Journal of Orthodontic and Periodontal Biomaterials Research

2022, Volume 2, Issue 1, Page No: 36-41

Galaxy Publication

Evaluation of Silorane-Based Adhesives for Orthodontic Bracket Bonding

Lucie Nowak[1], Tereza S. Svoboda[1], Marek P. Novak[1], Tomasz R. Kowalski[1], Pavel Kowalski[1]*, Tereza Novak[1]

[1]Department of Oral Biology, Faculty of Dentistry, Medical University of Warsaw, Warsaw, Slovakia.

***E-mail** ✉ pavel.kowalski@hotmail.com

Received: 05 February 2022; **Revised:** 18 April 2022; **Accepted:** 22 April 2022

ABSTRACT

A new epoxy-based resin, Filtek Silorane, has recently been introduced for restorative dental fillings. This study aimed to assess its effectiveness for orthodontic bracket bonding on unground enamel. Shear bond strength was tested using two adhesives—Filtek Silorane and Transbond XT—paired with steel, ceramic, and polymer brackets. Filtek Silorane was applied following either its self-etching primer protocol or conventional phosphoric acid etching, while Transbond XT, etched only with phosphoric acid, served as the control. All specimens underwent 1000 thermo-cycles between 5 and 55 °C. Shear testing was performed using an Instron 3344 machine, and ARI scores were recorded. Results indicated that Filtek Silorane exhibited poor adhesion to unprepared enamel, regardless of the etching method (0.87–4.28 MPa), whereas the control group showed significantly higher bond strength (7.6–16.5 MPa). ARI analysis revealed that failures with Filtek Silorane occurred at the enamel-adhesive interface, while failures with Transbond XT predominantly occurred at the adhesive–bracket interface. Overall, the epoxy-based resin Filtek Silorane is unsuitable for bonding brackets to unground enamel.

Keywords: Bracket bonding, Enamel, Silorane, Shear bond strength

How to Cite This Article: Nowak L, Svoboda TS, Novak MP, Kowalsk TR, Kowalski P, Novak T. Evaluation of Silorane-Based Adhesives for Orthodontic Bracket Bonding. J Orthod Periodontal Biomater Res. 2022;2(1):36-41. https://doi.org/10.51847/g6tMF3lKg9

Introduction

Since Buonocore introduced dental adhesives [1], numerous modifications have been pursued to create resins that are more stable, aesthetically appealing, or easier to handle [2]. Most dental resins are based on methacrylate chemistry, which polymerizes through free-radical–induced opening of double bonds that then react with other methacrylate molecules. A major limitation of methacrylate-based resins is the relatively high polymerization shrinkage, caused by increased viscosity that restricts the flow of unpolymerized monomers and radicals in the post-gel phase, resulting in material contraction [3]. This shrinkage poses a significant challenge for maintaining the marginal integrity of large restorations. Over the past decade, the polymerization shrinkage of methacrylate resins for posterior restorations has decreased to 1–3%, achieved through two key modifications: extending the methacrylate chain length from 86.1 g/mol to 514.6 g/mol, which reduced shrinkage from 22% to 8% [4], and incorporating nanoparticles as fillers, further lowering shrinkage to the current 1–3% [4]. Despite these advances, shrinkage remains a central concern in restorative dentistry, as evidenced by numerous studies.

Researchers have also explored alternatives to methacrylates to further reduce shrinkage. Epoxy-based resins polymerize via cationic opening of oxirane rings, resulting in minimal shrinkage [4, 5] or even slight expansion [6], which improves marginal integrity and reduces micro-leakage at the dentin–resin interface compared to conventional composites [7]. However, epoxy resins can present challenges, such as cytotoxicity [5], with epoxides capable of inducing chromosomal aberrations [5]. By combining oxiranes with hydrophobic siloxanes—oxidized silicones—these cytotoxic effects are eliminated, producing the so-called Siloranes, described by Guggenberger and Weinmann and patented by 3M/ESPE [8]. The high biocompatibility of siloranes is attributed to the inhibition of oxirane hydrolysis by siloxanes [9] and the low toxicity of the monomers [10]. Their hydrophobicity also reduces bacterial adhesion [11] and dye absorption [4]. Mechanically, siloranes demonstrate comparable e-modulus and flexural strength to methacrylates [11], though marginal adaptation and micropermeability results remain controversial [12, 13]. Shear bond strengths are generally lower for siloranes, both to dentin [14] and enamel [15], as well as to aged methacrylate blocks simulating restoration repairs [16].

