Clin Oral Invest (2013) 17:601–608
DOI 10.1007/s00784-012-0722-4

ORIGINAL ARTICLE

Repair of dental resin-based composites

Veronika Baur · Nicoleta Ilie

Received: 19 August 2011 / Accepted: 15 March 2012 / Published online: 11 April 2012

Abstract
Objectives The study analyzed the reparability and compatibility of light-curing resin-based composites (RBCs) of the categories "microhybrid," "nanohybrid," and "packable."
Materials and methods Six RBCs with different matrix and filler formulation—purely methacrylate-based composites (MBCs), ormocer-based composites (OBCs), and silorane-based composites (SBCs)—were used for the specimens. Every material was combined with itself and with the other five RBCs, resulting in a total of 36 combination groups (n=20). The specimens were polymerized, aged for 8 weeks in distilled water at 37 °C, and then repaired by means of a repair kit. Shear bond strength and fracture mode were measured after aging of the specimens, undergoing storage for 24 h in distilled water at 37 °C followed by thermocycling (5,000 cycles, 5–55 °C) and an additional 4-week storage in distilled water at 37 °C.
Results Data were statistically analyzed using ANOVA with TUKEY HSD post hoc test (α=0.05). On average, the OBC Admira reached the highest value as a substrate material (30.41 MPa), and the SBC Filtek Silorane reached the lowest value (8.14 MPa). Filtek Silorane was identified as the repair material with the highest bond strength value (28.70 MPa), while a packable composite reached the lowest bond strength value (15.55 MPa). The analysis of the break modes showed that adhesive breaks are typical when strength is at its lowest (6.27 MPa). A large number of cohesive fractures are conspicuous when identical materials are used for repair, except Filtek Silorane (2 % cohesive fractures).
Conclusions The study demonstrated that the effect of the different materials on bond strength varies strongly, depending on whether the material is used as filling or as repair material.
Clinical relevance It is generally advisable but not compulsory to combine identical RBCs.

Keywords Resin-based composites · Repair · Bond strength · Silorane · Ormocers

V. Baur · N. Ilie (✉)
Department of Restorative Dentistry, Dental School,
Ludwig-Maximilians-University,
Goethestr. 70,
80336 Munich, Germany
e-mail: nicoleta.ilie@dent.med.uni-muenchen.de

Introduction

For decades, restorative therapy in conservative dentistry has been increasingly marked by the use of resin-based composites (RBC) fillings. This development reflects a general trend towards minimally invasive approaches in line with the motto "Preserve if in doubt." In the past few years, numerous filling materials with improved aesthetic and technical properties have been introduced to the market, providing new treatment options in connection with minimally invasive approaches on the one hand, raising research questions on the other hand. In retrospect, the long-term stability of dental composite restorations has been improving constantly; however, failures or fractures of dental restorations can occur, resulting in repair or total replacement. The complete removal of a tooth-colored restoration results in the loss of tooth structure that is twice as high compared to amalgam or glass ionomer [1]. Repairing is an alternative to completely replacing a filling and has advantages regarding costs and treatment strategies.

Numerous studies on the methodology of the repair process [2–8] have raised the question as to whether and to what extent filling materials, which have become very diverse, are compatible. Intermediate agents were proved to have the strongest influence on composite repair bond strengths, whereas pretreatment of the substrate played a minor role [3]. Studies on repairing newer restorative materials with non-methacrylate organic matrix, like the silorane-based composites (SBCs), showed that the pretreatment of the surface could be done equivalent to the repair of methacrylate-based composites (MBCs), using silicon carbide paper for surface roughening, 37 % phosphoric acid for cleaning, and several intermediate agents for bonding [9]. Some studies demonstrated increased bond strength between SBCs and MBCs when a silane and a phosphate-dimethacrylate-based adhesive system were used for repair [9, 10]. Papacchini et al. illustrated that using a low-viscosity flowable composite as an intermediate agent for methacrylate-based composites resulted in an improvement in repair bond strengths [5]. Similar results can be achieved in silorane-based composites under the conditions that the low-viscosity flowable composite used as intermediate agent is also silorane based [9].

