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ORIGINAL ARTICLE

Five-year clinical performance of a silorane- vs a methacrylate-based composite combined with two different adhesive approaches

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Abstract

Objectives The objective of this study was to compare the 5-year clinical performance in posterior restorations of three restorative systems including a low-shrinkage system and a methacrylate-based composite combined either with an etch-and-rinse or a self-etch adhesive.

Materials and methods Each of 25 patients received three class I (occlusal) or class II restorations performed with each one of the three restorative systems: Filtek Silorane Restorative System including a two-step self-etch adhesive, Adper Scotchbond 1 XT (two-step etch-and-rinse adhesive) + Filtek Z250, and Adper Scotchbond SE (two-step self-etch adhesive) + Filtek Z250. All materials were applied as per manufacturer's instructions. Two blind observers evaluated the restorations at four different moments (baseline, after 1, 2, and 5 years) according to the USPHS-modified criteria. Kruskal-Wallis and Mann-Whitney *U* tests were conducted to compare the behavior of the restorative systems, while Friedman and Wilcoxon tests were applied to analyze the intrasystem data ($p < 0.05$).

Results After 5 years, marginal staining around the restorations with Adper Scotchbond SE + Filtek Z250 was statistically more frequent and severe than that of the restorations performed with the other two systems. Intrasystem comparisons revealed a deterioration of the marginal adaptation after 5 years for all systems. A significant number of restorations bonded with self-etch adhesives showed marginal staining after 5 years of clinical service. A deterioration of the color appearance and an increase of the surface roughness were also detected in the restorations performed with Adper Scotchbond SE + Filtek Z250.

Conclusions A deterioration of the marginal adaptation was evidenced for all restorative systems, while marginal staining was more frequently seen only around the restorations performed with self-etch adhesives.

Clinical relevance No advantage was found of the silorane- over the methacrylate-based composite when combined with an etch-and-rinse adhesive.

Keywords Clinical evaluation · Silorane · Low-shrinkage · Self-etch adhesive · Etch-and-rinse adhesive · Posterior restorations

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Introduction

Although in vitro studies are valid resources to learn about the behavior of dental materials, clinical trials represent the ultimate test to measure the clinical success of adhesives and composite resins [1]. However, the reliability of studies on clinical durability and effectiveness of dental materials increase with longer observation periods, since changes may be only detected in long-term investigations [2, 3].

In 2007, Filtek Silorane Restorative System was launched into the market as an alternative to the most commonly used methacrylate-based composite resins [4] in order to reduce the polymerization shrinkage, still the main drawback of these widely used materials [5, 6]. In fact, polymerization shrinkage is a potentially deleterious factor for the integrity and longevity of direct restorations, due to the release of stresses onto the adhesive interface [5, 6]. It may result in several undesirable situations, such as micro-leakage, marginal staining, gap formation, postoperative sensitivity, or cuspal deflection [7, 8]. However, information regarding the polymerization shrinkage of Filtek Silorane is controversial. While according to manufacturer's information [9], it undergoes up to 1 % of volumetric shrinkage, some authors found it to be very similar to that of Filtek Z250, a widely used methacrylate-based composite [10, 11]. On the contrary, recent studies have reported lower shrinkage for Filtek Silorane than for several methacrylate-based composites [12, 13].

The adhesive type and strategy are also critical for the success of the restoration. Etch-and-rinse adhesives are still considered the best materials when bonded to the enamel because of the etching pattern provided by phosphoric acid [14–16]. Meanwhile, adhesion to dentin remains compromised for the one-bottle etch-and-rinse adhesives [14, 17], as they lack a non-solvated hydrophobic coating, making these adhesives susceptible to hydrolytic degradation [18, 19].

On the other hand, self-etch adhesives are less technique-sensitive and easier to use. They may present different acidity, composition, and number of application steps [20]. Mild or ultra-mild self-etch adhesives are preferable, due to their potential to establish chemical adhesion to hydroxyapatite [21, 22], although the bonding quality depends on the constituent functional monomer of the adhesive resin [14, 20]. Moreover, there are considerable differences in the performance of two-versus one-step self-etch adhesives [15, 20, 23], inasmuch as the latter contain an increased concentration of hydrophilic monomers that make them less hydrolytically stable, behaving as semi-permeable membranes [24]. However, the mild self-etch adhesives are only able to promote a slight demineralization of the enamel surface; therefore, prior enamel acid etching is recommended in order to improve their adhesion to this substrate [25, 26]. The proprietary and specifically designed adhesive for Filtek Silorane is a two-step ultra-mild self-etch adhesive, which produces a very slight demineralization with subsequent resin infiltration when bonded to the enamel [27].

In spite of the time gone by since Filtek Silorane was launched, there is only one investigation that evaluates its clinical behavior for a period longer than 3 years [28]. Consequently, the aim of this study was to compare the 5-year clinical performance of three restorative systems in posterior restorations: the low-shrinkage Filtek Silorane Restorative System (with its proprietary adhesive) and a widely studied methacrylate composite, Filtek Z250, used either with a two-step etch-and-rinse adhesive or with a two-step self-etch adhesive. The null hypothesis tested was that there would be no difference in clinical behavior for the three restorative systems after 5 years.

Materials and methods

Inclusion criteria Once the research protocol was approved by the Ethics Committee of Rey Juan Carlos University, the subjects participating in the study signed a specific written informed consent, which had been previously endorsed by the same organism. All patients, with ages ranging from 18 to 60 (average 29.8), required three class I (occlusal) and/or class II restorations (Table 1). For every patient, each tooth was restored with a different restorative system (Table 2). Specific exclusion criteria are summarized in Table 3. Teeth to be restored could present both, failing restorations (with clinical or radiographic signs of recurrent caries or esthetic failures) or primary caries lesions. Coincidently, there was an even distribution in the number of restorations performed for each reason.

