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ORIGINAL ARTICLE

How to repair fillings made by silorane-based composites

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Abstract In 2007, the low shrinkage silorane-based composites with a completely new resin chemistry were introduced. As for the case of composite repair, the question of whether this new material class can be repaired with the same methods like dimethacrylate-based composites arises. The ability of a silorane-based composite (SBC) to be repaired was therefore examined in a shear-bond test. Specimens of SBC were polymerised, water-stored at 37°C for 1 week and then repaired with fresh dimethacrylate-based composite (MBC) or SBC material by using several intermediate agents (IMA). The shear-bond strength was then measured after an additional water storage of 1 week. As IMA, we tested an experimental silorane-flowable composite, two dimethacrylate-based flowable composites, a filled silorane system adhesive bond and a conventional unfilled adhesive, a silane in addition to an adhesive as well as a repair kit. Additionally, repairs of MBC with dimethacrylate-based flowable composite were prepared. Specimens of MBC and SBC bonded to dentine with the corresponding adhesives were used as a reference. The repairs of MBC with the flowable composite resin *Tetric Evo Flow* exhibited the highest mean repair bond strength value (42.2 MPa). For repair of SBC, the highest shear-bond strengths were measured for repairs using a silane additionally to a dimethacrylate-based adhesive resin, followed by repairs with the experimental silorane-based flowable composite resin *Hermes Flow* as IMA. SBC can be repaired in combination with a MBC; then a silane coupling agent plus a dimethacrylate-based IMA should be used. A silorane flowable as IMA is the best choice when SBC is to be repaired with SBC.

Keywords Silorane · Dimethacrylate · Repair · Shear strength

Introduction

In case of failure or fracture of an adhesive restoration, the repair procedure offers a minimal invasive alternative to a complete replacement of a filling.

The spectrum of resin-based composites in use is large, and little is known about the compatibility of materials differing in composition of matrix or filler particles. In case of using composites with different chemical formulation for the purpose of repair, it is an important assignment to examine the compatibility of different materials and to make sure that established methods for repair are still valid.

In 2007, a silorane-based composite was introduced. Due to its modified matrix consisting of siloxane and oxirane components, silorane-based composite (SBC) exhibits a reduced shrinkage of approximately 1% by volume per ring-opening cationic polymerisation [1]. On the basis of the differing chemical composition of the matrices of dimethacrylate-based composite (MBC) and SBC, it is highly probable that the compatibility of both is problematic. Being recently introduced, little is known about the bonding properties of the silorane. Tezvergil-Mutluay et al. [2] found out that the bond strength between a silorane and a dimethacrylate-based composite without any intermediate resin showed lowest values compared to silorane–silorane and dimethacrylate–dimethacrylate combinations without intermediate layer.

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Regarding the MBC, different mechanical and chemical procedures to enhance the bond strength between stored dimethacrylate-based filling material and fresh composite, like roughening the surface by diverse methods and the application of low-viscosity intermediate agents, have been examined in various studies [3–7].

Repairing composite without an intermediate agent (IMA) does not wet the composite surface at all locations [8]. The poor wettability could be explained by the high viscosity of the uncured repairing composite or by the polymerisation shrinkage that pulls the material away from the treated surface during the curing.

It has been widely studied that the roughening of substrate surfaces and the adjacent application of a low-viscosity resin lead to a considerable enhancement of dimethacrylate repair bond strengths. The study of Magni et al. [9] showed that the intermediate agent was the main factor affecting the composite repair strength, whereas the pretreatment played a minor role. Junior et al. [10] searched out that the roughening of the aged composite surface by sandblasting (aluminium oxide or silica coating) enhances the shear-bond strength independent of the primer, the silane coupling agent (Relyx Ceramic Primer, 3M ESPE) and/or the adhesive system (Adper SingleBondPlus, 3 M ESPE) used. A newer study by Rinastiti et al. [11] showed that surface conditioning of aged composite specimens by silica coating followed by silanisation and its specific intermediate adhesive layer application led to higher bond strengths than intermediate adhesive layer application alone after thermocycling and water storage, whereas Rathke et al. [12] found in their 2009 study that the more complicated use of silica-coated particles for sandblasting followed by a silane coupling agent had no advantage over common bonding systems (OptiBond FL, Excite). Filled [13–15] or unfilled adhesives [13] have been usually applied as intermediate agents for composite repair supporting the wetting of the roughened substrate. Frankenberger et al. [13] used the dentin bonding system Syntac classic alone or in combination to a flowable resin to enhance shear-bond strengths. Teixeira et al. [14] compared three filled self-etch systems and found best results for Prime&Bond NT, Dentsply. Brosh et al. [4] examined increased bond strengths of specimens repaired with unfilled Bis-GMA resin in contrast to samples without any IMA.

