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THE MICRO-SHEAR BOND STRENGTH OF TWO DIFFERENT REPAIR SYSTEMS TO INDIRECT RESTORATIVE MATERIALS

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https://doi.org/10.25241/stomaeduj.2020.7(4).art.1

ABSTRACT

Introduction The aim of this study was to evaluate the micro-shear bond strength (μSBS) of different repair systems (Clearfil Repair, iGOS Repair) to restorative materials for CAD/CAM (Cerasmart, Lava Ultimate, InCoris TZI , VITA Suprinity, VITA Mark II, IPS e.max CAD, IPS Empress CAD).
Methodology The 140 1.2 mm-thick specimens were prepared from CAD/CAM blocks (n=20) and thermocycled (10,000 cycles, 5–55°C, dwell time 20s). The specimens were randomly divided into two groups according to the repair system: Clearfil Repair (40% phosphoric acid+mixture of Clearfil Porcelain Bond Activator and Clearfil SE Bond Primer+Clearfil SE Bond+CLEARFIL MAJESTY ES-2) and iGOS Repair (40% phosphoric acid+ Multi Primer LIQUID+ iGOS Bond+ iGOS Universal). The composite resins were polymerized. All specimens were stored in distilled water at 37°C for 24 hours. The μSBS test was performed with a micro-shear testing machine (at 1 mm/min). The data were analyzed using two-way ANOVA, Tukey's multiple comparison tests at a significance level of $p<0.05$. Each failure modes were examined under a stereomicroscope at×16 magnification.
Results The type of CAD/CAM restorative material and repair system showed a significant effect on the μSBS ($p<0.05$). Specimens repaired with the iGOS Repair system showed the highest μSBS values than the Clearfil Repair system among all tested materials except for the InCoris TZI group ($p<0.05$).
Conclusion All groups, except for the InCoris TZI group, repaired with iGOS Repair system showed higher μSBS than Clearfil Repair. The type of restoration and repair material is important in the success of the fracture repair.

KEYWORDS

Micro-Shear Bond Strength; Repair System; CAD-CAM Materials; Adhesion; Dental Prosthesis Repair.

1. INTRODUCTION

Advances in ceramic materials have enabled the production and application of full ceramic restorations without metal. Especially in the last decade, the development of CAD/CAM systems has provided improvement of full ceramic systems and overcoming some of disadvantages of the restorations which arise from traditional construction technique [1-4].
Nowadays, there are many types of CAD/CAM materials mainly metal alloys, ceramic materials, composite resins, and PMMA's. CAD/CAM ceramic blocks could be feldspathic ceramics, lithium disilicate glass ceramics, yttrium tetragonal zirconia polycrystals or leucite-reinforced glass ceramics.

Peer-Reviewed Article
Citation: Atay A, Najafova L, Kurtulmus HM, Üşümez A. The micro-shear bond strength of two different repair systems to indirect restorative materials. *Stoma Edu J.* 2020;7(4):233-241.
Received: September 16, 2020; **Revised:** September 27, 2020; **Accepted:** October 25, 2020; **Published:** October 26, 2020
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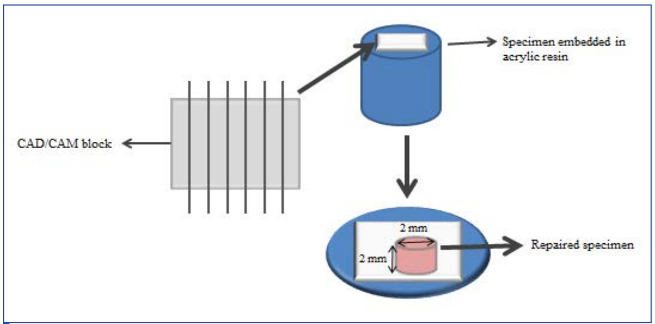

Figure 1. Schematic illustration of specimen preparation.

Figure 2. Specimen testing.

Table 1. Brand names, groups, abbreviations, lot numbers, material types, compositions and manufacturers of the CAD/CAM restorative materials used in the study.