Restorative procedure All restorations were performed by the same operator and placed under local anesthesia with rubber dam isolation. The cavity design was restricted to eliminate carious tissue from primary caries lesions or to remove the restorative material when existing restorations were replaced. Cavities were prepared using diamond burs (Komet-Brasseler, Lemgo, Germany) and no bevels on enamel cavosurface margins were done. In deep cavities, the dentin close to the pulp chamber was covered with a resin-modified glass ionomer cement (Vitrebond, 3M ESPE, St. Paul, MN, USA). An appropriate matrix system (Palodent, Dentsply DeTrey, Konstanz, Germany) and wood wedges were applied to the cervical margins of class II

Table 1 Number of evaluated restorations by location (tooth) and extension (class) for each restorative system

Restorative system	Number of restorations	Tooth		Class		
		Premolars	Molars	I	II	
					MO/OD	MOD
Filtek Silorane Restorative System	25	12	13	12	10	3
Adper Scotchbond 1 XT + Filtek Z250	25	8	17	14	10	1
Adper Scotchbond SE + Filtek Z250	25	13	12	12	12	1
Total (%)	75	33 (44)	42 (56)	38 (50.6)	32 (42.6)	5 (6.6)

Table 2 Materials used in the study (3M ESPE, St. Paul, MN, USA)

Adhesives (Batch no.)	Composition	Instructions for use	Type
Silorane System Adhesive (also known as LS System Adhesive or P90 System Adhesive) (Primer: 8AP; Adhesive: 8AK)	Primer: phosphorylated methacrylates, Bis-GMA, HEMA, water, ethanol, silane-treated silica filler, Vitrebond™ copolymer, initiators, stabilizers Adhesive: hydrophobic DMA, phosphorylated methacrylates, TEGDMA, silane-treated silica filler, initiators, stabilizers	Primer: application for 15″ with a black micro-brush, followed by gentle air dispersion and 10″ of light curing Adhesive: application with a green micro-brush, followed by gentle air dispersion and 10″ of light curing	Two-step self-etch
Adper Scotchbond 1 XT (also known as Adper Single Bond Plus or Adper Single Bond 2) (318655)	HEMA, Bis-GMA, GDMA, water, ethanol, silane-treated silica nanofiller, photo-initiator	Acid etch: phosphoric acid (Scotchbond™ Etchant, 3M ESPE): 35 % (15″). Rinse (10″). Blot excess water using a cotton pellet or mini-sponge. Do not air-dry Adhesive: apply 2–3 consecutive coats of adhesive for 15″ with gentle agitation using a fully saturated applicator. Gently air thin for 5″ to evaporate solvent. Light cure for 10″.	Etch-and-rinse
Adper Scotchbond SE (also known as Adper SE Plus) (Liquid A: 7AF; liquid B: 8AL)	Liquid A (colored wetting solution): water, HEMA, surfactant, rose bengal dye Liquid B (adhesive): UDMA, TEGDMA, TMPTMA, HEMA phosphate and MHP, bonded zirconia nanofiller, initiator system based on camphorquinone	Liquid A: apply to the cavity so that a continuous red-colored layer is obtained on the surface Liquid B: scrub into the entire wetted surface of the bonding area during 20″. Red color will disappear quickly, indicating that the etching components have been activated. Air-dry thoroughly for 10″. Apply second coat to the entire bonding surface. Light air application. Light cure for 10″	Two-step self-etch
Resin composites	Organic matrix	Inorganic filler	
Filtek Silorane (8BH)	3,4-Epoxycyclohexylethylcyclopolymethylsiloxane, bis-3,4-epoxycyclohexylethylphenylmethylsilane, yttrium fluoride (15 %), camphorquinone, iodum salt, stabilizers, pigments	Silanized quartz particles 50 % vol, 70 % weight Size 0.1–2 μm	
Filtek Z250 (7LY)	Silane-treated ceramic, bisphenol A polyethylene glycol diether dimethacrylate, UDMA, Bis-GMA, TEGDMA,water <2 %	Quartz and zirconia particles 60 % vol, 78 % weight Size 0.01–3.5 μm (0.6 μm average)	

UDMA urethane dimethacrylate, *GDMA* glycerol 1,3-dimethacrylate, *HEMA* 2-hydroxyethyl methacrylate, *Bis-GMA* bisphenol A diglycidyl methacrylate, *TEGDMA* triethylene glycol dimethacrylate, *TMPTMA* trimethylolpropane trimethacrylate (hydrophobic TMA), *MHP* methacrylic phosphate

Table 3 Exclusion criteria

General	Known allergy to resin-based materials or other materials used in this study
	Pregnancy or breastfeeding
	Chronic use of anti-inflammatory, analgesic, and psychotropic drugs
Oral	Fewer than 20 teeth
	History of tooth hypersensitivity
	Community Periodontal Index of Treatment Needs (CPITN) values higher than 2
	Extremely poor oral hygiene
	Bruxism
Teeth to be restored	Non-vital
	Abutment teeth for fixed or removable prostheses
	Without an occlusal relationship with natural dentition or without at least one adjacent tooth contact

preparations. The restorative systems evaluated in this study were Filtek Silorane Restorative System, Adper Scotchbond 1 XT + Filtek Z250, and Adper Scotchbond SE + Filtek Z250 (Table 2). Initially, the three restorative systems were randomly assigned to each of the three teeth in which restorative treatment was needed, regardless of the characteristics

Table 4 Modified USPHS criteria used

Criteria	Code	Definition
Color match	Alfa	Restoration matches adjacent tooth structure in color and translucency
	Bravo	Mismatch is within an acceptable range of tooth color and translucency
	Charlie	Mismatch is outside the acceptable range
Retention	Alfa	Full retention
	Bravo	Partial retention
	Charlie	Restoration is lost
Marginal adaptation	Alfa	Restoration closely adapted to the tooth. No crevice visible. No explorer catch at the margins or there was a catch in one direction
	Bravo	Explorer catch. No visible evidence of a crevice into which the explorer could penetrate. No dentin or base visible
	Charlie	Explorer penetrates into a crevice that is of a depth that exposes dentin or base
Anatomic form	Alfa	Restorations continuous with existing anatomic form
	Bravo	Restorations discontinuous with existing anatomic form but missing material not sufficient to expose dentin base
	Charlie	Sufficient material lost to expose dentin or base
Surface roughness	Alfa	Surface of restoration is smooth
	Bravo	Surface of restoration is slightly rough or pitted, but can be refinished
	Charlie	Surface deeply pitted, irregular grooves, and cannot be refinished
	Delta	Surface is fractured or flaking
Marginal staining	Alfa	No staining along cavosurface margin
	Bravo	<50 % of cavosurface affected by stain (removable, usually localized)
	Charlie	>50 % of cavosurface affected by stain
Sensitivity[a]	Alfa	None
	Bravo	Mild but bearable
	Charlie	Uncomfortable, but no replacement is necessary
	Delta	Painful. Replacement of restoration is necessary
Secondary caries	Alfa	Absent
	Bravo	Present

