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RESEARCH AND EDUCATION

Influence of proximal box elevation on microleakage in 3Y-TZP zirconia ceramic fixed dental prostheses after thermomechanical loading: A laboratory study

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ABSTRACT

Statement of problem. Deep subgingival defects at the abutment teeth for fixed dental prostheses (FDPs) are a common problem in prosthodontics. Surgical crown lengthening or orthodontic extrusion of the abutment teeth have been recommended treatment options. However, disadvantages such as extended treatment time, treatment costs, or surgical problems have to be considered. Proximal box elevation has been proposed as an alternative, but microleakage studies are lacking.

Purpose. The purpose of this in vitro study was to investigate the influence of proximal box elevation (PBE) and conventional foundation restoration on the microleakage of 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) ceramic FDPs after thermomechanical loading (TML).

Material and methods. Sixteen molars and 48 premolars were divided into 4 groups (n=8). Either fixed-to-fixed (premolar, molar) or cantilever FDPs (premolar, premolar) were fabricated. The pontic of both groups had a mesiodistal width of 7 mm. The proximal foundation restorations were placed using a self-etch adhesive system and a dual-polymerizing composite resin, and a standardized tooth preparation design was carried out. All FDPs were adhesively luted and subjected to TML (1.2 million cycles, 5/55 °C, 49 N). After TML, all specimens were placed in fuchsin and then sectioned in a sagittal direction. The sections were evaluated with respect to the penetration depth of the dye by light microscopy at 4 different interfaces: tooth and luting composite resin (TC), luting composite resin and restoration (CR), tooth and foundation restoration (TB), foundation restoration and luting composite resin (BC). As data were not normally distributed, nonparametric tests were used for statistical analysis (α=.05).

Results. Statistically significant differences were observed between the PBE and the control group (*P*<.05). Microleakage at the TB interface was detectable in all specimens of the PBE group, while 84.4% of the specimens of the control group showed leakage at the TC and TB interfaces. Leakage was detected at the CR interface in 3.1% of all specimens. No leakage was observed at the interface BC. Additionally, statistically significant differences were found within the same study specimen between the control (conventional foundation restoration) and the study side (PBE) (*P*<.05).

Conclusions. Irrespective of the pretreatment (experimental PBE or conventional foundation restoration), the adhesive bond of the foundation restoration and the luting composite resin to the dentin represented a limiting factor with regard to microleakage in fixed-to-fixed and cantilever FDPs. PBE was more frequently affected by microleakage than a conventional foundation restoration. (J Prosthet Dent 2025;133:1293.e1-e10)

The prosthodontic rehabilitation of teeth with deep subgingival defects or a retreatment of crowned teeth with caries at the crown margin and deep subgingival cavities after caries excavation is a frequently performed intervention.[1] The treatment can be challenging with regard to tooth preparation, impression making, dental dam isolation, or cementation, especially in teeth with deep proximal defects.[1] Additionally, the supracrestal tissue attachment may be violated. Traditionally, surgical crown lengthening has been the standard procedure for

All authors declare, that they do not have any conflicts of interest.

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Clinical Implications

Proximal box elevation has a significant influence on microleakage of 3Y-TZP ceramic fixed dental prostheses after thermomechanical loading.

placing the supporting tissues in a more apical location.[2] However, this procedure may result in an unfavorable gingival architecture by affecting the adjacent teeth and may expose root furcations or root concavities.[1] The orthodontic or surgical extrusion of abutment teeth has also been an accepted treatment option for overcoming the problems with deep proximal defects.[3,4] However, these procedures can be time consuming and expensive or result in root resorption in some patients.[5]

Proximal box elevation (PBE) using composite resin to relocate a subgingival margin more coronally has been proposed to address these concerns. PBE, also known as deep margin elevation or cervical margin relocation, was first described by Dietschi and Spreafico in 1998.[6] Since then, different laboratory investigations using different treatment procedures and materials have been performed, mostly with inlays, onlays, or partial crowns.[7–18] Additionally, systematic reviews or author comments on this topic are available.[19–22] Major influencing factors on the marginal adaptation of the restoration seem to be the choice of material used for elevation, the adhesive system used for luting, and the technique used to insert the resin material.

In a randomized clinical investigation comparing PBE and surgical crown lengthening over an observation period of 12 months with regard to biological factors, both treatment options were reported to be clinically successful, but surgical crown lengthening was considered the standard in the re-establishment of the supracrestal tissue attachment.[23] However, a systematic literature review concluded that crown lengthening surgery can be successful in the long-term retention of restored teeth but that PBE has a better survival ratio.[24]

Long-term clinical investigations on the influence of PBE on the outcome of crowns are sparse. Aziz et al.[25] evaluated 426 computer-aided design and computer-aided manufacture (CAD-CAM) crowns with and without PBE over an observation time of 10 years. The PBE was rated good in 74%, acceptable in 17.5%, and poor in 8.5% of the restorations. PBE had no negative effect on the health of the periodontal tissue. Overall, the authors concluded that the PBE technique resulted in excellent long-term results.

The authors are unaware of studies on the influence of PBE on microleakage in FDPs, either with a fixed-to-fixed or with a cantilever design. Therefore, in the present laboratory investigation, the influence of PBE and conventional foundation restorations as control (CO) on microleakage in CAD-CAM-fabricated, high-strength zirconia ceramic FDPs made from 3 mol% yttria-stabilized tetragonal zirconia polycrystal ceramic (3Y-TZP) with either a fixed-to-fixed or a cantilever design after thermomechanical loading was investigated. The null hypotheses were that no differences would be found between the PBE and the control side or between the fixed-to-fixed and the cantilever design.

