DENTAL MATERIALS 35 (2019) 1205–1213

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Repair bond strength of resin composite to restorative materials after short- and long-term storage

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ARTICLE INFO

Article history:
Received 28 November 2018
Received in revised form
22 April 2019
Accepted 7 May 2019

Keywords:
Amalgam
Resin composite
Ceramic
Artificial aging
Adhesion

ABSTRACT

Objectives. To investigate short- and long-term bond strength ("repair bond strength"; RBS) of a resin composite to six restorative materials using either a silane and a bonding agent or a universal "one-step self-etch" adhesive system.

Methods. Specimens were produced from an amalgam, a direct resin composite, two indirect resin composites, a hybrid ceramic, and a feldspar ceramic and stored for 3 months in tap water (37 °C). All specimens were then sandblasted (Al_2O_3; 25 µm) and either treated with Monobond Plus and OptiBond FL Adhesive (MP-OFL) or with Scotchbond Universal (SBU). Filtek Z250 was used as "repair composite", and RBS was measured by means of a micro shear bond strength test after 24 h or after 1 year. RBS values ($n = 15$/group) were statistically analyzed ($\alpha = 0.05$).

Results. RBS (MPa; mean values (standard deviations)) after 24 h for MP-OFL: 18.6 (3.2)–23.9 (5.0) and for SBU: 12.5 (4.9)–18.1 (4.6); after 1 year for MP-OFL: 8.9 (4.6)–19.8 (4.3) and for SBU: 5.6 (2.3)–18.8 (3.5). After 24 h, MP-OFL showed significantly higher RBS to the hybrid ceramic and the feldspar ceramic than did SBU ($p \leq 0.0001$) whereas there was no significant difference in RBS for the other four restorative materials. After 1 year, MP-OFL showed significantly higher RBS to the feldspar ceramic than did SBU ($p = 0.043$) whereas there was no significant difference in RBS for the other five restorative materials.

Significance. The use of a silane and a bonding agent seems more versatile for repairing restorations than the use of a universal "one-step self-etch" adhesive system.

1. Introduction

A broad range of restorative materials is available for replacement of tooth substance lost e.g. due to caries. Among these materials are amalgam, resin composites, and ceramics. However, regardless of restorative material, restorations have a limited life span and fail mainly because of marginal gap formation, secondary caries, or fracture of the restoration [1–4].

Basically, there are two treatment options for restorations that show partial failure: 1) complete replacement of the restoration and 2) repair of the restoration. Traditionally, repair

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https://doi.org/10.1016/j.dental.2019.05.008
0109-5641/

Table 1 – Restorative materials used.

Type	Restorative material	Manufacturer	LOT-number
Amalgam	ORALLOY MAGICAP S	Coltène/Whaledent, Altstätten, Switzerland	NE74
Direct resin composite	Filtek Z250	3M ESPE, St. Paul, MN, USA	N780440
Indirect resin composites[a]	Paradigm MZ100	3M ESPE, St. Paul, MN, USA	N543696
	Lava Ultimate	3M ESPE, St. Paul, MN, USA	N366024
Indirect hybrid ceramic[a]	VITA ENAMIC	VITA Zahnfabrik, Bad Säckingen, Germany	100003
Indirect feldspar ceramic[a]	VITABLOCS Mark II	VITA Zahnfabrik, Bad Säckingen, Germany	16390

[a] For CAD/CAM (CEREC, Sirona Dental Systems, Bensheim, Germany).

of restorations has been considered "patchwork dentistry" and consequently, dentists have opted for replacement of partially failed restorations in 50–71% of the cases [5]. According to a recent publication, however, repair of restorations has gained increased acceptance among dentists and is now also being practiced at a rising number of universities [6]. Nevertheless, repair of restorations is still controversially discussed in literature. Whereas some studies have shown similar or even increased life span of repaired restorations compared to replaced ones [7–11], one study showed that additional treatments were more often needed following repairs (7%) than following replacements (5%) [12]. Finally, a consensus recommendation tended toward repair of restorations [13], whereas a systematic review did not reveal any advantages of repaired restorations compared to replaced restorations [14].