More recently, several studies focused on the influence of storage time and conditions as well as the influence of different composite classes on bond strength [9, 11, 12]. Furthermore, artificial aging plays a crucial role in RBC repair, particularly imitating environmental influences. Thermocycling and water storage are well-accepted methods to simulate aging and to stress interfacial bonds [13]. In his study on artificial aging of RBCs, Hahnel et al. concluded that the duration of the aging process has a much stronger influence on several mechanical properties like Vickers hardness and flexural strength than the medium used for aging [11].

The diversity of resin-based restorative materials is also expressed in the variation of their filler size, morphology, amount, volume, distribution, or chemical composition, thus creating a large variety of composite categories. Nanohybrid composites with decreased filler size provide a larger surface area and thus a larger filler–matrix interface, being more prone to degradation through water uptake [14]. Comparing nanohybrid composites with microhybrid composites, a reduced stability during water storage for nanohybrid RBCs was measured [15]. The broad diversity of new materials requires the evaluation of their compatibility with respect to the repairing ability.

In this context, the objective of this study was to evaluate the respective bond strengths of six different resin-based composites—purely MBCs, OBCs, and SBCs—or their 36 possible combinations as repair or filling materials in a shear test procedure and to assess the influence for chemical compositions (methacrylate, ormocer, or silorane) and material type (nano- and microhybrid, and packable composites) on bond strength and fracture modes.

The tested null hypotheses were that (a) there will be no difference in bond strength whether an identical or different material is used for repair, (b) there will be no differences in bond strength and fracture pattern between different RBC classes (nano- and microhybrid or packable RBCs) or different matrix formulations (methacrylate-, ormocer-, and silorane-based composites).

Materials and methods

The RBCs used are listed in Table 1. Representative samples of important material classes were used: purely MBCs were compared with OBCs and SBCs. Another influential factor in the choice of RBCs was their belonging to the RBC classes as microhybrid, nanohybrid, or packable RBCs. Each of the six materials included in the study was used as

Table 1 Materials, manufacturer, chemical composition of the matrix and filler content by weight and volume percent

Composite	Manufacturer/bath	Resin matrix	Filler	Content (*v*/*w*)
Microhybrid				
Filtek Silorane	3M ESPE/20090206, 20090107	Bis-3,4-epoxycyclohexyl-ethylphenylmethylsilane, 3,4-epoxycyclohexyl-cyclopolymethylsiloxane	Quartz, yttrium fluoride	55/76
Esthet X	Dentsply/810271	BisGMA, BisEMA, TEGDMA	Ba-F-Al-B-Si glass, SiO_2	60/77
Admira	VOCO/0904426	Ormocers, BisGMA, UDMA, TEGDMA, BHT	SiO_2, Ba-Al-B-Si glass	63/81
Nanohybrid				
Filtek Supreme XT	3M ESPE/20081110	BisGMA, BisEMA, UDMA, TEGDMA	ZrO/SiO_2, SiO_2 nano-filler	59.5/78.5
Ceram X Duo	Dentsply/807003250, 811001324	MS, DM	Ba-Al-B-Si glass, SiO_2	57/76
Packable				
Teric Ceram HB	Ivoclar Vivadent/L28170	BisGMA, UDMA, TEGDMA	Ba glass, Ba-Al-F-Si glass, YbF, SiO_2, MO	56/78

BisGMA bisphenol A diglycidylmethaycrylate, *BisEMA* bisphenol A polyethylene glycol diether dimethacrylate, *DM* dimethacrylate resin, *MS* methacrylate-modified polysiloxane, *TEGDMA* triethyleneglycol dimethacrylate, *UDMA* urethane dimethacrylate, *Al* aluminum, *Ba* barium, *B* bor, *MO* mixed oxides, *Si* silicon, *SiO_2* silicon dioxide, *YbF3* ytterbium fluoride, *ZrO* zirconium oxide a substrate (filling) during the test series once, resulting in groups of 120 samples per material. Furthermore, the RBCs were chosen with regard to their classes and repaired with each of the six filling materials (Fig. 1).

The samples were produced by filling steel cylinders with a polyacryl-based resin (Technovit 4000®, Hereraus Kulzer, Wehrheim, German). A round cavity 2 mm in depth and 6 mm in diameter was shaped into the middle of this resin base. The corresponding RBCs (Table 1) were inserted into this cavity and cured for 20 s with a high-performing LED polymerization light (Bluephase LED®, Ivoclar Vivadent, 1,200 mW/cm², Schaan, Lichtensetein). Thus, 36 combinations (n=20) resulting in 720 samples were available for testing.