Two possible mechanisms of adhesion promoted by resin-based bonding agents are suggested [7]

a) Micro-mechanical retention promoted by penetration of the unfilled resin into surface irregularities.
b) Solvents in the adhesive systems may cause swelling and gelation of the surface layer, allowing the monomer in the layer of the repair filling access to the unconverted vinyl groups (–C=C) in the subsurface of the filling.

Frankenberger et al. [13] reported that an additional lining with a flowable composite leads to significantly better marginal quality and significantly lower leakage of composite repair, whereas Papacchini et al. [16] used flowable resins as intermediate agent without preliminary adhesive application, measuring enhanced microtensile bond strength and predominantly cohesive fracture modes of repaired composite specimens compared to specimens repaired solely with filled adhesive resins as intermediate agent.

The aim of this study was to evaluate the ability of silorane-based composite to be repaired by adopting repair protocols which have proved themselves in the repair of MBCs. The compatibility between conventional MBC and SBC was tested. Knowing from MBC that the use of flowable composites enhances the repair strength, it stands to reason to examine if repair strengths of aged fillings made by a SBC can be improved by using flowable composite resins as intermediate layer.

Among established dimethacrylate-based flowable materials, an experimental silorane-based flowable composite was used as intermediate agent.

The hypothesis that repairing SBC with MBC produces lower repair bond strengths than unmixed repairs was tested. It was further hypothesised that the application of a silorane-based flowable composite enhances the bond strength, when the repair is also a SBC and yields repair bond strengths comparable to repairs of MBC with the corresponding flowable composite.

Materials and methods

The materials used in this study are listed in Table 1.

The bond strength between aged filling material and applied materials was determined in a shear-bond test.

The following parameters were varied:

Filling (S = Filtek Silorane; M = Tetric Evo Ceram; D = Dentine)
Intermediate agent (SB = Silorane System Adhesive Bond; HB = Heliobond; SF = Hermes Flow; TF = Tetric Evo Flow; GF = Grandio Flow; CR = Clearfil Repair; ES = Espe Sil)
Repair (S = Filtek Silorane; M = Tetric Evo Ceram)

The substrates for the test specimens were prepared by filling the composites (Tetric Evo Ceram, Ivoclar Vivadent and Filtek Silorane, 3 M Espe) with a plastic filling instrument into a shaped cavity (2 mm depth, 6 mm diameter) of an acrylic cylinder (Fig. 1a, b), surrounded by a stainless steel cylinder. The “fillings” were cured with the LED-curing device Bluephase (IvoclarVivadent, Schaan, FL) for 20 s with a light intensity of 1,435 mW/cm^2. Spectral distributions and irradiance of the curing unit were

Table 1 Materials used in this study and the respective application mode

Composite	Batch #	Application mode	Material composition
Tetric Evo Ceram A3 (Ivoclar Vivadent, Schaan, FL)	k34039	20 s light curing of 2 mm thick layer	Bis-GMA, UDMA, Bis-EMA
Filtek Silorane A3 (3M Espe, St. Paul, MN, USA)	7AY	20 s light curing of 2 mm thick layer	1,3,5,7-Tetrakis (ethyl cyclohexane epoxy)-1,3,5,7-tetramethyl cyclot etrasiloxane-methyl-bis[2-(7-oxabicyclo[4.1.0]hept-3-yl) ethyl]phenyl