Brand Name	Material type	Composition	Manufacturer
Cerasmart	Hybrid ceramic	Matrix: Bis-MEPP, UDMA, DMA Filler: silica, barium glass nanoparticles (71 wt%)	GC Corp., Tokyo, Japan
Lava Ultimate	Resin nano ceramic	Matrix: Bis-GMA, UDMA, Bis-EMA, TEGDMA Filler SiO_2, ZrO_2, aggregated ZrO_2/ SiO_2 cluster (80wt%)	3M ESPE, Seefeld, Germany
InCoris TZI	Zirconium oxide sinter ceramic	ZrO_2+HfO_2+Y_2O_3 ≥99.0%, Y_2O_3 > 4.5 - ≤ 6.0%, HfO_2 ≤ 5% Al_2O_3 ≤ 0.5%, Other oxides ≤ 0.5%	Sirona Dental Systems GmbH, Bensheim, Germany
VITA Suprinity	Zirconia-reinforced lithium silicate ceramic	56–64% SiO_2, 15–21% Li_2O, 8-12% ZrO_2, 3-8% P_2O_5, 1-4% K_2O, 0-4% CeO_2	Vita Zahnfabrik H. Rauter GmbH, Bad Säckingen, Germany
VITA Mark II	Feldspar ceramic	56-64% SiO_2, 20-23% Al_2O_3, 6-9% Na_2O, 6-8% K_2O, 0.3-0.6% CaO, 0-0.1% TiO_2	VITA Zahnfabrik, Bad Säckingen, Germany
IPS e.max CAD	Lithium disilicate glass-ceramic	57-80% SiO_2, 11-19% Li_2O, 0-13% K_2O, 0-11% P_2O_5, 0-8% ZrO_2, 0-8% ZnO, 0-5% Al_2O_3, 0-5% MgO, 0-8% Colouring oxides	Ivoclar Vivadent, Schaan, Liechtenstein
IPS Empress CAD	Leucite-reinforced glass ceramic	60-65% SiO_2, 16-20% Al_2O_3, 10-14% K_2O, 3.5-6.5% Na_2O, 0.5-7% Other oxides, 0.2-1% Pigments	Ivoclar Vivadent, Schaan, Liechtenstein

Abbreviations: Bis-MEPP: 2,2-Bis(4- methacryloxypolyethoxyphenyl) propane; UDMA: urethane dimethacrylate; DMA: dimethacrylate; Bis-GMA: bisphenol A-glycidyl methacrylate; Bis-EMA: ethoxylated bisphenol A-glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; SiO_2: silicon dioxide; ZrO_2: zirconium dioxide; HfO_2: hafnium dioxide, Y_2O_3:yttrium Oxide; Al_2O_3: aluminium oxide; Li_2O: lithium oxide; P_2O_5: phosphorus pentoxide, K_2O: potassium oxide; CeO_2: cerium oxide; CaO: calcium oxide; TiO_2: titanium dioxide; ZnO: zinc oxide; MgO: magnesium oxide; Na_2O: sodium oxide.

In addition to these materials, polymer-infiltrated ceramics, nano-particulate resin composite and zirconia-reinforced lithium silicate ceramics have been recently introduced for CAD/CAM use [5].

It is stated that various factors such as failure on the bonding interface, parafunctional habits, internal stress, and inadequate occlusal adjustment can cause failure in spite of improvements in CAD/CAM materials [6]. In addition to these, chipping is shown as the most common cause of failure due to the brittleness properties of some ceramics [7,8]. The fracture rates of restorations are reported approximately 2-16%, and 75% in the maxilla [9,10]. These fractures are classified as cohesive (within repair system or the restorative material), adhesive (between the repair system and restorative material), and mixed (both cohesive and adhesive) [11]. The decision to repair or replace the fracture restoration is based on many factors such as fracture type, material properties and cost [12,13]. However, the studies which have revealed higher survival rates when restorations repaired with repair kits compared to replacement of restorations should be considered [14,15]. Today, the repair of ceramic restorations is divided into two as direct (oral repair) and indirect repair (extraoral repair). Indirect repair is not preferred by clinicians because of additional trauma to the restoration and soft tissue [16]. When resin-based cements are used for a full-ceramic cementation protocol, an intraoral repair system should be preferred on account of the difficulty of restoration removal [17]. Repairing a ceramic fracture with composite resin is more conservative, less time consuming, easier and less costly than the complete replacement of the restoration [18]. A number of surface conditioning methods are proposed for restorations to increase bond strength with resin composites. However, there is still no standard protocol for ceramic

Table 2. Brand names, chemical compositions and manufacturers of the repair systems used in the study.

