Aus der Poliklinik für Zahnärztliche Prothetik der
Ludwig-Maximilians-Universität München
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# Einfluss der Testmethode auf den Verbund zwischen CAD/CAM-Hochleistungspolymer und kunststoffbasierten Befestigungsmaterialien nach unterschiedlichen Vorbehandlungen

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# 1 Zusammenfassung

Ziel dieser Untersuchung war es, den Verbund zwischen einem CAD/CAM-Hochleistungskunststoff nach verschiedenen Vorbehandlungen sowie drei unterschiedlich zusammengesetzten Befestigungsmaterialien zu testen. Dazu wurden die Versuche in drei unterschiedlichen Testaufbauten durchgeführt und die Resultate anschließend miteinander verglichen.

Insgesamt wurden 420 CAD/CAM-Kunststoffscheiben (Substrate) mit der Dicke von 3 mm und maximaler Fläche von 10 x 10 mm standardisiert hergestellt und in drei Gruppen nach den Testmethoden randomisiert eingeteilt: n=180 für die Scherfestigkeit (SBS), n=180 für Haftzugfestigkeit (TBS) und n=60 für die Bestimmung der Adhäsionskraft (WA). Die Adhäsionskräfte wurden rechnerisch aus beiden zu verklebenden Flächen bestimmt. Dazu wurden, neben den unterschiedlich vorbehandelten CAD/CAM-Blöcken auf Glasträgern dünne Schichten (n=15) aus jedem Befestigungskunststoff aufgetragen und ebenfalls vermessen. Folgende Vorbehandlungen wurden getestet (n=15 pro Untergruppe): i) VP connect (VP), ii) visio.link (VL), iii) Clearfil Ceramic Primer (CP) und iv) keine Vorbehandlung (CG) als Kontrollgruppe. Als Befestigungsmaterial wurde jeweils RelyX ARC, Variolink II oder Clearfil SA Cement verwendet. SBS und TBS wurden nach 24h Lagerung in destilliertem Wasser bei 37°C und anschließendem Thermolastwechsel mit 5.000 Zyklen zwischen 5°C und 55°C mit der Verweildauer von 20 sek. gemessen. Nach der Bestimmung der Verbundfestigkeit fand die Bruchbildanalyse der Prüfkörper statt. WA wurde mittels einer Kontaktwinkelmessung, jeweils getrennt, einerseits für die vorbehandelten Substrate, andererseits für die unpolymerisierten Befestigungsmaterialien bestimmt und anschließend rechnerisch ermittelt. Die gewonnenen Daten wurden mit Mann-Whitney-U-, Kruskal-Wallis-H-, $Chi^2$-und Spearman-Roh-Tests ausgewertet.

Innerhalb von SBS- und TBS-Tests zeigten die CG, die Gruppen, die mit CP vorbehandelt wurden (unabhängig vom Befestigungsmaterial) und VP, welches mit Clearfil SA Cement vorbehandelt wurde, keinen Verbund. Allerdings war bei CG in Kombination mit RelyX ARC eine TBS von 5,6 ± 1,3 MPa messbar. Im Allgemeinen wurden die höchsten Verbundfestigkeiten für Gruppen, die mit VL behandelt wurden beobachtet. Die CG Gruppe, sowie Gruppen, die mit VL vorbehandelt wurden, zeigten eine niedrigere WA, als die mit VP oder CP behandelten Gruppen.

Insgesamt waren die gemessenen TBS-Werte höher als die SBS-Werte. Im Allgemeinen zeigten SBS und TBS ähnliche Trends innerhalb der geprüften Gruppen. Dagegen waren die WA Ergebnisse, nicht vergleichbar mit den im SBS/TBS Test erzielten Ergebnissen.

Für eine klinische Anwendung und somit einen guten und zuverlässigen Langzeitverbund, muss, anhand der in dieser Untersuchung erzielten Ergebnisse, der XHIPC-CAD/CAM-Kunststoff mit weiteren Adhäsiv-Systemen vorbehandelt werden. Von den hier geprüften Adhäsiv-Systemen, zeigte visio.link die höchsten Resultate und kann somit empfohlen werden.

# 2 Summary

The aim of this in-vitro study was to assess the bonding properties between CAD/CAM-resin and three resin composite cements combined with different bonding agents, using three test methods.

Four-hundred-twenty CAD/CAM-resin substrates were fabricated and divided into three test method groups: n=180 for shear bond strength (SBS), n=180 for tensile bond strength (TBS), and n=60 for determination of work of adhesion (WA). The substrates were pretreated as followed (n=15 per test method/resin composite cement/pretreatment): i) VP connect (VP), ii) visio.link (VL), iii) Clearfil Ceramic Primer (CP), and iv) no pretreatment (CG) acted as control group, and luted with RelyX ARC, Variolink II, or Clearfil SA Cement. SBS and TBS were measured after 24h $H_2O$/37°C + 5,000 thermal-cycles (5°C/55°C) and failure types were assessed. WA was determined for pretreated CAD/CAM-resin and non-polymerized resin composite cements. Data were analyzed with Mann-Whitney-U-, Kruskal-Wallis-H-, $Chi^2$- and Spearman-Roh-tests.

Within SBS and TBS tests, CGs and groups pretreated with CP (regardless of resin composite cements), and VP pretreated with Clearfil SA Cement showed no bond. However, CG combined with RelyX ARC showed the TBS of 5.6 ± 1.3 MPa. In general, highest bond strength was observed for groups treated with VL. CG, and groups pretreated using VL showed lower WA than the groups treated with VP or CP. Measured TBS values were higher than SBS ones. In general, SBS and TBS showed similar trends for the ranges of the values for the groups. WA results were not comparable with SBS/TBS results and admitted therefore no conclusions on it.

For a clinical use of XHIPC-CAD/CAM-resin, the bond surface should be additionally pretreated with adhesive systems, such as visio.link.

# 3 Introduction

The industrially standardized CAD/CAM-processing of polymers leads to significantly higher mechanical properties in comparison to manually polymerized resins.[1,11,27,30] Due to the high pressure and temperature during the fabrication of the blanks, there is a reduced risk of porosities and inhomogeneities for CAD/CAM manufactured restorations.[20,21,31] Not only improved mechanical properties, including wear resistance[19,30], but also advanced optical behavior, such as inferior discoloration[31], are among the advantages of CAD/CAM-resin materials, when compared to conventional polymerized resin. In addition to that the occlusal wear of resin materials is similar to that of enamel and therefore gentle to the natural antagonists.[33]

The first generation of CAD/CAM-resins was usually filled or unfilled polymethylmethacrylate (PMMA) with modified polymer networks.[32] However, the higher deformation caused by the low elastic modulus (2 GPa) of pure PMMA-resins was a limitation of these materials. Further developments lead to new and improved classes of resin materials, which can be optimized through the assembly of several components, such as dimethacrylate, with different organic and anorganic filler particles, and tend to be closer to the characteristics of human teeth.[6] The generation of this new CAD/CAM-resins came from the filling composites in preventive dentistry.

CAD/CAM-resins used as provisional reveal a wider range of indications than the conventionally produced ones. Clinical relevance in complex treatment concepts with lost vertical dimension of occlusion (VDO) and non-invasive preparation of the tooth makes it necessary to create a durable bond to the dental hard tissue even for a limited period of time.[8] The prolonged pretreatment time as well as the reproductability for the definite restoration are important advantages of the new CAD/CAM-methods.[12,13] Nevertheless, there is no certain recommendation available concerning the duration of the pretreatment time.[8] In general, the industrially standardized polymerization of CAD/CAM-resins results in a higher degree of conversion with less residual monomer in the material and made the bonding to resin composite cement difficult.[26] However, creating durable bond between the restoration and the tooth is crucial for long-term reliability and, therefore, its success.