The surfaces of the fillings were roughened with silicon carbide grinding paper (400 GRIT, Leco, St. Joseph, USA). Subsequently, the samples were stored at a temperature of 37 °C for 8 weeks in distilled water. Before the subsequent filling repair, the samples were roughened once more. To remove any grinding particles from the fillings' surfaces, they were covered in 40 % phosphoric acid gel (Clearfil Repair, Table 2) for 15 s, thoroughly rinsed with water, and dried with compressed air. The intermediate agent was applied and polymerized in accordance with the manufacturer's specifications listed in Table 2. The RBC repair to be tested was applied by means of a mold (diameter, 3 mm; height, 4 mm) in 2-mm increments separately polymerized for 20 s. The samples were then stored again in distilled water at a temperature of 37 °C for 24 h, followed by thermocycling (alternating immersion of the samples in distilled water with a temperature of 5 and 55 °C; 5,000 cycles; dwell time, 30 s). This procedure was followed by another aging period of the samples: they were stored in distilled water at a temperature of 37 °C for an additional 28 days.

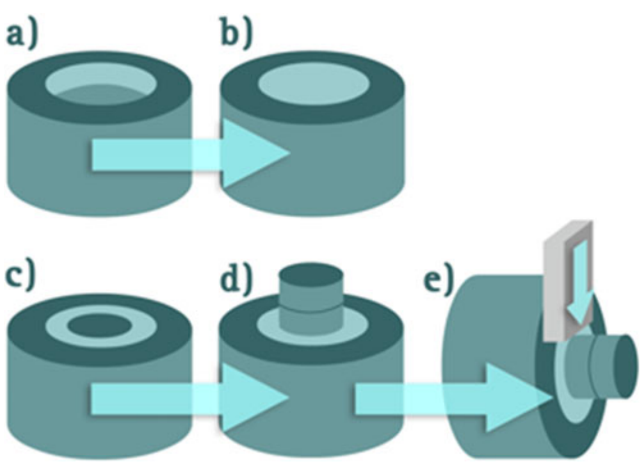

Fig. 1 Schematic diagram of the test procedure. **a** Production of the sample dies. **b** Filling the cavity with the substrate composite. **c** Treating the surface with the repair kit. **d** Application of the repair composite. **e** Measuring bond strength

The shear bond strength was measured with a universal testing machine (Willytec GmbH, Gräfelfing, Germany; cross-head speed, 0.5 mm/min). After the break, the exact type of fracture was identified by means of a stereomicroscope (Axioskop 2Mat, Zeiss, Germany, ×50) and classified as adhesive, cohesive (in filling or in repair), and mixed fractures (adhesive+cohesive in repair or adhesive+cohesive in filling). Pre-testing failures were recorded as 0 strength and were included in the statistical analysis.

Results were compared using one- and multiple-way ANOVA and Tukey HSD post hoc test (α=0.05) and partial eta-squared statistic (SPSS 19.0, Chicago, IL, USA). The results for bond strength were compared within each combination pattern (identical or different materials for repair and filling), material class (nanohybrid, microhybrid, packable), and matrix formulation (purely MBCs, OBCs, SBCs), respectively. The multivariate analysis tested the influence of the parameters "filling," "repair," "filling–repair combination," "filler volume," and "filler weight" (Table 5). The partial eta-squared statistic reports the practical significance of each term, based upon the ratio of the variation accounted for by the effect. Larger values of partial eta squared indicate a greater amount of variation accounted for by the model effect, to a maximum of 1.

Results

The study demonstrates that the effect of the different materials on bond strength varies strongly, depending on whether the material is used as a filling or as a repair material. Filtek Silorane showed the lowest average strength when used as a filling material (8.14 MPa). However, as a repair material, it had the highest bond strength (28.70 MPa). Table 3 provides an overview of the effect of materials on bond strength. As ANOVA showed, there were significant differences between the possible combinations of the selected RBCs due to these differences in material conditions. On average, OBCs used as filling materials reached the highest bond strengths, especially in combination with other OBCs or SBCs. Moreover, a packable MBC as filling material combined with another MBC showed high values. The combinations of the SBC Filtek Silorane as the filling material with the MBCs Tetric Ceram HB, Esthet X or Filtek Supreme XT as the repair material reached very low bond strengths (Table 4).