Brand	**Chemical composition**	**Manufacturer**
Clearfil Repair		
Clearfil SE Bond Primer	MDP, HEMA, dimethacrylate monomer, water, photoinitator	Kuraray, Okayama, Japan
Clearfil Porcelain Bond Activator	Bisphenol a polyethoxy dimethacrylate, MPS	
Clearfil SE Bond Bond	Silanated colloidal silica bisphenol A	
CLEARFIL MAJESTY ES-2	0.37-1.5 µm silanated barium glass filler, prepolymerized organic filler, BisGMA, hydrophobic aromatic dimethacrylate, dl-camphorquinone, accelerators, initiators, pigments, 78%wt filled	
iGOS Repair		
Multi Primer LIQUID	Ethanol, thiol compound, silane coupling agent	Yamakin CO., LTD., Kochi, Japan
iGOS Bond	ethanol, distilled water, methacrylate monomer, phosphate monomer, carboxylic monomer, photopolymerization initiator, etc.	
iGOS Universal	Methacrylate monomer, ceramics cluster filler (1-20 µm), submicron filler (SiO_2-ZrO_2-Al_2O_3:200-600 nm), spherical nano-filler (SiO_2 20 nm), fluoride sustained release filler (glass:700 nm), inorganic filler content rate approximately 55 vol%	

Abbreviations: MDP: 10-Methacryloyloxydecyl dihydrogen phosphate, HEMA: 2-hydroxyethyl methacrylate, MPS: 3- metacryloxypropyl trimethoxysilane, Bis-GMA: bisphenol A-glycidyl methacrylate, SiO2: silicon dioxide, ZrO2: zirconium dioxide, Al2O3: aluminium oxide. .

repair systems [19]. Micromechanical retention and chemical bonding procedures are necessary to increase the bonding strength between the ceramic and resin composite. Mechanical surface treatments provide micromechanical locking by creating micro roughness at the ceramic surface [20]. Hydrofluoric acid (HF) is the most commonly used chemical agent for roughening the porcelain surface. The other micromechanical bonding procedures include airborne particle abrasion by using aluminum oxide, tribochemical silica coating, or laser etching [21,22]. Sandblasting with Al_2O_3 particles increase the efficiency of the porcelain surface and the resin composite-porcelain bond strength. The application of silane increases the wettability of the ceramic and support the bond between the silica (inorganic phase) in the restorative materials and the methacrylate groups (organic phase) in the resin with Met-methacryloxypropyl trimethoxysilane (MPS) in its content [23-25].

The aim of this study was to investigate the micro-shear bond strength (μSBS) of two different repair systems to seven different types of CAD/CAM restorative materials and the failure types after μSBS test. The null hypotheses for this study were: a) There were no differences among the CAD/CAM restorative materials and b) between two repair systems.

2. MATERIALS AND METHODS

The tested CAD/CAM restorative materials and two ceramic repair systems are shown in Table 1 and Table 2. One hundred and forty 1.2 mm-thick specimens were prepared from CAD/CAM blocks using a low-speed diamond saw (Mecatome T180; Presi, Grenoble, France) under water cooling (n=20). VITA Suprinity and IPS e.max CAD discs were crystallized (VITA Suprinity: 840°C for 8 minutes, VITA Vacumat 40, VITA Zahnfabrik; IPS e.max CAD: 770°C for 5 min, then 850°C for 10 min, Ivoclar Vivadent AG) following the manufacturers' instructions. InCoris TZI discs were sintered for 2 hours at a temperature starting from 25°C to 1510°C according to the manufacturer's recommendations. Following the thermocycling (10,000 thermal cycles between 5°C-55°C with dwell and transfer times of 20 seconds, Thermocycler, Esetron Smart Robotechnologies, Ankara, Turkey), all specimens were embedded in a self-cure acrylic resin (Vertex Self Curing; Vertex-Dental, Netherlands) and polished with 400, 800, and 1200 SiC sheets respectively. The specimens of each CAD/CAM materials were randomly divided into two subgroups to constitute the 14 test groups for repair procedure (n=10).