Overall, however, repair of a restoration seems an attractive treatment option since repair tends to be less invasive than replacement, minimizing the risk of iatrogenic exposure of the pulp and the risk of damaging adjacent teeth, all in all reducing progression of the "restoration death spiral" [15–17]. Furthermore, repairing of a restoration may be considered more patient-friendly as it is likely to be faster, more cost-effective than replacement, and often does not require local anesthetics [16–18]. Due to favorable esthetic and mechanical properties, resin composite is a highly popular repair material. When repairing restorations with resin composite, a durable bond to the original, restorative material is essential. Several studies recommend sandblasting with aluminum oxide powder and subsequent application of first a silane and then a bonding agent as an effective adhesive pre-treatment [17,19–21]. A simplified pre-treatment consists of sandblasting followed by application of a universal "one-step self-etch" adhesive system already containing a silane. Consequently, the aim of this study was to investigate short- (24 h) and long-term (1 year) bond strength ("repair bond strength") of a resin composite ("repair composite") to six restorative materials (one amalgam, three resin composites (one direct resin composite and two indirect resin composites for CAD/CAM), and two indirect ceramics for CAD/CAM) using either a silane and a bonding agent (Monobond Plus and OptiBond FL Adhesive) or a universal "one-step self-etch" adhesive system (Scotchbond Universal). The study tested the following null hypotheses: 1) there are no differences in repair bond strength between the six restorative materials, 2) there are no differences in repair bond strength between the two pre-treatments, 3) there are no differences between short- and long-term repair bond strength.

2. Materials and methods

2.1. *Embedding of the restorative materials*

For each of the six restorative materials (Table 1), 60 discs or cubes were produced (two pre-treatments per restorative material and per storage duration ($n = 15$ per group)).

For the amalgam, discs of ORALLOY MAGICAP S were produced in a stainless steel mold (diameter: 6 mm, thickness: 3 mm) after 7 s of trituration in a Silamat S5 (Ivoclar Vivadent, Schaan, Liechtenstein). After 15 min, the discs were removed from the mold and stored (24 h, 37 °C, 100% relative humidity) for final hardening. For the direct resin composite, Filtek Z250 was filled in an identical mold as described above and the mold was covered with a Mylar strip (Hawe Stopstrip Straight, KerrHawe, Bioggio, Switzerland). The resin composite was made flush with the mold by use of glass slide and light-cured for 30 s with an LED curing unit (S.P.E.C. 3, Coltène/Whaledent, Altstätten, Switzerland; light power density: 1400 mW/cm^2). After removal of the Mylar strip, the discs were retrieved from the mold and stored (24 h, 37 °C, 100% relative humidity) for post-curing. For the four indirect restorative materials, cubes (8 × 8 × 8 mm) were cut from CAD/CAM-blocks of Paradigm MZ100, Lava Ultimate, VITA ENAMIC, and VITABLOCS Mark II. The discs and cubes were then embedded in cylindrical stainless steel molds with self-curing acrylic resin (Paladur, Heraeus Kulzer; Hanau, Germany). The molds were removed and all specimens were stored for 3 months at 37 °C in tap water for aging.

2.2. *Preparation of specimens for repair bond strength testing*

After storage, the specimens were removed from the tap water, thoroughly air-dried, and the surfaces of the restorative materials were pre-treated as listed in Table 2. Then, a split Teflon mold (inner diameter 1.5 mm ≈ bonding area 1.8 mm^2; height: 2 mm) was clamped onto the pre-treated surface and filled with the repair composite (Filtek Z250, 3 M ESPE; LOT-number: N783261). The repair composite was covered with a Mylar strip (Hawe Stopstrip Straight, KerrHawe) and light-cured for 20 s.

Table 2 – Pre-treatment of restorative materials.

Pre-treatment	
Monobond Plus and OptiBond FL Adhesive	Scotchbond Universal
1) Sandblast with CoJet Prep[a] and Al_2O_3 (25 μm)[b] 2) Water-spray, air-dry 3) Apply self-adhesive tape to define standardized bonding area (ø 2 mm^2) 4) Apply Monobond Plus for 60 s (Ivoclar Vivadent, Schaan, Liechtenstein; LOT-number: V33449) 5) Apply OptiBond FL Adhesive (Kerr, Scafati, Italy; LOT-number: 5839432), gentle air-dry, light-cure for 10 s	1) Sandblast with CoJet Prep[a] and Al_2O_3 (25 μm)[b] 2) Water-spray, air-dry 3) Apply self-adhesive tape to define standardized bonding area (ø 2 mm^2) 4) Rub in Scotchbond Universal for 20 s (3M ESPE, Neuss, Germany; LOT-number: 632635), gentle air-dry, light-cure for 10 s

[a] Sandblasting device: CoJet Prep (3M ESPE, Seefeld, Germany), 3.5 bar/50 psi, working distance ~3 cm.
[b] Aluminum oxide powder: Cobra 25 μm (Renfert, Hilzingen, Germany; stock number: 15941105).

Light-curing was performed with an LED curing unit (Demi, Kerr, Middleton, WI, USA; light power density: 1500 mW/cm^2). After light-curing, the specimens were placed in lightproof boxes to avoid any additional influence of ambient light on the polymerization process. Five minutes after completion of light-curing, and at room temperature, the Teflon mold was removed. All specimens were then returned to the lightproof boxes and kept at 37 °C and 100% humidity. Repair bond strength (RBS) was determined by means of a micro shear bond strength test. Whereas half of the specimens were subjected to RBS testing after 24 h, the other half was transferred to lightproof boxes filled with tap water and stored for 1 year until RBS testing.