There are several test methods that can be used to describe the bond strength of bonding agents, including the well-known shear bond tests and tensile bond strength tests, or newer and more accurate test methods, such as micro-shear and micro-tensile tests.[2] Both micro-methods gave higher bond strength values as a result of the smaller bonding area, but at the same time, they are very technique-sensitive and elaborate in comparison to the macro test methods.[10,14] However, macro test methods are more commonly used.[10,14] Therefore, the macro bond strength tests were applied due to their direct and quick results, as well as their ease of handling.[14]

Prior studies have investigated the bonding properties of resin composite cements to CAD/CAM-resin materials.[5,17,16,38] PMMA-based CAD/CAM-crowns without air-abrasion cemented on dentin abutments showed no bond in comparison to air-abraded crowns.[26] A further improvement of bond values was achieved by treatment of the crowns with silane coupling agents.[38] Other studies investigated the impact of using adhesive systems to bond of resin composite cements to CAD/CAM-resins and stated that the application of adhesive systems showed an improvement of bond strength results.[5,17]

Other important facts for the achievement of a durable bond are the chemical, physical and mechanical adhesion properties of the substrate surface as well as that of the resin cement. Generally, the mechanical adherence is the most powerful one, but resin – resin interfaces require also chemical bonding which can be improved by application of adhesive systems and the roughening of the surface.[18,24] These improvements of bond strength are shown to increase the wettability of the resin substrate surfaces and can be quantified with contact angle measurements.[18,23] This is the most common test method which gives important information about the work of adhesion (WA), the interfacial tension (IFT) and the spreading coefficient (SC) of the different materials.[18]

The aim of this study was to investigate the bond strength of different resin composite cements combined with different bonding agents to CAD/CAM-resin. The methods used were tensile bond strength test, shear bond strength test, and determination of work of adhesion. The hypotheses tested were: (1) the different bonding agents influence the bond strength, and (2) the different test methods lead to the same conclusions and trends about the bond strengths properties.

# 4 Materials and Methods

This study tested the bond strength properties to XHIPC-CAD/CAM-resin (Xplus3, Echzell, Germany) after following pretreatment methods using different bonding agents: VP connect (Merz Dental, Lütjenburg, Germany), visio.link (Bredent, Senden, Germany), or Clearfil Ceramic Primer (Kuraray Med., Sakazu, Japan). They were bonded with two conventional resin cements, RelyX ARC (3M ESPE, Seefeld, Germany) and Variolink II (Ivoclar Vivadent, Schaan, Liechtenstein), and a self-adhesive resin cement Clearfil SA Cement (Kuraray, Tokyo, Japan). A control group (CG) without a bonding agent was also used in combination with all cements. Bond strength of all combinations was examined with shear bond strength method (SBS), tensile bond strength method (TBS) and work of adhesion (WA), which was theoretically calculated.

For preparation of the specimens, the CAD/CAM-blanks were separated (Secotom-50, Struers, Ballerup, Denmark) in 420 slices (10 x 10 x 3 mm) and embedded in self-cured acrylic resin (ScandiQuick, ScanDia, Hagen, Germany) as shown in Figure 1 and 2. Under running water all specimens were polished with silicium carbide paper (SiC) from P80 up to P1200 (Struers) for 10 sec. each (Tegramin-20, Struers). Before pretreatment, the specimens were air-abraded for 10 sec. with mean powder size of 50 µm alumina oxide (Basic quattro 1S, Hilzingen, Germany) at an angle of 45º with a 10 mm distance, and subsequently cleaned in an ultrasonic bath with distilled water for 5 min. Then specimens were divided into 3 groups: n=180 for SBS and TBS, and n=60 for WA.

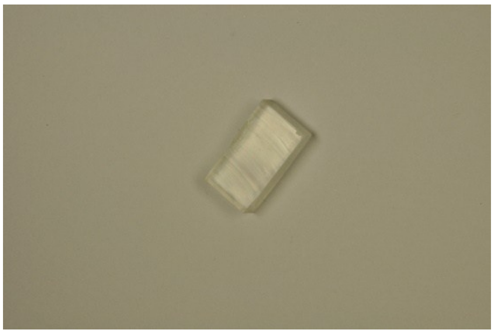

*Figure 1 CAD/CAM-blank separated*

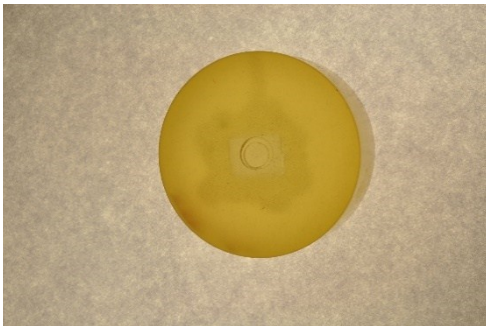

*Figure 2 CAD/CAM-blank embedded in acrylic resin*

The pretreatments using VP connect (Merz Dental, Lütjenburg, Germany), visio.link (bredent, Senden, Germany) or Clearfil Ceramic Primer (Kuraray Med., Sakazu, Okayama, Japan) were performed according manufacturers` instructions (n=45 per group). Manufacturer, composition, and LOT numbers of all used materials are described in Table 1.

*Table 1 Summary of materials used in the present study, their manufacturer with LOT number, and their composition*

| | Materials | Manufacture | Lot No. | Compositions |
|---|---|---|---|---|
| **CAD/CAM-blank** | XHIPC-CAD/CAM-blank | Xplus3, Echzell, Germany | 321120 | 50-80%: PMMA, 10-20%: UDMA, BDDMA, mutli-methacrylate, 5-15% filler |
| **Conditioning method** | VP connect | Merz Dental, Lütjenburg, Germany | 22912 | MMA |
| | visio.link | Bredent, Senden, Germany | 114784 | MMA, dimethacrylate PETIA, photoinitiators |
| | Clearfil Ceramic Primer | Kuraray Med., Sakazu, Okayama, Japan | | 3-Methacryloxypropyl trimethoxy silane, MDP, ethanol |
| **Resin cement** | Clearfil SA Cement | Kuraray Med., Sakazu, Okayama, Japan | 058AAA | PASTE A: MDP, Bis-GMA, TEGDMA, dimethylacrylate, Ba-Al fluorosilicate glass, $SiO_2$, benzoylperoxide, initiators PASTE B: Bis-GMA, dimethacrylate, Ba-Al fluorosilicate glass, $SiO_2$, pigments |
| | RelyX ARC | 3M ESPE, Seefeld, Germany | | Bis-GMA, TEGDMA amine, photoinitiator system (CQ), Benzoyl peroxide and stabilizers |
| | Variolink II | Ivoclar Vivadent, Schaan, Liechtenstein | Base: R35481 Catalyst: P84939 | Bis-GMA, TEGDMA, UDMA, benzoylperoxide, inorganic fillers, ytterbium trifluoride, Ba-Al fluorosilicate glass, spheroid mixed oxide, initiator, stabilizers, pigments |

TEGDMA: Triethylenglycoldimethacrylate,
MMA: Methylmethacrylate,
BDDMA: 1.4 Buthandioldimethacrylat;
Bis-GMA: Bisphenol A - glycidyl methacrylate,
UDMA: Urethane dimethacrylate,
MDP: 10-Methacryloyloxydecyl-dihydrogen phosphate,
PETIA:Pentaerythritoltriacrylate
CQ: Camphor Quinone

Following pretreatment were performed:

1. VP connect (VP) was applied as thin layer and air-dried for 180 sec.
2. visio.link (VL) was applied as thin layer and light cured for 90 sec. with a manufacturer recommended light unit (bre.Lux Power Unit, Bredent, Senden, Germany).
3. Clearfil Ceramic Primer (CP) was applied as thin layer and allowed to vaporize completely.
4. No further pretreatment of CAD/CAM-resin served as the control group (CG).

Each pretreatment group was subdivided according to the above listed resin composite cements (n=15 per group). Polymerization of resin composite cements (SBS and TBS test) was performed on two sides of the acrylic cylinder for 20 sec. each for 40 sec. in total (Elipar S 10, 3M ESPE, Seefeld, Germany). Immediately before the polymerization, the intensity of the LED light-curing unit was measured using an analyzing device (Marc V3, BlueLight analysis Inc., Halifax, NS, USA). The LED lamp had a light intensity of 1200 mW/cm$^2$. After the cementation, all specimens were stored in distilled water in an incubator at 37 ºC for 24 h (HERA cell 150 Thermo scientific, Heraeus, Hanau, Germany) and then artificially aged for 5,000 cycles of thermal aging (Thermocycler THE 1100, SD Mechatronik, Feldkirchen-Westerham, Germany) between 5 °C and 55 °C with a dwell time of 20 sec. Before the SBS and TBS tests, specimens were released in distilled water for 1 h at room temperature (23 °C).