Based on Wilson et al. [29]

[a] Measured by blowing a stream of compressed air with a dental syringe for 3 s at a distance of 2 cm from the tooth surface

Table 5 Number of evaluated restorations in each criterion for each experimental group (FS RS: Filtek Silorane Restorative System; 1XT + Z250: Adper Scotchbond 1 XT + Filtek Z250; SE + Z250: Adper Scotchbond SE + Filtek Z250)

Criteria	Code	Baseline			1 year			2 years			5 years		
Materials		FS RS	1XT + Z250	SE + Z250	FS RS	1XT + Z250	SE + Z250	FS RS	1XT + Z250	SE + Z250	FS RS	1XT + Z250	SE + Z250
Color match	Alfa	23	25	23	22	24	22	20	22	21	20	20	18
	Bravo	2	–	2	3	1	1	3	2	1	3	2	3
	Charlie	–	–	–	–	–	2	–	–	2	–	–	2
Retention	Alfa	25	25	25	24	25	25	23	24	24	23	22	23
	Bravo	–	–	–	1	–	–	–	–	–	–	–	1
	Charlie	–	–	–	–	–	–	–	–	–	–	–	–
Marginal adaptation	Alfa	24	25	25	17	21	18	16	20	16	12	18	14
	Bravo	1	–	–	7	4	7	7	4	8	11	4	9
	Charlie	–	–	–	1	–	–	–	–	–	–	–	–
Anatomic form	Alfa	25	25	25	24	25	25	23	24	24	22	22	21
	Bravo	–	–	–	–	–	–	–	–	–	1	–	2
	Charlie	–	–	–	1	–	–	–	–	–	–	–	1
Surface roughness	Alfa	23	24	25	22	22	21	20	20	20	18	20	17
	Bravo	2	1	–	2	3	4	3	4	4	5	2	6
	Charlie	–	–	–	–	–	–	–	–	–	–	–	–
	Delta	–	–	–	1	–	–	–	–	–	–	–	–
Marginal staining	Alfa	25	25	23	23	22	16	19	21	15	16	19	11
	Bravo	–	–	2	1	3	8	3	3	8	6	3	10
	Charlie	–	–	–	1	–	1	1	–	1	1	–	2
Sensitivity	Alfa	25	24	24	25	25	25	23	24	24	23	22	23
	Bravo	–	1	1	–	–	–	–	–	–	–	–	–
	Charlie	–	–	–	–	–	–	–	–	–	–	–	–
	Delta	–	–	–	–	–	–	–	–	–	–	–	–
Secondary caries	Alfa	25	25	25	24	25	25	23	24	24	23	22	23
	Bravo	–	–	–	1	–	–	–	–	–	–	–	–

of the tooth and restoration class. Randomization consisted in the attribution of a number (1, 2, and 3) to each one of the restorative systems and the later selection by the patient of one number for each tooth to be restored. However, interference in the randomization procedure within patients was eventually performed in order to equally distribute materials into some important variables, such as tooth type and position, and restoration class in such a way that the influence of those factors was minimized (Table 1). All adhesive systems were applied according to the manufacturer's instructions (Table 2). Composite resins were placed in 2-mm increments using an incremental layering technique and light curing each one for 20 s using a LED Demetron I polymerization unit (Kerr, Orange, CA, USA) with a minimum light output of 550 mW/cm^2. After polymerization, coarse finishing was accomplished with carbide burs and, if needed, with a #12 blade and aluminum oxide disks (Sof-Lex, 3M ESPE), while finishing of the occlusal surface was carried out with polishing points (Enhance and PoGo, Dentsply).

Clinical evaluation All restorations were evaluated after 1 week (baseline) and 1, 2, and 5 years for the following parameters: color match, retention, marginal adaptation, anatomic form, surface roughness, marginal staining, sensitivity, and secondary caries (Table 4). Two calibrated evaluators, who were not the operator, performed the clinical analysis fully blindly and separately at each recall, following the modified United States Public Health Service criteria (USPHS) (Table 4). Any later discrepancy in evaluation between the two examiners was immediately resolved at chair side in order to reach a consensus. Intraoral digital color photographs were taken with a 1.33 magnification at every recall appointment with a Nikon D80 camera and a 105-mm Micro-Nikkor lens (Nikon USA, Melville, NY, USA). For the statistical analysis, the Kruskal-Wallis and Mann-Whitney *U* non-parametric tests were used to compare the behavior of the three restorative systems at each evaluation moment. Friedman and Wilcoxon non-parametric tests were applied to compare the data obtained for each restorative system at each evaluation moment. The level of significance was set at $\alpha < 0.05$. The software used was IBM SPSS 19 for Windows (IBM Corporation, Armonk, NY, USA).

Results

A total of 75 restorations were placed in 25 patients. The distribution of the restorations was similar between class I (38) and class II (37) (Table 1). At the 5-year assessment, the patient revaluation rate was 96 %, as one patient did not attend since the call for the 2-year evaluation. However, a few other restorations could not be evaluated at 5 years due to several reasons.

The restoration revaluation rate for Filtek Silorane Restorative System was 92 % as one restoration showed signs of clinical failure (fracture of the restorative material, exposure of dentin, and presence of secondary caries) after 1 year of clinical use and, consequently, was replaced before the 2-year evaluation. Regarding Adper Scotchbond 1 XT + Filtek Z250, the revaluation rate was 88 %, since one restoration was replaced after 4 years at a different dental office and the patient was not able to inform the authors about the reason for the substitution. This restoration had been rated Alfa for every parameter and at every assessment with the only exception of Bravo in surface roughness at 1- and 2-year evaluations. Furthermore, one restoration could not be examined at 5 years because the tooth (third lower molar) was extracted. This restoration received Bravo ratings for marginal adaptation and staining at 1- and 2-year assessments. Finally, the revaluation rate for Adper Scotchbond SE + Filtek Z250 was 96 %, although one restoration could only be evaluated for retention and anatomic form due to a partial loss of the resin composite and dentin exposure. The results are summarized in Table 5.