Intermediate agent	Batch #	Application mode	Material composition
Heliobond (Ivoclar Vivadent, Schaan, FL)	K28890	Application of a thin layer, gently air blow, 10 s light curing	Bis-GMA, TEGDMA
Silorane System Adhesive Bond (3M Espe, St. Paul, MN, USA)	7AH	Application of a thin layer, gently air blow, 10 s light curing	TEGDMA, Phosphoric acid methacryloxy-hexylesters, 16-hexanediol dimethacrylate
Hermes Flow A3 (3M Espe, Seefeld, Germany)	H1Flow-PST0146	Application of a thin layer, 20 s light curing	1,3,5,7-Tetrakis (ethyl cyclohexane epoxy)-1,3,5,7-tetramethyl cyclot etrasiloxane-methyl-bis[2-(7-oxabicyclo[4.1.0]hept-3-yl) ethyl]phenyl
Tetric Evo Flow A3 (Ivoclar Vivadent, Schaan, FL)	K28619	Application of a thin layer, 20 s light curing	Bis-GMA, UDMA, Decandioldimethacrylate,
Grandio Flow A3 (Voco, Cuxhaven, Germany)	661487	Application of a thin layer, 20 s light curing	Bis-GMA, UDMA, TEGDMA, HEDMA
Clearfil Repair	41258		
Ketchant Gel	00423A	Apply etchtant 10 s, rinse, dry,	40% Phosphoric Acid
Porcelain bond activator	00221A	Mix activator and primer 1:1, apply, leave of 20 s,	γ-MPS, Bis-phenol A polyethoxy dimethacrylate, MPTS
Clearfil SE bond primer	00791A	air dry	MDP, HEMA, water
Clearfil SE Bond Bond (Kuraray, Tokio, Japan)	01150A	Apply thin layer of bonding, gently air blow, 10 s light curing	MDP, Bis-GMA, HEMA, hydrophobic dimethacrylate, silanated colloidal silica
Espe Sil (3M Espe, St. Paul, MN, USA)	284122	60 s application, air dry	Silane

Bis-GMA bis-phenol A diglycidylmethacrylate, *Bis-EMA* bis-phenol A polyetylene glycol diether dimethacrylate, *HEMA* 2-hydroxyethyl methacrylate, *HEDMA* hexanediol dimethacrylate, *MDP* 10-methacryloyloxydecyl dihydrogen phosphate, *γ-MPS* γ-methacryloxy propyltrimethoxy silane, *TEGDMA* triethyleneglycol dimethacrylate, *UDMA* urethane dimecrylate

determined by means of a calibrated fibre optic, spectrally resolving radiometer equipped with an integrating sphere (S2000, Ocean Optics, USA). Then, the substrate surfaces were flattened with 400-grit silicon carbide grinding paper (Leco, St. Joseph, USA) in order to achieve flat and equal surfaces. The surfaces were not polished because the substrates were roughened after storage anyway and the same material qualities are existent with or without polishing. The fillings were stored for 1 week at 37°C in distilled water. Initiating the repair procedure, the fillings were roughened again (400-grit silicon carbide paper) prior to bonding, cleaned with 37% phosphoric acid gel (Total Etch, IvoclarVivadent, Schaan, FL), rinsed with water and air-dried. The application of an intermediate agent (Fig. 1c) followed according to the manufacturer's advices as described in Table 1. All agents were applied conformable to manufacturer's instructions in small portions and were evenly spread out into a thin layer, without removing any material after application of the repair to avoid stress on the bond between the materials and to give clinical relevance.

The cylindrical repair (Fig. 1d) was placed in two increments of 2 mm thickness and 3 mm diameter each and cured like the filling. The specimens were stored again for 1 week at 37°C in distilled water and then loaded into a universal testing machine (MCE 2000ST, Quicktest Prüfpartner GmbH, Langenfeld, Germany) to measure the shear-bond strengths. The steel loading rod moved at a constant crosshead speed of 0.5 mm/min vertically to the specimen and parallel to the basic composite body (Fig. 1e). The load at fracture was recorded and related to the area of the bonded surface in order to calculate the shear strength.

