Effect of Internal, Office, and Home Bleaching on Shear Bond Strength of Enamel to Porcelain Laminate Veneers

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Purpose: To compare the effect of office, home, and internal bleaching on the shear bond strength (SBS) of enamel to porcelain laminate veneers. ***Materials and Methods:*** A total of 36 extracted maxillary central incisors were randomly assigned to four groups: *(1)* no bleaching (control); *(2)* office bleaching with 40% hydrogen peroxide (HP); *(3)* home bleaching with 15% carbamide peroxide; and *(4)* intracoronal bleaching with sodium perborate (SP) using the walking bleaching technique. All teeth were separately immersed in artificial saliva for 14 days. The enamel surface was then reduced by 0.5 mm, and IPS e.max Press ceramic discs were bonded using a resin cement. After 24 hours, all specimens were thermocycled (5,000 cycles, 5°C to 55°C). The SBS was measured using a universal testing machine, and the failure mode was determined using a stereomicroscope. One-way ANOVA and Tukey honest significant difference tests were used for data analysis ($P < .05$). ***Results:*** A significant difference was noted among the groups ($P < .001$). The highest SBS was noted in the control group (15.71 ± 5.39 MPa). The mean SBS in the office bleaching group (12.30 ± 4.64 MPa) was almost the same as the control. The lowest mean SBS belonged to the home bleaching group (5.39 ± 3.99 MPa). The mode of failure was adhesive in all four groups. ***Conclusion:*** If bleaching is intended to be followed by porcelain veneers, the office bleaching technique with 40% HP is recommended. Delaying the bonding procedure for 2 weeks does not appear to be effective with home or intracoronal bleaching. *Int J Prosthodont 2023;36:323–330. doi: 10.11607/ijp.7773*

Due to the recent advances in cosmetic dentistry and the increasing desires of patients to have a more pleasing smile, the demand for esthetic treatments has greatly increased.[1] Based on the intensity and type of tooth discoloration, the treatment options may include bleaching, direct composite veneers, porcelain laminate veneers, or full crowns.[2] Despite a long history of clinical use, composite veneers are associated with wear, marginal fracture, and discoloration.[3] Porcelain laminate veneers are a more durable option and are used for covering discolored teeth, diastema closure, and correction of lateral pegs and malposed teeth that cannot undergo orthodontic treatment.[4] Despite these benefits, the application of porcelain laminate veneers may be problematic in cases with severe discoloration, such as tetracycline stains.[5] In such cases, the simultaneous use of bleaching and porcelain veneers can be considered to achieve optimal esthetic results.[6]

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Tooth bleaching is a safe, effective, minimally invasive, and acceptable method for the treatment of discolored teeth. Different bleaching protocols and materials are available. Vital tooth bleaching techniques include office bleaching, dentist-supervised home bleaching, and over-the-counter bleaching.[7] Office bleaching is performed in dental clinics in one or more sessions.[8] Carbamide peroxide (CP) and hydrogen peroxide (HP) are the two components used most often. High concentrations are usually used in the office (25% to 40% HP and 30% to 35% CP), while materials containing up to 10% HP and 20% CP can be applied at home.[9,10]

Root-filling materials and medicaments remaining in the root canal system or the pulp chamber can cause coronal discoloration as a result of their penetration into the dentin tubules.[11] The walking bleaching technique is a standard method for the treatment of such cases.[2] In this method, sodium perborate (SP) mixed with water or HP is applied in the pulp chamber for a couple days. The procedure may be repeated until a favorable result is achieved.[11]

Obtaining a strong bond for bonded restorations is imperative to ensure success. Any modification to the enamel surface may affect the bond strength. Although tooth bleaching shows satisfactory esthetic results, some authors have reported that it may significantly decrease the bond strength of resin-bonded materials to hard tooth structures.[12] There is a significant controversy regarding the morphologic changes and variations in mineral components of enamel after bleaching. This lack of agreement in the literature comes from parameters related to the substrate, such as the origin of the samples, preparation procedures, age, and tooth preservation conditions, as well as the pH and concentration of the product used, timing, and interval of the procedure.[9,13,14]