## 4.1 Shear bond strength test method (SBS)

Resin composite cement was inserted in an acrylic cylinder (SD Mechatronik, Feldkirchen-Westerham, Germany) with an inner diameter of 2.9 mm that was centrally placed on the CAD/CAM material surface. To obtain a standardized and homogeneous cemented layer with a height of 0.5 mm, a screw with an outer diameter of 2.8 mm was driven into the core of the acrylic cylinder and loaded with 1 N. Excess resin cement could exit through the screw thread and was cleaned carefully. Polymerization and artificial aging was performed as described. For testing, the specimens were fixed in a Universal Testing Machine (Zwick 1445, Zwick, Ulm, Germany) with the CAD/CAM-resin surface parallel to the loading direction and the acrylic cylinder in horizontal direction and vertically loaded until fracture (1 mm/min) (Fig. 3).[5,28]

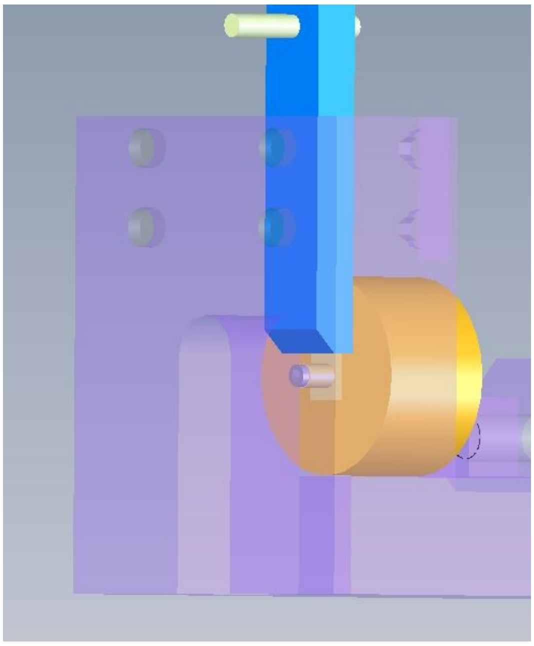

*Figure 3 Design of SBS Testing device*

## 4.2 Tensile bond strength test method (TBS)

An acrylic cylinder (SD Mechatronik) with an inner diameter of 2.9 mm was positioned on the pretreated CAD/CAM-resin. The resin composite cement was manually filled into the acrylic cylinder ensuring a porous-free consistency. Excess cement was carefully removed. Polymerization and artificially aging was performed analogue to the shear bond strength method. For testing, the specimens were fixed in special holding device, ensuring an axial moment-free force application in the Universal Testing Machine (Zwick 1445). The acrylic cylinder was held by a collet while an alignment jig that allowed self-alignment of the specimens. The device was installed to the load cell of the Testing Machine and pulled apart by an upper chain, guaranteeing a self-centring of the whole system. The TBS was measured by axially pulling with a constant crosshead speed of 5 mm/min until the specimens disconnected (Fig. 4).[17,29]

Both, SBS and TBS, were calculated according to the following equation. $\sigma$ [$N/mm^2$] = F/A (where σ: shear or tensile bond strength, F: load at fracture [N], and A: adhesive area [$mm^2$]).

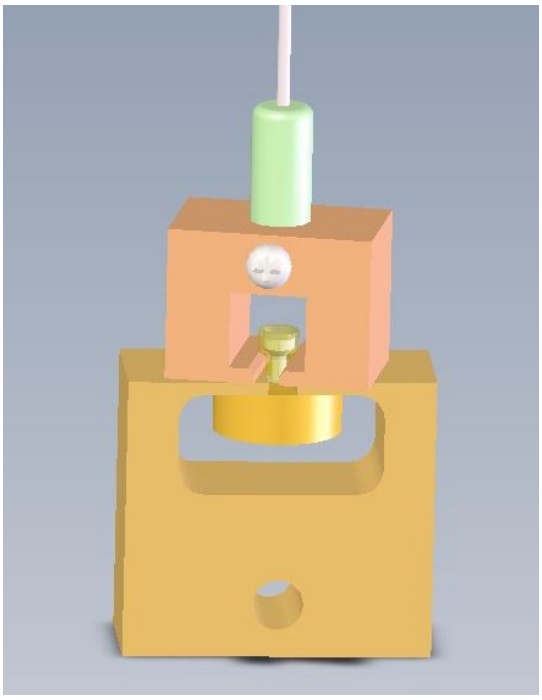

*Figure 4 Design of TBS Testing device*

## 4.3 Fracture type analyses after SBS or TBS measurements

After obtaining the SBS and TBS measurements, the failure type analyses were performed. The failure types were analyzed for adhesive, cohesive, and mixed fracture types (Fig. 5). The adhesive type was defined as fracture in the bonding area (interface), whereas the cohesive fracture was distinguished as fractures of the tested CAD/CAM-resin or otherwise of the cement. The mixed failure was used to describe more types of fractures (cohesive and adhesive) in one specimen. All failure types were evaluated by two calibrated examiners, who were unaware of the group allocation and treatment, under an optical microscope (Axioskop 2 MAT, Karl Zeiss Mikroskopie, Göttingen, Germany).

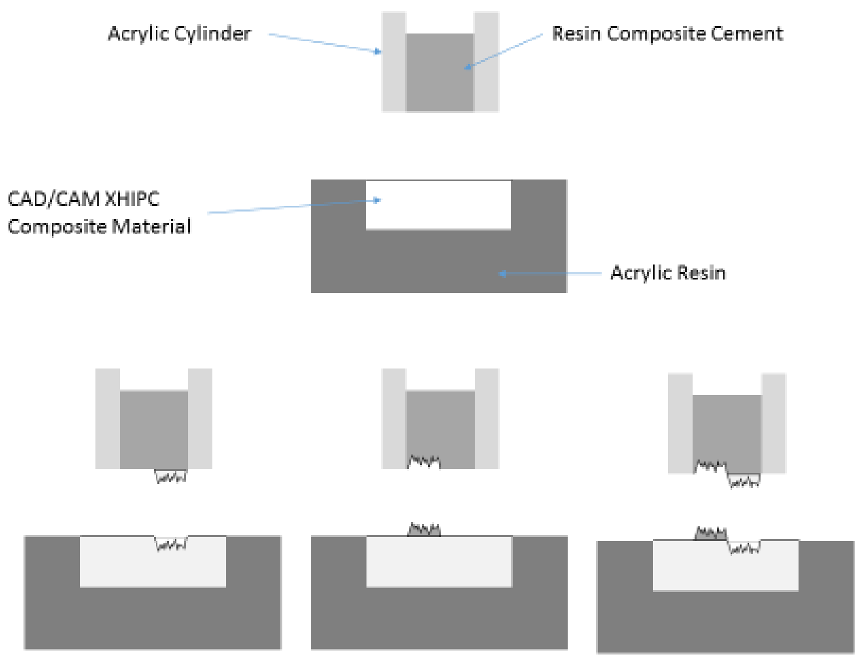


*Figure 5 Failure types analyses: above: adhesive failure; left down: cohesive failure among substrate, center down: cohesive failure among resin composite cement; and right down: mixed failure left to right*

## 4.4 Work of adhesion (WA) test method

To evaluate the theoretical work of adhesion, the surface of the pretreated CAD/CAM-resin, and the surface of all three non-polymerized resin composite cements (n=15 per group) were analyzed. The sessile drop technique was used to perform the contact angle measurement. The measurements were accomplished in a contact angle meter (EasyDrop, Krüss, Hamburg, Germany) using two microsyringes, one filled with distilled water and the other with diiodomethane (99%; Cat: 15.842-9, Sigma-Aldrich, Steinheim, Germany, LOT No: S65447-448) as polar and disperse fluids at room temperature (23 °C) (Fig. 6). An attached digital camera registered the applied fluid drops with a known volume (10 µl water and 5 µl diiodomethane) after exactly 1 sec. using of a special computer program (DSA4, Krüss), the height and diameter of each drop was measured and, therefore, the static contact angle was determined using two different computation methods depending on the angle of the fluid used (Fig. 7- Fig. 8). For flat angles the Circle Method was chosen. The contact angle constructed using distilled water was determined with the Tangent 1 Method. Each specimen was provided with three drops of distilled water and three drops of diiodomethane and the mean contact angle for each liquid was calculated.

