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An Assessment of Shear Bond Strength Between Ceramic Repair Systems and Different Ceramic Infrastructures

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Summary: The purpose of this study was to evaluate of shear bond strengths between two ceramic repair systems and different ceramic infrastructure materials. One hundred cylindrical specimens of ceramic infrastructure were fabricated with non precious metal alloy, zirconia, alumina, galvano, and glass ceramic: 20 non precious metal alloy (NP), 20 zirconia (Z), 20 alumina (A), 20 galvano (G), and 20 glass ceramic (GC). Specimens were divided into 2 subgroups. One half of the specimens were applied by Clearfil™ (CR) repair system and, another half of that were applied by Cimara&Cimara® Zircon (CZ) repair system. Bonded specimens were stored in 37°C distilled water for 24 h and were thermocycled at 5–55°C for 1,200 cycles with a 30-sec dwell time and 5-sec transfer time. Shear bond strengths were determined with a mechanical testing device. And mode of failure was recorded. Mann Whitney-U and Kruskal Wallis tests were applied to the data at 95% confidence interval level. Infrastructure groups displayed the following values in megapascals: $NP = 10.70 \pm 1.88$; $Z = 9.15 \pm 0.80$; $A = 11.65 \pm 0.70$; $GC = 10.95 \pm 0.80$; and $G = 6.88 \pm 0.88$. The Mann Whitney-U test results showed no significant difference between the repair systems. The Kruskal Wallis test results demonstrated significant difference between the infrastructures. The lowest bond strength values were observed in G group. In conclusion, average bond strength values were in accordance with previously reported values, therefore it can be suggested that intraoral repair of ceramic restorations can be temporary, but a satisfying alternative for patients. SCANNING 37:300–305, 2015. © 2015 Wiley Periodicals, Inc.

Key words: dentistry, ceramics, ceramic repair

Introduction

Dental ceramic restorations with all types of infrastructures are widely accepted and used in prosthodontics for oral rehabilitation (Abd Wahab et al., 2011). While they can be produced from zirconia, alumina, non-precious metal alloy, galvano (hard gold plating on non precious metal alloys), and glass ceramic, metal-supported ceramic restorations have become increasingly popular since the 1950s (Ikemura et al., 2011).

Due to toxic and allergic reactions and aesthetic reasons, noble metal alloys have been recommended instead of non-precious metal alloys; however, noble metals are very expensive. Therefore, galvano techniques, which are somewhat superior to conventional metal systems in terms of aesthetics and biocompatibility, have been developed (Raigrodski et al., '98).

Advancements in core materials such as glass ceramic, zirconia and alumina have also led to the increased use of all-ceramic restorations over the past ten years (Ikemura et al., 2011). However, issues such as intra-ceramic defects, parafunctional occlusion, and inappropriate infrastructure design may cause defects in these restorations (Haselton et al., 2001). While remaking the restoration is ideally the best solution, when the restoration is not completely damaged, it can be repaired intraorally (Beck and Dougles, 1990; Burke, 2002).

Advances in adhesive dentistry have enabled the development of repair systems, and a number of repair systems have been developed to facilitate the bonding of composites to porcelain and infrastructure materials (Chadwick et al., '98). Various methods of improving the bond strength between resin and infrastructure material have been demonstrated (Amaral et al., 2006; Amaral et al., 2008). Airborne-particle abrasion and acid etching have been recommended to achieve high

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bond strength (Dilber et al., 2012; Shin et al., 2014). However, although these applications are suitable for feldspathic ceramic; their effectiveness on ceramic materials such as zirconia and alumina are limited, due to their surface topography (Atsu et al., 2006). Therefore, adhesive primers and silane coupling agents may be used to enhance bonding after sandblasting or acid etching (Gourav et al., 2013).

