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Efficiency of different repair kits on bonding to aged dental resin composite substrates

Short title: Efficiency of repair kits

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Abstract

Objective: To assess the efficiency of intraoral repair kits on the tensile bond strength (TBS) of resin composites (RCs) to aged RC substrates.

Methods: 840 aged (six months, 37°C, distilled water) RC substrates (Tetric EvoCeram) were air-abraded (CoJet) with and without following phosphoric acid contamination or treated with silicon carbide (SiC) grinding paper. Seven repair kits were used as intermediate agents (Embrace First-Coat, CLEARFIL CERAMIC PRIMER, Tokuso Ceramic Primer, Monobond Plus+Heliobond; Scotchbond Universal, One Coat Bond and visio.link) for conditioning. Specimens were repaired using two direct RCs (Clearfil Majesty ES2 and Clearfil Majesty Posterior), stored in distilled water (37°C, 24h) and thermal aged (5°C/55°C, 10,000 cycles). The cohesive strength of the repair RCs (N=40) served as control and was determined by applying the RCs on the fresh polymerized substrates, followed by thermal-aging procedure. TBS and failure types were determined and evaluated with three-/one-way ANOVA, and chi-square test ($p<0.05$).

Results: The highest influence on the TBS was exerted by the intermediate agent (repair kit) (partial eta squared $\eta_P^2 = 0.320$, $p<0.001$), while the impacts of the repair RC ($\eta_P^2 = 0.017$, $p<0.001$) and surface pre-treatment ($\eta_P^2 = 0.015$, $p=0.003$) were significant but low. Except for Embrace First Coat and Tokuso Ceramic Primer, phosphoric acid contamination after air-abrasion maintains the TBS.

Conclusions: Air-abrasion induced superior TBS compared with grinding the surface with SiC paper prior to repair. Tested universal adhesives as well as the combination between a universal primer and an adhesive were in-vitro efficient intermediate agents for repairing aged RCs.

1. Introduction

Recent systematical reviews on the longevity of posterior resin composite (RC) restorations confirm that secondary caries and fracture are typically failures that appear after a longer time of service [1]. Restoration repair rather than replacement is a valuable treatment modality [2] that is in agreement with the concepts of minimal invasive dentistry [3] which is taught in most universities [4]. Restoration repair is more economical to the patient in terms of treatment time-saving and reduces tooth structure loss to the bur [5] compared with replacement and the fabrication of new restorations. *In-vivo* studies have also shown that restoration repair results in a higher survival probability than restorations replacement [6].

In repairing RC restorations, the surface pre-treatment and the intermediate agent were proved to be significant factors of influence on the repair bond strength [4]. However, it is not compulsory to combine identical RCs in terms of repair [7, 8]. Particularly challenging, but of high clinical relevance, is the repair of aged RC substrates. In-vitro studies generally indicate inferior repair bond strength of aged RC substrates compared with the cohesive strength of the original RCs [9, 10], a fact attributed to the increased water sorption and saturation of the aged material.

The clinical procedure for repairing resin restoration usually implies a surface pre-treatment method to create mechanical retention by means of roughening with diamond burrs, or air-abrasion of the surface, followed by cleaning the surface with phosphoric acid and the use of silane and adhesives as intermediate agents previously to bonding to RC [4, 11]. Different universal repair kits are available on the market, questioning their efficiency in repairing RC restorations as well. Moreover, universal adhesive systems were recently launched on the market, with fewer steps and less chances of error in the application process. Their chemical composition includes - in addition to methacrylic monomers - silane or phosphate monomers, allowing them to prime metal, silica-based ceramics, and zirconia restorations.

The aim of this study was therefore to analyze the efficiency of repairing aged RC substrates by using different surface pre-treatment and conditioning methods and different RCs as repair material. Since a contamination of the air-abraded surface with phosphoric acid might occur clinically during a restoration procedure, the study aims to simulate these conditions and to determine their impact on repair efficiency.