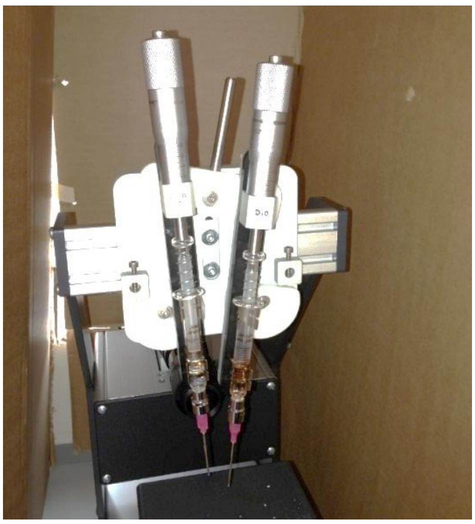

*Figure 6 Contact angle equipment within a dark box*

Based on the formula of OWENS, WENDT, RABEL and KAELBLE the computer program determined the surface free energies (SFE) of the CAD/CAM-resin in combination with all pretreatments as well as those of the resin cements.[15,22] All SFE results were divided into their polar and dispers shares.

$$\frac{(1+cos\theta)\cdot SFE_L}{(2\cdot\sqrt{SFE_L^D})}=\sqrt{SFE_S^P}\sqrt{\frac{SFE_L^P}{SFE_L^D}}+\sqrt{SFE_S^D}$$

$SFE_L^P$: Surface free energy of the liquid, polar component

$SFE_S^P$: Surface free energy of the solid, polar component

$SFE_L^D$: Surface free energy of the liquid, dispersive component

$SFE_S^D$: Surface free energy of the solid, dispersive component

$\theta$: contact angle

Subsequently, the WA between the CAD/CAM-resin after pre-treatment (BS) and the non-polymerized resin composite (RC) cement was calculated using the sum of the polar (SFE (P)) and disperse (SFE (D)) shares of the surface free energies (SFE). These results were put into a formula with the following connection to determine the work of adhesion

$$WA=2\cdot\sqrt{SFE_{BS}^D\cdot SFE_{RC}^D}+2\cdot\sqrt{SFE_{BS}^P\cdot SFE_{RC}^P}$$

Further formulas were used to calculate the interfacial tension (IFT) and the spreading coefficient (SC).

$$IFT = SFE_{BS} + SFE_{RC} - 2 \cdot \sqrt{SFE_{BS}^{D} \cdot SFE\sigma_{RC}^{D}} - 2 \cdot \sqrt{SFE\sigma_{BS}^{P} \cdot SFE_{RC}^{P}}$$

$$SC = \mathrm{WA} - 2 \cdot SFE_{RC}$$

$SFE_{\mathrm{BS}}$: Surface free energy of the bonding system, $SFE_{\mathrm{BS}}{}^{\mathrm{P}}$: polar component

$SFE_{\mathrm{RC}}$: Surface free energy of the resin composite cement, $SF\ {}_{\mathrm{RC}}{}^{\mathrm{P:}}$ polar component

$SFE_{\mathrm{BS}}$: Surface free energy of the bonding system, $SFE_{\mathrm{BS}}{}^{\mathrm{D}}$: dispersive component

$SFE_{\mathrm{RC}}$: Surface free energy of the resin composite cement, $SFE_{\mathrm{RC}}{}^{\mathrm{D}}$: dispersive component

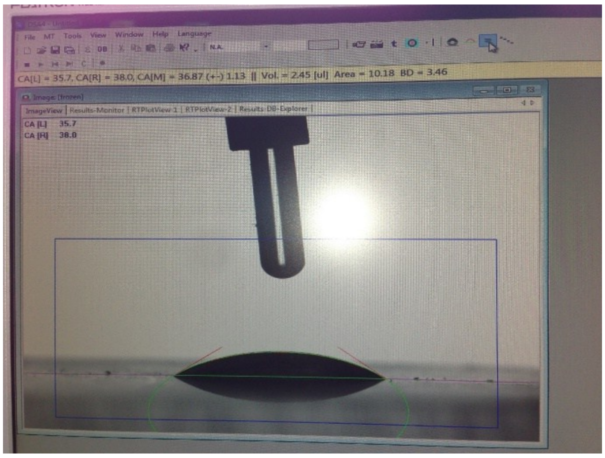


*Figure 7 Computer program for determination of SFE*

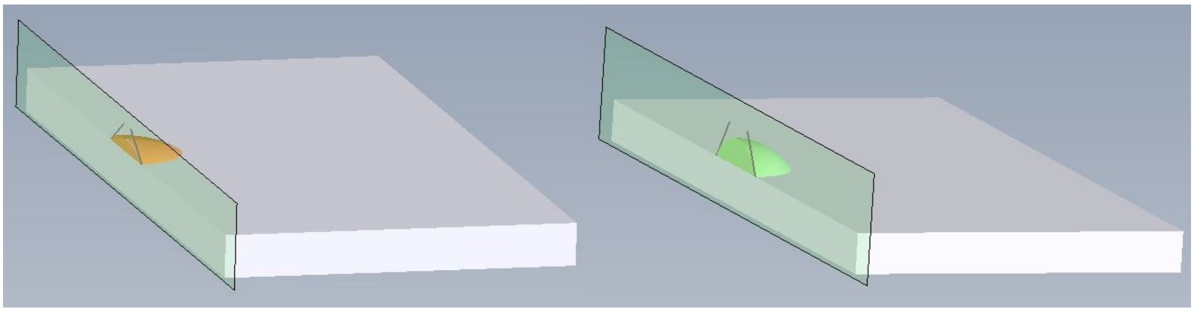

*Figure 8 Circle method for flat angles and Tangent 1 method for high angles*

## 4.5 Statistical analysis

The data were described with descriptive statistics. Normality of data distribution was tested using Kolmogorov-Smirnov and Shapiro-Wilk tests. The differences between the groups were determined using Mann-Whitney-U and Kruskal-Wallis-H tests (SPSS V20, SPSS INC, Chicago, IL, USA). Association between fracture type and pre-treatment was investigated by a $Chi^2$-test. In addition, the relative frequencies of fracture types, together with the corresponding 95% CI, were given using the Ciba Geigy Table.[37] The correlation between all parameters of all used test were non-parametric analyzed with Spearmann-Rho test. All results for statistical analyses with p-values below p=0.05 were considered to be statistically significant.

# 5 Results

Kolmogorov-Smirnov and Shapiro tests indicated that SBS, TBS, and WA groups were not normally distributed. Hence, non-parametric statistical analyzes were performed.

## 5.1 SBS test method results

CGs and groups pretreated using CP, regardless of resin cements used, as well as VP combined with Clearfil SA Cement, showed no bond to the CAD/CAM-resin (Table 2).

*Table 2 Mean values, standard deviation and 95% confidence intervals (CI) for SBS*

| Pre-treatment | Resin composite cement | SBS (MPa) | |
|---|---|---|---|
| | | Mean ± SD | 95% CI |
| VP | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $9.9 \pm 6.8^{C}$ | (5;15) |
| | Variolink II | $8.4 \pm 4.6^{B}$ | (5;12)* |
| VL | Clearfil SA Cement | $13.2 \pm 5.4^{B}$ | (9;17) |
| | RelyX ARC | $13.2 \pm 4.1^{C}$ | (9;16)* |
| | Variolink II | $17.0 \pm 3.8^{C}$ | (13;20)* |
| CP | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $0^{A}$ | 0 |
| | Variolink II | $0^{A}$ | 0 |
| CG | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $0^{A}$ | 0 |
| | Variolink II | $0^{A}$ | 0 |

* not normal distributed
$^{a,b,c}$: significant differences between resin composite cements within single pre-treatment group
$^{A,B,C}$: significant differences between pre-treatments within one resin composite cement

Among all resin composite cements, the highest bond strength (p<0.001) was observed for groups pretreated with VL (13.2–17.0 MPa). No differences were found between groups bonded with RelyX ARC combined with VP (9.9 ± 6.8 MPa) and VL (13.2 ± 4.1 MPa). Within the resin composite cement Variolink II, specimens pretreated using VL (17.0 ± 3.8 MPa) had higher SBS as compared to ones pretreated using VP (8.4 ± 4.6 MPa) (Fig. 9).