In orthodontic applications, some of these issues are less critical. Polymerization shrinkage is less relevant due to the thin adhesive layer between bracket and enamel, and water absorption or resin degradation is less concerning because the bond is only required for 1–3 years. The lower dye absorption and reduced bacterial adhesion are advantageous features. The primary concern, however, is shear bond strength to unetched enamel, which has not been thoroughly investigated. Previous studies by the resin developers indicated good adhesion to dentin and prepared enamel [17, 18]. The present study hypothesizes that if Filtek Silorane demonstrates strong adhesion to unground enamel and various bracket materials, it could achieve shear bond strengths comparable to or exceeding conventional methacrylate systems, making it a viable option for orthodontic bracket bonding.

Materials and Methods

This study assessed the shear bond strength of two adhesives—Transbond XT (3M/ESPE, Monrovia, CA, USA), used as a control, and Filtek Silorane (3M/ESPE, Monrovia, CA, USA)—in combination with three bracket types: ceramic (Clarity, 3M/ESPE), metal (Victory, 3M/ESPE), and composite (Esthetic Line, Forestadent, Pforzheim, Germany). Freshly extracted bovine teeth were used to simulate human enamel. After extraction, the roots were shortened and pulp tissue removed within 24 hours; crowns were then stored in frequently refreshed tap water at room temperature for 1–3 days. Tooth surfaces were polished with unfluoridated pumice (Kerr Pumice Fine, Orange, CA, USA) using a contra-angle handpiece at 2500 rpm for 10 seconds per specimen.

A total of 135 teeth were assigned to nine groups of 15 specimens. For Transbond XT, enamel surfaces were etched with 35% phosphoric acid for 30 seconds, followed by application of Transbond MIP primer, which was light cured for 10 seconds. For Filtek Silorane, two etching protocols were applied: either the self-etching Silorane primer alone or phosphoric acid etching for 30 seconds prior to the primer. The self-etching primer was applied for 15 seconds, gently air-dried for 10 seconds, and light cured for 10 seconds. Filtek Silorane bonding resin was then applied, air-dried for 10 seconds, and light cured for an additional 10 seconds. Brackets were carefully positioned on the tooth surface, excess adhesive removed, and cured for 20 seconds using an Ortholux LED light (3M/ESPE).

All samples were subjected to 1000 thermo-cycles between 5 °C (±1 °C) and 55 °C (±1 °C), with 25-second immersion per bath and a total cycle duration of 60 seconds. Teeth were embedded in methacrylate resin (Technovit 4071, Heraeus Kulzer, Germany), aligning the bonding surface parallel to the shear force vector, leaving a 0.5 mm clearance for the testing device. Shear bond strength was measured using an Instron 3344 machine at a crosshead speed of 1 mm/min. The Adhesive Remnant Index (ARI) was evaluated under 3.5× magnification according to Artun and Bergland [19], with scores ranging from 0 (no adhesive on enamel) to 3 (all adhesive remaining on the tooth).

Statistical analysis was conducted using GraphPad Prism (GraphPad, San Diego, CA, USA). As some groups deviated from normal distribution (Kolmogorov–Smirnov test), differences were assessed using ANOVA with Kruskal–Wallis and Dunn’s post-test at a significance level of $p \leq 0.05$.

Results and Discussion

After thermo-cycling, 23% of Filtek Silorane specimens detached spontaneously, irrespective of whether phosphoric acid was used prior to self-etching, while all Transbond XT samples remained intact. Filtek Silorane consistently demonstrated very low bond strength to unprepared bovine enamel, significantly lower ($p \leq 0.05$) than Transbond XT for all bracket types **(Table 1, Figure 1)**. ARI scoring revealed that failures in Filtek Silorane samples occurred predominantly at the enamel-adhesive interface, whereas in Transbond XT groups, failures were mainly observed at the adhesive–bracket interface **(Table 1, Figure 2)**.