MATERIAL AND METHODS

The institutional review board of the study center approved the use of extracted teeth in this laboratory investigation (ethics committee of the Christian-Albrechts-University at Kiel, AZ: D528/19). Patients with molars or premolars requiring extraction were informed about this laboratory study and donated their teeth after providing informed written consent. After extraction, all teeth were stored for 2 weeks in 0.1% thymol solution. After 2 weeks, the teeth were stored in fully demineralized water until the beginning of the investigation. Sixteen human molars and 48 human premolars were randomly divided into 4 groups with 8 FDPs per group (n=8). As teeth with uniform diameters were used, all teeth were distributed randomly to the groups by the investigator (M.R.). The teeth were taken in pairs from the demineralized water and then assigned to the test groups in order. That is, the first 2 to group A1, the next 2 to group A2, the next 2 to group B2, and so on. In one main group (n=16), a fixed-to-fixed FDP with 1 molar and 1 premolar as abutment teeth was investigated. In the other main group (n=16), cantilever FDPs with 2 premolars as abutment teeth were tested (Fig. 1). Both main groups were divided into 2 subgroups depending on the arrangement of the PBE, with the conventional foundation restoration as the control (CO) (Fig. 1).

To simulate the periodontal ligament, the tooth roots were coated with a 0.25-mm-thick artificial periodontal membrane made of a gum resin (Anti-Rutsch-Lack, batch number: 5504010500C; Wenko Wenselaar GmbH) placed 4-mm apical to the cemento-enamel junction (CEJ). The teeth were then fixed along their long axis in an autopolymerizing polyester resin (Technovit 4000, batch number: K010209; Kulzer GmbH) 4-mm apically to the cemento-enamel junction. Two standardized artificial mesial and distal defects simulating a proximal cavity were created at each abutment tooth. For premolars, the cavities had a mesiodistal width of 1 mm and a buccolingual width of 2 mm. All molars had a standardized cavity dimension of 1.5 mm in the mesiodistal direction and 3 mm in the buccolingual direction. Depending on the subgroup, either the mesial or the distal cavity of each abutment tooth was extended up to

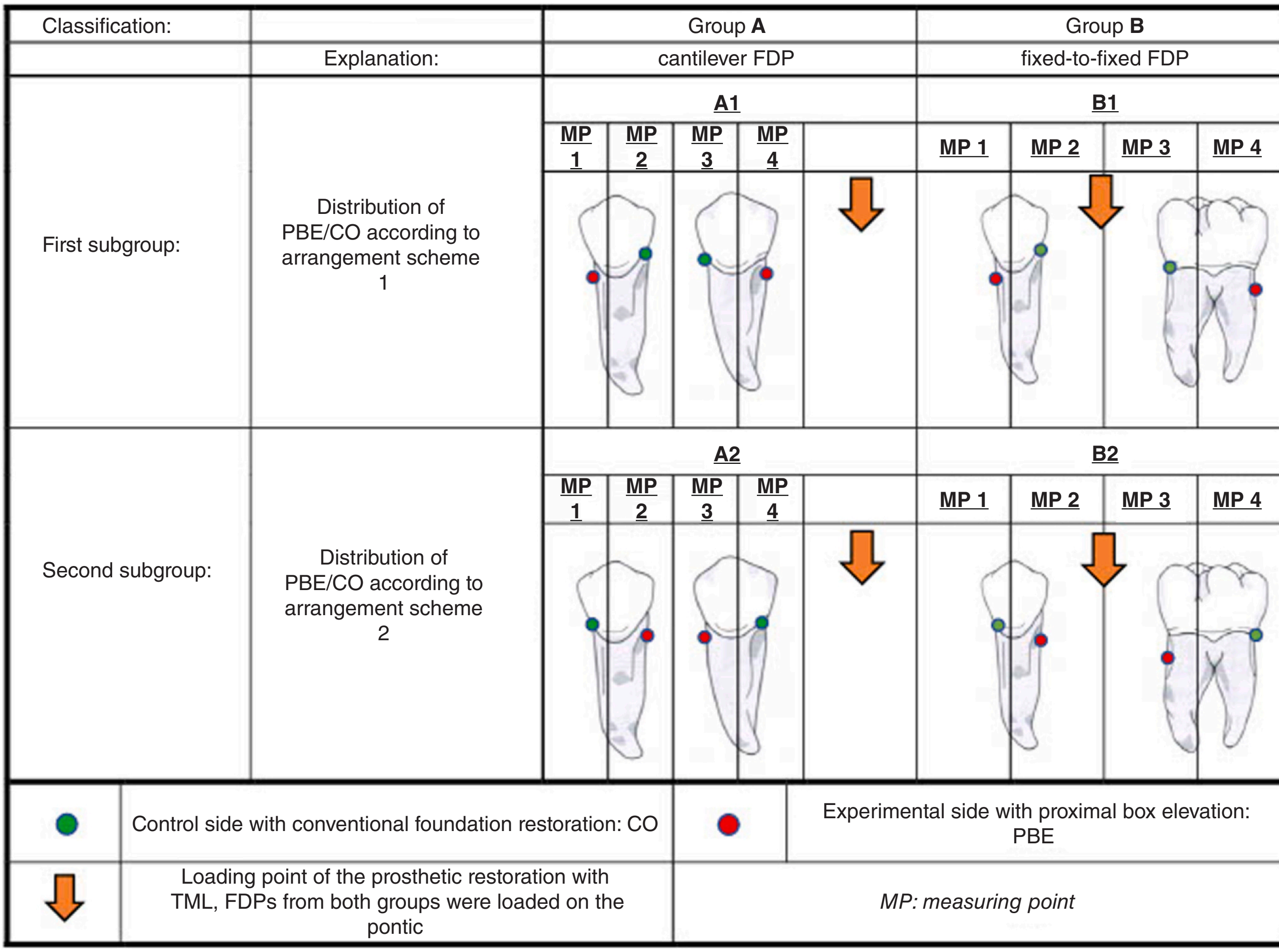


Figure 1. Study design with 2 main and 2 subgroups according to arrangement of CO and PBE (modified from Strub et al, 2011).[30] CO, control; PBE, proximal box elevation.