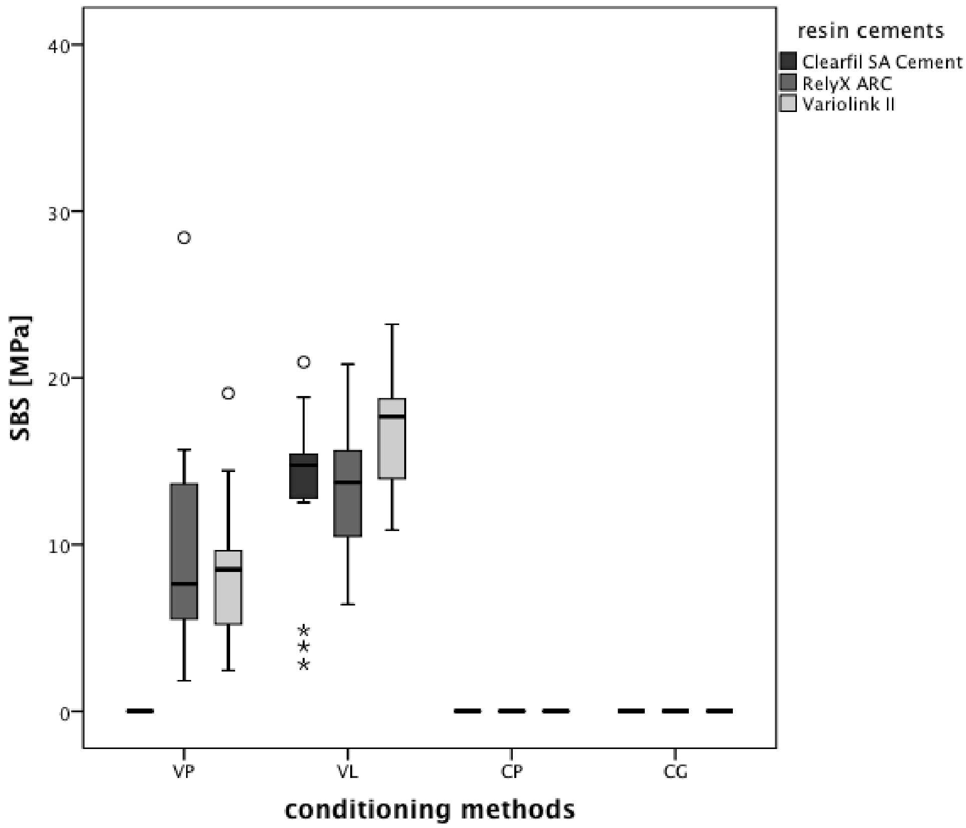


*Figure 9 Box plot for SBS results*

## 5.2 TBS test method results

Except for CG cemented with RelyX ARC, which had TBS values of 5.6 ± 1.3 MPa, CGs cemented with Clearfil SA Cement and Variolink II, all groups pretreated with CP, and VP combined with Clearfil SA Cement showed no bond (Table 3). Analogous to the SBS results, RelyX ARC and Variolink II pretreatment using VL (23.0–25.3 MPa) showed a higher TBS ($p<0.001$) when compared to groups pretreated with VP (16.9–18.0 MPa) (Fig. 10).

*Table 3 Mean values, standard deviation and 95% confidence intervals (CI) for TBS*

| Pre-treatment | Resin composite cement | TBS (MPa) | |
|---|---|---|---|
| | | Mean ± SD | 95% CI |
| VP | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $18.0 \pm 5.0^{C}$ | (14;21)* |
| | Variolink II | $16.9 \pm 5.0^{B}$ | (13;20)* |
| VL | Clearfil SA Cement | $24.1 \pm 7.2^{B}$ | (19;29)* |
| | RelyX ARC | $25.3 \pm 5.0^{C}$ | (21;29)* |
| | Variolink II | $23.0 \pm 4.2^{C}$ | (19;26)* |
| CP | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $0^{A}$ | 0 |
| | Variolink II | $0^{A}$ | 0 |
| CG | Clearfil SA Cement | $0^{A}$ | 0 |
| | RelyX ARC | $5.6 \pm 1.3^{B}$ | (3;7)* |
| | Variolink II | $0^{A}$ | 0 |

* not normal distributed
$^{a,b,c}$: significant differences between resin composite cements within single pre-treatment group
$^{A,B,C}$: significant differences between pre-treatments within one resin composite cement

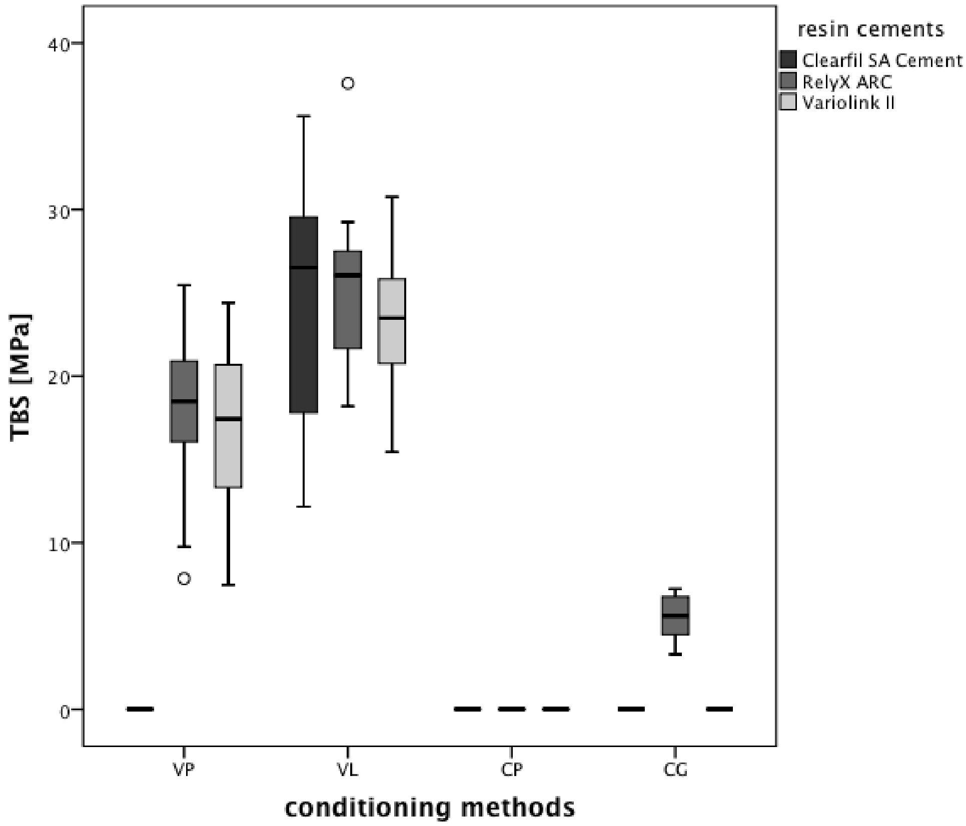


*Figure 10 Box plot for TBS results*

## 5.3 Fracture types

Different fracture types for all of the tested groups were observed ($p<0.001$; Table 4). For RelyX ARC combined with VP in the SBS test, 53% of the specimens showed cohesive fractures in the CAD/CAM-resin. For Variolink II combined with VP, 67% showed cohesive failures in resin composite cement in the SBS test. Variolink II specimens in combination with VL showed 47% cohesive in resin cement, 13% mixed, and 40% adhesive fractures in the SBS test. For the TBS test, specimens pretreated with VL and cemented with Clearfil SA Cement had 33% adhesive, 20% cohesive in resin cement, and 47% mixed failures. Specimens cemented with RelyX ARC combined with VL showed 60% adhesive, 33% cohesive in resin cement, and 7% mixed failures in the TBS test. SBS and TBS tests of the remaining specimens in all of the tested groups showed predominantly adhesive failure types.