The SBC (Filtek Silorane, shade A3) was used as filling as well as repair material. The MBC (Tetric Evo Ceram, shade A3) was used as repair material and for the reference group also as a filling material. As intermediate agents, a filled phosphate-dimethacrylate-based (Silorane System

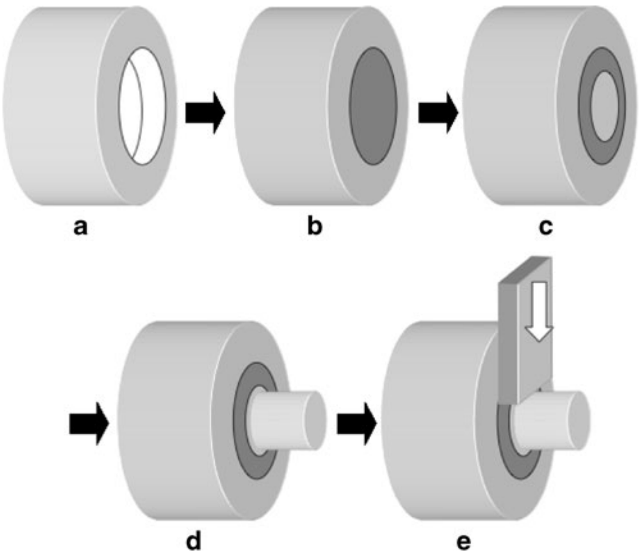

Fig. 1 Experimental set up for the shear test. **a**, **b** Preparation of the basic composite body. **c** Application of an intermediate agent. **d** Application of the repair composite. **e** Shear testing (*white arrow* is showing the direction of the force)

Adhesive Bond) and unfilled conventional (Heliobond, Ivoclar Vivandent) adhesive, flowable dimethacrylate-based (Tetric Evo Flow, Ivoclar Vivandent and Grandio Flow, Voco) and silorane-based composites (Hermes Flow, 3 M Espe) were used. A repair set (Clearfil repair, Kuraray) consisting of four components—an etching agent, a primer, a bonding agent and a silane coupling agent—was used in comparison with the application of a silane (Espe Sil, 3 M Espe) plus an unfilled resin (Heliobond). To examine the influence of the mode of application, the two flowable composites basing on dimethacrylate (Tetric Evo Flow and Grandio Flow) were applied in two different ways: per dental spatula (TF2, GF2) or spread by gentle air stream (TF1, GF1).

Fourteen combinations (n=10) of Filling, Repair and Intermediate agent were selected (Filling+Repair+Intermediate Agent): S+S+SB, S+S+SF, S+M+SB, S+M+HB, S+M+SF, S+M+TF1, S+M+TF2, S+M+GF1, S+M+GF2, S+M+CR, S+M+ES/HB, M+M+TF, D+S, D+M.

The M+M+TF group was used as a reference.

Additionally, the bond strength to dentin of the MBC and SBC was measured, by bonding the materials to dentine with the corresponding dentine adhesive (Silorane System Adhesive, 3 M; Espe/Syntac, Heliobond/Syntac Ivoclar Vivadent). Therefore, ten human molars were cut 2 mm beneath the dentin–enamel junction with a low-speed diamond wheel saw (Isomet) horizontally into two halves. The halves were randomly assigned to the two groups. The composites were then applied and cured similarly to the repair samples. These two groups of specimens—D+S and D+M—were used as a control.

For fractographic analysis, the specimens were examined under a stereomicroscope (Axioskop 2Mat Zeiss) and scanning electron microscope (Supra 55 VP, Zeiss, Germany) at different magnifications between ×17 and ×1,000 (×50—stereomicroscope) to determine the fracture pattern.

For statistical analysis, SPSS version 17 was used

The data on shear-bond strength values for all groups were analysed by one-way analysis of variance (ANOVA). Tukey honestly significant difference multiple comparisons were used to identify statistical homogeneous subsets as indicated by superscript letters (α=0.05).

Results

The measured shear-bond strengths are given in Table 2. ANOVA showed significant differences among groups (p<0.05).