2 mm apically to the CEJ, representing the PBE. The other defect terminated just apically to the CEJ.

To ensure that both cavities were limited to dentin and not partly in enamel, the area was etched with 35% phosphoric acid (K-ETCHANT syringe, batch number: AN0128; Kuraray Noritake Dental Inc) for 5 seconds. The proximal defects were conditioned with a self-etching, light-polymerizing 2-step adhesive (Clearfil SE Bond, batch number primer: 9R0341, batch number bond: A90594; Kuraray Noritake Dental Inc). First, the primer was applied to the entire box with an applicator brush (Microbrush; Young Innovations Europe GmbH) and left for 20 seconds. Then, the solvent was evaporated with a gentle, oil-free stream of air. As a second step, the adhesive was applied to the entire cavity with an applicator brush and distributed with a gentle, oil-free air stream. Finally, the adhesive was polymerized for 10 seconds with the light-emitting diode (LED) polymerization lamp (RADII-CAL; SDI) with an irradiation wavelength of 440 to 480 nm and a light intensity of 1200 mW/cm^2.

A foundation restoration material (Clear Fil DC core plus, batch number: 9R0208; Kuraray Noritake Dental Inc) was delivered from an automix syringe on the control side and for the PBE with a transparent universal strip (frasaco GmbH) in place. After application, the foundation restoration material was light polymerized with the RADII-CAL polymerization lamp for 20 seconds per side. After light-polymerization was completed, the dual-polymerizing foundation restoration material was polymerized for a further 6 minutes. As, clinically, the PBE terminated 2 mm apical to the gingiva, a dual-polymerizing composite resin that can be used in one increment was applied.

All abutment teeth received a standardized tooth preparation (preparation angle of 3 degrees, minimum height of 4 mm) with a uniform retention and resistance form using a parallelometer (Ceramill Aqua; Amann Girrbach AG) (Fig. 2A, B). The tooth preparation margin followed the CEJ except for the area of the control side, where the preparation margin was placed 1 mm apical to the CEJ, providing a 1-mm ferrule at the control side and

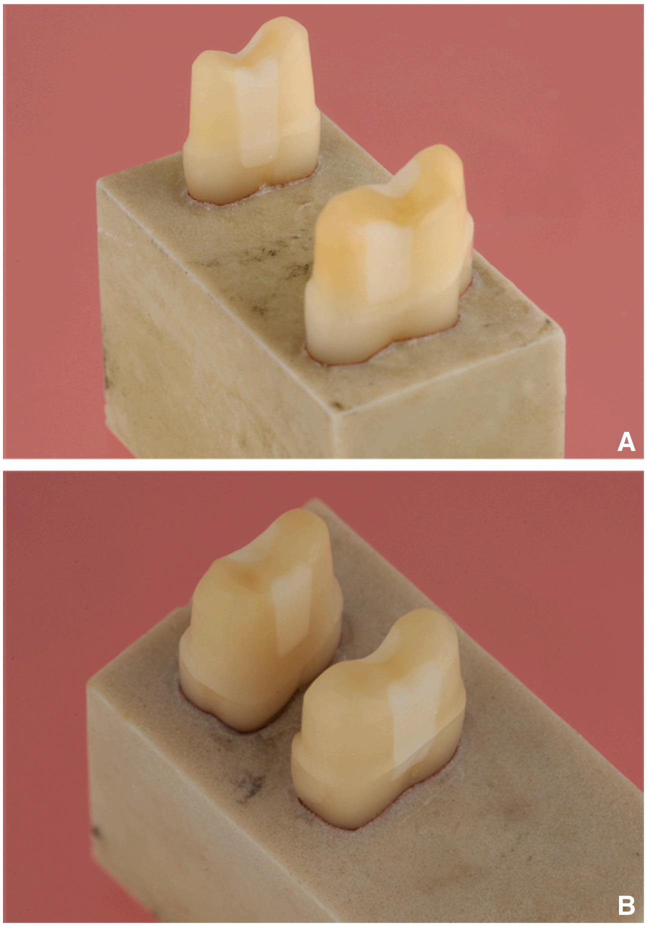


Figure 2. Preparation design of study specimen. A, Fixed-to-fixed FDP with PBE at premolar and conventional foundation restoration as control at molar. B, Cantilever FDP with PBE at right premolar and conventional foundation restoration as control at left premolar. FDP, fixed dental prosthesis; PBE, proximal box elevation.

a PBE at the experimental side of the abutment tooth (Fig. 2A, B).

Digital scans (D900-Scanner; 3Shape A/S) were made and all FDPs were digitally designed (CAD-Software; 3Shape Dental System) and milled from high-strength 3Y-TZP zirconia ceramic (Katana Zirconia HTML, batch number: EBJED; Kuraray Noritake Dental Inc). The connectors of the fixed-to-fixed FDPs had a height of 3 mm and a width of 3 mm, and the connectors of the cantilever FDPs had a height of 4 mm and a width of 3 mm, with rounded edges. After airborne-particle abrasion of the intaglio crown surfaces with 50-μm alumina particles at a pressure of 0.1 MPa, all FDPs were adhesively luted with a resin cement (Panavia V5, batch number: A20028; Kuraray Noritake Dental Inc) using the phosphate monomer containing primers (Clearfil Ceramic Primer Plus, batch number: 9H0048; Kuraray Noritake Dental Inc and Tooth Primer, batch number: AA0070; Kuraray Noritake Dental Inc) under constant contact load of 7.4 N in a custom loading apparatus.

