 1, (B) Type 3, (C) Type 4, (D) Type 5

Discussion

This study evaluated whether if IDS had a beneficial effect on fracture strength and failure behavior of molars restored with resin composite onlays extending below and above CEJ, or not. To the best of our knowledge, the influence of IDS on the fracture strength of resin composite onlays with different level of proximal extensions and involvement of two cusps was not previously tested. Based on the study's results, IDS did not affect the fracture strength of resin composite onlays, whereas restorations ending above the CEJ were found to be more resistant than those ending below CEJ.

Moreover, neither the IDS nor the level of proximal extension affected the failure behavior of the restorations. Thus, the null hypothesis that IDS will have no beneficial effect on the fracture strength, failure mode, and reparability of the restorations extending below or above CEJ can be partially accepted. The onlays located above the CEJ without IDS showed the highest fracture strength.

The results of the present study were in accordance with the results of a study by van den Breemer et al. (6) that obtained values for fracture strength showing no significant difference arising from the application of IDS. Magne et al. (15) reported a higher rate for non-reparable failure below the CEJ (50%) for CAD-CAM generated resin composite onlays ending 1 mm above the CEJ with IDS than the non-reparable failure rate in Group 3 of the present study (10%), which had a similar preparation design and IDS. Notably, in the current study, dentin was removed from the compromised cusp, and an artificial crack was made to challenge the fracture strength depending on the presence or absence of polyethylene fiber in addition to IDS. Thus, the lower survival rate in the study by Magne et al. compared to that in the present study could be attributed to this weakened cusp design. Likewise, this study found no beneficial effect of fiber reinforcement on the fracture strength of resin composite onlays. In the study by Kois et al. (16), composite overlays without IDS were found to have comparable fracture strength (1,614 ±250 N) and a higher non-reparable fracture rate (74%) than the onlays without IDS examined in the present study (Groups 2 and 4). However, considering the different materials and preparation designs, this result should be interpreted cautiously. In the study by Kois et al. (16), the overlays were made of a laboratory-processed composite material (Radica, Dentsply, York, PA, USA) recommended for provisional restorations by the manufacturer. To the best of our knowledge, in vitro studies of the fracture strength of resin composite onlays with IDS are scarce. Therefore, the present study is essential to provide evidence of the fracture resistance and behavior of resin composite onlays. Based on the results of the study by van den Breemer et al. (6) mentioned above and those of the present study, IDS application appears to have no influence on the improvement of fracture strength in resin composite indirect restorations.

A recent systematic review concluded that using IDS with a three-step adhesive system and a layer of flowable resin composite enhanced the bond strength of resin-based restorations (17). However, in the present study, the rate of adhesive-cohesive fractures, which might be considered an indicator of good adhesion, was not significantly different among the groups. Moreover, adhesive failure was observed in Group 1. These results are consistent with those of a randomized clinical study in which no significant difference was found between partial ceramic indirect restorations with or without IDS (18). Nevertheless, further studies are required to evaluate the clinical outcomes of indirect resin composite restorations in combination with IDS. The interaction between partial ceramic restoration and IDS might differ from that between resin-based partial indirect restorations and IDS, as shown in the study by van den Bremer et al. (6). Notably, in vitro studies have demonstrated improved fracture strength for partial ceramic restorations (6,13), which was not confirmed in the clinical study by van den Breemer et al. (18).

The results of clinical studies using IDS (19-21) are promising. It appears that there is no scientific reason not to recommend IDS in routine clinical practice as suggested by Qanungo et al. (22). Based on the results of the present study, IDS might be preferable for indirect restorations extending below the CEJ considering the other benefits of IDS, such as reduced post-operative sensitivity and decreased bacterial leakage. These benefits do not include improved fracture resistance, as no significant difference was found between the fracture resistance of onlays below CEJ with and without IDS. However, the onlays above the CEJ without IDS showed higher fracture strength than those without. Thus, applying IDS might be unnecessary for large defects above the CEJ. Further studies are needed to confirm whether degree of substance loss and preparation design affect the fracture strength of laboratory-processed partial indirect resin composite restorations.

The study design of this in vitro study, which involved loading forces until fracture, was a limitation because it did not provide accurate simulation of the oral environment. The forces used in a laboratory setting exceed the regular physiologic masticatory forces, and the repetitive nature of the forces in the oral environment cannot be replicated in a laboratory (23). Likewise, dentin thickness after caries or defective restoration removal is unlikely to be uniform in the oral environment, and undercuts are common in clinical scenarios. Therefore, the results of this in vitro study cannot be extrapolated to clinical conditions.

Conclusion

Within the limitations of this study, the following conclusions can be made:

1. Resin composite onlays above the CEJ without IDS showed the highest fracture strength.
2. No difference was found between the fracture resistance of resin composite onlays below CEJ with or without IDS.
3. Level of proximal extension influenced fracture strength, whereas the presence of IDS had no significant effect on fracture strength.
4. No difference was found among groups regarding failure mode and reparability.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from the Istanbul Medipol University Non-Interventional Clinical Trials Ethics Committee, in accordance the World Medical Association Declaration of Helsinki, with the approval number: E-10840098-772.02-4580.

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