*Table 4 Relative failure type frequencies with 95% CIs for each failure type after SBS and TBS measurements (%)*

| Resin composite cement | Pre-treatment | Adhesive | Cohesive (resin composite cement) | Cohesive (XHIPC) | Mixed |
|---|---|---|---|---|---|
| **SBS** | | | | | |
| **Clearfil SA** | VP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | VL | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | **Chi²-test** | **-** | | | |
| **Rely X ARC** | VP | 20 (3;49) | 13 (1;42) | 53 (25;80) | 13 (1;42) |
| | VL | 73 (43;93) | 7 (0;33) | 20 (3;49) | 0 (0;23) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 60 (31;85) | 13 (1;42) | 20 (3;49) | 7 (0;33) |
| | **Chi²-test** | **p=0.006** | | | |
| **Variolink II** | VP | 33 (10;63) | 67 (37;89) | 0 (0;23) | 0 (0;23) |
| | VL | 40 (15;69) | 47 (20;75) | 0 (0;23) | 13 (1;42) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | **Chi²-test** | **p=0.001** | | | |
| **TBS** | | | | | |
| **Clearfil SA** | VP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | VL | 33 (10;63) | 20 (3;49) | 0 (0;23) | 47 (20;75) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | **Chi²-test** | **p<0.001** | | | |
| **Rely X ARC** | VP | 80 (50;97) | 7 (0;33) | 0 (0;23) | 13 (1;42) |
| | VL | 60 (31;85) | 33 (10;63) | 0 (0;23) | 7 (0;33) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | **Chi²-test** | **p=0.010** | | | |
| **Variolink II** | VP | 87 (58;99) | 13 (1;42) | 0 (0;23) | 0 (0;23) |
| | VL | 93 (67;100) | 0 (0;23) | 0 (0;23) | 7 (0;33) |
| | CP | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | CG | 100 (77;100) | 0 (0;23) | 0 (0;23) | 0 (0;23) |
| | **Chi²-test** | **p=0.163** | | | |

## 5.4 Surface characteristics results, such as SFE, Surface polarity, WA, IFT and SC

The results of SFE and Surface polarity are depicted in Table 5.

*Table 5 Mean values, standard deviation and 95% confidence intervals (CI) for SFE with disperse and polar components plus percentage stage of surface polarity for CAD/CAM-resin after pretreatment and resin composite cement separately*

| | SFE ($mJ/m^2$) | | $SFE^d$ ($mJ/m^2$) | | $SFE^p$ ($mJ/m^2$) | | Surface polarity (%) | |
|---|---|---|---|---|---|---|---|---|
| | **Mean ± SD** | **95% CI** | **Mean ± SD** | **95% CI** | **Mean ± SD** | **95% CI** | **Mean ± SD** | **95% CI** |
| **Pretreatment** | | | | | | | | |
| VP | 64.4 ± 0.7[c] | (63;66) | 48.8 ± 0.3[c] | (48;50) | 15.6 ± 0.6[b] | (14;17) | 24.3 ± 0.7[b] | (23;26) |
| VL | 45.8 ± 0.6[a] | (44;47) | 43.1 ± 0.4[a] | (42;44) | 2.7 ± 0.4[a] | (2;4) | 5.8 ± 0.8[a] | (4;7) |
| CP | 64.9 ± 2.4[c] | (63;67) | 48.5 ± 0.6[c] | (47;50) | 16.3 ± 2.3[b] | (14;19)* | 25.1 ± 2.5[b] | (23;28) |
| CG | 48.1 ± 3.0[b] | (46;51) | 46.0 ± 2.0[b] | (44;48) | 2.1 ± 2.5[a] | (0;5)* | 4.3 ± 4.7[a] | (1;8)* |
| **Resin Composite Cement** | | | | | | | | |
| Clearfil SA Cement | 55.1 ± 2.0[c] | (53;57) | 43.8 ± 0.6[a] | (43;45) | 11.3 ± 2.1[c] | (9;13) | 20.4 ± 2.9[c] | (18;23) |
| RelyX ARC | 49.9 ± 1.7[b] | (48;52) | 44.2 ± 0.4[a] | (43;45) | 5.3 ± 1.1b | (4;7) | 10.7 ± 2.1[b] | (9;13) |
| Variolink II | 47.4 ± 0.8[a] | (46;49) | 46.3 ± 0.6[b] | (45;48) | 1.1 ± 0.5a | (0;2) | 2.3 ± 1.1[a] | (1;4) |

* not normal distributed

[a,b,c]: significant differences between groups

Descriptive statistics are summarized in Table 6.

*Table 6 Mean values, standard deviation and 95% confidence intervals (CI) for WA, IFT and SC*

| Pre-treatment | Resin composite cement | WA (mN/m) | | IFT (mN/m) | | SC (mN/m) | |
|---|---|---|---|---|---|---|---|
| | | Mean ± SD | 95% CI | Mean ± SD | 95% CI | Mean ± SD | 95% CI |
| VP | Clearfil SA Cement | $119.0 \pm 2.3^{c,B}$ | (117;121) | $0.6 \pm 0.4^{a,A}$ | (0;2) | $8.8 \pm 1.8^{a,B}$ | (7;11) |
| | RelyX ARC | $111.1 \pm 1.8^{b,B}$ | (109;113) | $3.3 \pm 1.7^{b,B}$ | (1;5)* | $11.3 \pm 2.9^{b,B}$ | (9;14)* |
| | Variolink II | $103.2 \pm 2.0^{a,B}$ | (101;105) | $8.6 \pm 1.3^{c,B}$ | (7;10) | $8.4 \pm 1.2^{a,C}$ | (7;10) |
| VL | Clearfil SA Cement | $97.9 \pm 1.6^{c,A}$ | (96;100) | $3.0 \pm 1.0^{b,B}$ | (1;5) | $-12.3 \pm 2.7^{a,A}$ | (-15;-10) |
| | RelyX ARC | $94.8 \pm 0.8^{b,A}$ | (93;96) | $0.9 \pm 1.3^{a,A}$ | (0;3)* | $-4.9 \pm 2.9^{b,A}$ | (-8;-2) |
| | Variolink II | $92.7 \pm 1.2^{a,A}$ | (91;94) | $0.5 \pm 0.4^{a,A}$ | (0;2) | $-2.1 \pm 0.7^{c,A}$ | (-4;-1) |
| CP | Clearfil SA Cement | $119.4 \pm 4.0^{c,B}$ | (116;123)* | $0.6 \pm 0.3^{a,A}$ | (0;2) | $9.1 \pm 1.7^{a,B}$ | (7;11)* |
| | RelyX ARC | $111.1 \pm 2.1^{b,B}$ | (109;113) | $3.6 \pm 1.9^{b,B}$ | (2;6) | $11.4 \pm 3.3^{b,B}$ | (9;14)* |
| | Variolink II | $103.2 \pm 2.4^{a,B}$ | (101;106)* | $9.1 \pm 1.6^{c,B}$ | (7;11) | $8.3 \pm 1.6^{a,C}$ | (7;10) |
| CG | Clearfil SA Cement | $98.0 \pm 5.8^{a,A}$ | (94;102) | $5.2 \pm 2.9^{c,C}$ | (3;8) | $-12.2 \pm 5.5^{a,A}$ | (-16;-8) |
| | RelyX ARC | $95.4 \pm 3.6^{a,A}$ | (92;98) | $2.6 \pm 2.2^{b,AB}$ | (0;5) | $-4.3 \pm 5.4^{b,A}$ | (-8;0) |
| | Variolink II | $95.0 \pm 2.5^{a,A}$ | (93;97) | $0.6 \pm 0.7^{a,A}$ | (0;2)* | $0.1 \pm 2.7^{c,B}$ | (-2;3) |

* not normal distributed
$^{a,b,c}$: significant differences between resin composite cements within single pre-treatment group
$^{A,B,C}$: significant differences between pre-treatments within one resin composite cement

Within the pre-treatment groups, VP and CP showed the highest SFE values together with dispers and polar components of SFE. For VP, VL and CP Variolink II showed lowest values for WA, followed by RelyX ARC and Clearfil SA Cement in ascending order. Concerning IFT values groups VP and CP showed highest values with Variolink while for VL the combination with Clearfil SA Cement resulted in highest values. Groups VP and CP results in combination with RelyX ARC in highest SC results, while for VL highest SC values were observed in combination with

Variolink II. For control groups without pretreatment no differences were found for WA results between resin composite cements used, while CG combined with Clearfil SA Cement showed highest IFT results and lowest SC values. Opposed to this CG with Variolink II resulted in lowest IFT values and highest SC results.