Although HP is a potent and effective whitening agent, its safety and possible adverse effects are in question. Morphologic changes, variations in the microhardness and mineral components of enamel and dentin, changes at the dentin-enamel junction, and structural alterations in dentin have been reported following HP application.[9] It has been shown that HP breaks down and forms free radicals (ie, nascent oxygen and hydroxyl radicals) on the enamel surface.[15] Residual oxygen in interprismatic spaces can prevent the resin from penetrating the bleached enamel and polymerizing. Morphologic changes and alterations in enamel composition, such as increased porosity and loss of prismatic structure and calcium, can weaken the adhesive surface and adversely affect the bond strength.[15,16] Structural changes in the enamel have also been described with CP at low concentrations.[10,17–19] On the other hand, one study revealed that tooth bleaching for 21 days with 10% CP and 7.5% HP demonstrated no significant changes in micromorphology or microhardness of the enamel.[20]

Another critical parameter is the timing of bonding following bleaching. Cheng et al showed that the bond strength decreases by 25% to 60% if the bonding procedure is carried out immediately after bleaching.[1] Evidence also shows that the bond strength of restorations bonded to the enamel surface improves when a period has elapsed before cementation. Accordingly, a waiting time of 24 hours to 3 weeks has been suggested.[1]

The literature has already described the effects of different bleaching agents and concentrations on the bond strength of adhesive materials to bleached enamel[1,16,21,22]; however, information regarding a comparison of various bleaching protocols on the shear bond strength (SBS) of enamel to laminate veneers is missing. Thus, the present study aimed to compare the effects of office bleaching, home bleaching, and internal bleaching on the SBS of enamel to porcelain laminate veneers. The null hypothesis was that they would all have the same effect on the SBS of porcelain veneers to enamel after 2 weeks.

MATERIALS AND METHODS

Thirty-six sound human maxillary central incisors were evaluated in this experimental study. The teeth were free of caries, fractures, and cracks. The study design was approved by the ethics committee of Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1398.034). Dental plaque, calculus, and residual tissues were removed, and the teeth were immersed in 0.1% thymol (Azmiran) at 4°C. The specimens were randomly assigned to four groups (n = 9): *(1)* control, *(2)* office bleaching, *(3)* home bleaching, and *(4)* intracoronal bleaching.

Specimen Preparation

In group 2 (office bleaching), the teeth were bleached with 40% HP gel (Opalescence Boost, Ultradent Products) in two sessions with a 1-week interval. According to the manufacturer's instructions, a 1-mm–thick layer of the bleaching gel was applied on the labial surface of the teeth and left for 20 minutes in each session. The surface was periodically checked, and the gel was reapplied on areas that needed replenishing. The gel was removed with surgical suction and then thoroughly rinsed with an air/water spray and high-volume suction. This procedure was repeated three times in each session. The teeth were stored in artificial saliva during the bleaching intervals.

The teeth in group 3 (home bleaching) were bleached with 15% CP gel (Opalescence PF, Ultradent Products) for 2 weeks. A 1-mm–thick layer of the bleaching gel was applied on the labial surface of the teeth and left for 4 hours daily. The gel was removed with surgical suction and then thoroughly rinsed with an air/water spray and high-volume suction.

In group 4, the teeth underwent standard root canal treatment (palatal access, step-back technique, master

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apical file 40, lateral condensation, and AH26 sealer [Dentsply Sirona]). Root filling material was removed 2 mm under the cementoenamel junction (CEJ) level, and the canal was sealed with a 2-mm–thick resin-modified glass ionomer (UltraCem, Ultradent Products). SP (Merck) was mixed with distilled water in a 2:1 ratio (g/mL) and placed in the access opening according to the manufacturer's instructions. The access was sealed with noneugenol, nonresin provisional restorative material (UltraTemp, Ultradent Products). The teeth were stored in artificial saliva for 1 week. After 1 week, the bleaching agent was removed, and the access cavity was rinsed and restored with UltraTemp.[11,23]