Comparison of the performance of the three restorative systems at 5 years

All restorative systems resulted in a percentage of Alfa ratings of 100 % at 5-year evaluation for the categories sensitivity and secondary caries. However, Alfa ratings for color match, retention, anatomic form, surface roughness, and, specially, marginal adaptation decreased for all the restorative systems without resulting in any statistical differences. Marginal staining was the only parameter showing statistically significant differences among systems. Restorations performed with Adper Scotchbond SE + Filtek Z250 resulted in more intense and frequent marginal staining than the ones performed with the other two restorative systems ($p = 0.006$). No determinant differences were appreciated between the clinical behavior of class I and II restorations. Twelve class I restorations were rated Bravo for marginal adaptation after 5 years, the same number recorded for class II restorations. Additionally, 13 class I restorations were considered Bravo or Charlie (12/1) for marginal staining at the 5-year assessment, versus 10 class II restorations (8/2).

Baseline vs 5-year evaluation for each restorative system

Filtek Silorane Restorative System Marginal adaptation ($p = 0.002$) and marginal staining ($p = 0.007$) values showed a statistical deterioration after 5 years of clinical use. Regarding color match, two restorations did not exactly emulate the adjacent tooth structure at any of the assessments and they were scored Bravo (Fig. 1). Therefore, only one restoration, a class II restoration in a lower molar, showed a true color modification over time. The failure rate for this restorative system was 4 % after 5 years of clinical use.

Adper Scotchbond 1 XT + Filtek Z250 Only a significant deterioration of the marginal adaptation was detected at 5 years ($p = 0.046$). Color match, marginal staining, and surface roughness parameters resulted in worse rankings at 5 years, although with no statistical repercussion. No Charlie ratings were assigned to this restorative system for any of the criteria. All the restorations were clinically acceptable after 5 years and the failure rate was 0 %. Postoperative sensitivity, described as a slight discomfort associated with cold beverages, was revealed by one patient during the first week after the restoration placement, disappearing afterwards.

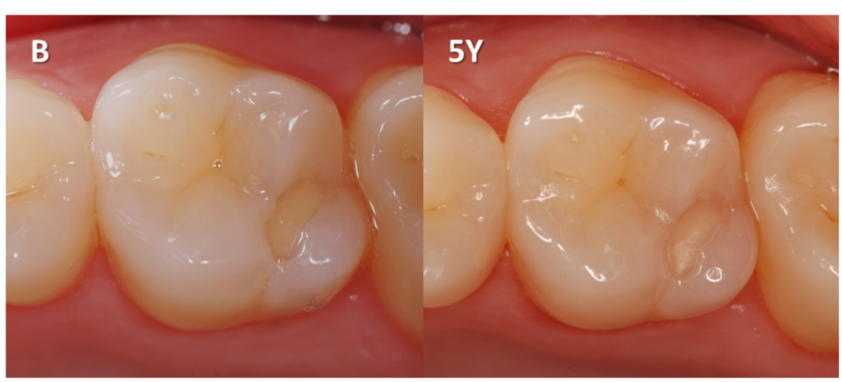

Fig. 1 First maxillar molar. Class I occlusal restoration with Filtek Silorane Restorative System. This restoration was rated Bravo for color parameter in all the evaluations because of the poor esthetic characteristics of the composite resin. Marginal adaptation was rated Bravo at a 5-year assessment. *B*, baseline; *5Y*, 5-year recall

Adper Scotchbond SE + Filtek Z250 Marginal adaptation ($p = 0.003$), marginal staining ($p = 0.001$), and surface roughness ($p = 0.014$) were significantly worse at 5 years than at baseline. All these criteria showed the same trend, as the significant differences were detected in the second year of clinical use and remained stable at the 5-year assessment. Additionally, color stability also decreased at the 5-year evaluation, resulting in a statistically significant difference ($p = 0.025$). This restorative system was the only one receiving Charlie ratings for color match, in two class I restorations in molars. These findings were detected at the 1-year evaluation and the authors recommended replacing both restorations at that moment. However, both patients refused the treatment and the restorations received the same scores 4 years later. Therefore, attending to the USPHS criteria, these two restorations and the one previously mentioned were clinically unacceptable. The failure rate was 12.5 % after 5 years of clinical use. One patient experienced postoperative sensitivity after restoration placement, which wore off after a few days.

Discussion

Resin composites are widely considered the first-choice material for posterior direct restorations [30], regardless of the type of cavity. For this reason, teeth requiring both class I and class II restorations were included in this study as it had been done in previous investigations [31, 32]. In fact, as explained before, it was recorded an equal distribution of the results between both kinds of restorations, which is in contrast with a recent meta-analysis that concluded that a higher number of restored surfaces is related with a higher risk of failure [33]. The design of the cavities included no bevels at the occlusal margins, since it has been repeatedly not recommended for causing the unnecessary loss or damage to sound tooth tissue [28, 34]. About the cavosurface margins of proximal boxes, the authors also opted not to bevel them, as, although it may enhance the marginal adaptation of the restoration, other clinical drawbacks (loss of enamel from the gingival margin and creation of thin flashes of excess resin composite in proximal areas) have been reported [34].

Regarding the selection of the restorative systems evaluated in this study, we must acknowledge that comparison of the different adhesives with the same composite resin, although advisable, was not possible, due to the novel and differentiating chemistry of Filtek Silorane, which demanded its exclusive adhesive system, composing an indivisible binomial. Furthermore, the materials used in this study were the different alternatives that 3M ESPE provided for the restorations of posterior teeth in 2008. With hindsight, the authors recognize a comparison with a mild or ultra-mild two-step self-etch adhesive could have been more suitable. But at the time the experiment was designed, a comparison with a novel product seemed more promising. Further, besides the acidity, the specific functional monomer included in self-etch adhesives plays a fundamental role in the bonding efficacy, as it is the final responsible of the resistance and longevity of the resulting calcium salt [20].