All specimens were thermomechanically loaded with 49 N (lowering speed: 30 mm/s, 1.2 million mechanical load cycles and simultaneous 4400 thermal cycles) in a 2-axis mastication simulator (CS-4; SD Mechatronik GmbH). The load was applied by using an adapted steatite ball (CeramTec GmbH) as an antagonist to load the center of the circular contact surface of the pontic. This was followed by a lateral sliding movement of 0.3 mm in the direction of the central fissure. The fixed-to-fixed FDPs were loaded between the 2 abutment teeth on the pontic in the position of the second premolar, whereas the cantilever FDPs were loaded extra-axially on the cantilever (Fig. 3). For the entire duration of the mastication simulation, all specimens were also subjected to an alternating temperature bath from 5 °C to 55 °C with a dwell time of 36 seconds at each temperature. After thermomechanical loading, all specimens were immersed in a 0.5% Fuchsin solution for 24 hours at room temperature, embedded in autopolymerizing polyester resin (Technovit 4071, batch number: K010219; Kulzer GmbH), and then cut open in thin sections. A diamond cut-grinder (Primus; Walter Messner GmbH) was used to cut the embedded specimens. Each specimen was completely cut into successive 250-μm-thick,

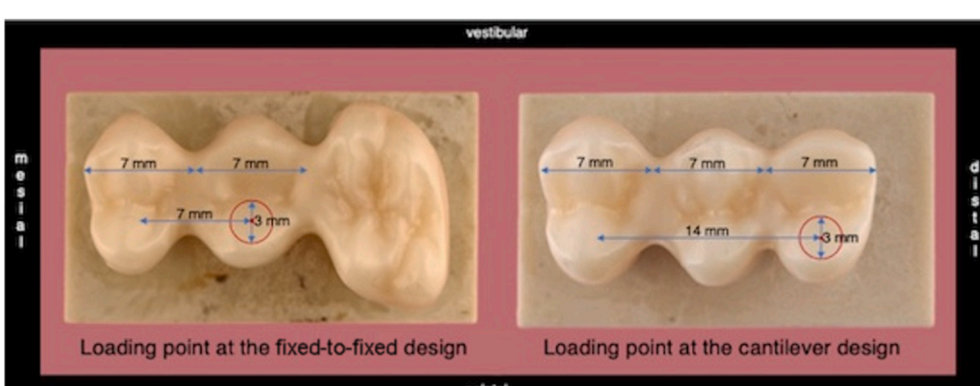
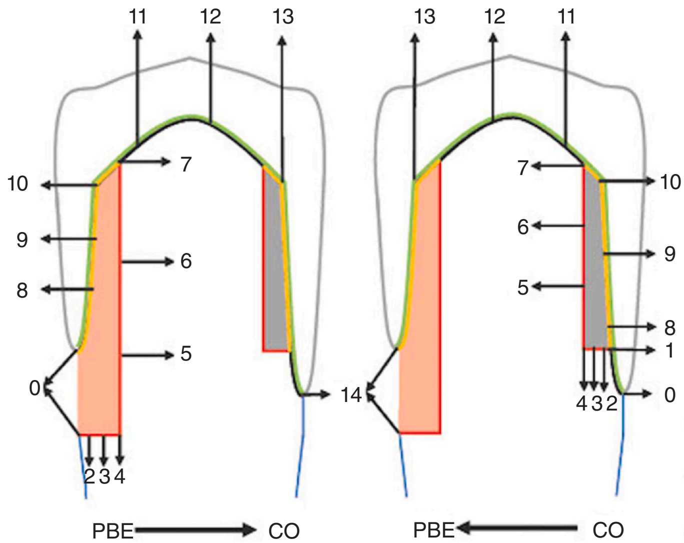


Figure 3. Loading point with diameter of 3 mm at pontic for both FDP designs. FDP, fixed dental prosthesis.



Scale of the leakage of the Interfaces	
0	No leakage
1	Leakage up to the vertical level of the beginning of the foundation restoration
2	Leakage up to 1/3 of the cervical horizontal shoulder
3	Leakage up to 2/3 of the cervical horizontal shoulder
4	Leakage up to the total length of the cervical horizontal shoulder
5	Leakage up to 1/3 of the axial wall
6	Leakage up to 2/3 of the axial wall
7	Leakage up to the total length of the axial wall
8	Leakage up to 1/3 of the chamfer
9	Leakage up to 2/3 of the chamfer
10	Leakage up to the total length of the chamfer
11	Leakage up to 1/3 of the occlusal surface
12	Leakage up to 2/3 of the occlusal surface
13	Leakage up to the total length of the occlusal surface
14	Continuous leakage (PBE-CO)

Interfaces	Legend
Tooth - Luting composite resin (TC), black	Conventional foundation restoration, dark gray
Luting composite resin - Restoration (CR), green	Foundation restoration in form of PBE, orange
Tooth - Foundation restoration (TB), red	Foundation restoration, light gray
Foundation restoration - Luting composite resin (BC), yellow	Root, blue

Figure 4. Penetration depth at interfaces, left for penetration at PBE site and right for penetration at control side. PBE, proximal box elevation.

longitudinal sections in the mesiodistal direction at right angles to the floor of the proximal cavities. These sections were analyzed for the penetration depth of the dye (microleakage) using a stereomicroscope (Wild M420; Wild Heerbrugg AG) with ×25 magnification (Fig. 4). The tooth and luting composite resin (TC), luting composite resin and restoration (CR), tooth and foundation restoration (TB), foundation restoration and luting composite resin (BC) interfaces were evaluated (Fig. 4).