All specimens, including those in group 1, which did not receive any treatment, were separately stored in artificial saliva for 2 weeks. The artificial saliva consisted of 1 mg sodium carboxymethylcellulose, 4.3 mg xylitol, 0.1 mg potassium chloride, 5 mg calcium chloride, 40 mg potassium phosphate, 1 mg potassium thiocyanate, and 100 mg distilled deionized water at pH 7 and was changed twice daily.[24]

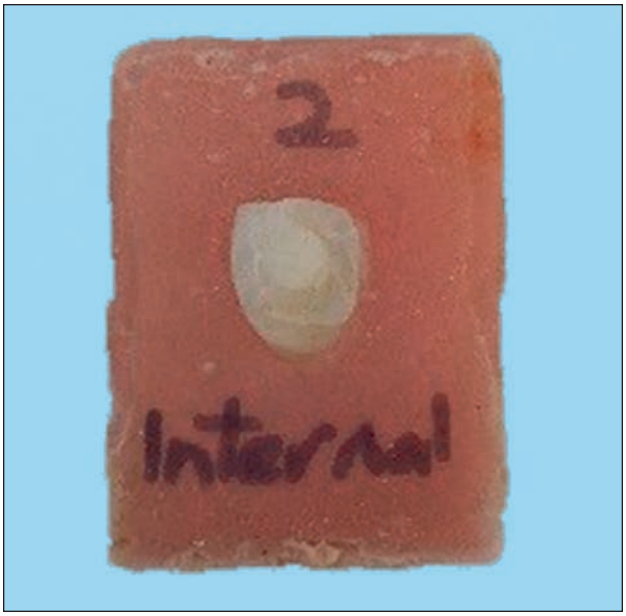


Fig 1 Specimen mounted in a block of autopolymerizing acrylic resin.

Preparation of Ceramic Discs

A total of 36 IPS e.max Press (Ivoclar Vivadent) ceramic discs (3-mm thickness and 4-mm width) were fabricated according to the manufacturer's instructions and stored in distilled water until the bonding procedure. The discs were waxed (S-U-CERAMO-CARVING-WAX, Schuler-Dental), sprued, and pressed after investment. The ceramic discs were finished with diamond burs (Shenzhen Perfect Medical Instruments) and glazed. The previously mentioned disc dimensions were used to ensure proper placement of the universal testing machine blade at the disc-tooth interference during the SBS test.

Bonding Procedure

The roots were separated from the crowns 2 mm below the CEJ using a tapered fissure bur (#882, Teezkavan) under water irrigation. The enamel surface of each specimen was reduced by 0.5 mm. Self-limiting depth-cutting burs of 0.5 mm (#834, Teezkavan) were used to define depth cuts, and a chamfer diamond bur (#850, Teezkavan) was used to refine the preparation. The amount of reduction was also checked using a putty index (Asia Chemi Teb).

The bonding procedure of the discs to the enamel surface was performed according to the manufacturer's instructions for cementation of IPS e.max via Choice 2 light-curing resin cement (Bisco Dental Products). The porcelain discs were etched for 90 seconds with 9.5% hydrofluoric acid (Porcelain Etchant, Bisco Dental Products). Afterward, one to two coats of silane (Bis-Silane, Bisco Dental Products) were applied to the discs for 30 seconds and air dried. The enamel surfaces were etched with 32% phosphoric acid (Uni-Etch w/BAC, Bisco Dental Products) for 15 seconds, thoroughly rinsed for 20 seconds, and excess water was removed; however, the surfaces were not overdried. Next, two coats of bonding agent (All-Bond 3, Bisco Dental Products) were applied to the enamel surfaces and gently air dried and light cured for 10 seconds. A very thin layer of porcelain bonding resin (Bisco Dental Products) was applied to the bonding surfaces of the discs. Next, A1 shade of Choice 2 cement was applied on the prepared surfaces of the discs. The discs were seated on the middle third of the enamel surfaces in a specially designed cementing device to apply standardized static weight (49 Nm) to ensure a fixed load on each disc during cementation[24] and were then light polymerized with a light intensity of 470 Mv/cm^2 for 5 seconds. Each specimen was further light cured for 40 seconds on all surfaces after the removal of excess cement. The emitting tip of the curing light was held as near and vertical to the resin surface as possible.