Based on the significant values of the partial η^2, it can be stated that the filling material generally has a greater influence on the bond strength and failure type as the repair material (η^2: material filling, 0.516; material repair, 0.293) (Table 5). The repair of identical materials in this study significantly differed from the repair of different materials (p=0.0008). The same effect was detected for material combinations of different matrix formulation (p=0.0026).

Table 2 Repair kit used

Repair kit	Bath	Composition	Instructions for use
Clearfil Repair	41270		
K-etchand Gel	00444A	40 % phosphoric acid	15-s contact time, rinse, dry
Clearfil SE bond primer	00877A	MDP, HEMA, water	Blend, 5-s contact time, slightly disperse with blown air
Porcelain bond Aktivator	00231B	γ-MPS, Bisphenol A polyethoxydimethacrylate, MPTS	
Clearfil SE bond	01291A	MDP, BisGMA, HEMA, hydrophobic dimethacrylate, silicic acid	Apply sparsely, slightly disperse with blown air, 10 s light curing

BisGMA bisphenol A diglycidil, *HEMA* 2-hydroxyethyl methacrylate, *MDP* 10-methacryloyloxydecyl dihydrogen phosphate, *γ-MPS* γ -methacryloxy propyltrimethoxy silane

When materials with different RBC classes (microhybrid, nanohybrid, packable) were analyzed, bond strengths differed less.

Figure 2 provides an overview of the main fracture types by group and frequency. The diagram exemplifies that the combination of Filtek Silorane as the filling material with MBCs (Esthet X, Filtek Supreme XT, Tetric Ceram HB) as the repair material frequently leads to adhesive fractures. The combination of Filtek Silorane with OBC also shows an increased number of adhesive fractures. However, when Filtek Silorane is used as a repair material, a general rise in the number of cohesive fractures in fillings and repairs could be observed. Cohesive fractures in fillings and repairs

Table 3 Effect of materials on bond strength

	Filling		Repair	
	Medium value	Standard deviation	Medium value	Standard deviation
Material				
Filtek Silorane	8.14	7.95	28.70	8.63
Esthet X	18.43	11.03	26.11	13.42
Tetric Ceram HB	23.10	9.64	15.55	9.29
Filtek Supreme XT	22.15	9.33	17.65	11.09
Ceram X duo	28.38	9.96	21.60	11.96
Admira	30.41	8.44	21.19	11.03
Material group				
SBCs	8.14	7.95	28.70	8.63
MBCs	21.23	10.20	19.78	12.25
OBCs	29.39	9.27	21.40	11.48
Material type				
Microhybrid	21.41	12.91	25.62	11.93
Nanohybrid	22.15	9.33	18.60	10.63
Packable	23.10	9.64	15.55	9.29
Percent by volume				
55	8.14	7.95	28.70	8.63
56	30.41	8.44	21.19	11.03
57	28.38	9.96	21.60	11.96
59.5	22.15	9.33	17.65	11.09
60	18.43	11.03	26.11	13.42
63	23.10	9.64	15.55	9.29
Percent by weight				
76	18.39	13.56	25.17	10.99
77	18.43	11.03	26.11	13.42
78	30.41	8.44	21.19	11.03
78.5	22.15	9.33	17.65	11.09
81	23.10	9.64	15.55	9.29

Table 4 Medium values of bond strength in MPa and standard deviations (SD) in the individual repair cases (ANOVA with Tukey HSD post-hoc test, α=0.05)

Filling/repair	Filtek Silorane	Esthet X	Tetric Ceram HB	Filtek Supreme XT	Ceram X duo	Admira
Filtek Silorane	17.2^{def} (9.9)	2.8^{a} (2)	2.0^{a} (2.3)	5.4^{a} (3.6)	13.2^{bcde} (8)	7.9^{abc} (4.4)
Esthet X	29.5^{ijk} (4.8)	30.1^{ijk} (10.2)	17.6^{def} (9.5)	8.2^{abc} (5.1)	12.1^{bcd} (4.3)	13.0^{bcde} (6.7)
Tetric Ceram HB	28.1^{hijk} (7.1)	34.7^{k} (7.8)	16.6^{cdef} (6)	12.1^{bcd} (5.2)	24.2^{fghij} (6.5)	22.8^{fghij} (4.9)
Filtek Supreme XT	31.5^{jk} (5.8)	27.2^{ghijk} (9.3)	16.7^{cdef} (8.0)	21.3^{efghi} (6.2)	18.2^{def} (9.6)	17.9^{def} (6.5)
Ceram X duo	29.9^{ijk} (5.6)	30.5^{jk} (8.8)	19.2^{defg} (8.4)	29.2^{ijk} (5.6)	30.7^{jk} (16.4)	30.7^{jk} (5.8)
Admira	36.0^{k} (5)	31.5^{jk} (8.6)	20^{defgh} (7.1)	29.7^{ijk} (6.5)	30.7^{jk} (6.6)	34.7^{k} (6.4)