Several studies in the literature have reported on the repair of metal–ceramic restorations (Haselton et al., 2001; Kumbuloglu et al., 2003; Gourav et al., 2013), however, there is no information about the repair of infrastructures that include metal alloy (non-precious), zirconia, alumina, galvano, and glass ceramic in a collective manner.

Thus, the aim of this study was to evaluate the bond strength of ceramic repair systems to five ceramic infrastructure materials. The null hypothesis of the study was that the bond strength of ceramic repair systems to infrastructure materials is not statistically significant ($\alpha = 0.05$).

Materials and Methods

A total of 100 disc-shaped ceramic infrastructure materials (7 mm in diameter and 2 mm thick) were fabricated: 20 from non-precious metal alloy (NP), 20 from zirconia (Z), 20 from alumina (A), 20 from galvano (G) (hard gold plate on non-precious metal alloy), and 20 from glass ceramic blocks (GC). A total of ten sub-groups of ten samples each were created. The materials used and their manufacturing information are presented in Table I.

The materials were embedded in self-cure acrylic resin (Ruby Dent, Istanbul, Turkey) using special moulds (Multiclips, Ballerup, Denmark) with the bonding surfaces exposed. The specimens were polished (Tegrapol-11, Ballerup, Denmark) by wet grinding using 500-grit silicon carbide (SiC) paper under water cooling for 2 min in order to achieve a standard surface. The bonding surfaces of all specimens were airborne-particle abraded with 50-μm aluminum oxide (Al_2O_3) for 10 s at a pressure of 2.5 atm and distance of 20 mm from the specimen surface using an intraoral blasting machine (Hager&Werken GmbH&Co KG, Duisburg, Germany). They were then cleaned ultrasonically for five minutes in distilled water and dried using oil-free compressed air (Elmasonic S100H; Elma GmbH&Co KG, Singen, Germany). Every group was divided into two subgroups: half of the specimens were treated with the Clearfil™ repair system (Kuraray Co., Osaka, Japan), (CR) and the other half with the Cimara&Cimara® Zircon repair system (Voco GmbH, Cuxhaven, Germany), (CZ). The repair systems were applied according to the manufacturers' instructions. The composite resin was applied using a plastic matrix (5.6 mm internal diameter and 2.0 mm length), and the repair composite was light polymerized for 40 sec by using a light-emitting diode (LED) 800 mW/cm^2 power polymerizing unit (Dentanet-LD, Ankara, Turkey).

Clearfil™ repair system: 40% thixotropic phosphoric acid, alloy primer, porcelain bond activator, primer, bond, and opaquer.

Cimara&Cimara® Zircon repair system: Cimara bur, Silan, opaquer, bond for metal alloys, primer, and bond for zirconia and alumina, and composite resin.

All specimens were stored in 37°C distilled water for 24 h. Then, they were thermocycled in water (5°C and 55°C) for 1,200 cycles with a 30 s dwell time and a 5-sec transfer time.

The specimens were fixed in a steel mould and seated in a shear testing jig. Shear bond strengths were determined with a mechanical testing device (Instron 3345, High Wycombe, Bucks, UK) at a crosshead speed of 0.5 mm/min (Fig. 1).

The surfaces were then observed with a scanning electron microscope (SEM) at 50, 100, and 500 magnification, and the failure types were analyzed. Data were first analyzed using the Kolmogorov–Smirnov test to determine whether the data fit a normal distribution (SPSS version 15.0, Chicago). Because the bond strength results did not show normal distribution, the Mann–Whitney U test was used to compare the repair systems. The Kruskal–Wallis test was used for multiple comparisons within the groups ($p < 0.05$).