Statistical analysis was performed using a software program (IBM SPSS Statistics, v29.0.0.0; IBM Corp). The mean leakage depth at each measuring point of all specimens from the same group was used. As the data were not normally distributed, the Friedman test followed by a post hoc test was used to detect differences between the different measuring points (MP1-MP4) within a group. The Mann-Whitney-U-test was used to detect differences of the same measuring point between the 2 subgroups (B1/B2 and A1/A2) of the same main group (α=.05). *P* values were adjusted for multiple testing.

RESULTS

All specimens of all groups revealed microleakage at the PBE site, at the interface of the tooth and the foundation restoration (Table 1, Figs. 4, 5). At the control side, a lower incidence of microleakage was detected. Overall, 84.4% of the specimens of the control side were affected by leakage at the interface tooth and luting composite resin (Fig. 6) with a maximum dye penetration of value 1, followed by leakage along the interface tooth and foundation restoration. In 1 of 32 specimens (3.1%), leakage was also observed at the interface of the luting composite resin and the restoration, in addition to leakage at the interface of the tooth and the foundation restoration and the tooth and the luting composite resin (Fig. 7). No leakage was observed at the interface between the foundation restoration and the luting composite resin at either the PBE or the control side.

The mean leakage values for the different measuring points of all groups are shown in Figure 8. Higher mean leakage values were observed at the PBE sides compared

Table 1. Microleakage at adhesive interfaces

Pretreatment	Interface	Relative Frequency of Leakage: h_{32} (Interfaces)
Conventional foundation restoration and proximal box elevation (PBE)	Foundation restoration - Luting composite resin (BC)	0%
	Luting composite resin – Restoration (CR)	3.1%
Conventional foundation restoration	Tooth - Luting composite resin (TC) + Tooth - Foundation restoration (TB)	84.4%
PBE	Tooth - Foundation restoration (TB)	100%

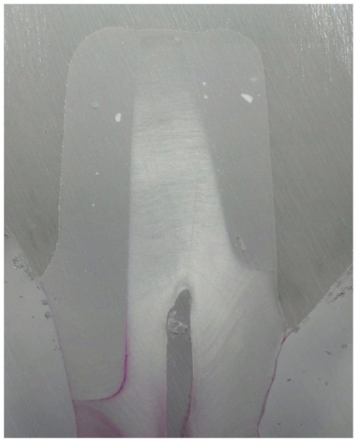


Figure 5. Leakage at PBE site at interface tooth and foundation restoration. PBE, proximal box elevation.

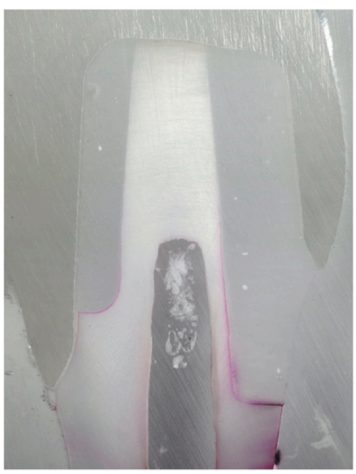


Figure 6. Leakage at control site at interfaces tooth and luting composite resin, and tooth and foundation restoration.

with the control sides. Analyzing the different measuring points within 1 group, a statistically significant difference could be observed between a PBE and a control side ($P<.05$). The mean leakage scores of each specimen are shown in Tables 2 to 5. On analyzing the same measuring point between 2 subgroups, meaning PBE versus control at the same measuring point, statistically significant differences ($P<.05$) were found for all 4 measuring points of the cantilever FDPs and for measuring points MP2, MP3, and MP4 for the fixed-to-fixed FDPs (Table 6).

DISCUSSION

The null hypothesis that no difference would be found between the PBE and the control was rejected. After thermomechanical loading, no leakage was observed at the interface BC. However, microleakage occurred at the interface TB on the PBE side and also at the interface TC on the control side, through which the dye had previously penetrated. Microleakage was detected in 100% of the PBE series and in 84.4% of the control series. A failure of the adhesive bond between the dentin and the directly applied material (foundation restoration and luting composite resin) appeared to be responsible for the microleakage.

The long-term bond strength to dentin is significantly lower and less predictable than that to enamel[10,17] because of the technique-sensitive luting method and the composition of the tooth structure.[18,26] This challenging adhesive bond between the cervical dentin and the composite resin and the stable bond between the foundation restoration material for the proximal box elevation and the luting composite resin

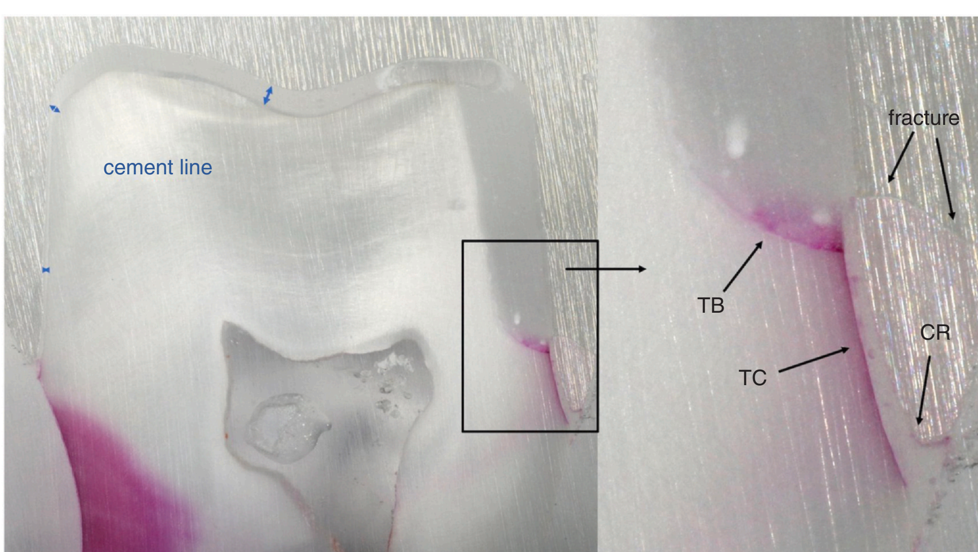


Figure 7. Leakage at interfaces luting composite resin and restoration, tooth and foundation restoration, and tooth and luting composite resin.