As to the results found after 5 years of clinical use, intersystem comparisons determined that Filtek Silorane and the etch-and-rinse adhesive Adper Scotchbond 1 XT + Filtek Z250 resulted in statistically similar clinical parameters in posterior restorations. However, the other system, formed by the self-etch adhesive Adper Scotchbond SE + Filtek Z250, showed an increase in marginal staining. Thus, the null hypothesis must be rejected. Moreover, intrasystem comparison (performed between the baseline and 5-year status for each restorative system) detected a significant decrease in the marginal adaptation for all the restorative systems. An increase in the marginal staining values for both systems including self-etch adhesives (Filtek Silorane and Adper Scotchbond SE + Filtek Z250) was also recorded, although it was mainly due to a higher number of Bravo scores, which reflects an acceptable clinical situation.

Marginal discoloration may be considered a clinical sign indicating that a restoration is prone to failure or, at least, that the adhesive interface degrades [15, 35] being associated with several factors such as mechanical wear of the adhesive interface, overfilling, or gaps at marginal locations [36]. Nonetheless, the nature of the adhesive system is crucial as a high predisposition to staining has been traditionally attributed to mild self-etch adhesives due to their poor etching ability at enamel margins [15, 26, 37]. As mentioned before, Filtek Silorane Adhesive system is considered an ultra-mild self-etch adhesive (pH = 2.7). However, marginal staining of Filtek Silorane was detected for the first time after 5 years of clinical use, in contrast with a recent study which found this trend at the 18-month assessment [37]. To our knowledge, the present study is the first where the evolution of the staining behavior of Filtek Silorane has been clinically evaluated at four different moments in subjects followed up for 5 years.

On the other hand, Adper Scotchbond SE is a strong self-etch adhesive (pH = 1) with high etching ability. However, it showed marginal discoloration at all the evaluations, something consistent with clinical studies analyzing this adhesive [38] or other self-etch adhesives with a similar acidity [15]. A recent clinical research by Perdigão et al. [39] did not detect any increase in the staining of Adper Scotchbond SE until the 18-month evaluation, which is partially in contrast with the early marginal staining observed in our study. However, they only evaluated restorations at non-carious cervical lesions, which are not exposed to masticatory loads [40] and are much less susceptible to the effects of shrinkage stresses than classes I and II, due to a more favorable geometry [2]. In an attempt to improve the stability of the material, the presentation of Adper Scotchbond SE propounds a separation of the water and the

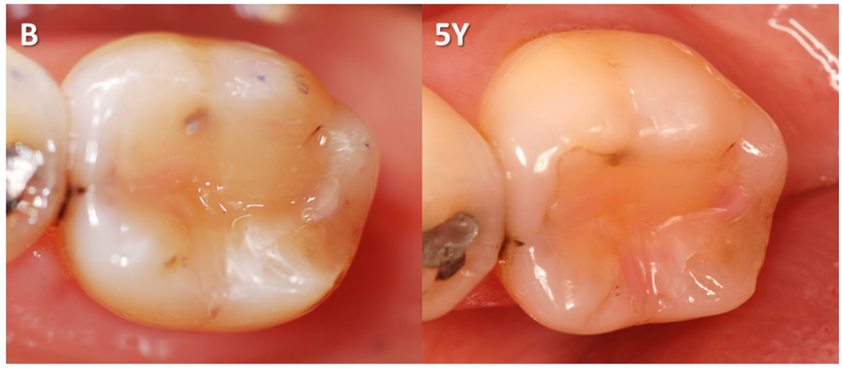

Fig. 2 First mandibular molar. Class I occlusal restoration with Adper Scotchbond SE + Filtek Z250. Marginal staining was rated Charlie (>50 % of cavosurface is affected) at a 5-year evaluation. Staining has progressed in depth across the adhesive interface, causing color changes in the resin composite close to the bonded walls. *B*, baseline; *5Y*, 5-year recall

adhesive solution [41]. Thereby, liquid A is a 2-hydroxyethyl methacrylate (HEMA)-water solution without etching capacity, while liquid B contains both the acidic hydrophilic and the hydrophobic monomers. Once inside the cavity, liquid A is supposed to turn from pink to yellow once liquid B is applied. However, this activation may lead to an incomplete conversion of the acidic monomers and their inclusion in a HEMA-rich and still-colored adhesive interface, enhancing its susceptibility to hydrolytic degradation and staining [42, 43]. This possibility was clinically corroborated by the presence of the characteristic pink color in most of the stained margins around Adper Scotchbond SE + Filtek Z250 restorations (Fig. 2). Moreover, a previous in vitro study reported high color instability after water immersion of a self-etch adhesive (One-Up Bond F) with a very similar color-change mechanism to that of Adper Scotchbond SE [43].

For Adper Scotchbond SE, the intrasystem comparison detected a significant worsening in three additional clinical parameters: color match, surface roughness, and marginal adaptation. Regarding the first one, it is noteworthy that the results from the 2-year evaluation had already detected an increase in color degradation although it did not lead into a statistical difference [44]. The present results, obtained 3 years later, allow asserting that discoloration of the adhesive interface is able to affect the color appearance of the entire restoration [43]. Accordingly, all Adper Scotchbond SE + Filtek Z250 restorations which rated Bravo or Charlie for color match showed a variable saturation of pink, even at the baseline evaluation. Secondly, regarding surface roughness, its clinical relevance is lower than that of other parameters included in the USPHS criteria, although high values may increase the susceptibility of a restoration to color modifications or premature wear, due to its retentive capability [45]. The surface roughness values recorded by this system should not be different from those of Adper Scotchbond 1 XT + Filtek Z250, since both systems include the same resin composite, which was always applied, finished, and polished in the same way. It is noteworthy that assessing the surface roughness tactilely is considered a highly subjective procedure [46].