Highest mean repair bond strength values (42.2 MPa) were measured for the dimethacrylate–dimethacrylate composite combination M+M+TF (dimethacrylate-based composite+dimethacrylate-based composite+Tetric Evo Flow). For repair of silorane-based composite, the highest shear-bond strengths were observed for the repairs with dimethacrylate-based composite and silane plus adhesive, Clearfil Repair or EspeSil plus Heliobond as intermediate layer (S+M+CR and S+M+ES/HB groups), followed by the S+S+SF group, the repair of silorane-based composite with the experimental silorane-flowable composite resin. The above-named repairs of silorane-based composite showed lower bond strengths than the M+M+TF reference, but the difference was statistically not significant. The three groups showed significant higher strength values than the control group D+S. All other silorane groups except the S+M+SF (silorane-based composite+dimethacrylate-based composite+silorane-based flowable composite) did not significantly differ from the D+S control. The S+M+SF group exhibited the lowest bond strengths. When the flowable dimethacrylate-based composite Tetric Evo Flow was spread with a dental spatula (S+M+TF2 group), the

Table 2 Mean shear-bond strength in MPa (SD), each group n=10

S+M+SF	6.8^{a} (3.0)
S+M+HB	10.2^{ab} (4.2)
S+M+GF1	15.6^{abc} (6.3)
S+S+SB	19.4^{bc} (5.8)
S+M+TF1	21.3^{bcd} (6.9)
D+S	21.4^{bcd} (8.6)
S+M+GF2	22.4^{cde} (9.1)
S+M+SB	23.3^{cde} (7.3)
S+M+TF2	26.2^{cdef} (7.7)
D+M	31.6^{defg} (11.0)
S+S+SF	33.0^{efg} (11.4)
S+M+ES/HB	37.8^{fg} (8.9)
S+M+CR	38.6^{g} (6.9)
M+M+TF	42. 2^{g} (4.7)

Subgroups not significantly different from each other are designated with same subscripts

S Filtek Silorane, *M* Tetric Evo Ceram, *D* Dentine, *SB* Silorane System Adhesive Bond, *HB* Heliobond, *SF* Hermes Flow, *TF* Tetric Evo Flow, *GF* Grandio Flow, *CR* Clearfil Repair, *ES* Espe Sil shear-bond strengths were comparable to the S+S+SF and S+M+ES/HB groups. If an air stream was used to spread the flowable resin Tetric Evo Flow (S+M+TF1 group), the repair strengths decreased and were distinguished significantly from S+S+SF. The same effect was detected for the S+M+GF1 and S+M+GF2 groups, silorane-based composite+dimethacrylate-based composite with Grandio Flow. Shear-bond strengths of repairs using the Silorane System Adhesive Bond as intermediate agent between silorane and dimethacrylate (S+M+SB group) were significantly lower than the silane plus adhesive repairs S+M+ES/HB and S+M+CR.

Fracture surface analyses are shown in Fig. 2. Three types of fractures were identified: cohesive fracture inside one composite layer, adhesive fracture in the IMA layer and mixed-cohesive and adhesive-fracture modes.

The M+M+TF reference group and the silane plus adhesive group S+M+CR produced 90% cohesive fractures, the S+S+SF group 70%. All other groups exhibited mainly adhesive fractures. The control D+M showed more cohesive fracturing (60%), whereas the fractures of the D+S control appeared mostly adhesive (60%).

Figure 3 shows representative examples of the three fracture patterns: adhesive, cohesive and mixed fractures

Discussion

Silorane-based composites were developed with the intention to solve the problems of polymerisation shrinkage, polymerisation stress and water sorption. The silorane matrix is built by a monomer with a new chemical composition of siloxane and oxirane moieties. Shrinkage is reduced by the cationic ring-opening polymerisation of the cycloaliphatic oxirane sites. The cyclosiloxane back-