The null-hypotheses tested were that (1) the pre-treatment method (air-abrasion, air-abrasion with phosphoric acid contamination and grinding with silicon carbide [SiC]-paper); (2) the conditioning method (comprising of seven different repair kits) and (3) the repair RC shows no impact on the tensile bond strength (TBS) to aged RC substrates.

2. Material and Methods

This study analyzed the TBS of aged RC substrates (Tetric Evo Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) in combination with different methods of conditioning for repair with two different RCs (CLEARFIL MAJESTY ES 2 and CLEARFIL MAJESTY Posterior, Kuraray, Japan). The compositions and batch number of all tested materials are shown in Table 1.

2.1 Specimen preparation

A total of 840 substrates were prepared by filling the composite with a plastic filling instrument into a shaped cavity (2 mm in depth, 6 mm in diameter) of an acrylic cylinder (ScandiQuick, ScanDia, Hagen, Germany; Lot.No: 542125/142125) surrounded by a stainless steel cylinder. The specimens were cured with the LED-curing device Elipar S10 (3M ESPE, Seefeld, Germany) for 20 s with a light intensity of 1,200 mW/cm^2. Surfaces were polished during water-cooling with a series of SiC papers up to SiC P2400 (Tegramin-20, Struers). Thereafter, all polished surfaces were aged for six months in distilled water at 37°C while the storage media was changed weekly.

The specimens were then randomly divided into three pre-treatment methods (n=280): (1) CoJet air-abrasion (3M ESPE), (2) CoJet air-abrasion followed by phosphoric acid contamination and (3) grinding with SiC paper (Gritt 400, LECO). For air-abrasion with CoJet, silicatized sand (30 µm, Lot.No. 516365) was applied for 10 s at a distance of 10 mm from the specimen's surface and a pressure of 3 bars. Thereafter, specimens were cleaned with distilled water for 30 s. The phosphoric acid (34%, 3M ESPE, Seefeld, Germany, Lot.No. 520594) contamination was simulated by acid application for 30 s followed by cleaning with distilled water for 30 s.

Thereafter, the specimens were randomly divided into seven main groups for different conditioning methods (n=40), as follows: (1) Embrace First Coat, (2) CLEARFIL CERAMIC PRIMER, (3) Tokuso Ceramic Primer included in the Bistite II DC kit, (4) Ceramic Repair System Kit: Monobond Plus + Heliobond, (5) Scotchbond Universal, (6) One Coat Bond; and 7) visio.link.

The application steps are described in Table 1. Subsequently, the conditioned specimens were repaired using two different RCs (CLEARFIL MAJESTY ES 2 and CLEARFIL MAJESTY Posterior, n = 20 per RC). The specimens were positioned into a holding device and an acrylic cylinder (SD Mechatronik, Feldkirchen-Westerham, Germany) with an inner diameter of 2.9 mm and a height of 4.5 mm for repairing, which was fixed on the conditioned RC surface, filled with RC and axially loaded with 100 g. Light polymerization was performed with the same LED-curing device as the substrates, with three sequences of 20 s each, by applying the curing unit perpendicular directly onto the acrylic cylinder from three directions. Subsequently, the specimens were stored for 24 h at 37°C in distilled water to allow for post-polymerization and then additionally aged for 10,000 thermal cycles between 5°C and 55°C with a dwelling time of 20 s (Thermocycler THE-1100, SD Mechatronik). The cohesive strength of the three RCs was used as control. Therefore, substrates were prepared as described above in a shaped cavity (2 mm in depth, 6 mm in diameter) of an acrylic cylinder, followed by an immediate (directly after polymerization) application of the same repair material. Specimens were thereafter stored and aged as the repaired specimens.

2.2 Tensile bond strength measurement

The Universal Testing Machine (MCE 2000 ST, Quicktest, Langenfeld, Germany) was used for tensile strength measurements by positioning the specimens in a special device that provided a moment-free axial force application. A collet held the acrylic cylinder, while an alignment jig allowed for the self-centering of the specimen. The device was attached to the load cell and pulled apart by the upper and lower chain, allowing the whole system to be self-aligned. The specimens were loaded at a crosshead speed of 5 mm/min until debonding of the cylinders occurred. Values were recorded at the time of the debonding of the cylinders. Bond strength was expressed by dividing the force by the bonded surface area.