Superscript letters indicate statistically homogeneous subgroups

manifested quite frequently in the combination of Esthet X with Tetric Ceram HB. The combination of Filtek Silorane as the filling and the repair material leads to a massive increase in the number of adhesive–cohesive fractures in repairs. The packable material Tetric Ceram HB used as a filling material frequently leads to cohesive fractures, while adhesive fractures are most frequent in microhybrid composites. However, when Tetric Ceram HB was used as a repair material, an increasing number of adhesive fractures became evident.

Discussion

The trend in restorative dentistry towards repairing insufficient composite restorations requires reliable repair procedures. In general, repairing a composite restoration is considered to be a more conservative treatment option than replacing the entire filling. Not only is a repair the faster treatment method, there are also two major advantages speaking in favor of it: an increased survival probability of the treated tooth and a reduced strain on the patient during treatment [16]. However, the quality and durability of a repaired composite restoration remains questionable. The present study investigated the influences of different material combinations on shear bond strength. It is partially based on the results of previous studies which focused mainly on the repair process [5, 10, 17].

Due to the lack of a standard protocol for the artificial aging process, different studies are usually based on different procedures. The objective of the thermal cycling is to simulate the thermal strain on the bonding surface by the influence of liquids and a temperature change between 5 and 55 °C. Moreover, repeated temperature changes lead to a continuous weakening of the bonding surfaces between resin matrix and filling material [7], which is most likely due to the differing thermal expansion coefficients [9]. In this study, the first filling as well as the combination of substrate and repair filling was exposed to extensive aging. Brendeke et al. give the aging protocol of the present study additional clinical importance as their study proved that a 2-month aging process in water correlates with significantly lower bond strengths than a 1-week aging process in water or acid [18].

A uniform repair process pattern was chosen for this study in order to focus exclusively on the comparison of the bond strengths of different composite combinations. The repair was carried out with Clearfil Repair, which proved to be the best system for the combination of MBCs and SBCs in previous studies [10, 17]. Clearfil Repair is a phosphate-dimethacrylate-based adhesive system containing an additional silane component, which improves the wettability of the substrate surface and causes a chemical (siloxane) bond with the inorganic filling materials [11, 18]. In a study by Tezvergil et. al., Clearfil Repair, including the application of silane and monomer primer combination, followed by application of unfilled adhesive resin, showed higher shear bond strength values than Compoconnect (Heraus Kulzer) and Scotchbond Multi-Purpose adhesive resin (3M-ESPE) [10]. Looking at the bond of MBCs and SBCs, Tezvergil-Mutluay et al. assume that the phosphate residue reacts with the oxirane residue of the silorane, and the acrylate group reacts with the methacrylate [17]. To the extent of Clearfil Repair being the most reliable system for the mentioned

Table 5 Influences on bond strength, η^2

Factor	Bond strength	Fracture pattern
Material filling	0.516	0.249
Material repair	0.293	0.044
Material filling × material repair	0.257	0.167
Group filling	0.329	0.171
Group repair	0.114	0.010
Group filling × group repair	0.058	0.039
Vol% filling	0.516	0.249
Vol% repair	0.293	0.044
Vol% filling×vol% repair	0.257	0.167
Wt% filling	0.163	0.065
Wt% repair	0.152	0.041
Wt% filling×wt% repair	0.114	0.097