2.3. *RBS testing and failure mode determination*

The RBS testing was performed by use of a wire (stainless steel, diameter 0.6 mm) at a crosshead speed of 1 mm/min in a universal testing machine (Zwick Z1.0 TN, Zwick, Ulm, Germany). The maximum force (F_{max} (N)) was recorded and the RBS values (MPa) were calculated (F_{max} (N)/bonding area (mm^2)) resulting in 15 RBS values per group for statistical analysis. After RBS testing, the failure mode of each specimen was determined under a stereomicroscope (Leica ZOOM 2000, Leica; Buffalo, NY, USA) at 30× magnification and classified as: 1) cohesive failure in restorative material, 2) adhesive failure between restorative material and bonding agent, 3) adhesive failure between bonding agent and repair composite, 4) cohesive failure in repair composite, or 5) mixed failure (combinations of failure modes 1–4).

2.4. *Statistical analysis*

A Shapiro-Wilk's test showed that the RBS values were normally distributed ($p = 0.0529$) and thus, RBS values were analyzed with a parametric ANOVA to test for significance of the factors “restorative material”, “pre-treatment”, and “storage duration” as well as for significance of their interactions. For post-hoc tests, two-sample Student's t tests were performed and all *p*-values were corrected with Bonferroni-Holm adjustment for multiple testing. The significance level was set at $\alpha = 0.05$. All statistical analysis was performed with R 3.3.3 (The R Project for Statistical Computing, Vienna, Austria; www.R-project.org). Failure modes after RBS testing were analyzed descriptively.

3. Results

After 24 h, the RBS values between the repair composite and the six restorative materials ranged from (mean values (standard deviations)) 18.6 (3.2) to 23.9 (5.0) MPa for Monobond Plus and OptiBond FL Adhesive and from 12.5 (4.9) to 18.1 (4.6) MPa for Scotchbond Universal. After 1 year, the RBS values ranged from 8.9 (4.6) to 19.8 (4.3) MPa for Monobond Plus and OptiBond FL Adhesive and from 5.6 (2.3) to 18.8 (3.5) MPa for Scotchbond Universal. RBS for the six restorative materials is shown in Fig. 1 (pre-treatment with Monobond Plus and OptiBond FL) and Fig. 2 (pre-treatment with Scotchbond Universal). RBS for the two pre-treatments and a given restorative material is shown in Fig. 3.

The parametric ANOVA found a significant effect of each of the factors “restorative material”, “pre-treatment”, and “storage duration” (all $p < 0.0001$) as well as significant interactions between the two factors “restorative material” and “pre-treatment”, “restorative material” and “storage duration”, and “pre-treatment” and “storage duration” (all $p < 0.0001$). There was no significant interaction between all three factors ($p = 0.387$).

3.1. *Restorative material*

Regarding the effect of restorative material, the post-hoc tests found the short-term RBS to ORALLOY MAGICAP S to be significantly lower than the RBS to VITA ENAMIC when Monobond Plus and OptiBond FL Adhesive had been used as pre-treatment ($p = 0.008$) (Fig. 1). There were no other significant differences in short-term RBS among the six restorative materials. When Scotchbond Universal had been used as pre-treatment, significantly lower short-term RBS was achieved to VITABLOCS Mark II than to the other five restorative materials ($p \leq 0.025$) (Fig. 2). There were no other significant differences in short-term RBS among the restorative materials. After long-term storage and following pre-treatment with Monobond Plus and OptiBond FL Adhesive, the post-hoc tests found significantly lower RBS to VITABLOCS Mark II than to any of the other five restorative materials ($p \leq 0.043$) (Fig. 1). RBS

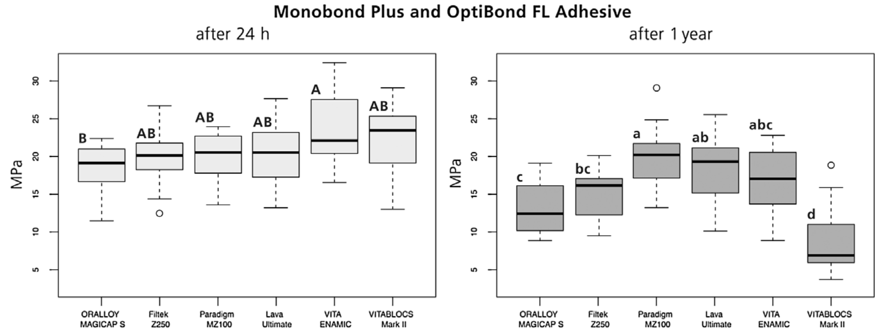

Fig. 1 – Repair bond strength (MPa; medians, lower and upper quartiles as well as minima and maxima) for the six restorative materials after pre-treatment with Monobond Plus and OptiBond FL. Different upper case letters indicate statistically significant differences after 24 h. Different lower case letters indicate statistically significant differences after 1 year.