2.3 Fracture analysis

The fracture pattern was determined by analyzing the specimens under a stereomicroscope (Axioskop 2MAT, Carl Zeiss Microscopy, LLC, Thornwood, NY, US). The fracture mechanism was divided into three different types: (1) adhesive, when the failure occurred in the interface between the substrate and the repair RC; (2) cohesive, when the failure was in the substrate ore repair RC; and (3) mixed. Fractures occurring during the thermal aging process were recorded as pre-failures and considered as 0 MPa.

2.4 Statistical analysis

The measured data were analyzed using descriptive statistics such as mean and standard deviation. Normality of data distribution was tested using the Shapiro-Wilk test. Three- and one-way ANOVA followed by the Scheffé post-hoc test were computed to determine the significant differences among the pre-treatment or conditioning method groups. The impact of RC type was calculated using an unpaired two-sample t-test. The effect strength of the parameters intermediate agent, surface pre-treatment and repair RC on the TBS was assessed in a multivariate analysis (general linear model with partial eta-squared statistics). Relative frequencies of failure types were provided. A chi-square test was used to detect differences in frequencies of failure types in different groups. The statistical tests were performed with SPSS Version 21.0 (SPSS INC, Chicago, IL, US). P values smaller than 0.05 were considered statistically significant in all tests.

3. Results

3.1 Tensile bond strength measurement

The highest influence on the TBS was exerted by the intermediate agent (repair kit) (partial eta squared $\eta_P^2 = 0.320$, $p<0.001$), while the impacts of the repair RC ($\eta_P^2 = 0.017$, $p<0.001$) and surface pre-treatment ($\eta_P^2 = 0.015$, $p=0.03$) were significant but very low. The effects of the binary and ternary combinations of the three parameters were significant for all combinations except for surface pre-treatment method coupled with repair RC ($p = 0.065$).

With regard to the intermediate agent, the significantly lowest TBS was achieved when Embrace First Coat was used, followed by the group of Tokuso Ceramic Primer and CLEARFIL CERAMIC PRIMER, while the significantly highest TBS were achieved when repairing with One Coat Bond, Scotchbond Universal, Monobond Plus + Heliobond, or visio.link.

In terms of RC used to repair the substrates, slightly but significantly higher TBS values were obtained when CLEARFIL MAJESTY ES 2 was chosen as repair RC ($p<0.001$).

As for the three used surface pre-treatment methods, the air-abrasion with CoJet induced significantly higher TBS compared with CoJet treatment with phosphoric acid contamination ($p = 0.014$) or grinding the surface with SiC paper ($p = 0.01$), while no significant differences were found between the last two mentioned pre-treatment methods ($p = 0.99$).

The three-way ANOVA interactions between the effects were significant ($p= 0.018$). Therefore, the fixed effects of surface pre-treatment, intermediate agent and RCs cannot be compared directly as the higher order interactions between them were found to be significant. Consequently, several different analyses were computed and divided by levels of surface pre-treatment, as well as the use of intermediate agent and RCs, depending on the hypothesis of interest. The results of the descriptive statistics (mean, SD) with one-way ANOVA and unpaired t-test results for the TBS of each tested group are presented in Table 2.