SBS Test

All specimens were mounted in blocks (2.5 mm × 3.5 mm) of autopolymerizing acrylic resin (Acropars) while the labial surface faced upward (Fig 1). All specimens were thermocycled (Vafaei Industrial) for 5,000 cycles, equivalent to 6 months of clinical service, in water baths between 5°C and 55°C with a dwell time of 30 seconds and a transfer time of 10 seconds.[1] After 24 hours, the teeth were placed in a universal testing machine (Zwick/Roell Z020, Zwick) at a crosshead speed of 1 mm/minute until debonding. The force was applied perpendicular to the disc-tooth interface (Fig 2). The maximum failure load

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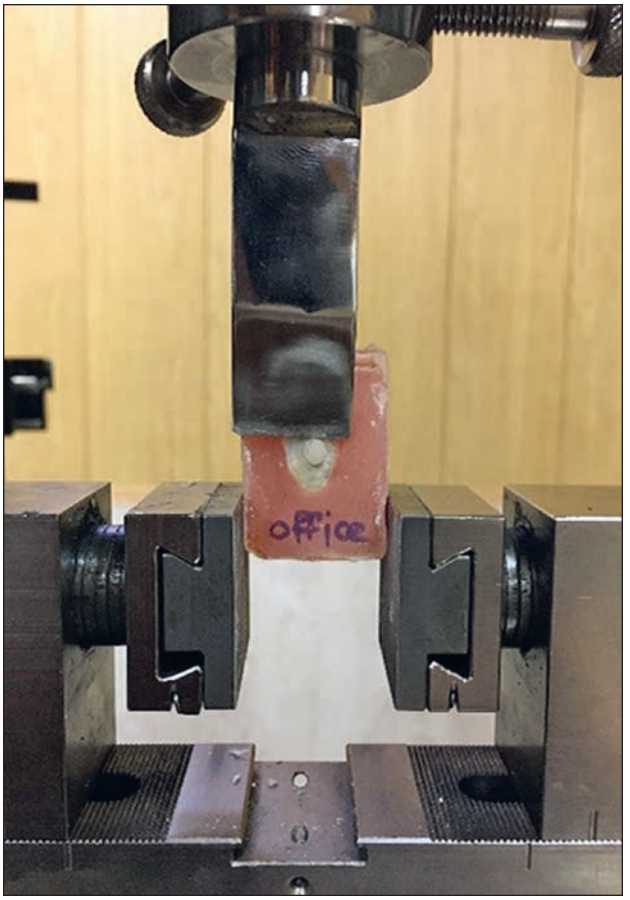


Fig 2 Universal testing machine used to examine the SBS.



Fig 3 Adhesive failure at the cement-laminate interface observed under a stereomicroscope at ×10 magnification.

(in Newtons) was recorded and converted into megapascals by dividing the failure load by the bonding area (12.56 mm^2).[25]

Mode of Failure

After SBS testing, all specimens were observed under a stereomicroscope (SMZ800, Nikon) at ×10 magnification for the assessment of failure mode (Fig 3). The mode of failure was categorized as adhesive (failure at the enamel-laminate interface), cohesive (failure in the enamel or laminate alone), or mixed (both adhesive and cohesive).

Statistical Analysis

The mean SBS of the study groups was compared using one-way ANOVA and Tukey test via SPSS version 20 ($P < .05$).

RESULTS

Table 1 and Fig 4 show the measures of central dispersion of the mean SBS (MPa) of the study groups. One-way ANOVA showed a significant difference between groups for SBS ($P < .001$). The highest mean SBS belonged to the control group (15.7 ± 5.3 MPa), followed by the office bleaching group (12.3 ± 4.6 MPa). No statistically significant difference was found between these two groups ($P = .3$ MPa); in contrast, the values for the home bleaching (5.3 ± 3.9 MPa) and internal bleaching groups (8.5 ± 3.0 MPa) were significantly lower than the values in the control group ($P < .05$; Table 1). The lowest mean SBS belonged to the home bleaching group.

Mode of Failure

The predominant mode of failure in all teeth in all four groups was adhesive. Adhesive failure was divided into three groups: failure between the cement and enamel, failure between the cement and laminate, and both. The frequency distribution is presented in Fig 5.