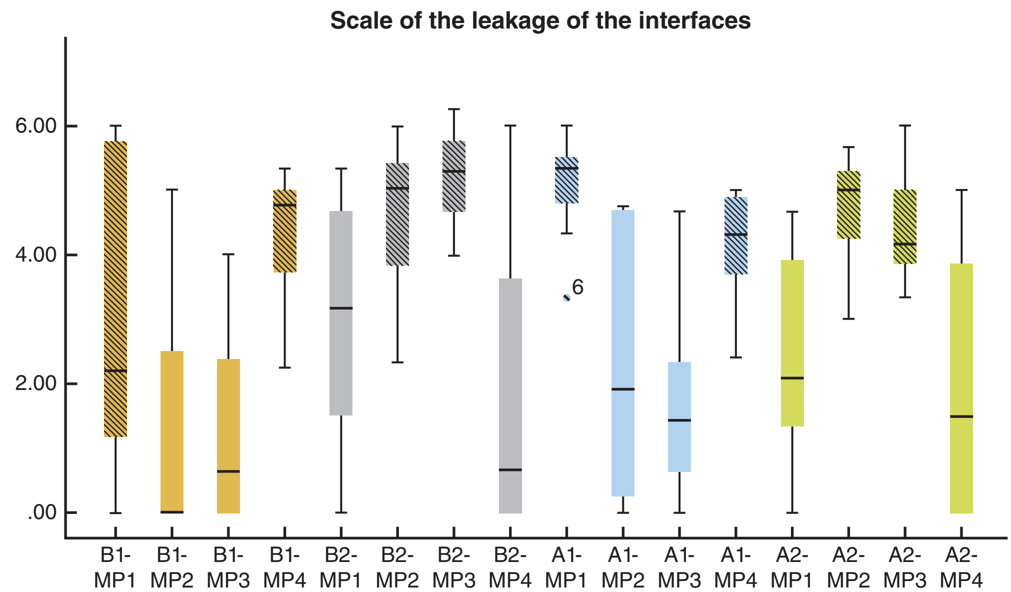


Figure 8. Box-plots for all measuring points 1–4 (mean) for all groups, experimental side with PBE *hatched*.

Table 2. Group B1, mean leakage score of each specimen (1–8) at measuring points 1–4

B1	MP 1	MP 2	MP 3	MP 4
1	1	0	0	$5.3\overline{3}$
2	$1.3\overline{3}$	0	1.25	2.25
3	$2.6\overline{6}$	0	0	4.8
4	1.75	0	0	3.5
5	5.5	0	2.5	4.75
6	0	0	4	5
7	6	5	0	4
8	6	5	2.25	5

B, fixed-to-fixed FDP; MP, measuring point.
Proximal box elevation (*red*)
Control (*green*)

Table 3. Group B2, mean leakage score of each specimen (1–8) at measuring points 1–4

B2	MP 1	MP 2	MP 3	MP 4
1	$3.3\overline{3}$	$3.3\overline{3}$	5.25	2.5
2	3	$5.3\overline{3}$	$5.3\overline{3}$	4.75
3	$5.3\overline{3}$	6	6.25	6
4	$4.6\overline{6}$	5	5	0
5	0	$4.3\overline{3}$	4	0
6	3	5	5.75	0
7	$4.6\overline{6}$	5.5	5.75	$1.3\overline{3}$
8	0	$2.3\overline{3}$	$4.3\overline{3}$	0

B, fixed-to-fixed FDP; MP, measuring point.
Proximal box elevation (*red*)
Control (*green*)

have been reported in previous investigations[16,19,27] and were confirmed in the present study.

In the present study, a self-etching, light-polymerizing, 2-step adhesive system, considered one of the standard adhesives, was used.[28] A dual-polymerizing composite resin, which is inherent to the system, was used for the PBE as well as the foundation restoration at the control side. In another investigation on PBE in combination with inlays, the adhesive system Clear Fill SE Bond showed higher sealing ability than an etch-and rinse-adhesive when margins were located on dentin.[9] In other investigations, different material combinations were used for PBE as, for example, self-adhesive resin cements in combination with a light-polymerizing restoration material[7,11] or resin modified glass ionomer.[15] However, a systematic review of adhesive strategies in

Table 4. Group A1, mean leakage score of each specimen (1–8) at measuring points 1–4

A1	MP 1	MP 2	MP 3	MP 4
1	$5.3\overline{3}$	$4.6\overline{6}$	0	$4.6\overline{6}$
2	$5.3\overline{3}$	0	2	3.75
3	$5.6\overline{6}$	$4.6\overline{6}$	$1.3\overline{3}$	$3.6\overline{6}$
4	$5.3\overline{3}$	0.5	1.5	4.75
5	5.25	2.5	1.25	4
6	$3.3\overline{3}$	$1.3\overline{3}$	$4.6\overline{6}$	5
7	$4.3\overline{3}$	0	$2.6\overline{6}$	5
8	6	4.75	0	2.4

A, cantilever FDP; MP, measuring point.
Proximal box elevation (*red*)
Control (*green*)

Table 5. Group A2, mean leakage score of each specimen (1–8) at measuring points 1–4