Results

Shear bond strength values are shown in the Table II. The infrastructure groups and bond strengths were as

TABLE I Infrastructure materials, repair systems, and their abbreviations

Material	Manufacturer	Lot no.
Non-precious metal alloy (NP)	Kera C, Wörth, Germany	P 08-89
Zirconia (Z)	Zirkonzahn SRL, Brunico, Italy	ZRAB0911
Alumina (A)	Vita Zahnfabrik In-Ceram Alumina, Sackingen, Germany	D-79713
Galvano (G)	Gammat Free, Gramm GmbH & Co, Tiefenbronn, Germany	0.156
Glass ceramic (GC)	Vitablocks for CEREC/Inlab Mark II, Sackingen, Germany	3 M2C I2
Clearfil™ Repair System (CR)	Kuraray Co., Osaka, Japan	1971 EU
Cimara&Cimara® Zircon Repair System (CZ)	Voco GmbH, Cuxhaven, Germany	REF 1198
Clearfil Majesty Esthetic	Kuraray Co., Osaka, Japan	CE0197

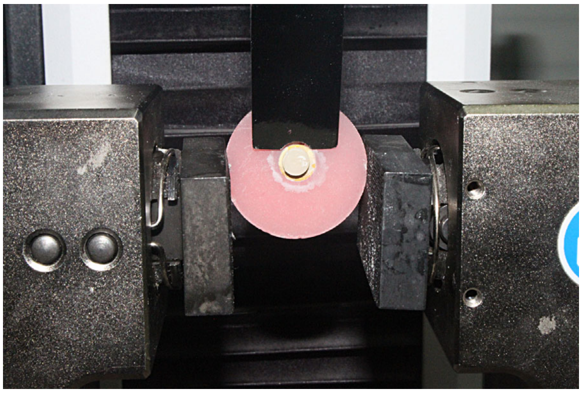

Fig. 1. Measurement of shear bond strength.

follows (MPa): $A = (11.65 \pm 0.70)$, $GC = (10.95 \pm 0.80)$, $NP = (10.70 \pm 1.88)$, $Z = (9.15 \pm 0.80)$, and $G = (6.88 \pm 0.88)$.

The highest shear bond strength value obtained in this study was 26.1 MPa, from the non-precious metal alloy infrastructure treated with the CR™ repair system (NP_{CR}). The lowest shear bond strength value was 3.5 MPa, from the non-precious metal alloy infrastructure treated with the CZ® repair system (NP_{CZ}). In general evaluation, there was no statistically significant difference between the repair systems ($p > 0.05$) (Table III).

When the infrastructures were evaluated, the differences in bond strength between the infrastructures were statistically significant (Table IV).

When the subgroups were evaluated, there was a statistically significant difference between the non-precious metal alloy group and the glass ceramic group treated with the CZ® repair system (NP_{CZ}–GC_{CZ}) (($p < 0.05$); a statistically significant difference was found between the CZ® and CR™ repair systems in the non-precious metal alloy group (NP_{CR}–NP_{CZ}) ($p > 0.05$); a statistically significant difference was found between the non-precious metal alloy and galvano groups treated with the CR™ repair system (NP_{CR}–G_{CR}) ($p < 0.05$); there was a statistically significant difference between the galvano and alumina groups treated with the CZ® repair system (A_{CZ}–G_{CZ}) ($p < 0.05$); and a statistically significant difference was found between the non-precious metal alloy and zirconia groups treated with the CZ® repair system (NP_{CZ}–Z_{CZ}) ($p < 0.05$) (Table V).

The SEM analysis of the interfaces revealed adhesive and mix failure (Table VI and Figs 2 and 3).

Table II Shear bond strengths (MPa) of the subgroups and the explanations of abbreviations

Subgroup	Median	Std. error
NP_{CZ} (10)	4.55	0.25
NP_{CR} (10)	19.75	1.10
Z_{CZ} (10)	10.30	1.02
Z_{CR} (10)	8.80	1.29
A_{CZ} (10)	13.90	072
A_{CR} (10)	9.50	0.81
G_{CZ} (10)	7.00	0.42
G_{CR} (10)	6.85	0.41
GC_{CZ} (10)	9.90	1.46
GC_{CR} (10)	11.55	0.75