All tested groups were etched using 40% phosphoric acid (K-ETCHANT Syringe, Kuraray, Osaka, Japan) for 5 seconds, rinsed under a water spray and dried to clean the adhesive surface except for the InCoris TZI specimens, which Isopropyl alcohol was used for the same aim. For the roughening procedure, InCoris TZI, Lava Ultimate and Cerasmart specimens were sandblasted with 50 µm Al_2O_3 at 2.8 bar pressure (Renfert GmbH, Hilzingen, Germany) for 30 seconds at a distance of 10 mm according to instruments of

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Table 3. Results of two-way ANOVA.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Ceramic type	291.424	6	48.571	38.480	.001
Repair system	187.272	1	187.272	148.367	.001
Ceramic type * Repair system	294.759	6	49.126	38.921	.001

Table 4. Mean and SD values for µSBS (MPa).

	Clearfil Repair	iGOS Repair System
	µSBS values (Mean ± SD)	**µSBS values (Mean ± SD)**
Cerasmart	$7.41\pm0.70^{A, abc}$	$10.06\pm0.63^{B, a}$
Lava Ultimate	$4.66\pm0.90^{A, d}$	$7.16\pm1.05^{B, b}$
InCoris TZI	$8.69\pm1.03^{A, c}$	$4.76\pm1.24^{B, c}$
VITA Suprinity	$8.17\pm1.34^{A, bc}$	$12.80\pm1.73^{B, d}$
VITA Mark II	$7.29\pm1.05^{A, abc}$	$8.09\pm0.75^{A, b}$
IPS e.max CAD	$6.95\pm1.01^{A, ab}$	$11.60\pm1.18^{B, de}$
IPS Empress CAD	$6.34\pm1.53^{A, a}$	$11.37\pm1.10^{B, e}$

** Capital superscripts correspond 70the same line, lower case superscripts correspond to the same column.*
**Significantly different at p <0.05.*

Table 5. Failure mode distribution.

	Adhesive (%)			Cohesive (%)			Mixed (%)		
	Clearfil Repair	iGOS Repair	p	Clearfil Repair	iGOS Repair	p	Clearfil Repair Kit	iGOS Repair	p
Cerasmart	40	10	.303	0	0	-	60	90	.303
Lava Ultimate	50	0	**.002***	0	50	**.002***	50	50	-
InCoris TZI	0	90	**.001***	30	0	.211	70	10	**.001***
VITA Suprinity	20	20	-	20	20	-	60	60	-
VITA Mark II	30	30	-	20	0	.114	50	70	.351
IPS e.max CAD	0	0.2	.114	80	50	.138	20	30	.603
IPS Empress CAD	10	0	.292	10	30	.248	80	70	.603

**Significantly different at p <0.001.*

repair kit. IPS e.max CAD and VITA Suprinity were etched 60 sec, VITA Mark II and IPS Empress CAD were etched 120 sec with 10 % Hydrofluoric acid [26-28] (Angelus, Londrina, PR, Brazil) and then rinsed thoroughly under a water spray for 10 seconds, air-dried for 10 seconds according to manufacturer's instruction of repair kits. All of the specimens were cleaned by ultrasonic cleaner for 10 min and air-dried for 10 seconds.

Following the surface conditioning procedures, a transparent polyvinylchloride cylinder with a hole in the center (2 mm diameter and 2 mm deep) was used for the application of the repair systems to the ceramic surfaces according to the manufacturer's instructions (Fig. 1). The specimens treated with the Clearfil Repair system, the Clearfil SE Bond Primer and the Porcelain Bond Activator were mixed in a 1:1 ratio and applied for 5 seconds. Then, Clearfil SE Bond was applied and light-cured for 10 seconds (Elipar S 10, 3M ESPE, St Paul, MN, USA) (1200mW/cm^2, 430–480 nm). The specimens treated with iGOS Repair, Multi Primer LIQUID was applied to the specimen surface and allowed to dry for about 60 seconds. Then iGOS Bond applied and light-cured for 10 seconds, then the composite resins were polymerized with the same curing unit for 20s. After polymerization, the transparent polyvinylchloride cylinder was carefully removed using a scalpel. During the experiment time, all specimens were stored in distilled water at 37° C for 3 days.