Considering the repair kits individually, no impact of both, repair RC and pre-treatment method was observed for Monobond Plus + Heliobond (p=0.675 for repair RC and p=0.674 for the pre-treatment method) and visio.link (p=0.905 and 0.150, respectively). The pre-treatment had no impact (p=0.217), but a significant impact of the repair RC was observed for Scotchbond Universal (η_P^2=0.061, p=0.009; CM-ES2 induced higher TBS compared to CMP). The repair RC had no impact, but a significant impact of the pre-treatment method was observed for following intermediate agents: CLEARFIL CERAMIC PRIMER (p=0.10 for the repair RC and η_P^2=0.105, p=0.002 for the pre-treatment method, while CoJet & Phosphoric acid and CoJet induced similar TBS (p=0.213), both higher than SiC-Paper treatment (p=0.024 and p=0.001)), Tokuso Ceramic Primer (p=0.066 and η_P^2 = 0.076, p=0.017; CoJet & Phosphoric acid and CoJet induced significant similar TBS (p=0.33) and higher than SiC-Paper (p=0.081 and p=0.005)) and One Coat Bond (p=0.142 and η_P^2=0.064, p=0.032; SiC-Paper treatment induced significant similar TBS to CoJet (p=0.24) and higher than CoJet & Phosphoric acid treatment (p=0.009); both Phosphoric acid treatment were similar (p=0.147)). As for Embrace First Coat, the repair RC shows a higher impact on the TBS (η_P^2=0.239, p<0.001, CM-ES2 induced higher TBS compared to CMP) compared with the pre-treatment method (η_P^2=0.133, p<0.001; CoJet induced higher TBS compared to CoJet & Phosphoric acid (p<0.001) and SiC-Paper(p=0.003), while the last two treatment are equivalent (p=0.348), while the significantly highest TBS was achieved by treating the surface with CoJet and repairing with CLEARFILMAJESTY ES2. All other combinations were statistically significantly lower.

There was no significant difference among the cohesive strength of both repair RC (p=0.182). The cohesive strength of the repair material was reached only in three repair combinations: (1) visio.link + CLEARFIL MAJESTY Posterior+ SiC-Paper, (2) Visio.link + CLEARFIL MAJESTY ES2 + CoJet with Phosphoric acid contamination and (3) Monobond Plus + Heliobond + CLEARFIL MAJESTY Posterior + CoJet. All other repair methods induced lower TBS than the cohesive strength of the repair material.

3.2 Failure types

The predominant type of failure was adhesive (46.2%), followed by cohesive (39.2%), while mixed (6.1%) or pre-failure (3.1%) was rarely observed. The frequencies of the failure types within one surface pre-treatment method or repair composite are shown as percentages in Table 3. According to the chi-square test, significantly different failure types between the pre-treatment methods or repair RC were observed (p<0.001), while for the intermediate agent, this was valid only in a few situations: Tokuso Ceramic Primer with both repair RC and CLEARFIL CERAMIC PRIMER combined with CLEARFIL MAJESTY ES 2.

4. Discussion

Thermal fluctuations, saliva and food with varying acidities, as well as the impact and abrasive forces of occlusion and mastication induce degenerative changes not only in teeth but also in restorative materials [12]. Therefore, repair of restorations aiming to preserve tooth structure has become more and more popular [4]. Yet the repair strength of RC restoration has been reported as only 19%–52% [13], 25%–50% [14], 41%–62% [15, 16], or 67%–82% [17] of the cohesive strength of the original RC, depending on the surface treatment and testing method. Therefore, reliable clinical surface pre-treatment methods and efficient intermediate agents for repair are in focus. Moreover, it must be taken into account that during the repair of an RC restoration, the prepared cavity usually exposes enamel and dentin. For that reason, a conditioning of the tooth structure with phosphoric acid might be required, also contaminating the pre-treated RC surface.

There is no standardized method or period of time for aging RCs previous to the repair process. Several methods are proposed such as the immersion in deionized water for one week (37 degrees C) [18], 9 days [19], one month (60°C) [20], two months [18, 21], 6 months [22], one year [23, 24], immersion in citric acid for one week [18, 22], boiling in water (8 h) [18], thermocycling (5,000 times, 5 degrees C to 55 degrees C) [18, 21], 6 years in 1% NaCl solution [25] or an in-vitro exposure to oral biofilm [26]. Aging the composite substrates through water storage for at least two months was shown to produce significantly lower bond strengths than those of shorter storage time (1 week of water or acid storage) [18], therefor the substrates were aged in the present study for six months in water at 37°C.

The TBS data showed that it was possible to attain the cohesive strength of the repair RCs in all of the analyzed pre-treated surfaces for an appropriate repair combination, which were visio.link + CLEARFIL MAJESTY Posterior for the SiC paper pre-treatment of the surface, visio.link + CLEARFIL MAJESTY ES2 for CoJet with phosphoric acid contamination, and Monobond Plus + Heliobond + CLEARFIL MAJESTY Posterior for the CoJet pre-treatment.