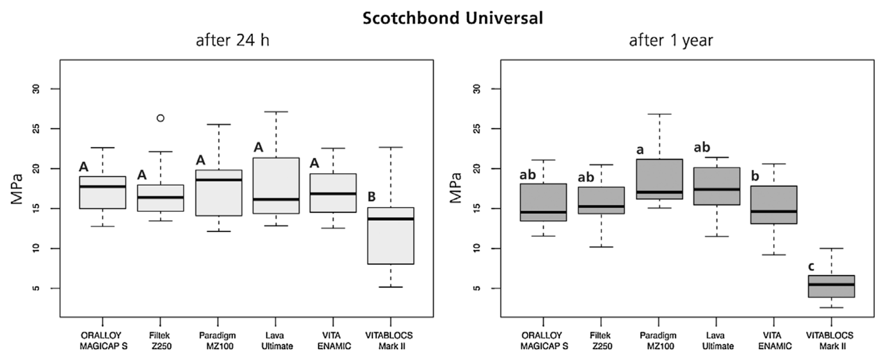

Fig. 2 – Repair bond strength (MPa; medians, lower and upper quartiles as well as minima and maxima) for the six restorative materials after pre-treatment with Scotchbond Universal. Different upper case letters indicate statistically significant differences after 24 h. Different lower case letters indicate statistically significant differences after 1 year.

was significantly lower to ORALLOY MAGICAP S and Filtek Z250 than to Paradigm MZ100 ($p \leq 0.011$), and RBS to ORALLOY MAGICAP S was also significantly lower than the RBS to Lava Ultimate ($p = 0.007$). There was no significant difference in RBS to Paradigm MZ100, Lava Ultimate, and VITA ENAMIC and there was also no significant difference in RBS between ORALLOY MAGICAP S, Filtek Z250, and VITA ENAMIC. Finally, there was no significant difference in RBS between Filtek Z250, Lava Ultimate, and VITA ENAMIC. When Scotchbond Universal had been used as pre-treatment, significantly lower long-term RBS was achieved to VITABLOCS Mark II than to any of the other five restorative materials ($p < 0.0001$) (Fig. 2), and the RBS to VITA ENAMIC was significantly lower than to Paradigm MZ100 ($p = 0.023$). There were no other significant differences in long-term RBS among the restorative materials.

3.2. *Pre-treatment*

Regarding the effect of pre-treatment, the post-hoc tests found Monobond Plus and OptiBond FL Adhesive to yield significantly higher short-term RBS to VITA ENAMIC and to VITABLOCS Mark II than did Scotchbond Universal ($p \leq 0.0001$), whereas there was no significant difference in short-term RBS between the two pre-treatments for the other four restorative materials (Fig. 3). Monobond Plus and OptiBond FL also resulted in significantly higher long-term RBS to VITABLOCS Mark II than did Scotchbond Universal ($p = 0.043$), whereas there was no significant difference in long-term RBS between the two pre-treatments for the other five restorative materials.

3.3. *Storage duration*

Regarding the effect of storage duration and following pre-treatment with Monobond Plus and OptiBond FL Adhesive, the post-hoc tests found significantly lower RBS to ORALLOY MAGICAP S, Filtek Z250, VITA ENAMIC, and VITABLOCS Mark II after 1 year storage than after 24 h ($p \leq 0.001$) (Fig. 3). In contrast, there was no significant difference between short- and long-term RBS to Paradigm MZ100 and to Lava Ultimate. When Scotchbond Universal had been used as pre-treatment, RBS only deteriorated significantly for one out of the six restorative materials. Thus, RBS to VITABLOCS Mark II was significantly lower after 1 year storage than after 24 h ($p < 0.0001$), while for the other five restorative materials there was no significant difference between short- and long-term RBS.