Thirdly, marginal adaptation is the only parameter for which all the restorative systems exhibited significantly worse results after 5 years of clinical use. The deterioration of the marginal integrity had been already detected at the 2-year assessment [44], regardless of the adhesive type. This finding agrees with previous research, in which a similar clinical performance was observed between self-etch and etch-and-rinse adhesives [26, 47]. Marginal adaptation has been described as one of the most relevant factors that influence the clinical outcome of an adhesive restoration [48]. However, it is noteworthy that the deterioration of the adaptation scores of all the restorative systems may be considered slight, as it was exclusively due to a diversion from Alfa to Bravo, a clinical condition still considered as acceptable [49]. Moreover, the USPHS criteria are not as sensitive as the FDI World Dental Federation

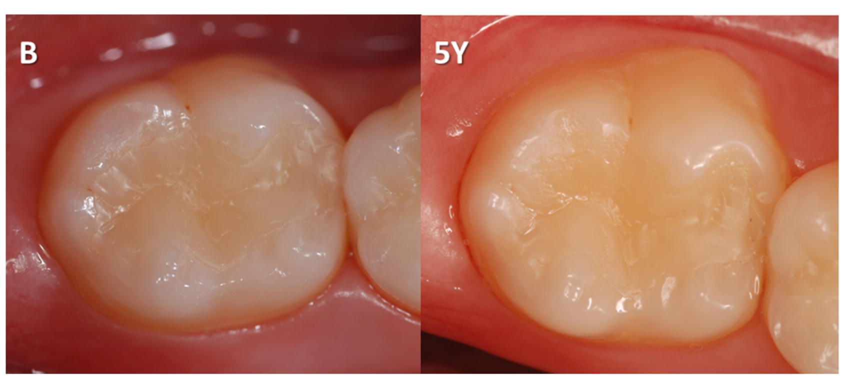

Fig. 3 Second mandibular molar. Class I occlusal restoration with Adper Scotchbond 1 XT + Filtek Z250. Surface roughness was rated Bravo (surface is slightly rough or pitted, but can be refinished) at a 5-year evaluation. *B*, baseline; *5Y*, 5-year recall

criteria [40, 50, 51] and seem to be restrictive and rigorous, especially for this parameter. Therefore, some clinical outcomes could have been magnified, while the reality is that the more evident marginal defects of the Bravo-rated restorations would have been simply resolved by polishing or by the application of a sealant (Fig. 1).

Marginal adaptation may be affected by the adhesive type and the polymerization shrinkage of the composite [52]. However, in order to isolate the direct effect of the latter, the adaptation should preferably be valued at baseline, because clinical consequences, such as wear and integrity of the adhesive interface, might have also modified the marginal adaptation along the 5 years of the study.

Although Filtek Silorane has shown better marginal adaptation values than methacrylate-based composites in vitro [12, 53], clinical information is quite contradictory and generally limited to short-term analysis. Some papers have detected a worse marginal adaptation than that of methacrylate-based composites in posterior restorations [38, 54, 55]. This background may confirm that reduced shrinkage per se does not guarantee the attenuation of stress effects in restored teeth [11] or the interfacial integrity of the restoration [10]. On the contrary, several studies determined that the marginal adaptation of Filtek Silorane placed in posterior restorations was similar for both kinds of composites, irrespective of the adhesive strategy used with the methacrylate-based composite [28, 44, 51, 56–58]. Yaman et al. [59] also compared Filtek Silorane Restorative System with a methacrylate-based composite combined both with self-etch and etch-and-rinse adhesives in the only clinical study in class V restorations, concluding that they all performed similarly. Furthermore, Burke et al. [31] found satisfactory clinical outcomes of Filtek Silorane after 2 years in a study with no control group. The present 5-year results agree with these investigations and confirm that Filtek Silorane provides adequate clinical performance yet does not surpass the behavior of a methacrylate-based composite when combined with an etch-and-rinse adhesive (Fig. 3).

Conclusion

Within the limitations of the present study, no benefit was found in the silorane- over the methacrylate-based composite when combined with an etch-and-rinse adhesive for the evaluated criteria after 5 years of clinical use. Deterioration in marginal adaptation was evidenced for all restorative systems, while the frequency of marginal staining only increased around the restorations performed with the self-etch adhesives.

Ethical standards The authors of the present manuscript certify that this study involving human subjects is in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments and that it has been approved by the relevant institutional Ethical Committee.

Consent for publication Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors of this manuscript certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

References

1. De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, Van Meerbeek B (2005) A critical review of the durability of adhesion to tooth tissue: methods and results. J Dent Res 84:118–132. doi:10.1177/154405910508400204
2. Van Meerbeek B, Peumans M, Poitevin A, Mine A, Van Ende A, Neves A, De Munck J (2010) Relationship between bond-strength tests and clinical outcomes. Dent Mater 26:e100–e121. doi:10.1016/j.dental.2009.11.148
3. Bayne SC (2012) Correlation of clinical performance with 'in vitro tests' of restorative dental materials that use polymer-based matrices. Dent Mater 28:52–71. doi:10.1016/j.dental.2011.08.594
4. Barszczewska-Rybarek IM (2009) Structure-property relationships in dimethacrylate networks based on Bis-GMA, UDMA and TEGDMA. Dent Mater 25:1082–1089. doi:10.1016/j.dental.2009.01.106
5. Versluis A, Tantbirojn D, Pintado MR, DeLong R, Douglas WH (2004) Residual shrinkage stress distributions in molars after composite restoration. Dent Mater 20:554–564. doi:10.1016/j.dental.2003.05.007
6. Schneider LF, Cavalcante LM, Silikas N (2010) Shrinkage stresses generated during resin-composite applications: A review. J Dental Biomech 2010. pii:131630. doi:10.4061/2010/131630
7. Calheiros FC, Sadek FT, Braga RR, Cardoso PE (2004) Polymerization contraction stress of low-shrinkage composites and its correlation with microleakage in class V restorations. J Dent 32:407–412. doi:10.1016/j.jdent.2004.01.014
8. González-López S, Vilchez-Díaz MA, de Haro-Gasquet F, Ceballos L, de Haro-Muñoz C (2007) Cuspal flexure of teeth with composite restorations subjected to occlusal loading. J Adhes Dent 9:11–15
9. Weinmann W, Thalacker C, Guggenberger R (2005) Siloranes in dental composites. Dent Mater 21:68–74. doi:10.1016/j.dental.2004.10.007
10. Boaro LC, Gonçalves F, Guimarães TC, Ferracane JL, Versluis A, Braga RR (2010) Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater 26:1144–1150. doi:10.1016/j.dental.2010.08.003