An essential aspect in increasing the bond strength to a substrate is inducing mechanical retention by increasing the bonded surface area [27, 28]. Both pre-treatment methods used in this study – air-abrasion and grinding with SiC paper meet these requirements. The results showed that pre-treatment with the CoJet system generated significantly higher TBS than pre-treatment by grinding with SiC paper, while an impact of acid contamination on the pre-treated surface with the CoJet is tolerated by most repair kits. Monobond Plus is known as a universal primer for conditioning of all types of restoration surfaces because it combines three different functional methacrylates: silane methacrylate, phosphoric methacrylate and sulfide methacrylate. Similar is mentioned for the universal adhesive Scotchbond Universal, which contains silane or phosphoric acid monomers in addition to regular methacrylic monomers. This advocates a significant contribution to the bond of the silane or phosphoric monomers, which are able to prime the inorganic filler of the aged RC and represent a high amount of the RC surface. Another bonding mechanism was followed in visio.link, which does not contain phosphoric acid monomers but rather high-molecular-weight acrylates such as pentaerythritol triacrylate ($C_{14}H_{18}O_7$) or pentaerythritol tetraacrylate ($C_{17}H_{20}O_8$). Acrylates are known to be more reactive than methacrylates, thus, the adhesive might allow for a chemical bond with the remaining unsaturated carbon-carbon double bonds in the matrix of the aged RC. As for One Coat Bond, the self-etching adhesive induced similar TBS results as Scotchbond Universal and visio.link. The chemical composition identifies the material as a methacrylate-based adhesive (UDMA), with methacrylate modified polyacrylic acid content. The content of HEMA allows for a more hydrophilic character, improving the connection to aged composite substrates, characterized by increased water sorption and saturation.

As for the analyzed silane primers Embrace First Coat, CLEARFIL CERAMIC PRIMER and Tokuso Ceramic Primer, lower TBS values were identified. Their excellent properties in priming ceramics [29-31] proved to be insufficient for repairing aged RCs. The last-mentioned repair kits, except for Embrace First Coat, were not light cured when previously applying the repair RCs and were also more fluid compared with the other tested systems, thus making them more difficult in handling. An interesting comparison in view of the effect of priming ceramics offers the study of Taira et al. [31]. Their data attested higher bond strength between resin and a leucite-reinforced ceramic when using Tokuso Ceramic Primer and CLEARFIL CERAMIC PRIMER as primer compared with Monobond Plus. Also in repairing aged composites performed Tokuso Ceramic Primer and CLEARFIL CERAMIC PRIMER statistical similar, irrespective of the surface pre-treatment or repair RC, while the additional use of an adhesive (Heliobond) with Monobond Plus repealed in the present study the bonding deficit attested above. CLEARFIL CERAMIC PRIMER and Monobond Plus are similarly composed, containing the 3-(trimethoxysilyl)-propyl methacryl (MTS) as silane monomer, which proved to promote the bonding of resin to porcelain [32], while the acidic adhesive monomer is a methacrylated acidic phosphate ester. The type of silane monomer employed in the other analyzed materials is not explicitly declared so far.

The impacts of the repair RC ($\eta_P^2=0.017$, $p<0.001$) on the bond strength was identified as significant but was very low, which is in accordance with previous published data attesting that it is not compulsory to combine identical RCs for repair [7, 8]. Moreover, RCs with different monomer matrices —methacrylate, ormocer, or silorane – are compatible and might be combined as substrate and repair materials [7].

Conclusions:

All null-hypothesis were rejected. Air-abrasion of aged substrates improved the repair strength inducing superior TBS compared with grinding the surface with SiC paper prior to repair, while the effect of phosphoric acid contamination is material dependent. Analyzed universal adhesives, as well as the combination between a universal primer and an adhesive were in-vitro efficient intermediate agents for repairing aged RCs, while the use of silane primers alone was less efficient. All tested hypotheses are therefore rejected.