DISCUSSION

In the present study, delaying the bonding procedure of porcelain laminate veneers to enamel for 2 weeks and a 0.5-mm reduction of the enamel surface after office bleaching resulted in average SBS values close to the

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Table 1 Measures of Central Dispersion of SBS (MPa) in Each Study Group (n = 9)

Group	Minimum	Maximum	Mean	SD	*P* value
Control	9.27	26.54	15.71	5.39	–
Office bleaching	5.39	20.96	12.30	4.64	.362
Home bleaching	1.23	13.42	5.39	3.99	.000
Internal bleaching	4.01	12.45	8.59	3.08	.008

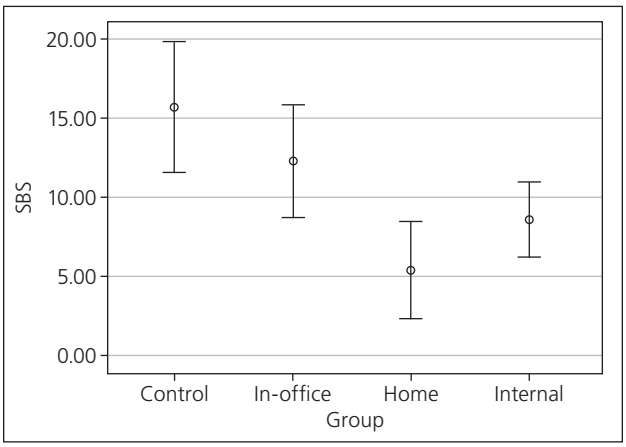


Fig 4 Error bars and 95% CI of the mean SBS of porcelain laminate veneers to bleached enamel.

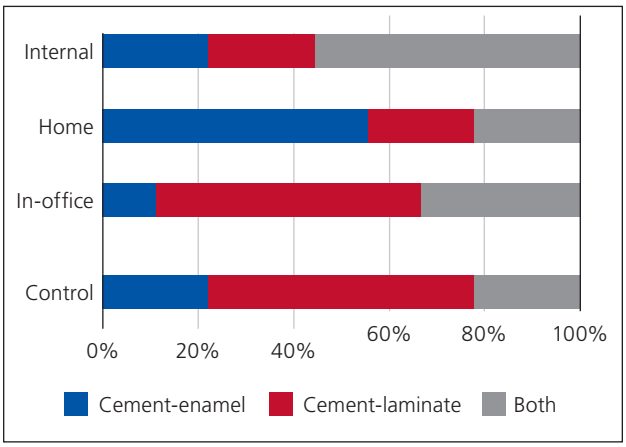


Fig 5 Distribution of the different adhesive failure modes in the study groups.

controls; however, these values were significantly lower after internal and home bleaching. Therefore, the null hypothesis that the three bleaching techniques would have the same effect on SBS of porcelain veneers to enamel after 2 weeks was rejected.

Bleaching treatments with oxidizing agents have proved to be effective for correcting and reducing intrinsic and/or external discoloration resistant to mechanical cleaning through breaking the double bonds of chromophores; however, such treatments can also lead to mineral loss and increased surface roughness, therefore decreasing the bond strength of enamel to adhesive materials.[1,12,26] The presence of free radicals that inhibit resin penetration and polymerization, loss of calcium and phosphate, and increased porosities of the enamel surface have been attributed as the causes.[27,28] Enamel is the most mineralized tissue in the human body, consisting of 96% mineral and 4% organic components.[29] The structure of enamel hydroxyapatite can change as a result of bleaching.[8] Ben-Amar et al reported an increase in enamel surface porosities and a significant decrease in enamel bond strength to composite resins after bleaching with CP.[30] Studying the effects of various home bleaching techniques on enamel properties, De Miranda et al found an initial loss of structural organization with 10% HP gel and 10% HP whitening strips after 4 weeks and 10% CP after 8 weeks. They stated that oxidation of proteins in enamel with sacrificial bonds capable of unfolding against tensions and recovering their arrangement with the removal of forces seems to be decisive for altering the mechanical behavior of the enamel.[31] Oliveira et al also showed that the use of 10% CP reduces the surface microhardness of enamel.[32] Titley et al stated that in SEM analysis of bleached samples with 35% HP to which composite resin was bonded, large areas of the enamel surface were free of resins. They suggested an interaction between the resin and the remaining peroxides on the enamel surface, which can prevent complete polymerization of the resin.[33] An increased organic ratio of enamel as a result of denaturation of proteins has also been observed.[34] As a result, the literature suggests that the bonding processes should not be performed immediately after bleaching. This delay will help removal of oxygen, residual peroxide, or peroxide-related materials, and therefore remineralization of the enamel will occur in the presence of saliva.[33,35] Studies have suggested a period of 24 hours to 3 weeks before cementation.[1,36,37] The present study considered a 2-week interval. Although the available information is not enough regarding the number of free radicals remaining at different depths of enamel after bleaching, it is thought that changes usually occur on the surface. Therefore, the preparation of enamel may partially eliminate the effect of residual