A2	MP 1	MP 2	MP 3	MP 4
1	$2.6\overline{6}$	5	5	$4.6\overline{6}$
2	$3.3\overline{3}$	$5.3\overline{3}$	4	0
3	1.5	3.5	3.75	$1.6\overline{6}$
4	$1.3\overline{3}$	5	4	$1.3\overline{3}$
5	0	3	6	5
6	4.5	$5.6\overline{6}$	$3.3\overline{3}$	0
7	$1.3\overline{3}$	5	$4.3\overline{3}$	0
8	$4.6\overline{6}$	5.25	5	3

A, cantilever FDP; MP, measuring point.
Proximal box elevation (*red*)
Control (*green*)

cervical lesions concluded that no bonding strategy seems better than the others and that the adhesive efficacy cannot be characterized by bonding strategy.[29]

Another reason for microleakage in proximal foundation restorations may be the methodological procedure of the increment technique. Previous studies analyzing the marginal integrity of the proximal box elevation in single-tooth restorations showed partially different results,[19–22] with no uniform pattern for the increment technique in terms of number and size of increments. The large volume of the one increment in this laboratory study, as well as the box-shaped defect architecture of the artificial defects, led to a C-factor of 2, which has an unfavorable effect on the adhesive bond.[30] Increased polymerization stresses and polymerization shrinkage might have occurred as a result and which might have led to material breakage in the marginal area and finally to leakage at the interface between the tooth and the foundation restoration. Additionally, this laboratory study showed a limitation of resin bonding to the dentin for both the conventional foundation restoration (microleakage in 84.4% of the specimens) and the proximal box elevation (microleakage in 100% of the specimens). Further laboratory studies with a different methodology are therefore necessary to reduce the risk of microleakage occurring at the interfaces of tooth and luting composite resin and of tooth and foundation restoration.

The study design did not include interim treatment of the prepared abutment teeth combined with immediate dentin sealing. A systematic review on immediate dentin sealing for indirect bonded restorations revealed an improved bond strength, fewer gap formations, and decreased bacterial leakage.[31] In the present laboratory investigation, no complete immediate dentin sealing was performed, and, whether immediate dentin sealing would have reduced microleakage either at the PBE or the control site remains unclear.

Microleakage at the interface of the luting composite resin and the restoration (CR) was only detected in 1 of 4 measurement points in 1 of 32 specimens. The reason for this single occurrence of microleakage at this interface could have been the visible fracture in the cervical area of the restorative material at this measuring point (Fig. 8). In this specimen, a fracture of the restoration occurred, probably associated with a slight undersizing of the restoration. As the position of the fracture of the restoration correlated with the penetration depth of the fuchsin dye and with the microleakage at the interface luting composite resin and restoration, a correlation between the fractured restoration and the microleakage is likely.

Limitations of the investigation included the phosphoric acid etching of the proximal cavities for 5 seconds to ensure that both cavities were completely limited to dentin and not partly to enamel, as phosphoric acid of dentin weakens the bond strength when using a self-etch system for bonding.[32] Because of the limited research on microleakage in fixed dental prostheses restored with a proximal box elevation, further experimental investigations are necessary.

Table 6. Results of post hoc tests for groups B1, B2, A1, A2

group	MP	*P*	
B1	MP 2-MP 1	.121	n.s.
	MP 3-MP 1	.121	n.s.
	MP 2-MP 3	>.999	n.s.
	MP 2-MP 4	**.040**	**significant**
	MP 3-MP 4	**.040**	**significant**
	MP 1-MP 4	>.999	n.s.
B2	MP 4-MP 1	>.999	n.s.
	MP 4-MP 2	.054	n.s.
	MP 4-MP 3	**.002**	**significant**
	MP 1-MP 2	.156	n.s.
	MP 1-MP 3	**.008**	**significant**
	MP 2-MP 3	>.999	n.s.
A1	MP 3-MP 2	>.999	n.s.
	MP 3-MP 4	.252	n.s.
	MP 3-MP 1	**.012**	**significant**
	MP 2-MP 4	.488	n.s.
	MP 2-MP 1	**.030**	**significant**
	MP 4-MP 1	>.999	n.s.
A2	MP 4-MP 1	>.999	n.s.
	MP 4-MP 3	.071	n.s.
	MP 4-MP 2	**.012**	**significant**
	MP 1-MP 3	.121	n.s.
	MP 1-MP 2	**.022**	**significant**
	MP 3-MP 2	>.999	n.s.

A, cantilever FDP; B, fixed-to-fixed FDP; MP, measuring point, n.s., not significant.
Proximal box elevation (*red*); Control (*green*).

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The adhesive bond between the foundation restoration, the luting composite resin, and the dentin was a limiting factor with regard to microleakage in fixed-to-fixed FDPs and cantilever FDPs.
2. Proximal box elevation was more frequently affected by microleakage than a conventional foundation restoration.

REFERENCES

1. Magne P, Spreafico RC. Deep margin elevation: A paradigm shift. *Amer J Esthet Dent*. 2012;2:86–96.
2. Pontoriero R, Carnevale G. Surgical crown lengthening: A 12-month clinical wound healing study. *J Periodontol*. 2001;72:841–848.
3. Carvalho CV, Bauer FP, Romito GA, Pannuti CM, De Micheli G. Orthodontic extrusion with or without circumferential supracrestal fiberotomy and root planing. *Int J Periodontics Restorative Dent*. 2006;26:87–93.
4. Dietrich T, Krug R, Krastl G, Tomson PL. Restoring the unrestorable! Developing coronal tooth tissue with a minimally invasive surgical extrusion technique. *Br Dent J*. 2019;226:789–793.
5. Krug R, Connert T, Soliman S, Syfrig B, Dietrich T, Krastl G. Surgical extrusion with an atraumatic extraction system: A clinical study. *J Prosthet Dent*. 2018;120:879–885.
6. Dietschi D, Spreafico R. Current clinical concepts for adhesive cementation of tooth-colored posterior restorations. *Pract Periodontics Aesthet Dent*. 1998;10:47–54.
7. Frankenberger R, Hehn J, Hajtó J, et al. Effect of proximal box elevation with resin composite on marginal quality of ceramic inlays in vitro. *Clin Oral Investig*. 2013;17:177–183.
8. Juloski J, S KO, Ferrari M. No correlation between two methodological approaches applied to evaluate cervical margin relocation. *Dent Mater J*. 2020;39:624–632.