11. Tantbirojn D, Pfeifer CS, Braga RR, Versluis A (2011) Do low-shrink composites reduce polymerization shrinkage effects? J Dent Res 90:596–601. doi:10.1177/0022034510396217
12. Gregor L, Bortolotto T, Feilzer AJ, Krejci I (2013) Shrinkage kinetics of a methacrylate- and a silorane-based resin composite: effect on marginal integrity. J Adhes Dent 15:245–250. doi:10.3290/j.jad.a28603
13. Park JK, Lee GH, Kim JH, Park MG, Ko CC, Kim HI, Kwon YH (2014) Polymerization shrinkage, flexural and compression properties of low-shrinkage dental resin composites. Dent Mater J 33:104–110. doi:10.4012/dmj.2013-126
14. Peumans M, Kanumilli P, De Munck J, Van Landuyt K, Lambrechts P, Van Meerbeek B (2005) Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. Dent Mater 21:864–881. doi:10.1016/j.dental.2005.02.003
15. Perdigão J, Dutra-Corrêa M, Anauate-Netto C, Castilhos N, Carmo AR, Lewgoy HR, Amore R, Cordeiro HJ (2009) Two-year clinical evaluation of self-etching adhesives in posterior restorations. J Adhes Dent 11:149–159. doi:10.3290/j.jad.a15327
16. Pashley DH, Tay FR, Breschi L, Tjäderhane L, Carvalho RM, Carrilho M, Tezvergil-Mutluay A (2011) State of the art etch-and-rinse adhesives. Dent Mater 27:1–16. doi:10.1016/j.dental.2010.10.016
17. Van Meerbeek B, De Munck J, Yoshida Y, Inoue S, Vargas M, Vijay P, Van Landuyt K, Lambrechts P, Vanherle G (2003) Buonocore memorial lecture. Adhesion to enamel and dentin: current status and future challenges. Oper Dent 28:215–235
18. De Munck J, Vargas M, Iracki J, Van Landuyt K, Poitevin A, Lambrechts P, Van Meerbeek B (2005) One-day bonding effectiveness of new self-etch adhesives to bur-cut enamel and dentin. Oper Dent 30:39–49
19. Breschi L, Mazzoni A, Ruggeri A, Cadenaro M, Di Lenarda R, De Stefano DE (2008) Dental adhesion review: aging and stability of the bonded interface. Dent Mater 24:90–10. doi:10.1016/j.dental.2007.02.009
20. Van Meerbeek B, Yoshihara K, Yoshida Y, Mine A, De Munck J, Van Landuyt KL (2011) State of the art of self-etch adhesives. Dent Mater 27:17–28. doi:10.1016/j.dental.2010.10.023
21. Yoshida Y, Van Meerbeek B, Nakayama Y, Snauwert J, Hellemans L, Lambrechts P, Vanherle G, Wakasa K (2000) Evidence of chemical bonding at biomaterial hard tissue interfaces. J Dent Res 79:709–714. doi:10.1177/00220345000790020301
22. Yoshioka M, Yoshida Y, Inoue S, Lambrechts P, Vanherle G, Nomura Y, Okazaki M, Shintani H, Van Meerbeek B (2002) Adhesion/decalcification mechanisms of acid interactions with human hard tissues. J Biomed Mater Res 59:56–62. doi:10.1002/jbm.1216
23. Baracco B, Fuentes MV, Garrido MA, González-López S, Ceballos L (2013) Effect of thermal aging on the tensile bond strength at reduced areas of seven current adhesives. Odontology 101:177–185. doi:10.1007/s10266-012-0073-2
24. Tay FR, Pashley DH, Suh BI, Carvalho RM, Itthagarun A (2002) Single-step adhesives are permeable membranes. J Dent 30:371–382. doi:10.1016/S0300-5712(02)00064-7
25. Peumans M, De Munck J, Van Landuyt KL, Poitevin A, Lambrechts P, Van Meerbeek B (2010) Eight-year clinical evaluation of a 2-step self-etch adhesive with and without selective enamel etching. Dent Mater 26:1176–1184. doi:10.1016/j.dental.2010.08.190
26. Ermis RB, Temel UB, Cellik EU, Kam O (2010) Clinical performance of a two-step self-etch adhesive with additional enamel etching in class III cavities. Oper Dent 35:147–155. doi:10.2341/09-089-C
27. Mine A, De Munck J, Van Ende A, Cardoso MV, Kuboki T, Yoshida Y, Van Meerbeek B (2010) TEM characterization of a silorane composite bonded to enamel/dentin. Dent Mater 26:524–532. doi:10.1016/j.dental.2010.01.010
28. Lynch CD, Opdam NJ, Hickel R, Brunton PA, Gurgan S, Kakaboura A, Shearer AC, Vanherle G, Wilson NH (2014) Guidance on posterior resin composites: Academy of Operative Dentistry—European Section. J Dent 42:377–383. doi:10.1016/j.jdent.2014.01.009
29. Wilson MA, Cowan AJ, Randall RC, Crisp RJ, Wilson NH (2002) A practice-based, randomized, controlled clinical trial of a new resin composite restorative: one-year results. Oper Dent 27:423–429
30. Schmidt M, Dige I, Kirkevang LL, Vaeth M, Hørsted-Bindslev P (2015) Five-year evaluation of a low-shrinkage silorane resin composite material: a randomized clinical trial. Clin Oral Investig 19:245–251. doi:10.1007/s00784-014-1238-x
31. Burke FJ, Crisp RJ, James A, Mackenzie L, Pal A, Sands P, Thompson O, Palin WM (2011) Two year clinical performance of a low-shrink resin composite material in UK general dental practices. Dent Mater 27:622–630. doi:10.1016/j.dental.2011.02.012
32. Van Dijken JW, Pallesen U (2015) Randomized 3-year clinical evaluation of class I and II posterior resin restorations placed with a bulk-fill resin composite and a one-step self-etching adhesive. J Adhes Dent 17:81–88. doi:10.3290/j.jad.a33502
33. Opdam NJ, van de Sande FH, Bronkhorst E, Cenci MS, Bottenberg P, Pallesen U, Gaengler P, Lindberg A, Huysmans MC, van Dijken JW (2014) Longevity of posterior composite restorations: a systematic review and meta-analysis. J Dent 93:943–949. doi:10.1177/0022034514544217
34. Hilton TJ, Broome JC (2006) Direct posterior esthetic restorations. In: Summit JB, Robbins JW, Hilton TJ, Schwartz RS (eds) Fundamentals of operative dentistry: a contemporary approach, 3rd ed. Quintessence Publishing Co, Illinois, pp. 289–339
35. Hayashi M, Wilson NH (2003) Failure risk of posterior composites with post-operative sensitivity. Oper Dent 28:681–688
36. Türkün LS (2005) The clinical performance of one- and two-step self-etching adhesive systems at one year. J Am Dent Assoc 136:656–664. doi: 10.14219/jada.archive.2005.0239
37. Fron H, Vergnes JN, Moussally C, Cazier S, Simon AL, Chieze JB, Savard G, Tirlet G, Attal JP (2011) Effectiveness of a new one-step self-etch adhesive in the restoration of non-carious cervical lesions: 2-year results of a randomized controlled practice-based study. Dent Mater 27:304–312. doi:10.1016/j.dental.2010.11.006
38. Gonçalves FS, Leal CD, Bueno AC, Freitas AB, Moreira AN, Magalhães CS (2013) A double-blind randomized clinical trial of a silorane-based resin composite in class 2 restorations: 18-month follow-up. Am J Dent 26:93–98
39. Perdigão J, Dutra-Corrêa M, Saraceni CH, Ciaramicoli MT, Kiyan VH, Queiroz CS (2012) Randomized clinical trial of four adhesion strategies: 18-month results. Oper Dent 37:3–11. doi:10.2341/11-222-C
40. Demarco FF, Corrêa MB, Cenci MS, Moraes RR, Opdam NJ (2012) Longevity of posterior composite restorations: not only a matter of materials. Dent Mater 28:87–101. doi:10.1016/j.dental.2011.09.003
41. Salz U, Zimmermann J, Zeuner F, Moszner N (2005) Hydrolytic stability of self-etching adhesive systems. J Adhes Dent 7:107–116. doi:10.3290/j.jad.a10282
42. Mine A, De Munck J, Cardoso MV, Van Landuyt KL, Poitevin A, Kuboki T, Yoshida Y, Suzuki K, Lambrechts P, Van Meerbeek B (2009) Bonding effectiveness of two contemporary self-etch adhesives to enamel and dentin. J Dent 37:872–883. doi:10.1016/j.jdent.2009.06.020
43. Gaintantzopoulou M, Kakaboura A, Loukidis M, Vougiouklakis G (2009) A study on colour stability of self-etching and etch-and-rinse adhesives. J Dent 37:390–396. doi:10.1016/j.jdent.2009.01.010