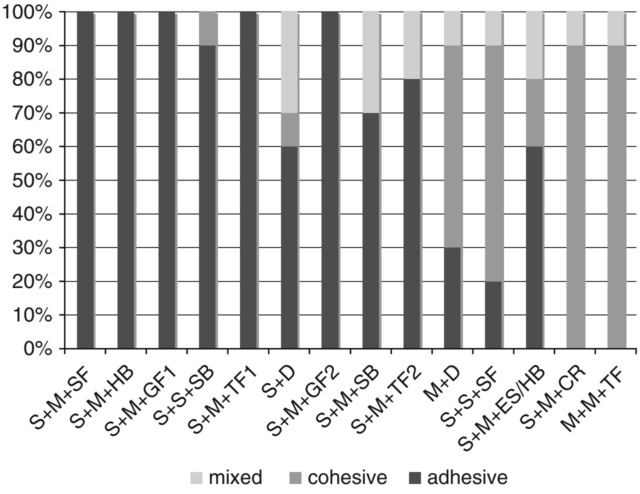

Fig. 2 Percentages of failure modes of each group (n=10)

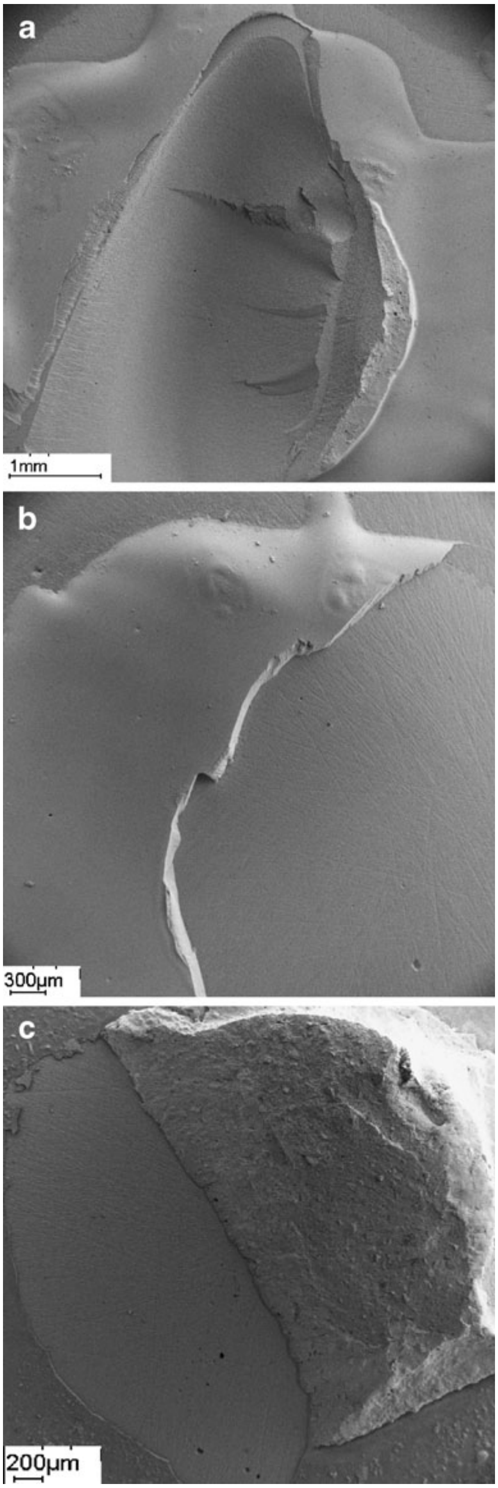

Fig. 3 **a**–**c** Typical fracture patterns. **a** Representative cohesive fracture of the repaired filling side (S+S+SF) with radial dissemination of cracks. **b** Representative adhesive fracture of the repaired filling side (S+M+SF). The adhesive facture occurred between filling an intermediate layer and between intermediate layer and repairing composite. **c** Representative mixed fracture (S+S+SB). Adhesive fracture in parts and cohesive in progress within the repairing composite

bone intensifies the hydrophobic character of the silorane composite, exhibited in decreased water sorption, solubility and diffusion coefficient compared with conventional dimethacrylate-based materials [1]. Apart from the predominant radical polymerisation initiation in conventional composites, the cationic ring-opening polymerisation of silorane-based composite is less sensitive to oxygen compared with methacrylate-based materials [17]. Further, SBC showed good mechanical properties, comparable to clinically successful dimethacrylate-based composite materials [18, 19].