The *µ*SBS test was performed with a micro-shear testing device (MOD Dental, Esetron Smart Robotechnologies, Ankara, Turkey) at 1 mm/min crosshead speed using a knife edge-shaped indenter, which was 5 mm in diameter and 1 mm away from the ceramic-composite interface, placed between the composite resin and the CAD/CAM restorative material (Fig. 2). A micro-shear load was applied until a fracture occurred, and the value was recorded in Newtons (N). The results were expressed in megapascal (MPa) values. Following μSBS test, the failure modes of specimens were examined under a stereomicroscope (Leica M320, Leica Microsystems (Schweiz) AG, Heerbrugg, Switzerland) at × 16 magnifications and recorded as adhesive, cohesive or mix failure type.

2.1. Statistical analysis

All statistical analyses were performed using SPSS for Windows (12.0, SPSS Inc, Chicago, IL, USA). The homogeneity of variance and normality of distribution for variables were evaluated by Levene and Shapiro Wilk test, respectively. Two-way ANOVA and Tukey-HSD multiple comparison tests were used for statistical analyses. In all tests, $p<0.05$ was considered as statistically significant.

3. RESULTS

3.1. μSBS test

The two-way ANOVA revealed that the differences among the CAD/CAM restorative material types and the composite repair material types were statistically significant ($p<0.05$). There were interactions between surface treatments and the materials ($p<0.05$) (Table 3). The mean μSBS test values and differences among the groups are presented in Table 4.

Specimens repaired with the iGOS Repair system showed the highest µSBS values as compared to the Clearfil Repair system among all tested materials except for the InCoris TZI group ($p<0.05$). The Lava Ultimate group showed the lowest µSBS values among the materials repaired with the Clearfil Repair system, while the InCoris TZI group showed the lowest μSBS test values among the materials repaired with the iGOS Repair system ($p<0.05$). Regarding the VITA Mark II group, there was no significant difference in the μSBS test values between the Clearfil Repair system (7.29±1.05 MPa) and the iGOS Repair system (8.09±0.75 MPa) ($p>0.05$). The VITA Suprinity group showed the highest μSBS values among the other material groups when repaired with the iGOS Repair system ($p<0.05$). The µSBS values were found in the InCoris TZI (8.69±1.03), VITA Suprinity (8.17±1.34), Cerasmart (7.41±0.70) and VITA Mark II (7.29±1.05) groups repaired with the Clearfil Repair system, respectively, however, there were statistically insignificant differences among them ($p>0.05$).

3.2. Stereomicroscopic analysis

The failure mode distribution of different repair systems and different CAD/CAM restorative materials are presented in Table 5. According to the Chi-square Test, significantly different failure types among the tested groups were observed ($p<0.001$). Adhesive fractures were mostly obtained in the InCoris TZI group repaired with iGOS Repair system while mix failures were mostly obtained in the InCoris TZI group repaired with the Clearfil Repair system. There were significant differences between the iGOS and Clearfil Repair systems for adhesive and cohesive failures in the Lava Ultimate group ($p<0.001$).

4. DISCUSSION

In the current study, the μSBS of two different repair systems to CAD/CAM restorative materials were tested. Based on the results, the null hypotheses that types of CAD/CAM restorative materials and different repair systems would not affect the bond strength were rejected. It was observed that the success of the repair system depends on the CAD/CAM restorative materials.

All CAD/CAM materials tested in this study are prosthetic restoration materials. Fractures may occur in these materials during usage. Direct application of composite resins is a good alternative to extra-oral repair techniques because composite resins are easier to apply, and they are low cost materials. Their usage would depend on the cause and grade of the fractures [29,30]. When repairing the fracture, a conditioned surface is required to strengthen the adhesion of the repair material to the restoration surface. It is a challenge for the clinician to choose the right option among many repair systems with different conditioning steps. Surface treatments, including acid etching, sandblasting (50 µm Al_2O_3), application of a universal adhesive (silane containing) and their combinations are commonly used for intraoral repair or cementation of indirect restorations [31-33]. A low viscosity composite may exhibit a larger volumetric shrinkage. At the same time, they have better surface wetting properties which prevent development of defects during repair. Contrarily, resin composites with higher filler content, would have a high modulus of elasticity which causes a lower volumetric shrinkage and a higher shrinkage stress at the restoration-resin interface. This stress would negatively affect the bond strength. Considering these contradictory effects, it is not easy to project on the success of a chosen material [34]. In the present study, two different types of composites were used: 1) Clearfil Majesty ES-2 is a nanohybrid composite and 2) iGOS Universal is a hybrid composite. The compositions of these composite materials were quite different from each other. The fact that these materials have different flexural strength may explain the different μSBS results of the two repair systems [35].