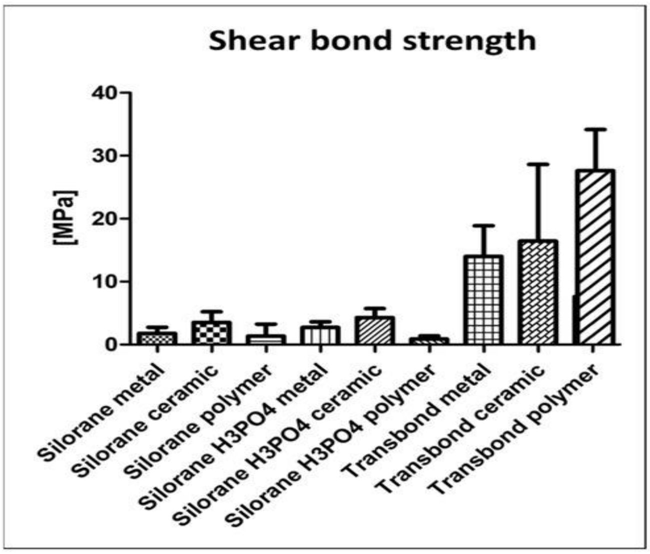

Figure 1. Average shear bond strengths with standard deviations; Filtek Silorane groups showed significantly lower values compared to Transbond XT ($p \leq 0.05$)

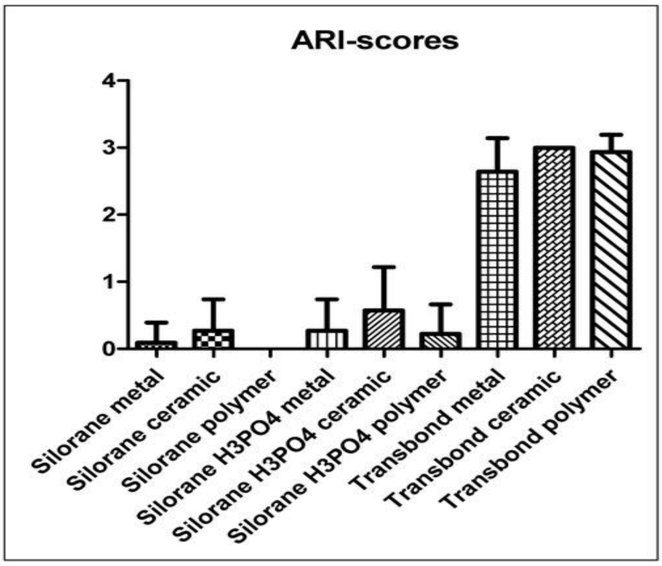

Figure 2. ARI scores for all groups. Higher scores reflect failure at the enamel–adhesive interface, while lower scores indicate failure at the bracket–adhesive interface

Table 1. Comparison of the mean shear bond strength [N], standard deviations (SD) and ARI. The column significance shows differences according to the shear bond strength ($p \leq 0.05$)

Adhesive and Etching Mode	Group Name, Bracket Type, n	Shear Bond Strength [MPa], (SD)	Significance at $p \leq 0.05$	ARI Score
Filtek Silorane, Silorane self-etching primer	A, ceramic, 14	3.50 (1.71)	G–K	0.27
	B, polymer, 4	1.37 (1.87)	G–K	0
	C, metal,11	1.77 (0.97)	G–K	0.09
Filtek Silorane, conventional etching, Silorane primer	D, ceramic, 15	4.28 (1.43)	G–K	0.57
	E, polymer, 9	0.87 (0.53)	G–K	0.22
	F, metal, 15	2.71 (0.91)	G–K	0.27
Transbond XT, Conventional etching, Transbond MIP	G, ceramic, 15	16.5 (12.2)	A–F, K	3.0
	H, polymer, 15	7.62 (3.62)	A–F, K	2.9
	I, metal, 15	14.0 (4.89)	A–F, K	2.6

Due to the increasing difficulty in obtaining extracted human teeth because of advances in conservative dentistry, bovine incisors were used in this study as a substitute for human enamel. The ISO 11,405 standard recommends bovine enamel for adhesive shear testing, and literature supports its use, reporting comparable [20–23] or slightly lower [24] bond strengths. Retentive etching patterns differ minimally between the two species, with no significant impact on adhesion [22], and histological and anatomical features are largely similar [22, 23, 25], supporting the suitability of bovine enamel as a model.