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oxygen and structural changes resulting from bleaching and improve the bond strength.[1]

Office bleaching is often used when results are expected faster.[8] In the present study, 40% HP was used, and the mean values for SBS in this group were lower than the controls; however, this difference was not statistically significant. Borges et al showed that the bond strength values after bleaching with 35% HP and 35% CP were significantly different from the controls after 1 week and 2 weeks but not 3 weeks.[38] In a study by Beltagui et al, bonding of IPS e.max Press discs to bleached enamel with 40% HP caused a significant decrease in the average values of SBS immediately but not after 7 days.[16] In the two mentioned studies, the duration of bleaching was 20 minutes; however, the total bleaching time in the present study was 60 minutes. It can be concluded that, if the bleaching time is reduced, it is likely that a shorter delay is required for bonding.

Home bleaching is a standard and safe method of tooth whitening.[8] Although the concentrations used for home bleaching are lower, the longer duration of treatment appears to have a significant effect on the bond strength. In the current study, 15% CP caused a significant reduction in the SBS of porcelain laminate discs to the enamel. Mortazavi et al declared that bleaching with 15% CP and bonding of composite resin 24 hours later caused a significant reduction in bond strength.[39] Cavalli et al investigated the effect of delayed bonding for 24 hours and 1 week, 2 weeks, and 3 weeks after bleaching with 10% to 20% CP. They declared that the bond strength first decreased compared to the controls, but not after 3 weeks.[40] In El Mourad, bleaching with 20% CP and delayed bonding for 24 hours using five different adhesive systems reduced the bond strength in all groups compared to the controls.[41] In the present study, which increased the bonding delay to 2 weeks, enamel reduction did not improve the bond strength of home bleaching. This might indicate that this time was insufficient to neutralize the effect of free radicals and structural changes in the enamel. Metz et al demonstrated that home bleaching with 15% CP and delayed bonding of composite veneers after 2 weeks did not cause a significant reduction in bond strength.[42] The results of Basting et al also showed that bleaching with 10% to 22% CP and delayed bonding of composite resin after 15 days did not reduce the bond strength to enamel.[36] It is important to see how the bond strength will perform in the long run and under various conditions, such as temperature changes inside the mouth. The two previously mentioned studies, however, failed to do so.

The walking bleaching technique is a standard method for discolored nonvital teeth that can be performed using SP or HP.[8] SP is easier to control and safer than HP. In the presence of acid, warm air, or water, it breaks down to form sodium metaborate, HP, and nascent oxygen.[43] Internal bleaching caused a significant reduction in SBS in the present study. Because the bleaching material is applied inside the pulp chamber, a 0.5-mm reduction of the enamel surface does not improve the bond strength. In internal bleaching, the bleaching agent penetrates from the dentin to the enamel, and resin restoration of the teeth that have undergone internal bleaching requires a delay of at least 1 to 4 weeks.[44,45] Shinohara et al indicated that intracoronal bleaching with SP significantly decreases the bond strength of composite resins to the enamel surface after delayed bonding by 7 days.[46] Gungor et al also stated that intracoronal bleaching with HP, SP, and CP significantly decreases the bond strength of orthodontic brackets cemented with composite resin to enamel after delayed bonding by 4 weeks.[44]