In the present study, CAD/CAM materials were selected based on their conditioning concepts and compositions. Using the sandblasting method, the surface is blasted with aluminum oxide particles to roughen and increase the bonding surface of the restoration material [36]. Sandblasting reinforces wetting with resin, reduces surface tension, and increases the total surface area [11]. During the use of the HF acid for repairing glassy-matrix ceramics, the HF acid creates microporosity on the ceramic surface to provide mechanical locking with the resin. Etching of the bonding surface with HF acid followed by the application of a silane as a coupling agent is a commonly used technique for bonding. It enhances the bond strength of silica-based ceramics [37]. The HF acid acts on the silicone dioxide present in the glass phase [38]. The silane monomer has a bifunctional group called silanol which interacts with the ceramic surface together with a methacrylate group that co-polymerizes with the organic matrix of composite resins [33]. Silane also increases the wettability of the ceramic surface and allows the resin to penetrate deeper into its microscopic pores. This mechanism also reinforces the ceramic-resin bonding [39]. In the current study, only the specimens in the the InCoris TZI, Lava Ultimate and Cerasmart groups were sandblasted with 50 µm Al_2O_3 at 2.8 bar pressure, while the VITA Suprinity, VITA Mark II , IPS e.max CAD and IPS Empress CAD groups were treated with HF according to the manufacturer's instructions. However, silane, which is available in the repair system, was applied to the surface of all samples after surface treatment. Düzyol et al. [40]. investigated the HF etching mechanism of several restoration materials and they concluded that, alumina crystals in feldspar ceramic, lithium disilicate crystals in lithium disilicate reinforced ceramic and zirconia fillers and resin matrix in resin nano ceramic are structural parts of these materials that were not affected by the acid etching. Lithium disilicate reinforced ceramic contains a lower percentage of glass phase compared to leucite reinforced and feldspar ceramic. Therefore, in our study IPS Empress CAD and VITA Mark II groups were etched with HF acid for 120 seconds, while IPS e.max CAD group was etched for 60 seconds. Previous studies stated that lithium disilicate reinforced glass ceramic presented higher microtensile bond strength (μTBS) compared to feldspatic ceramic and leucite reinforced glass ceramic [40-42]. In the current study, there was no significant difference in bond strength values among the VITA Mark II, IPS e.max CAD and the IPS Empress CAD groups repaired with the Clearfil system. However, the VITA Mark II group repaired with iGOS showed significantly lower µSBS compared to the IPS e.max CAD and IPS Empress CAD groups. Karcı et al. [43] investigated SBS of different repair systems to IPS e.max CAD and IPS Empress CAD. They found that the SBS values of the IPS Empress CAD are higher than those for the IPS e.max CAD. On the contrary, in the present study, there was no significant difference between the μSBS values of IPS e.max CAD and IPS Empress CAD groups. Üstün et al. [44] stated that the Vita Suprinity group presented lower bond strength values than the other groups (Vita Enamic, IPS e.max CAD, Lava Ultimate) subjected to HF etching because the zirconia-reinforced lithium silicate ceramic group contains 8-12% ZrO_2 by weight. However, in the current study, the μSBS values of the VITA Suprinity group repaired with two repair systems showed no significant difference in bond strength compared to the IPS e.max CAD subjected to HF etching. We assume that after silanization, the zirconia content of VITA Suprinity might become more active for bonding and this may positively affect the μSBS values of VITA Suprinity. For the iGOS Repair system, the μSBS values of all groups were significantly higher compared to the Clearfil repair system except for the InCoris TZI and the VITA Mark II materials. High filler content, homogenization technology and diversity of functional monomers included in the iGOS system might contribute to the adhesive strength of this system [35].