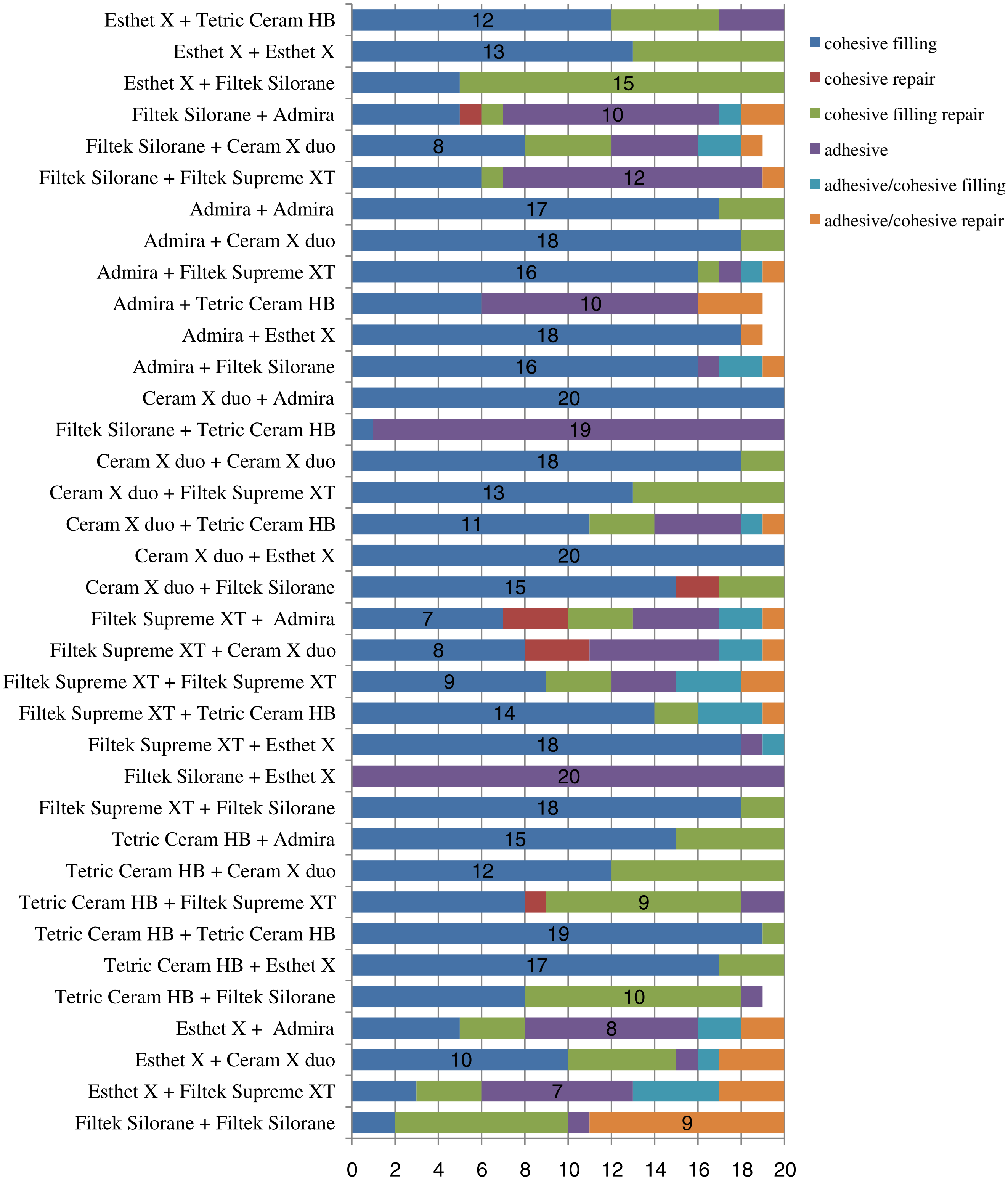

Fig. 2 Overview of the frequency of main fracture types by group

combining procedures, the study used a single system, which facilitated direct comparison of the results regarding the bond strengths of all composites used [9, 10, 17, 19].

The evaluation of the results proved that bond strength generally depends more on the filling material than on the repair material (higher η^2). If the dentist is unable to identify the substrate composite, the fact that the repair material plays a less important role makes the clinical routine somewhat easier.

A major objective of this study was to compare the bond strength of identical materials with the bond strength of differing materials, i.e., finding out to what extent certain materials can be repaired with the same material. The results show that all materials, except for Tetric Ceram HB, that were combined with the same RBC reached a comparatively high or the highest possible bond strength. Consequently, it is generally advisable but not compulsory to combine identical RBCs. A possible reason for lower bond strength in the homologous repair of Tetric Ceram HB, which represents one of the high-filled composites, is the lower wettability of the higher-filled composite. It is conspicuous that Tetric Ceram HB generally achieves better results as a filling material than as a repair material.