44. Baracco B, Perdigão J, Cabrera E, Ceballos L (2013) Two-year clinical performance of a low-shrinkage composite in posterior restorations. Oper Dent 38:591–600. doi:10.2341/12-364-C
45. Reis AF, Giannini M, Lovadino JR, Ambrosano GM (2003) Effects of various finishing systems on the surface roughness and staining susceptibility of packable composite resins. Dent Mater 19:12–18. doi:10.1016/S0109-5641(02)00014-3
46. Hickel R, Roulet JF, Bayne S, Heintze SD, Mjör IA, Peters M, Rousson V, Randall R, Schmalz G, Tyas M, et al (2007) Recommendations for conducting controlled clinical studies of dental restorative materials. Clin Oral Investig 11:5–33. doi:10.1007/s00784-006-0095-7
47. van Dijken JW, Pallesen U (2011) Four-year clinical evaluation of class II nano-hybrid resin composite restorations bonded with a one-step self-etch and a two-step etch-and-rinse adhesive. J Dent 39:16–25. doi:10.1016/j.jdent.2010.09.006
48. Frankenberger R, Krämer N, Lohbauer U, Nikolaenko SA, Reich SM (2007) Marginal integrity: is the clinical performance of bonded restorations predictable in vitro? J Adhes Dent 9(Suppl 1):107–116. doi:10.3290/j.jad.a11974
49. Bekes K, Boeckler L, Gernhardt CR, Schaller HG (2007) Clinical performance of a self-etching and a total-etch adhesive system—2-year results. J Oral Rehabil 34:855–861. doi:10.1111/j.1365-2842.2007.01745.x
50. Mena-Serrano A, Kose C, De Paula EA, Tay LY, Reis A, Loguercio AD, Perdigão J (2013) A new universal simplified adhesive: 6 month clinical evaluation. J Esthet Restor Dent 25:55–69. doi:10.1111/jerd.12005
51. Walter R, Boushell LW, Heymann HO, Ritter AV, Sturdevant JR, Wilder Jr AD, Chung Y, Swift Jr EJ (2014) Three-year clinical evaluation of a silorane composite resin. J Esthet Restor Dent 26:179–190. doi:10.1111/jerd.12077
52. Van Meerbeek B, Braem M, Lambrechts P, Vanherle G (1993) Evaluation of two dentin adhesives in cervical lesions. J Prosthet Dent 70:308–314. doi:10.1016/0022-3913(93)90213-8
53. Mahmoud SH, Al-Wakeel Eel S (2011) Marginal adaptation of ormocer-, silorane-, and methacrylate-based composite restorative systems bonded to dentin cavities after water storage. Quintessence Int 42:e131–e139
54. Schmidt M, Kirkevang LL, Hørsted-Bindslev P, Poulsen S (2011) Marginal adaptation of a low-shrinkage silorane-based composite: 1-year randomized clinical trial. Clin Oral Investig 15:291–295. doi:10.1007/s00784-010-0446-2
55. Baracco B, Perdigão J, Cabrera E, Giráldez I, Ceballos L (2012) Clinical evaluation of a low-shrinkage composite in posterior restorations: one-year results. Oper Dent 37:117–129. doi:10.2341/11-179-C
56. Efes BG, Yaman BC, Gurbuz O, Gumuştaş B (2013) Randomized controlled trial of the 2-year clinical performance of a silorane-based resin composite in class 1 posterior restorations. Am J Dent 26:33–38
57. Yazici A, Ustunkol I, Ozgunaltay G, Dayangac B (2014) Three-year clinical evaluation of different restorative resins in class I restorations. Oper Dent 39:248–255. doi:10.2341/13-221-C
58. Mahmoud SH, Ali AK, Hegazi HA (2014) A three-year prospective randomized study of a silorane- and methacrylate-based composite restorative systems in clas II restorations. J Adhes Dent 16:285–292. doi:10.3290/j.jad.a31939
59. Yaman BC, Doğruer I, Gümüştaş B, Efes BG (2014) Three-year randomized clinical evaluation of a low-shrinkage silorane-based resin composite in non-carious cervical lesions. Clin Oral Investig 18:1071–1079. doi:10.1007/s00784-013-1079-z