3.4. *Failure modes*

The distribution of failure modes after short-term RBS testing is shown in Table 3 and Fig. 4 shows representative areas of the

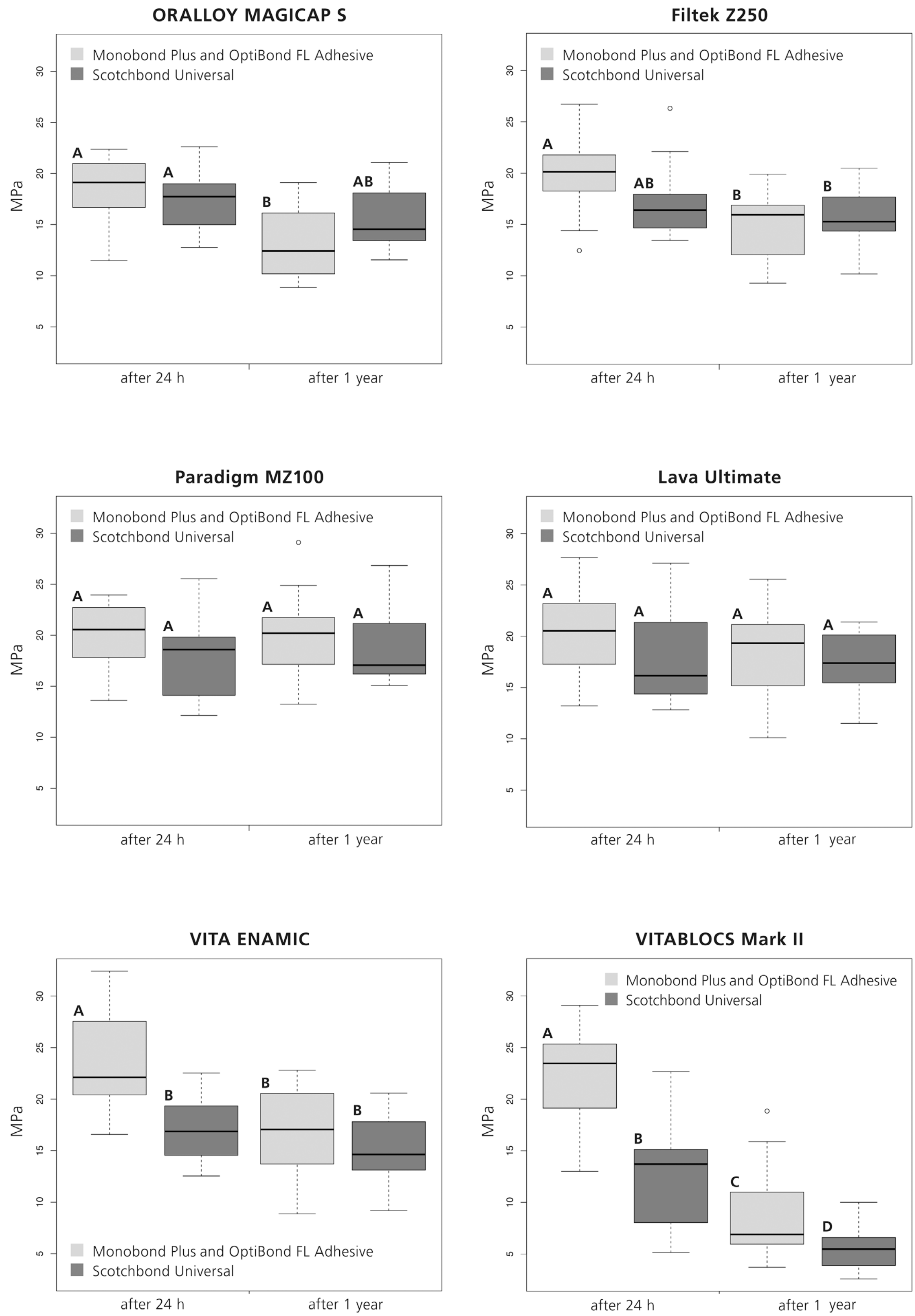

Fig. 3 – Repair bond strength (MPa; medians, lower and upper quartiles as well as minima and maxima) for the two pre-treatments (i.e. Monobond Plus and OptiBond FL or Scotchbond Universal) and a given restorative material. Different upper case letters indicate statistically significant differences between the two pre-treatments.

Table 3 – Distribution of failure modes after short-term RBS testing (24 h; $n = 15$/group).

	1) Cohesive failure in restorative material (%)	2) Adhesive failure between restorative material and bonding agent (%)	3) Adhesive failure between bonding agent and repair composite (%)	4) Cohesive failure in repair composite (%)	5) Mixed failure (%)
Monobond Plus and OptiBond FL Adhesive					
ORALLOY MAGICAP S	0	100	0	0	0
Filtek Z250	46.7	6.7	6.7	0	40
Paradigm MZ100	46.7	6.7	0	0	46.7
Lava Ultimate	26.7	46.7	0	0	26.7
VITA ENAMIC	60	0	6.7	6.7	26.7
VITABLOCS Mark II	26.7	13.3	0	13.3	46.7
Scotchbond Universal					
ORALLOY MAGICAP S	20	66.7	0	0	13.3
Filtek Z250	40	13.3	0	6.7	40
Paradigm MZ100	40	6.7	0	0	53.3
Lava Ultimate	46.7	0	6.7	0	46.7
VITA ENAMIC	60	20	0	0	20
VITABLOCS Mark II	6.7	86.7	0	0	6.7

Table 4 – Distribution of failure modes after long-term RBS testing (1 year; $n = 15$/group).