It is known that, after ageing processes of dimethacrylate composite resin, the number of available vinyl groups available for crosspolymerisation is decreased. To enhance shear-bond strengths though, aged composite surfaces are generally treated by mechanical grinding, acid etching and resin coating. In the present study, water storage (37°C) for 1 week was used to obtain an aged substrate surface since we observed no significant differences in bond strengths if samples were stored for 1 week or 1 month [20].

Now, it was of interest to expose which intermediate resin and method is required to produce acceptable repair bond strengths for repair of SBC.

Apparently, the control group (M+M+TF), which was exclusively made of dimethacrylate-based composite, produced highest shear-bond strengths of all groups. Values diminished when silorane-based composite was used for repair, however, the differences between the M+M+TF group and the S+M+CR and S+M+ES/HB were not significant.

For silorane repair, highest shear-bond strengths were achieved when silorane-based composite was repaired with dimethacrylate-based composite using a silane coupling agent in addition to an adhesive, like the Porcelaine Bond Activator from the Clearfil Repair set of the S+M+CR group or the Espe Sil of the S+M+ES/HB group. Thus, our first hypothesis, mixed repairs would produce lower bond strengths than repairs made of one sort of composite resin, SBC or MBC, was rejected.

In addition to the silane component, Heliobond, a dimethacrylate-based unfilled resin, was used for the S+M+ES/HB group. Clearfil SE primer and bond, a phosphate-dimethacrylate-based adhesive, was utilised for the S+M+CR group, which also contains a silane component. Differences between the groups were not significant, although Tezvergil-Mutluay et al. [2] detected an increase of shear-bond strength when a phosphate-dimethacrylate-based adhesive was applied between increments of silorane and a dimethacrylate (Z250, 3 M Espe). Regarding the comparatively low values of the group using solely Heliobond between silorane and dimethacrylate (S+M+HB), it is conjecturable that the silane is the decisive factor for adhesion between aged silorane surface and low-viscosity resin. A chemical bonding to the silorane composite resin matrix is presumed, in contrast to the use of silane for repair of MBC, where the true benefit of using silane coupling agents is still controversial. Söderholm and Roberts [8], for example, found no significant difference in repair strength between adhesive monomer system of Scotchbond and Scotchprime, and silane-toluene materials. Swift et al. [21] reported that the application of silane and Bondlite—a phosphate ester enamel bonding material—did not significantly enhance the repair strength compared with Bondlite alone. The application of the adhesive, following the silane, is supposed to be necessary to act as a stress-absorbing elastic layer between the more viscose composites.

Since the differences between M+M+TF and S+S+SF groups are obvious (9.2 MPa) but not significant, the hypothesis that repairing SBC with SBC using a silorane flowable resin as intermediate agent would lead to shear-bond strengths comparable to MBC repaired with MBC and a dimethacrylate-based flowable composite as intermediate agent is accepted. It can be concluded that, using a flowable composite for repairing composites based on the same chemical composition leads to acceptable results. Remembering the fact that the silorane-based composite was intended for the use in posterior teeth where restorations are subjected to high mechanical load, the mixed repairs with SBC and MBC using a silane coupling agent seem to be more reliable.

Higher bond strength was reached by using a silorane-based flowable material as intermediate agent for the silorane–silorane repair combination than by using the Silorane System Adhesive Bond, which is not silorane-based but phosphate-dimethacrylate-based. The effect of the use of a silorane flowable for silorane repair might be similar to the stress-bearing ability of flowable resins for dimethacrylate repair due to its higher elasticity and fracture toughness. A higher rigidity is documented for filled adhesives than for flowable composites, most likely affecting their stress-relieving potential. Based on the chemical similarity, the chemical connection between the silorane composite and silorane, flowable resin presumably is more stable than the hypothesised bond between the phosphate groups of the phosphate-dimethacrylate-based adhesive and the SBC. A reaction of the phosphate group with oxirane and the acrylate group with dimethacrylate is supposed by Tezvergil-Mutluay et al. [2]. In their study, they found an increase in shear-bond strength between a silorane and a dimethacrylate-based composite using a phosphate-dimethacrylate-based intermediate resin compared to a dimethacrylate-based intermediate resin. A previous study also evidenced that the use of a phosphate-dimethacrylate-based intermediate resin increases the shear-bond strength of repairs between SBC and MBC [22].