Within the resin composite cements Clearfil SA Cement showed the highest SFE value, followed by RelyX ARC and Variolink II resulting in lowest values for SFE and percentage stage of surface polarity. In general for all composite resin cements higher WA and SC values were observed in combination with VP and CP than with VL and CG. Within Clearfil SA Cement highest IFT values were observed for CG. Within RelyX ARC and Variolink II the groups VP and CP showed higher IFT values compared to VL and GC. WA results are shown in Figure 11.

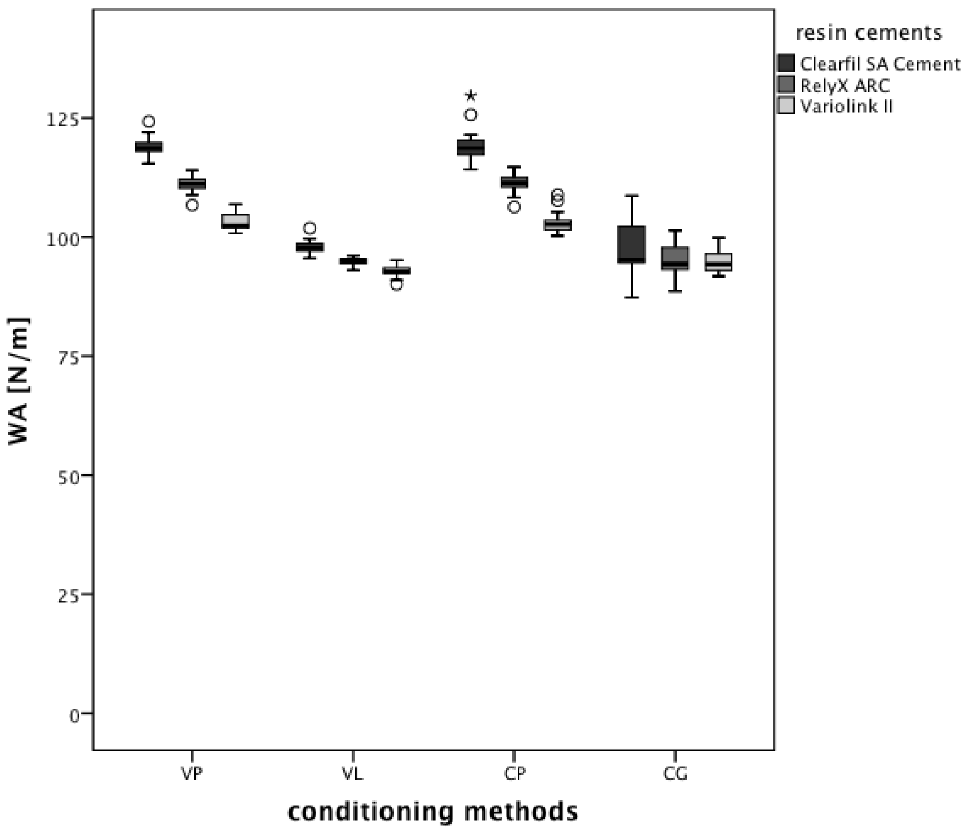


*Figure 11 Box plot for WA results*

## 5.5 Correlation between test methods

TBS values for Clearfil SA Cement combined with VL, RelyX ARC combined with VP, and VL, CG, and Variolink II combined with VL and VP were significantly higher than those examined using the SBS test method ($p<0.001$). Specifically, RelyX ARC without additional pretreatment showed no bond with SBS, while TBS values of 5.6 ± 1.3 MPa were observed. Between TBS and SBS a positive correlation ($r^2=0.259$, $p<0.001$) was observed.

SBS values showed a negative correlation to SFE plus disperse components of SFE of CAD/CAM-resin, a negative correlation to SFE plus polar component of SFE as well as the percentage stage of surface polarity of resin composite cement and to WA and SC values. TBS correlated to all measured parameters with the exception of disperse component of SFE of resin composite cement and IFT values (Table 7).

*Table 7 Non-parametric correlation between single test methods*

| Values for: | CAD/CAM resin after pretreatment | | | |
|---|---|---|---|---|
| Test | SFE | $SFE^d$ | $SFE^p$ | Surface polarity in % |
| SBS | r=-0.321<br>p<0.001 | r=-0.471<br>p<0.001 | r=-0.146<br>p=0.051 | r=-0.139<br>p=0.062 |
| TBS | r=-0.383<br>p<0.001 | r=-0.487<br>p<0.001 | r=-0.258<br>p=0.001 | r=-0.256<br>p=0.001 |
| **Values for:** | **Resin composite cement** | | | |
| **Test** | **SFE** | **$SFE^d$** | **$SFE^p$** | **Surface polarity in %** |
| SBS | r=-0.184<br>p=0.013 | r=0.139<br>p=0.063 | r=-0.194<br>p=0.009 | r=-0.195<br>p=0.009 |
| TBS | r=-0.155<br>p=0.040 | r=0.066<br>p=0.384 | r=-0.153<br>p=0.043 | r=-0.152<br>p=0.043 |
| **Values for:** | **CAD/CAM resin after pretreatment together with resin composite cement** | | | |
| **Test** | **WA** | **IFT** | **SC** | |
| SBS | r=-0.342<br>p<0.001 | r=-0.033<br>p=0.656 | r=-0.212<br>p=0.004 | |
| TBS | r=-0.420<br>p<0.001 | r=-0.044<br>p=0.561 | r=-0.297<br>p<0.001 | |

# 6 Discussion

This in-vitro study showed that different bonding agents influenced the adhesion between CAD/CAM-resin and resin composite cements, regardless of the test method used. Pretreatment using VL and VP (except when used in combination with Clearfil SA Cement) significantly improved the SBS and TBS compared to unpretreated surfaces or surfaces pretreated with MDP-based Clearfil Ceramic Primer. The bonding agents VL and VP contain MMA monomer. Consequently, it can be proposed that the tested CAD/CAM-resin was dissolved at its surface by application of VL and VP and the free carbon double bindings (C-C) polymerized with the carbon compounds of the bonding agent combined with the resin composite cement. VL showed the highest results, and this leads to the suggestion that the component PETIA has an additionally high solvent capacity. The supplementary polymerization process, after application of the bonding layer, consequently creates a strong connection between the XHIPC material and the MMA of the bonding agent that can be described as anchoring. In contrast, the adhesion with industrially polymerized resin after pretreatment with MDP monomers cannot be created. Therefore, the hypothesis that the use of bonding agent has an impact on bond strength, is validated.

In principle, the objective of surface air-abrasion is both, cleaning and achieving micro-retention for bonding properties. Another study reported that air-abrasion of CAD/CAM-resin crowns slightly improved the bond strength and is necessary to create bond to resin composites.[26] In contrast to the assumption that a rougher surface provides a higher bond due to a larger bonding surface area and additional mechanical undercuts, air-abrasion in the present study demonstrated no bond for SBS and low TBS results (RelyX ARC cement: 5.6 MPa).