	1) Cohesive failure in restorative material (%)	2) Adhesive failure between restorative material and bonding agent (%)	3) Adhesive failure between bonding agent and repair composite (%)	4) Cohesive failure in repair composite (%)	5) Mixed failure (%)
Monobond Plus and OptiBond FL Adhesive					
ORALLOY MAGICAP S	0	53.3	13.3	6.7	26.7
Filtek Z250	26.7	6.7	6.7	33.3	26.7
Paradigm MZ100	46.7	0	13.3	0	40
Lava Ultimate	20	33.3	0	6.7	40
VITA ENAMIC	0	46.7	26.7	6.7	20
VITABLOCS Mark II	0	86.7	6.7	0	6.7
Scotchbond Universal					
ORALLOY MAGICAP S	0	33.3	0	20	46.7
Filtek Z250	33.3	0	13.3	13.3	40
Paradigm MZ100	73.3	6.7	0	0	20
Lava Ultimate	73.3	0	0	6.7	20
VITA ENAMIC	6.7	20	26.7	0	46.7
VITABLOCS Mark II	0	100	0	0	0

five failure modes by means of scanning electron micrographs. The failure mode varied depending on the restorative material, the pre-treatment, and the storage duration. For ORALLOY MAGICAP S and both pre-treatments, the predominant failure mode was adhesive failure between restorative material and bonding agent. For Filtek Z250 and for Paradigm MZ100, and again for both pre-treatments, the two predominant failure modes were cohesive failure in the restorative material and mixed failure. For Lava Ultimate and the Monobond Plus and OptiBond FL Adhesive pre-treatment, the predominant failure mode was adhesive failure between restorative material and bonding agent. When Scotchbond Universal had been used as pre-treatment, the two predominant failure modes were cohesive failure in restorative material and mixed failure. For VITA ENAMIC and both pre-treatments, the predominant failure mode was cohesive failure in restorative material. Finally, for VITABLOCS Mark II the predominant failure mode following pre-treatment with Monobond Plus and OptiBond FL Adhesive was mixed failure, whereas adhesive failure between restorative material and bonding agent was the predominant failure mode following pre-treatment with Scotchbond Universal.

The distribution of failure modes after long-term RBS testing is shown in Table 4. For ORALLOY MAGICAP S and the Monobond Plus and OptiBond FL Adhesive pre-treatment, the predominant failure mode was adhesive failure between restorative material and bonding agent. When Scotchbond Universal had been used as pre-treatment, the predominant failure mode was mixed failure. For Filtek Z250 and the Monobond Plus and OptiBond FL Adhesive pre-treatment, there were three predominant failure modes: cohesive failure in restorative material, cohesive failure in repair composite, and mixed failure. When Scotchbond Universal had been used, cohesive failure in restorative material and mixed failure were the two predominant failure modes. For Paradigm MZ100 and both pre-treatments, mainly cohesive failure in restorative material was observed. For Lava Ultimate and with the Monobond Plus and OptiBond FL Adhesive pre-treatment, the two predominant failure modes were adhesive failure between restorative material and bonding agent and mixed failure. When Scotchbond Universal had been used, the predominant failure mode was cohesive failure in restorative material. For VITA ENAMIC and the Monobond Plus and OptiBond FL Adhesive pre-treatment, the predominant failure mode was adhesive failure between restorative material and bonding agent. When Scotchbond Universal had been used, the predominant failure mode was mixed failure. Finally, for VITABLOCS Mark II and for both pre-treatments, the predominant failure mode was adhesive failure between restorative material and bonding agent.

4. Discussion

The present study investigated short- and long-term bond strength of a resin composite to various restorative materials pre-treated by sandblasting with aluminum oxide powder followed either by application of Monobond Plus and OptiBond FL Adhesive or of Scotchbond Universal.

Regarding the restorative material, significant differences in repair bond strength were found and thus, the first null hypothesis (that there are no differences in repair bond strength between the six restorative materials) cannot be accepted. However, when Monobond Plus and OptiBond FL Adhesive had been used as pre-treatment (Fig. 1), all restorative materials (with the exception of ORALLOY MAGICAP S versus VITA ENAMIC) achieved similar repair bond strength values after 24 h, indicating that a pre-treatment with a silane and a bonding agent after sandblasting with aluminum oxide powder can promote a bond to restorative materials as diverse as amalgam, resin composite, and ceramic. However, it is noteworthy that the two ceramic materials showed the same repairability as the other four restorative materials despite the fact that both manufacturers recommend pre-treatment with hydrofluoric acid instead of sandblasting. A previous study reported that pre-treatment of VITA ENAMIC with hydrofluoric acid led to higher bond strength than did pre-treatment with sandblasting [22], which suggests that substituting sandblasting with hydrofluorid acid etching in the present study might have resulted in higher repair bond strength to VITA ENAMIC and VITABLOCS Mark II. Considering that the hydrofluoric acid VITA CERAMICS ETCH recommended by the manufacturer is not approved for intraoral use and that repair of a restoration with resin composite inevitably takes place intraorally, sandblasting with aluminum oxide powder is a viable alternative to pre-treatment with hydrofluoric acid.