9. Da Silva D, Ceballos L, Fuentes MV. Influence of the adhesive strategy in the sealing ability of resin composite inlays after deep margin elevation. *J Clin Exp Dent*. 2021;13:e886–e893.
10. Müller V, Friedl KH, Friedl K, Hahnel S, Handel G, Lang R. Influence of proximal box elevation technique on marginal integrity of adhesively luted cerec inlays. *Clin Oral Investig*. 2017;21:607–612.
11. Pereira LFO, Perucelli F, Souza EM, Rached RN. Influence of cervical margin relocation with direct restorative materials on the marginal integrity of CAD-CAM composite inlays. *Am J Dent*. 2022;35:30–36.
12. Chen YC, Lin CL, Hou CH. Investigating inlay designs of class II cavity with deep margin elevation using finite element method. *BMC Oral Health*. 2021;21:264.
13. Grassi EDA, de Andrade GS, Tribst JPM, et al. Fatigue behavior and stress distribution of molars restored with MOD inlays with and without deep margin elevation. *Clin Oral Investig*. 2022;26:2513–2526.
14. Vertolli TJ, Martinsen BD, Hanson CM, Howard RS, Kooistra S, Ye L. Effect of deep margin elevation on CAD/CAM-fabricated ceramic inlays. *Oper Dent*. 2020;45:608–617.
15. Moon W, Chung SH, Chang J. Effect of deep margin elevation on interfacial gap development of CAD/CAM inlays after thermomechanical cycling. *Oper Dent*. 2021;46:529–536.
16. Da Silva Gonçalves D, Cura M, Ceballos L, Fuentes MV. Influence of proximal box elevation on bond strength of composite inlays. *Clin Oral Investig*. 2017;21:247–254.
17. Metz M, Durski M, Chou J, Crim G, Harris B, Lin WS. Microleakage of lithium disilicate crown margins finished on direct restorative materials. *Oper Dent*. 2016;41:552–562.
18. Spreafico R, Marchesi G, Turco G, et al. Evaluation of the in vitro effects of cervical marginal relocation using composite resins on the marginal quality of CAD/CAM crowns. *J Adhes Dent*. 2016;18:355–362.
19. Juloski J, Köken S, Ferrari M. Cervical margin relocation in indirect adhesive restorations: A literature review. *J Prosthodont Res*. 2018;62:273–280.
20. Eggmann F, Ayub JM, Conejo J, Blatz MB. Deep margin elevation - Present status and future directions. *J Esthet Restor Dent*. 2023;35:26–47.
21. Samartzi TK, Papalexopoulos D, Ntovas P, Rahiotis C, Blatz MB. Deep margin elevation: A literature review. *Dent J*. 2022;10:1–17.
22. Aldakheel M, Aldosary K, Alnafissah S, Alaamer R, Alqahtani A, Almuhtab N. Deep margin elevation: Current concepts and clinical considerations: A review. *Medicina*. 2022;58:1–20.
23. Farouk AT, Hassanein OES, Fahmy OI, Elkady AM, ElNahass H. Biological evaluation of indirect restorations in endodontically treated posterior teeth with deeply located proximal margins following deep margin elevation versus surgical crown lengthening: A randomized controlled trial. *Clin Oral Investig*. 2023;28:24.
24. Mugri MH, Sayed ME, Nedumgottil BM, et al. Treatment prognosis of restored teeth with crown lengthening vs. deep margin elevation: A systematic review. *Materials ((Basel))*. 2021;14.
25. Aziz AM, Suliman S, Sulaiman TA, Abdulmajeed A. Clinical and radiographical evaluation of CAD-CAM crowns with and without deep margin elevation: 10-Year results. *J Prosthet Dent* 2024.
26. Kugel G, Ferrari M. The science of bonding: From first to sixth generation. *J Am Dent Assoc*. 2000;131:20–25.
27. Cardoso MV, de Almeida Neves A, Mine A, et al. Current aspects on bonding effectiveness and stability in adhesive dentistry. *Aust Dent J*. 2011;56:31–44.
28. Dreweck F, Burey A, de Oliveira Dreweck M, Fernandez E, Loguercio AD, Reis A. Challenging the concept that OptiBond FL and Clearfil SE Bond in NCCLs are gold standard adhesives: A systematic review and meta-analysis. *Oper Dent*. 2021;46:E276–E295.
29. Dreweck FDS, Burey A, de Oliveira Dreweck M, Loguercio AD, Reis A. Adhesive strategies in cervical lesions: Systematic review and a network meta-analysis of randomized controlled trials. *Clin Oral Investig*. 2021;25:2495–2510.
30. Strub JR, Kern M, Türp JC, Witkowski S, Heydecke G, Wolfart S. Curriculum Prothetik - Band II (4. Auflage). Berlin: Quintessence; 2011.
31. Qanungo A, Aras MA, Chitre V, Mysore A, Amin B, Daswani SR. Immediate dentin sealing for indirect bonded restorations. *J Prosthodont Res*. 2016;60:240–249.
32. Frankenberger R, Lohbauer U, Roggendorf MJ, Naumann M, Taschner M. Selective enamel etching reconsidered: Better than etch-and-rinse and self-etch? *J Adhes Dent*. 2008;10:339–344.

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