NP_{CZ}: Non-precious metal alloy infrastructure treated with Cimara&Cimara®Zircon repair system. NP_{CR}: Non-precious metal alloy infrastructure treated with Clearfil™ repair system. Z_{CZ}: Zirconia infrastructure treated with Cimara&Cimara®Zircon repair system. Z_{CR}: Zirconia infrastructure treated with Clearfil™ repair system. A_{CZ}: Alumina infrastructure treated with Cimara&Cimara®Zircon repair system. A_{CR}: Alumina infrastructure treated with Clearfil™ repair system. G_{CZ}: Galvano infrastructure treated with Cimara&Cimara®Zircon repair system. G_{CR}: Galvano infrastructure treated with Clearfil™ repair system. GC_{CZ}: Glass ceramic infrastructure treated with Cimara&Cimara®Zircon repair system. GC_{CR}: Glass ceramic infrastructure treated with Clearfil™ repair system.

Discussion

In the present study, infrastructure materials were only evaluated because numerous studies have evaluated the bond strength of resin material to veneering ceramic or metal (Abd Wahab et al., 2011; dos Santos et al., 2006; Raposo et al., 2009; Yesil et al., 2007) and several studies have evaluated the bond strength of resin composites to infrastructure materials by applying several surface treatments (Dias de Souza et al., 2011; Gokce et al., 2007; Fonseca et al., 2009).

Two ceramic repair systems and five infrastructure materials were evaluated in the present study. While the CZ® repair system contains a hybrid composite, there is no composite in the CR™ repair system. Therefore, a hybrid composite resin (Clearfil Majesty Esthetic; Kuraray Dental, Okayama, Japan) was used in order to provide standardization between the repair systems. Studies have shown that for repair purposes, the use of hybrid composite resin results in higher bond strength (Gourav et al., 2013; Mohamed et al., 2014).

As a result of the overall evalution, the Mann Whitney-U test showed no statistical difference between the CZ® and CR™ repair systems. Therefore, the null hypothesis, "the bond strength of ceramic repair systems to infrastructure materials is not statistically significant," was accepted. However; considered the NP group

Table III Repair systems

Repair system	N	Bond strength Median	Std. Error	p
CR	50	9.75	0.75	0.06
CZ	50	8.60	0.62	

CR: Clearfil™ Repair System; CZ: Cimara&Cimara®Zircon Repair System; p represents Mann Whitney-U test

TABLE IV Infrastructures and their bond strengths

	Bond strength			p
B	N	Median	Std Error	
NP	20	10.70 [a]	1.88	
Z	20	9.15 [b]	0.80	<0.001
A	20	11.65 [c]	0.70	
G	20	7.00 [d]	0.88	
GC	20	10.95 [e]	0.80	

NP: Non precious metal alloy; Z: Zirconia; A: Alumina; G: Galvano; GC: Glass ceramic**;** Different letters refer to diference between the groups tested. *p* represents Kruskal Wallis test.

in itself, there was a significant difference between the repair systems. Although the CR™ repair system includes a 10-methacryloyloxydecyl dihydrogen phosphate (MDP) containing primary agent for metal alloys, the CZ® system does not. As such, it can be concluded that the CZ® repair system exhibited the lowest bond strengths in the NP and G groups. Studies have shown that it is necessary to use MDP containing priming agents for high bond strengths (de Oyague et al., 2009; Fonseca et al., 2009; Magne et al., 2010; Ikemura et al., 2011).

The physical properties of alumina and zirconia ceramics differ from those of feldspathic ceramic (Meshramkar, 2010). These ceramics are not affected by acid etching due to their highly crystalline structure (Ozcan and Vallittu 2003; Della Bona et al., 2007). Sandblasting with Al_2O_3 powder and acid treatment were applied to alumina ceramic in previous studies, and the researchers reported that the surfaces of the ceramics were resistant against these treatments (Kern and Thompson '95; Ozcan et al., 2001). In the present study, neither of the repair systems contained an acid etching treatment for Z and A infrastructure materials. Instead, they included MDP containing primary agent.