For orthodontic purposes, ideal shear bond strength should minimize bracket failures during treatment while allowing easy debonding at the end to prevent enamel damage or hypersensitivity [26]. In this study, Filtek Silorane exhibited shear bond strengths to unground bovine enamel below the minimum values recommended by Reynolds [27], regardless of etching method. These results were considerably lower than those reported in studies by the developers of Silorane [17, 18]; however, two key differences in methodology may explain this. First, previous studies used ground bovine enamel or dentin, simulating prepared cavity surfaces rather than intact enamel, which is more mineralized and typically provides lower adhesion [28, 29]. Second, the earlier investigations did not include thermo-cycling, which is known to significantly affect bond strength [30–33] due to stress induced at the adhesive interface from differences in thermal expansion between enamel and composite. Filtek Silorane may be particularly sensitive to such thermal stresses. Although standard thermo-cycles (5 °C to 55 °C) may not perfectly reflect in vivo conditions, the bond strength of Transbond XT was largely unaffected by this process, consistent with prior studies [32, 34, 35]. Previous work has also shown that certain self-etching primers experience spontaneous debonding under identical thermo-cycling, while conventional etching remains stable [36], indicating that thermo-cycling effectively distinguishes adhesives with differing stress tolerance.

ARI analysis showed that Transbond XT failures primarily occurred at the bracket–adhesive interface, while Filtek Silorane failures were concentrated at the enamel–adhesive interface, regardless of bracket type. This prevented further evaluation of Filtek Silorane's bonding performance with different brackets. Overall, Filtek Silorane demonstrated insufficient adhesion to unprepared enamel.

Conclusion

Currently, siloranes cannot be considered a viable alternative to conventional methacrylate adhesives for orthodontic bracket bonding.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: None

References

1. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res. 1955;34(6):849–53.
2. Fugolin APP, Pfeifer CS. New resins for dental composites. J Dent Res. 2017;96(10):1085–91.
3. Stepto RFT. Polymer Networks: Principles of Their Formation, Structure and Properties. London: Blackie Academic and Professional Publishing; 1998.
4. Weinmann W, Thalacker C, Guggenberger R. Silorane in dental composites. Dent Mater. 2005;21(1):68–74.
5. Schweikl H, Schmalz G, Weinmann W. The induction of gene mutations and micronuclei by oxiranes and siloranes in mammalian cells in vitro. J Dent Res. 2004;83(1):17–21.
6. Belfield K, Zang G. Photoinitiated cationic ring-opening polymerization of a cyclosiloxane. Polym Bull. 1997;38(2):165–8.
7. Sauro S, Pashley D, Mannocci F, Tay F, Pilecki P, Scherriff M, Watson T. Micropermeability of current self-etching and etch-and-rinse adhesives bonded to deep dentine: a comparison study using a double-staining/confocal microscopy technique. Eur J Oral Sci. 2008;116(2):184–93.