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

Tables and Figures

Table 1: Materials, composition and form of application as used in the study: a) Resin composites, b) Repair kits

Table 2: Descriptive statistic (mean, M, and standard deviation, SD) for the tensile bond strength (MPa) as function of repair method. The cohesive TBS of the repair composite CLEARFIL MAJESTY™ Posterior (CMP) and CLEARFIL MAJESTY™ES2 (CM-ES 2) is additionally indicated. Superscript Greek letters indicate statistically homogeneous subgroups within a column, while Latin letters mark the statistic with a row (Tukey's HSD test, α = 0.05).

Table 3: Failure type analyses (frequency of occurrence in %) for surface pre-treatment method and repair RC.

Figure 1: Design of the tensile strength test

Table 1: Materials, composition and form of application as used in the study.

a) Resin composites

Resin composite	Manufactures	Lot No.	Matrix	Filler wt%; vol%
Tetric Evo Ceram	Ivoclar Vivadent	S12963	Bis-GMA,TEGDMA, Hydrophobic aromatic dimethacrylate	Ba-glass, YF_3 Mixedoxid, Pre-polymerized organic filler 75–76%; 53–55%.
Clearfil Majesty Posterior	Kuraray	0120BA	Bis-GMA,TEGDMA Other: Hydrophobic aromatic dimethacrylate	glass ceramics, alumina, silica 92%; 82%
Clearfil Majesty ES 2		0019AA	Bis-GMA, Hydrophobic aromatic dimethacrylate	barium glass, Pre-polymerized organic filler

b) Repair kits

Repair Kit	Manufactures	Lot No.	Compositions	Application
Embrace First Coat	PULPDENT Corporation	130422	Acrylate Resins, no solvents	Application and light curing for 20 s
CLEARFIL CERAMIC PRIMER	Kuraray	570002	MTS, MDP, ethanol	Application and air-drying
Tokuso Ceramic Primer in Bistite II DC kit	Tokuyama Dental	027M	silane monomer, ethanol	Mixing A + B Application 10 s
		527M	phosphate monomer, ethanol	
Ceramic Repair System Kit: Monobond Plus	Ivoclar Vivadent	S05679	MTS, Methacrylated phosphoric acid ester, ethanol	Application 60 s
Heliobond		S09854	Bis-GMA, TEGDMA	Application and light curing for 10 s
Scotchbond Universal	3M ESPE, Seefeld, Germany	521215	MDP Phosphate Monomer, DM, HEMA, Vitrebond Copolymer, Filler, Ethanol, Water, Silane	Application and light curing for 10 s
One Coat Bond	Coltene/ Whaledent	F24457	HEMA, hydroxypropylmethacrylate, methacrylate modified polyacrylic acid, UDMA, glycerol, DM, amorph silicic acid, water (5%),	Application and light curing for 10 s
visio.link	bredent, Senden, Germany	114784	methyl methacrylate, pentaerythritol triacrylate, pentaerythritol tetraacrylate, diphenyl(2,4,6,-trimethylbenzoyl)-phosphineoxide	Application and light curing for 30 s

Abbreviations: Bis-GMA, bisphenol-A diglycidyl ether dimethacrylate; TEGDMA, Triethyleneglycol dimethacrylate; UDMA, Urethane dimethacrylate; HEMA, Hydroxyethylmethacrylate; DM, dimethacrylate; MTS, 3-trimethoxysilylpropyl methacrylate; MDP, 10-Methacryloyloxydecyl dihydrogen phosphate

Data are provided by manufacturers

Table 2: Descriptive statistic (mean, M, and standard deviation, SD) for the tensile bond strength (MPa) as function of repair method. The cohesive TBS of the repair composite CLEARFIL MAJESTY™ Posterior (CMP) and CLEARFIL MAJESTY™ES2 (CM-ES 2) is additionally indicated. Superscript Greek letters indicate statistically homogeneous subgroups within a column, while Latin letters mark the statistic with a row (Tukey's HSD test, $\alpha = 0.05$).