The CAD/CAM-resin was bonded with two conventional resin cements (RelyX ARC and Variolink II) and one self-adhesive cement (Clearfil SA Cement). The main difference between the SBS and TBS values can be described by the configuration of the two conventional resin cements. Both contain Bis-GMA and TEGDMA with filler particles, and Variolink II also contains UDMA. The self–adhesive Clearfil SA Cement is based on 10-methacryloyloxydecyl-dihydrogenate (MDP). For VP connect, the CAD/CAM-resin showed no sufficient bond with Clearfil SA Cement, but it showed high values when used in combination with RelyX ARC cement (SBS: 9.9 MPa, TBS: 18.0 MPa) and Variolink II (SBS: 8.4 MPa, TBS: 16.9 MPa). Nevertheless, this study shows that higher bonding values can be achieved with conventional resin cements. This fact is also confirmed by other studies using both types of resin cements[5,17] and can be explained by the chemical structure of the PMMA-based CAD/CAM-material, which consists of UDMA and filler particles. The highest bonding properties (SBS and TBS) were observed in groups pretreated with visio.link. Visio.link contains PETIA as solution, MMA monomers, and dimethacrylates. In contrast, VP connect contains only MMA and assumedly swell the surface more ineffectively as in combination with PETIA. Therefore, the measured SBS and TBS gave lower values when compared to specimens pretreated with visio.link.

Groups treated using Ceramic Primer, showed no bond. Ceramic Primer and the self-adhesive resin composite are based on MDP monomers. In these monomers, one of the binding sites is occupied by MDP, leaving only one site for the resin cement. This could be the reason why the bond is not that strong. Also the lack of inorganic fillers in the CAD/CAM-blank is an argument for the insufficient bonding capacity. This conclusion is reinforced by the fact that there is no bonding with Clearfil Ceramic Primer independent of the resin cement and the test method used.

In order to simulate the clinical situation, artificial/accelerated aging by water storage and thermal cycling were used, since they are proven to induce a reduction of bond strength.[25] Conversely, other studies showed an increase of bond strength after aging, claiming that it supports the post–polymerization process.[5] Nevertheless, long-term validations of in-vitro tests do not necessarily correspond to the clinical results. Therefore, prolonged artificial aging by 6 months, instead of 24 h, water treatment should be performed.[38] Thermal cycling is used to imitate the changing temperatures in the oral environment. The dwell time is important in order to avoid excessively fast thermal changes that can lead to an early debonding. Aging procedures were executed to imitate the corresponding clinical deterioration of 4 to 5 months in the oral medium, because this can affect the bond strength.[34] Water uptake was shown to be higher in cements containing only TEGDMA, such as RelyX ARC. In contrast, Variolink II, which contains a mixture of TEGDMA and UDMA, has superior mechanical properties due to the presence of many crosslinks.[35] In general; RelyX ARC with visio.link presented higher TBS values (25.3 MPa) than Variolink II with visio.link (23.0 MPa) after artificial aging.

Consistent with this study, two previous studies used the same laboratory with the same devices, workflow (pretreatment times, lighting conditions, etc.), and LOT numbers of the tested resins.[5,17] Only the operator differed, which can cause slightly different outcomes. The results of these studies confirm that TBS gives higher values than SBS, and that additional pretreatment is necessary for a durable bond.[5,17] In the present study, similar tendencies between TBS (5.6–25.3 MPa) and SBS (8.4–17.0 MPa) were observed. The differences in mean values can be assumed to be caused by the use of the different type of force application. Therefore, the second hypothesis of this study, that the different test methods have no influence on the results, was rejected.

Many studies discuss the validity and evidence of these different macro bond strength test methods and their relevance to the clinical situation, as well as the variation in the conclusions between these special tests.[14,16] These investigations have differences, such as the dimension of specimens, type of testing jig, settings of testing machines, and stress distribution at the bonding interface. This makes it difficult to compare the results and thus it is debatable if there is still a lack of standardization.[10,14,16] Within bond strength tests the applied force is divided by the bonding area in order to obtain the bond strength in MPa (N/mm²).[36] The TBS test method applies the force vertically and, thus, pulls the junction apart. It was observed that more adhesive failures occur using this test method and, therefore, estimates the clinically more realistic situation.[9,14] Kelly et al. mentioned that the tensile stresses for the TBS test method are even higher than for SBS tests due to the more unequal distribution at the exterior interface.[16] This study used the same substrate geometry, acrylic cylinders with same cross-sections, and, therefore, an equal bond area, but different crosshead speed for SBS (1 mm/min) and TBS (5 mm/min). The study showed also higher TBS values than those of SBS. However, the measured values showed similar tendencies in the group ranging and can be compared. As the validation of this investigation proved, the SBS and TBS test methods can be recommended as easy and reliable screening methods for the testing of resin materials.

Further investigation showed that cumulative numbers of cohesive failures could lead to the assumption of an increased strength of the bonding systems.[36] In addition, Kelly et al. argues that cohesive and mixed failures do not involve the bonding interface and, therefore, cannot be taken into consideration for investigations into interfacial fractures.[16] However, the present study showed mostly adhesive failures for SBS and TBS, so it may be that the method of examination has to be seen as user-dependent despite all attempts of standardization.

The measurement of the work of adhesion gives important information about a materials´ surface and its characteristics and is shown to be an important factor for the adhesion performance of the tested materials.[3,7] In the present study, all resin cements were measured in an uncured form with two different liquids. The CAD/CAM-blank was pretreated and polymerized before the determination of contact angles under atmospheric pressure. The tested CAD/CAM-resin surface was plane, so the contact angle measurement could be evaluated directly with the sessile drop technique using the Owens and Wendt, Rable and Kaeble formula.[15,22] In this study, the groups pretreated with CP or VP, for instance, have almost similar WA results. Clearfil SA Cement has the highest WA (VP: 119.0 N/m, CP: 119.4 N/m) followed by Rely X ARC (VP 111.1 N/m; CP 111.1 N/m) and Variolink II (VP: 103.2 N/m, CP: 103.2 N/m). VL has the lowest WA results (92.7–97.9 N/m) independent of the resin cement used. However, the calculated WA values showed other tendencies in the SBS and TBS group ranging and cannot be compared. Additionally to the single parameter WA further surface characteristics are necessary to understand the process of bonding properties. This shows, that every single surface characteristic has to be observed in order to avoid false statements. However, these findings are important as destructive tests of bond strength (SBS, TBS) were commonly used to measure adhesion energy without taking into consideration the in measureable plastic deformation at the interface.[24]

Nevertheless, it should be noted that the acid-based (polar) resin cements tended to have higher adhesion energy, as well as those with a low degree of cross-linking, due to bifunctional monomers.[3] Asmussen et al. argues that the test of the surface free energy could also be conducted between the plain CAD/CAM-blank and the different pre-treatments with adhesives in an uncured form, in order to find a relation to bonding characteristics of polymerized and unpolymerized adhesives.[4] Moreover, surface roughness could increase the surface area involving a lower contact angle, and can also evoke complete wetting of the surface. Surface roughness increases fracture energy and stress distribution at the interface, when destructive forces are applied.[23,24] Though many authors discussed this topic using different equations and unities, it is a new method for dental materials, and there are still few reference values, so any comparison is difficult.

In the present study, all test methods used with the geometrical specimens did not represent the clinical situation. The results are most likely not directly comparable to the clinical situation and, therefore, further studies with clinical application are needed.

# 7 Schlussfolgerung

Anhand der in dieser Untersuchung erzielten Ergebnisse, kann behauptet werden, dass für eine adhäsive Befestigung von CAD/CADM-Hochleistungskunststoffen ein zusätzliches Adhäsiv-System notwendig ist. Unter den hier geprüften Adhäsiv-Systemen zeigte visio.link die zuverlässigsten Verbundfestigkeiten. Ein Einfluss der geprüften Befestigungsmaterialien wurde nicht beobachtet. Die Vorbehandlung mittels Clearfil Ceramic Primer, sowie die Kombination zwischen VP Connect und Clearfil SA Cement, kann in der geprüften Kombination nicht empfohlen werden. Die erzielten Resultate aus dieser Untersuchung müssen in weiteren klinischen Studien bestätigt werden. Ebenfalls sollten in Bezug auf die Verbundfestigkeit zu dem XHIP-CAD/CAM-Hochleistungskunststoff weitere Kombinationen mit anderen Adhäsiv-Systemen und Befestigungsmaterialien untersucht werden.

SBS zeigt trotz ähnlicher Tendenzen zwischen den geprüften Gruppen tiefere Verbundfestigkeiten als TBS. Ein Vergleich zwischen SBS/TBS und der rechnerisch ermittelten Adhäsionskraft ist nicht möglich.

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# 9 Abbildungsverzeichnis

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