The tested InCoris TZI group repaired with Clearfil showed higher bond strength values than the iGOS group. This should be a result of 10-methacryloyloxydecyl dihydrogen phosphate (MDP) content in the Clearfil SE Bond. MDP containing primers form a chemical bond between resin cements and ceramics [45]. This chemical bond is formed between the hydroxyl groups of zirconia and phosphate ester monomers of MDP [46]. Blatz et al. [47] investigated the effect of Al_2O_3 sandblasting on bond strength between zirconia ceramics and self-adhesive resin cements. The sandblasted specimens presented higher bond strength values compared to the groups without sandblasting. The bond strength of MDP containing resin cements was also significantly higher than the other groups.

Previous studies show that low bond strength values are associated with adhesive failures [48,49]. Stawarczyk et al. [34] investigated the tensile bond strength values of resin nano ceramic (Lava Ultimate) specimens which presented mostly cohesive failures. While Üstün et al. [44] reported that the Lava Ultimate and Vita Enamic specimens showed only cohesive failures in their study. In the present study, hybrid ceramic, the Cerasmart group did not show any cohesive failures. The Lava Ultimate group repaired with the iGOS Repair system showed higher μSBS values than the Clearfil Repair system which showed no adhesive failure (0%) and the fractures were cohesive (50%) or mixed (50%). Adhesive fractures were mostly obtained in the InCoris TZI groups repaired with the iGOS Repair system which indicates that the bonding interface was weaker than Clearfil Repair. No adhesive failure was observed in the InCoris TZI material repaired with the Clearfil Repair system. Üstün et al. [44] investigated the SBS of different repair systems (Ceramic Repair and Clearfil repair) to CAD/CAM restorative materials (Vita Suprinity, Lava Ultimate, IPS e.max CAD, and Vita Enamic) and revealed complete adhesive failure in the Vita Suprinity and IPS e.max CAD groups repaired with Clearfil Repair. On the contrary, in the present study, the VITA Suprinity group repaired with both repair sets presented mixed, adhesive and cohesive failures, and the IPS e.max CAD group repaired with the Clearfil Repair system, presented

80% cohesive failure and 20% mixed failure.

This study has several limitations. The clinical aging of restorative materials would change their chemical and mechanical properties. These changes would affect their repairability as well. In the current study, the specimens were subjected to thermal cycling before they were repaired, because fractures occur during clinical use.

Future studies should be focused on the effect of thermocycling after repair process in order to compare changes. Another limitation of this study is that in order to investigate the bond strength between resin and ceramic, the repaired specimens were only subjected to shear forces. Clinically, repaired restorations are exposed to several intraoral stresses such as tensile, shear, compressive, and oblique forces. Additionally, the bond strength of the repaired restorations should be investigated clinically, in order to verify the outcomes of in vitro studies.

5. CONCLUSIONS

Within the limitations of this study, the following conclusions could be drawn:

1. All groups, except for the InCoris TZI group, repaired with iGOS Repair system showed higher μSBS than Clearfil Repair system.
2. The Clearfil Repair system, which contains MDP phosphate monomer, showed higher μSBS values than iGOS Repair for InCoris TZI.
3. The μSBS of two different repair systems applied to indirect restorative materials is dependent on the micro-structure of both tested materials.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

AA: Study and experimental design, data gathering, analysis and interpretation of the results, manuscript writing LN: Sample preparation, performed the experiment and manuscript writing HMK: Study and experimental design, manuscript proofreading AU: Study and experimental design, analysis and interpretation of the results, manuscript proofreading.

ACKNOWLEDGMENTS

None.

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Questions

1. Choose the appropriate surface treatment method below to repair fractured restorations below:

❑a. Etching with hydrofluoric acid;
❑b. Sandblasting with Al2O3;
❑c. Tribochemical silica coating;
❑d. All of them.

2. What is the effect of silane application in the surface treatment process?

❑a. Increases the wettability of the ceramic;
❑b. Creates micro roughness on the ceramic surface;
❑c. Cleans the ceramic surface;
❑d. Dissolves the glass matrix and the crystalline structure.

3. Which of the following is not one of the advantages of repairing a ceramic fracture with composite resin?

❑a. More conservative;
❑b. Less time consuming;
❑c. Less costly;
❑d. None.

4. According to the results of this study, which restorative material repaired with Clearfil Repair system showed favorable shear bond strength than repaired with iGOS Repair system?

❑a. Feldspar ceramic;
❑b. Lithium disilicate glass-ceramic;
❑c. Zirconium oxide sinter ceramic;
❑d. Resin nano ceramic.