Thermocycling is an in vitro process routinely used to simulate the natural aging of bonded interfaces.[47,48] It causes mechanical stresses and accelerates the hydraulic degradation of adhesive hydrophilic components and hybrid layer collagen fibrils. These factors can cause depreciation at the bonding site.[49] However, it should be noted that thermocycling alone might not be sufficient to simulate the oral environment, and other methods, such as dynamic loading, could be accompanied by more realistic results.[47]

The mode of failure was adhesive in all specimens in the present study, which shows a weak bond between cement-laminate and enamel-laminate. The highest frequency of failures at the cement-laminate interface was observed in the office group, while the highest frequency of failures at the cement-enamel interface was noted in the home group, which may be due to insufficient penetration and polymerization of the resin cement into the enamel, as well as higher structural and compositional changes following bleaching with 15% CP. Failures were reported to be of adhesive,[36] mixed,[24] and cohesive types[50] in other studies. The differences may be due to how the teeth were prepared, storage conditions, and the type of porcelains and cement used.

Despite recent advances, the bonding interface is still considered the weakest point in adhesive restorations.[51] Bond strength can be assessed by laboratory methods or clinical trials. Although the relationship between laboratory test results and the reliability of clinical performance remains questionable, laboratory tests can be used to gather data quickly, easily, and for a specific parameter. Laboratory methods for evaluating bond strength are divided into static and dynamic tests. Static tests are performed in a macro or micro design based on the bonded area.[52] Owing to the simplicity of specimen preparation, testing protocol, and lower incidence of pretest failure, SBS is commonly used for bond strength assessment; however, finite element analysis has demonstrated that conventional (macro) SBS tests might result

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in nonuniform and heterogenous stress patterns.[53,54] Results of SBS and failure mode analysis are also influenced by loading technique and specimen dimensions; therefore, they should be interpreted with caution for clinical usage.[51]

CONCLUSIONS

Delaying the bonding procedure of laminate veneers for 2 weeks does not appear to affect the bond strength of these restorations to the enamel surface when home or intracoronal bleaching is planned to be performed; therefore, if the treatment plan includes bleaching followed by porcelain laminate veneers, it is recommended to perform office rather than home bleaching.

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The authors report no conflicts of interest.

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Literature Abstract

The Lack of Keratinized Mucosa as a Risk Factor for Peri-Implantitis: A Systematic Review and Meta-Analysis

This study aimed to investigate the effect of the lack of keratinized mucosa on the risk of peri-implantitis, while also accounting for possible confounding factors. A literature search was conducted in PubMed and Scopus, including human studies that assessed the presence and width of keratinized mucosa in relation to the occurrence of peri-implantitis. Twenty-two articles were included, and 16 cross-sectional studies we meta-analyzed. The prevalence of peri-implantitis was 6.68-62.3% on patient-level and 4.5-58.1% on implant-level. The overall analysis indicated that the lack of keratinized mucosa was associated with a higher prevalence of peri-implantitis (OR = 2.78, 95% CI 2.07-3.74, $p < 0.00001$). Similar results were shown when subgroup analyses were performed, including studies with a similar case definition of peri-implantitis (Marginal Bone Loss, MBL ≥ 2 mm) (OR = 1.96, 95% CI 1.41-2.73, $p < 0.0001$), fixed prostheses only (OR = 2.82, 95% CI 1.85-4.28, $p < 0.00001$), patients under regular implant maintenance (OR = 2.08, 95% CI 1.41-3.08, $p = 0.0002$), and studies adjusting for other variables (OR = 3.68, 95% CI 2.32-5.82, $p = 0.007$). Thus, the lack of keratinized mucosa is a risk factor that increases the prevalence of peri-implantitis and should be accounted for when placing dental implants.

Mahardawi B, Jiaranuchart S, Damrongsirirat N, Arunjaroensuk S, Mattheos N, Somboonsavatdee A, Pimkhaokham A. *Sci Rep* 2023;13:3778. **References:** 64. **Reprints:** A Pimkhaokham: atiphan.p@chula.ac.th—*Steven Sadowsky, USA*

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