8. Palin M, Fleming G, Nathwani H, Burke F, Randall R. In vitro cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. Dent Mater. 2005;21(4):324–35.
9. Eick D, Smith R, Pinzino C, Kostoryz E. Stability of silorane dental monomers in aqueous systems. J Dent. 2006;34(6):405–10.
10. Eick D, Kotha S, Chappelow C, Kilway K, Giese G, Glaros A, Pinzino C. Properties of silorane-based dental resins and composites containing a stress-reducing monomer. Dent Mater. 2007;23(8):1011–7.
11. Buergers R, Schneider-Brachert W, Hahnel S, Rosentritt M, Handel G. Streptococcal adhesion to novel low-shrink silorane-based restorative. Dent Mater. 2009;25(2):269–75.
12. Yantcheva SM. Marginal adaption and micropermeability of class II cavities restored with three different types of resin composites—a comparative ten-month in vitro study. Polymers (Basel). 2021;13(10):1660.
13. Hepdeniz OK, Ermis RB. Comparative evaluation of marginal adaption and microleakage of low-shrinking composites after thermocycling and mechanical loading. Niger J Clin Pract. 2019;22(5):633–41.
14. Jaafoura S, Kikly A, Sahtout S, Trabelsi M, Kammoun D. Shear bond strength of three composite resins to fluorosed and sound dentine: in vitro study. Int J Dent. 2020;2020:4568568.
15. Haajizadeh H, Nemati-Karimooy A, Nasseh A, Rahmanpour N. Evaluating shear bond strength of enamel and dentin with or without etching: a comparative study between dimethacrylate-based and silorane-based adhesives. J Clin Exp Dent. 2015;7(4):e563–8.
16. Kouros P, Koliniotou-Koumpia E, Spyrou M, Koulaouzidou E. Influence of material and surface treatment on composite repair shear bond strength. J Conserv Dent. 2018;21(3):251–6.
17. Syrek A, Kappler O, Guggenberger R, Weinmann W, Dede K, Loll H, Thalacker C. One-year bond strength evolution of the silorane restorative system. In: Proceedings of the IADR 86th General Session & Exhibition; 2008 Jul 3; Toronto, Canada.
18. Thalacker C, Heumann A, Weinmann W, Guggenberger R, Syrek A. Shear bond strengths of silorane versus methacrylate restorative systems. In: Proceedings of the IADR 86th General Session & Exhibition; 2008 Jul 3; Toronto, Canada.
19. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod. 1984;85(4):333–40.
20. Fowler CS, Swartz ML, Moore BK, Rhodes BF. Influence of selected variables on adhesion testing. Dent Mater. 1992;8(4):265–9.
21. Krifka S, Börzsönyi A, Koch A, Hiller KA, Schmalz G, Friedl KH. Bond strength of adhesive systems to dentin and enamel—human vs. bovine primary teeth in vitro. Dent Mater. 2008;24(7):888–94.
22. Nakamichi I, Iwaku M, Fusayama T. Bovine teeth as possible substitutes in the adhesion test. J Dent Res. 1983;62(10):1076–81.
23. Reis AF, Giannini M, Kavaguchi A, Soares CJ, Line SR. Comparison of microtensile bond strength to enamel and dentin of human, bovine and porcine teeth. J Adhes Dent. 2004;6(2):117–21.
24. Oesterle LJ, Shellhart WC, Belanger GK. The use of bovine enamel in bonding studies. Am J Orthod Dentofacial Orthop. 1996;113(5):514–9.
25. Bachmann L, Craievich AF, Zezell DM. Crystalline structure of dental enamel after Ho:YLF laser irradiation. Arch Oral Biol. 2004;49(11):923–9.
26. Scribante A, Gallo S, Celmare RL, D’Anto V, Grippaudo C, Gandini P, Sfondrini FM. Orthodontic debonding and tooth sensitivity of anterior and posterior teeth. Angle Orthod. 2020;90(6):766–73.
27. Reynolds I. A review of direct orthodontic bonding. Br J Orthod. 1975;2(3):171–8.
28. Ermis R, De Munck J, Cardoso M, Coutinho E, Van Landuyt K, Poitevin A, Lambrechts P, Meerbeek B. Bonding to ground versus unground enamel in fluorosed teeth. Dent Mater. 2007;23(10):1250–5.
29. Kanemura N, Sanoh H, Tagami J. Tensile bond strength to and SEM evaluation of ground and intact enamel surfaces. J Dent. 1999;27(7):523–30.
30. Bishara S, Ajlouni R, Laffoon J. Effect of thermocycling on the shear bond strength of a cyanoacrylate orthodontic adhesive. Am J Orthod Dentofacial Orthop. 2003;123(1):21–4.
31. Elekdag-Turk S, Turk T, Isci D, Ozkalayci N. Thermocycling effects on shear bond strengths of a self-etching primer. Angle Orthod. 2008;78(2):351–6.
32. Daub J, Berzins D, Linn B, Bradley T. Bond strength of direct and indirect bonded brackets after thermocycling. Angle Orthod. 2006;76(2):295–300.

33. Bishara S, Khowassah A, Oesterle L. Effect of humidity and temperature changes on orthodontic direct-bonding adhesive systems. J Dent Res. 1975;54(4):751–7.
34. Grubisa H, Heo G, Raboud D, Glover K, Major P. An evaluation and comparison of orthodontic bracket bond strengths achieved with self-etching primer. Am J Orthod Dentofacial Orthop. 2004;126(2):213–9.
35. Linn B, Berzins D, Dhuru V, Bradley T. A comparison of bond strength between direct- and indirect-bonding methods. Angle Orthod. 2006;76(2):289–94.
36. Brauchli L, Zeller M, Wichelhaus A. Shear bond forces of seven self-etching primers after thermo-cycling. J Orofac Orthop. 2011;72(5):371–80.