Surface pre-treatment	SiC-Paper				CoJet				CoJet & Phosphoric acid			
Repair resin composite	CMP		CM-ES 2		CMP		CM-ES 2		CMP		CM-ES 2	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Embrace First Coat	1.2^{α} b	1.0	4.2^{α} b	2.9	1.6^{α} b	3.0	$8.8^{\alpha\beta}$ a	7.6	1.1^{α} b	0.8	2.8^{α} b	1.2
CLEARFIL CERAMIC PRIMER	9.7^{β} ab	8.3	5.3^{α} a	3.4	13.3^{β} b	6.7	$11.5^{\alpha\beta\gamma}$ b	5.7	$10.4^{\beta\gamma}$ ab	6.7	11.0^{β} ab	4.8
Tokuso Ceramic Primer	$4.5^{\alpha\beta}$ b	6.6	7.0^{α} ab	4.8	11.5^{β} a	8.4	8.0^{α} ab	4.5	$4.6^{\alpha\beta}$ b	4.7	12.1^{β} a	5.8
Monobond Plus + Heliobond	13.8^{γ} a	7.1	15.3^{β} a	6.1	$17.8^{\beta\gamma}$ a	7.4	$14.1^{\beta\gamma}$ a	6.0	14.8 a	8.7	$15.4^{\beta\gamma}$ a	5.2
Scotchbond Universal	11.7^{γ} a	8.0	17.8^{β} a	6.2	15.2^{β}a	8.2	16.7^{γ} a	6.3	$11.4^{\beta\gamma}$ a	9.0	$14.6^{\beta\gamma}$ a	5.9
One Coat Bond	14.2^{γ} ab	8.0	16.4^{β} a	6.5	13.2^{β} ab	5.7	$13.9^{\beta\gamma}$ ab	3.6	$10.1^{\beta\gamma}$ b	6.3	$12.6^{\beta\gamma}$ ab	7.3
visio.link	$15.6^{\gamma\delta}$ a	7.7	15.3^{β} a	5.3	13.8^{β} a	7.4	15.9^{γ} a	7.3	13.3^{γ} a	9.5	$17.9^{\gamma\delta}$ a	7.2
Cohesive strength	22.4^{δ}	5.6	23.0^{γ}	2.9	22.4^{γ}	5.6	23.0^{δ}	2.9	22.4^{δ}	5.6	23.0^{δ}	2.9

Table 3: Failure type analyses (frequency of occurrence in %) for surface pre-treatment method and RC.

Failure type	Surface pre-treatment			Repair resin composite	
	SiC-Paper	CoJet	CoJet & Phosphoric acid	CMP	CM-ES 2
adhesive	55.4	40.0	43.2	50.0	42.4
cohesive	31.8	46.1	39.6	34.0	44.3
mixed	5.4	6.1	6.8	2.1	10.0
pre-failure	4.3	2.1	2.9	5.7	.5

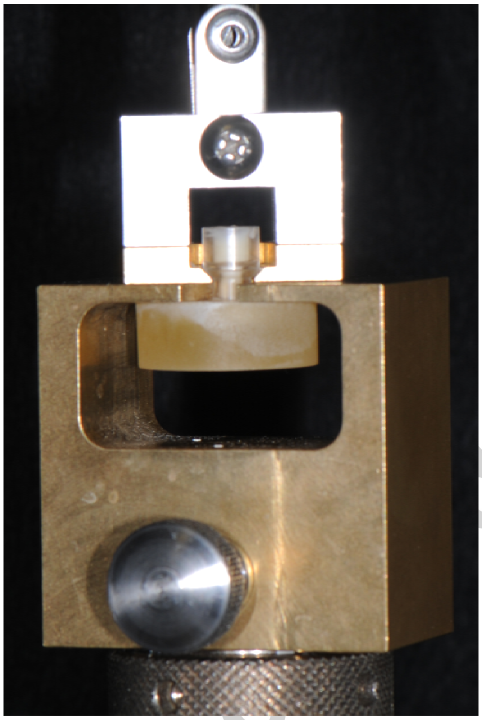

Figure 1: Design of the tensile strength test

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