When Scotchbond Universal had been used as pre-treatment (Fig. 2), all restorative materials except VITABLOCS Mark II achieved similar repair bond strength values after 24 h. Consequently, the silane integrated in Scotchbond Universal seems to be equally efficient on amalgam as on the composite-based restorative materials and VITA ENAMIC. Interestingly,

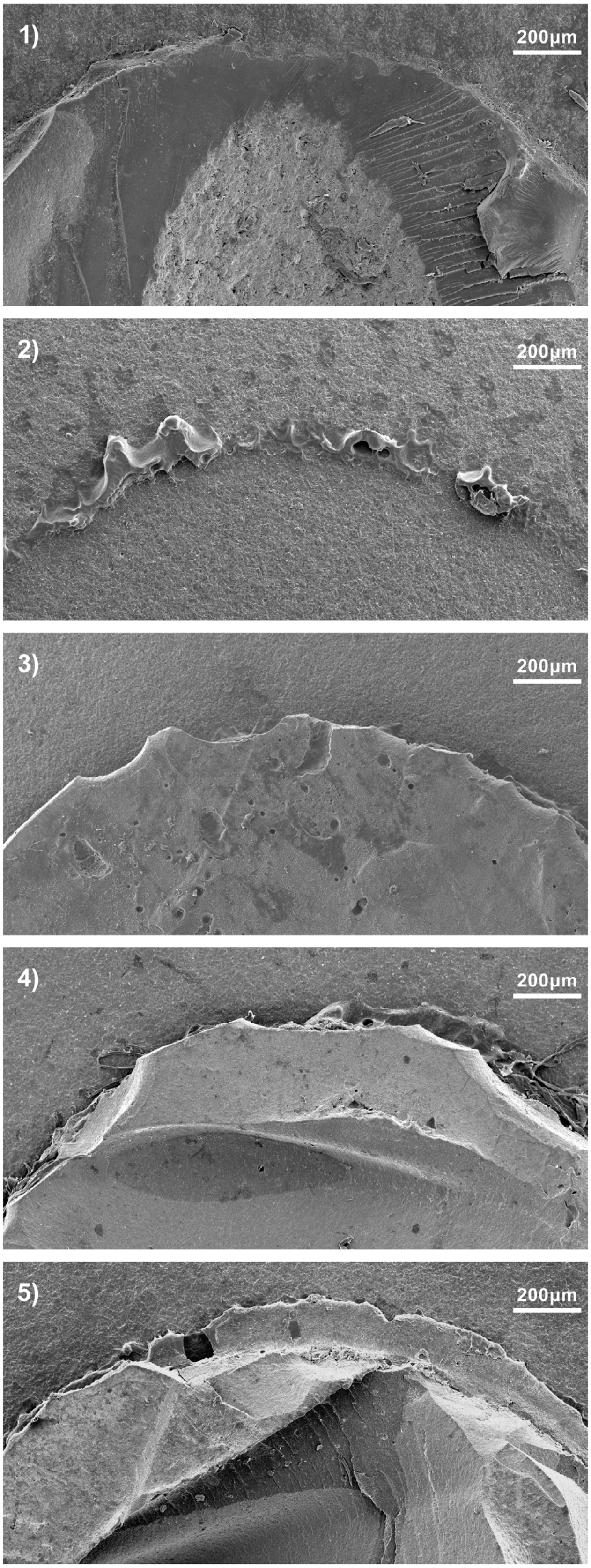

Fig. 4 – Scanning electron micrographs showing representative areas of the five failure modes: 1) cohesive failure in restorative material, 2) adhesive failure between restorative material and bonding agent, 3) adhesive failure between bonding agent and repair composite, 4) cohesive failure in repair composite, 5) mixed failure. Gold-palladium sputter coating (100 s, 50 mA; Balzers SCD 050, Balzers, Liechtenstein), 75× magnification (JEOL JSM6010PLUS/LV, JEOL, Tokyo, Japan).

and in contrast to Monobond Plus and OptiBond FL Adhesive, pre-treatment with Scotchbond Universal resulted in cohesive failure in ORALLOY MAGICAP S (Table 3). This implies that the bond of Scotchbond Universal to the amalgam was stronger than the bond within the amalgam itself. One reason for the significantly lower repair bond strength of VITABLOCS Mark II could be too low a concentration of the silane integrated in Scotchbond Universal for the silane to be effective on feldspar ceramics. This explanation is supported by a study of Yoshihara et al., who showed that adding additional silane to Scotchbond Universal significantly increased bond strength to a glass ceramic-like material [23]. As previously discussed, pre-treating VITABLOCS Mark II with hydrofluoric acid prior to application of Scotchbond Universal might have increased the bond strength.