In this study, 80% adhesive failure and 20% mixed failure were determined in the NP group; 80% adhesive failure and 20% mixed failure were determined in the Z group; 85% adhesive failure and 15% mixed failure were determined in the A group; 95% adhesive failure and 5% mixed failure were determined in the G group; 80% adhesive failure and 20% mixed failure were determined in the GC group. The failure mode analysis showed that adhesive failure (84%) was greater than mixed failure (16%). No cohesive failure was observed (Table VI). This result is similar to that of Dias de Souza et al. (2011).

Roman-Rodriguez et al., (2010) reported on the bond strengths between different resins and all ceramic infrastructure materials. They used Panavia™ F resin cement (a combination of sandblasting with 80-μm Al_2O_3, porcelain bond activator, and Clearfil™ SE bond) and obtained the highest bond strength. Similarly, 50-μm Al_2O_3, porcelain bond activator + Clearfil™ SE bond primer and Clearfil™ SE bond were used in this study. The results obtained in the current study were similar to those of Roman-Rodriguez et al. (2010)

In this study shear bond strength test was preferred because of the fact that it is widely used in studies related to dentistry (Fahmy and Mohsen, 2010). Several authors have used shear bond testing for evaluating the intraoral repair systems and informed bond strength values in the range of 5.56–29.9 MPa (Coornaert et al., '84; Wolf et al., '92; Diaz-Arnold et al., '93; Suliman et al., '93; Chung and Hwang, '97; Haselton et al., 2001; Blatz et al., 2003; dos Sants et al., 2006; Saraç et al., 2013). These values is in accordance with the current study except for only one subgroup (NP_{CZ}).

The highest bond strengths actually were observed in non-precious metal alloy specimens treated with the CR™ repair system. However, the bond strength values in non-precious metal alloy treated with the CZ® repair system were very low, which is why the mean bond strength values of NP group were low.

There was no difference between the repair systems in the GC group. The surface treatments for GC material were the same in both repair systems, except for acid etching. The CR™ repair system has an etching process, but the CZ® system does not. Therefore, it can be concluded that chemical surface treatments are more important than acid etching to achieve a desired bond strength.

TABLE V Statistical results of the subgroups

	Z_{CR}	A_{CR}	G_{CR}	GC_{CR}	NP_{CZ}	Z_{CZ}	A_{CZ}	G_{CZ}	GC_{CZ}
NP_{CR}	0.740	0.129	***0.000***	1.000	***0.000***	1.000	1.000	***0.000***	1.000
Z_{CR}		1.000	1.000	1.000	***0.009***	1.000	1.000	1.000	1.000
A_{CR}			1.000	1.000	0.074	1.000	1.000	1.000	1.000
G_{CR}				0.802	1.000	0.647	***0.006***	1.000	0.868
GC_{CR}					***0.002***	1.000	1.000	0.346	1.000
NP_{CZ}						***0.001***	0.000	1.000	***0.002***
Z_{CZ}							1.000	0.274	1.000
A_{CZ}								***0.002***	1.000
G_{CZ}									0.377

Darker and italicized expressions represent significant statistical differences.

TABLE VI Failure types and the specimens

Failure type	NP_{CR}	Z_{CR}	A_{CR}	G_{CR}	GC_{CR}	NP_{CZ}	Z_{CZ}	A_{CZ}	G_{CZ}	GC_{CZ}
Adhesive	6	8	9	9	8	10	8	8	10	8
Mix	4	2	1	1	2	0	2	2	0	2