Looking at bond strengths in relation to an ideal repair material, Filtek Silorane achieves the highest values. It is difficult to specify a minimum value for bond strength after a repair. However, a reference value of 18 to 20 MPa can be found in the literature [20]. Filtek Silorane can be regarded as the ideal repair material, for it provides appropriate values in all combinations with the tested materials, except the combination with itself. In the latter case, a value only slightly below the mentioned reference value is being achieved. It can be assumed that the otherwise optimal results of Filtek Silorane used as a repair filling are on the one hand due to its comparatively low polymerization shrinkage [21], which leads to a minor formation of gaps to the substrate composite or the bonding agent layer. Filtek Silorane therefore possibly provides a surface that is less prone to failures. On the other hand, the hydrophobic behavior of the SBCs [21] may have influence on the repairability. Especially during extensive artificial aging, RBCs are exposed to degradation processes, which cause, among other things, increased water sorption and thus deterioration of the structure. Due to their hydrophobic siloxane component, SBCs are more hydrophobic than MBCs [21]. Water sorption and solvability are reduced [22], suggesting smaller changes in material properties during storage. In this study, the siloranes showed mechanical properties similar to those of the tested MBCs after storage. They even proved to be more stable when stored in alcohol and additionally exposed to thermocycling [23]. As mentioned before, Admira, which represents an OBC, achieved the highest average values as a substrate material. Except for the study by Magni et al. [3], there is a lack of literature on repairs with OBCs, making a comparison with other studies difficult. Tagtekin compared Admira with a conventional hybrid composite. He identified the highest surface roughness as well as the greatest hardness and resistance to wear and tear in Admira, compared to a microhybrid composite (Amelogen, Ultradent). However, he identified these values after only 24 h of artificial aging [24]. Above all, not only the strong resistance to wear and tear, but also the high strength value and surface roughness, may underline this study's suggestion of using the ormocer-based material Admira as a reliable substrate material.

Other studies on the repair of RBCs already explain the classification of fracture patterns into adhesive, cohesive, and mixed fractures [5, 10, 25]. Looking at the frequency of fracture patterns, a general large number of cohesive fractures is conspicuous. Especially Filtek Silorane as the repair material with the highest bond strength values shows a significantly increased number of cohesive fractures in fillings and repairs. However, if a Filtek Silorane filling is combined with the MBC Esthet X, Filtek Supreme XT, or Tetric Ceram HB as the repair material, a large number of adhesive fractures can be observed. Cohesive fractures show that the filling material with its mechanical and physical properties represents the weak point in the bond, whereas the bond between substrate and filling composite seems to be reliable [26]. Low wettability, the chemical compound of the bonding system, and the possible occurrence of technical faults such as voids or porosities can cause the weaker bond in the event of adhesive fractures.

A further continuous development in the range of RBCs can be expected. For some time, many manufacturers have invested in the development of low-shrinkage composites, and more recently, some of these materials such as tricyclodecane–urethane dimethacrylate (TCD–urethane) or composites of dimer acid based are clinically in use [27]. Especially these materials of new matrices require more research on repair and composite fillings. Desiderata such as increasing durability of the denture, preventing unnecessary loss of tooth structure and preventing pulp tissue traumas, are easier to realize if materials and methods relevant for repairing dental restoration composites are well developed in all their forms.

Conclusions

The bond strength depends more on the substrate than on the selected repair material. This fact makes the clinical success of the repair difficult to predict, because the substrate, which was used, is rarely known for the practitioner. On average, the ormocer Admira could be identified as a substrate material with the highest values and Filtek Silorane as repair material with the highest bond strengths. In general, homologue repaired materials result in all combinations of reliable bond strengths. Looking at the exact failure mode of the specimens, high bond strengths correlated with cohesive fracture patterns, whereas at low strengths, an increased incidence of adhesive fracture modes was observed.