The use of silorane-based flowable composite as intermediate layer between SBC and the MBC led to drastically decreased bond strengths compared to the unmixed groups M+M+TF and S+S+SF. Fractographic analysis showed solely adhesive fractures between the silorane-based flowable and the MBC layer in this case. Strength was enhanced slightly when Heliobond was spread between SBC and the MBC instead of the silorane flowable and more explicit when the dimethacrylate-based flowable composites Tetric Evo Flow (Ivoclar Vivadent) and Grandio Flow (Voco) were spread by compressed air. The increase in strength compared to S+M+SF was significant when the layer of flowable composite was produced by spreading the flowable material with a dental spatula. The flowable intermediate agents were applied in two methods. First of all, we treated them as an adhesive being spread by air stream, which was strictly experimental, and second of all, the usual manner, like a filling material being applied with an instrument. The groups spread by spatula produced slightly higher bond strengths. Maybe thereby a thicker layer was produced which appears more stress-absorbing. However, the application method did not influence the bond strength significantly. As for none of these named groups a chemical bonding to the silorane matrix is supposed, the ability of the intermediate agent to penetrate surface irregularities, the differences of hydrophilic properties between materials and the ability of the intermediate agent to act as stress-absorbing layer are presumed to produce varieties among groups. Micro-mechanical material properties of the experimental Hermes Flow must be explored further to fathom wide differences between S+M+SF and dimethacrylate-flowable groups.

The S+M+GF1 and GF2 and the S+M+TF1 and TF2 groups are statistically comparable to the S+M+SB group, where a chemical bonding between the phosphate-dimethacrylate-based adhesive Silorane System Adhesive Bond and the silorane-based composite and between the Silorane System Adhesive Bond and the dimethacrylate composite body is presumed, but compared with the reference group M+M+TF, the values of these specimens appeared low.

Due to the fact that the dentist normally has no information about the chemical composition of the existing composite, the repair of existing silorane restorations is critical, since all repairs of silorane-based composite with dimethacrylate composite resin were lower than the M+M+TF reference with the exception of the groups in which a silane was used, and from the S+S groups, repair of silorane-based composite with silorane-based composite, only the repairs with the experimental silorane-based flowable resin led to results comparable to M+M+TF reference. Even though the benefit from silane coupling agent for repair of dimethacrylate-based composite is not fully explained, the routine application of silane for repair of composite resin could solve the problem of material combinations leading to weak linkage. Then a dimethacrylate-based composite should be used as repair filling material. From this point of view, repair using a dimethacrylate-based repair system including a silane component would be a good recommendation for all situations. A negative facet of this method is the fact that potential detrimental effects on enamel and dentin bonding of silane contamination of the tooth substrates are still not thoroughly clarified. If the filling material is definitely known, for silorane-based composite the S+S+SF repair and the M+M+TF combination for repair of dimethacrylate-based composite can be recommended to avoid silane contamination.

Within the limitations of this study it can be concluded that it is possible to repair silorane-based composite with the same material and even in combination with dimethacrylate-based composite, if the appropriate repair technique is utilised. For clinical practice, it is important to emphasise that for the case of being unable to identify the present filling material, a silorane flowable composite should not be applied. Then, for certainty, a silane component additionally to an adhesive and dimethacrylate-based composite filling material should be used.

At the current test set-up, the C-factor of the even substrate surface is low, resulting possibly in a low shrinkage stress on the adhesive bonds. Future experiments should evaluate the ability of repaired SBC restorations to withstand mechanical loadings through fatigue tests. High C-factor conditions, such as in the repair of restoration margins involving the adjoining tooth structure, should also be assessed.

The elastic moduli of component materials in a shear-bond strength test may affect results. The differences in stiffness between substrate, intermediate bonding layer and repair material may under- or over-estimate bond strengths.

Conflict of interest The authors declare that they have no conflict of interest.

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