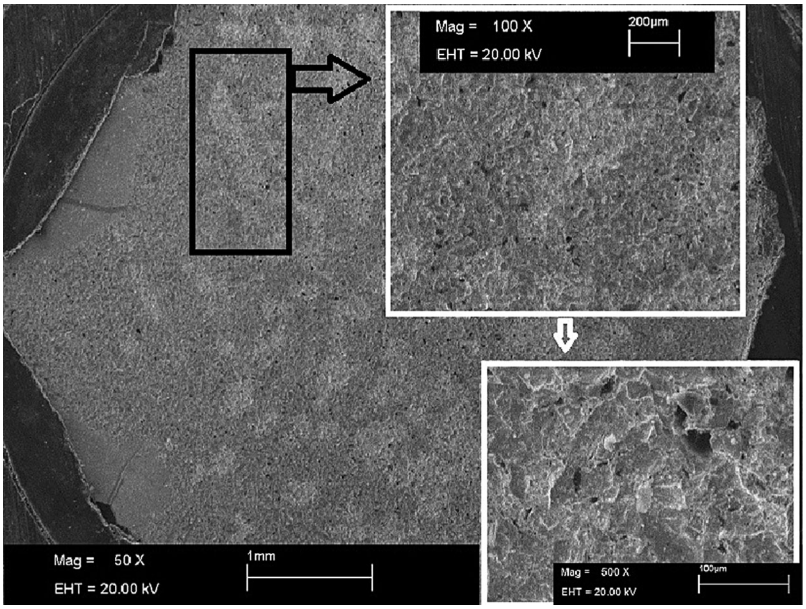

Fig. 2. SEM image of a specimen showing adhesive failure with ×50, 100, and 500 magnification (from the group of G_{CZ}).

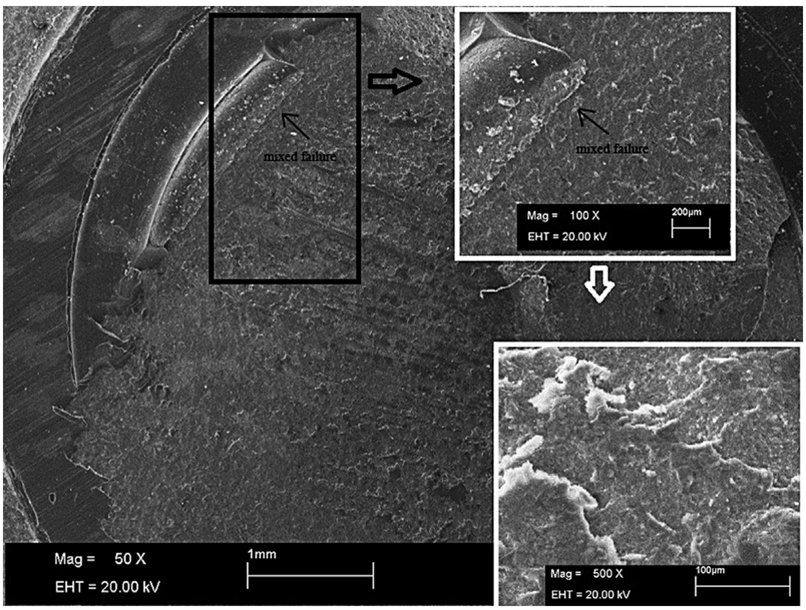

Fig. 3. SEM image of a specimen showing mix failure with ×50, 100, and 500 magnification (from the group of GC_{CR}).

Overall, the G group had the lowest bond strength in both the CZ® and CR™ repair systems. Because the gold content of the G group evaluated in the present study was 99.9%, the metal substructure that was galvano coated did not have an oxide layer; therefore, the metal priming agent in the CR™ repair system could not be effective.

Conclusions

Within the limitations of the current in vitro study, the following conclusions can be drawn:

1. There was no difference between the repair systems.

2. The G group exhibited the lowest average bond strengths.
3. In addition to conclusion 2, the NP group treated with CZ® repair system showed the lowest bond strengths, therefore the surface treatments of this repair system is insufficient to provide stronger bond strength to non precious metal alloys.
4. İntraoral ceramic repair systems can be considered as a temporary, but an effective solution for patiens.

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