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

References

1. Krejci I, Lieber CM, Lutz F (1995) Time required to remove totally bonded tooth-colored posterior restorations and related tooth structure loss. Dent Mater 11:34–40
2. Brosh T, Pilo R, Bichacho N, Blutsein R (1997) Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. J Prosthet Dent 77:122–126
3. Magni E, Ferrari M, Papacchini F, Hickel R, Ilie N (2009) Influence of ozone on the composite-to composite bond. Clin Oral Invest 15:249–256
4. Özcan M, Barbosa SH, Melo RM, Galhano GAP, Bottino MA (2007) Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dent Mater 23:1276–1282
5. Papacchini F, Magni E, Radovic I, Mazzitelli C, Monticelli F, Goracci C, Polimeni A, Ferrari M (2007) Effect of intermediate agents and pre-heating of repairing resin on composite-repair bonds. Oper Dent 32–4:363–371
6. Rathke A, Tymina Y, Haller B (2008) Effect of different surface treatments on the composite-composite repair bond strength. Clin Oral Invest 13:317–323
7. Rinastiti M, Özcan M, Siswomihardjo W, Busscher HJ (2012) Effects of surface conditioning on repair bond strength of non-aged and aged microhybrid, nanohybrid, and nanofilled composite resins. Clin Oral Invest (in press)
8. Yesilyurt C, Kusgoz A, Bayram M, Ulker M (2009) Initial repair bond strength of a nano-filled hybrid resin: effect of surface treatments and bonding agents. J Esthet Restor Dent 21:261
9. Ivanovas S, Hickel R, Ilie N (2011) How to repair fillings made by silorane-based composites. Clin Oral Ivest 15:915–22
10. Tezvergil A, Lassila LV, Vallittu PK (2003) Composite-composite repair bond stregth: effect of different adhesion primers. J Dent 31:521–525
11. Hahnel S, Heinrich A, Bürgers R, Handel G, Rosentritt M (2010) Investigation of mechanical properties of modern dental composites after artificial aging for one year. Oper Dent 35–4:412–419
12. Lührs A, Görmann B, Jacker-Guhr S, Guertsen W (2011) Repairability of dental siloranes in vitro. Dental Mater 27:144–149
13. Sideridou T, Achilias DS, Kyrikou E (2004) Thermal expansion characteristics of light-cured dental resins and resin composites. Biomaterials 25:3087–3097
14. Curtis AR, Shortall AC, Marquis PM, Palin WM (2008) Water uptake and strength characteristics of a nano-filled resin-based composite. J Dent 36:186–193
15. Ilie N, Hickel R (2009) Macro-, micro- and nao-mechanical investigations on silorane and methacrylate-based composites. Dent Mater 25:810–819
16. Mjör IA (1993) Repair versus replacement of failed restorations. Int Dent J 43:466–472
17. Tezvergil-Mutluay A, Lassila LVJ, Vallittu PK (2008) Incremental layers bonding of silorane composite: the initial bonding properties. J Dent 36:560–563
18. Brendeke J, Ozcan M (2007) Effect of physicochemical aging conditions on the composite-composite repair bond strength. J Adhes Dent 9:399–406
19. Maneenut C, Sakoolnamarka R, Tyas MJ (2010) The repair potential of resin composite materials. Dent Mater 27:e20–e27
20. Puckett AD, Holder R, O'Hara JW (1991) Strength of posterior composite repairs using different composite/bonding agent combinations. Oper Dent 16:136–140
21. Weinmann W, Thalacker C, Guggenberger R (2005) Siloranes in dental composites. Dent Mater 21:68–74
22. Palin WM, Fleming GJ, Burke FJ, Marquis PM, Randall RC (2005) The influence of short and medium-term water immersion on the hydrolytic stability of novel low-shrink dental composites. Dent Mater 21:852–863
23. Ilie N, Hickel R (2009) Investigations on mechanical behavior of dental composites. Clin Oral Invest 13:427–438
24. Tagtekin DA, Yanikoglu CF, Bozkurt FO, Kologlu B, Sur H (2004) Selected characteristics of an Ormocer and a conventional hybrid resin composite. Dent Mater 20:487–497
25. Loomans BAC, Vivan Cardoso M, Roeters FJM, Opdam NJM, De Munck J, Huysmans MCDNJM, Van Meerbeek B (2011) Is there one optimal repair technique for all composites? Dent Mater 27:701–709
26. Oilo G (1993) Bond strength testing–what does it mean? Int Dent J 43:492–498
27. Boaro LC, Goncalves 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