After 1 year storage and when Monobond Plus and OptiBond FL Adhesive had been used as pre-treatment (Fig. 1), Paradigm MZ100 and Lava Ultimate generally achieved higher repair bond strength than did the other four restorative materials. Thus, Paradigm MZ100 yielded significantly higher repair bond strength than did Filtek Z250, although Paradigm MZ100 is manufactured and polymerized under industrial conditions and therefore may be assumed to have a lower content of residual monomer available for co-polymerization and consequently reduced bonding capacity. Compared to the other five restorative materials, VITABLOCS Mark II achieved significantly lower repair bond strength indicating that the repairability of this restorative material may be poorer. Again, it is possible that pre-treatment with hydrofluoric acid would have increased the bond strength to VITA ENAMIC and VITABLOCS Mark II.

After 1 year storage and when Scotchbond Universal had been used as pre-treatment (Fig. 2), all restorative materials except VITABLOCS Mark II achieved similar repair bond strength values. As mentioned previously, it is possible that pre-treatment with hydrofluoric acid and/or an increase in the silane concentration of Scotchbond Universal might have improved the bond strength [22].

Regarding the pre-treatment, significant differences in repair bond strength was found and thus, the second null hypothesis (that there are no differences in repair bond strength between the two pre-treatments) cannot be accepted. Nevertheless, the two pre-treatments resulted in similar bond strength for four of the six restorative materials following 24 h storage and for five of the six restorative materials following 1 year storage (Fig. 3). After 24 h storage, Monobond Plus and OptiBond FL Adhesive resulted in significantly higher repair bond strength to VITA ENAMIC and VITABLOCS Mark II than did Scotchbond Universal whereas after 1 year storage, Monobond Plus and OptiBond FL Adhesive showed significantly higher repair bond strength only to VITABLOCS Mark II. The higher short- and long-term repair bond strength of Monobond Plus and OptiBond FL Adhesive to these ceramic-based restorative materials may be related to the difference in interaction time of the silanes between the two pre-treatments. Thus, Monobond Plus was applied to the restorative material and left to interact for 60 s prior to the application of OptiBond FL Adhesive. In contrast, Scotchbond Universal was applied and rubbed in for only 20 s resulting in an interaction time of the integrated silane of one third of that of Monobond Plus.

Finally, regarding the storage duration, significant differences in repair bond strength were found and thus, the third null hypothesis (that there are no differences between short- and long-term repair bond strength) cannot be accepted. When Monobond Plus and OptiBond FL Adhesive had been used as pre-treatment (Fig. 1), repair bond strength to four of the six restorative materials had deteriorated during the 1 year storage, more so for the ceramic-based restorative materials VITA ENAMIC and VITABLOCS Mark II, which was also reflected in a high frequency of adhesive failures between restorative material and bonding agent (Table 4). When Scotchbond Universal had been used as pre-treatment the repair bond strength deteriorated only for VITABLOCS Mark II (Fig. 2). For the remaining five restorative materials, pre-treatment with Scotchbond Universal provided a more constant repair bond strength than did Monobond Plus and OptiBond FL Adhesive. However, it should be borne in mind that, regardless of storage duration, pre-treatment with Scotchbond Universal resulted in lower repair bond strength to the ceramic-based restorative materials.

5. Conclusions

Most restorative materials used nowadays are tooth-colored. This means that in the clinical setting and with the exception of amalgam, the type and/or brand of a restorative material to be repaired in many cases cannot be determined. Consequently, when repairing restorations it seems advisable to use a silane (e.g. Monobond Plus) followed by a bonding agent (e.g. OptiBond FL Adhesive) after sandblasting with aluminum oxide powder. A universal “one-step self-etch” adhesive system with an integrated silane (e.g. Scotchbond Universal) should be used with caution, as the universal adhesive system showed significantly lower repair bond strength to two of six restorative materials when determined after 24 h and significantly lower repair bond strength to one of six restorative materials when determined after 1 year.

Acknowledgments

The authors would like to thank all companies for providing the materials needed. Furthermore, we thank G. Fischer (www.significantis.ch; former assistant at the Institute of Mathematical Statistics and Actuarial Science, University of Bern) for the statistical analysis.

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