



## Shear bond strength of three composite resins to metal and porcelain substrates

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### Abstract

This study was formulated to evaluate and compare the shear bond strength of three light curing composites (Tetric Evo Ceram, IPS Empress Direct, DFL) bonded to metal and porcelain. Forty eight specimens were prepared in the form of metal disks (8mm diameter and 4mm thickness) using lost wax technique, and equally divided in to two surface groups: Metal (A) and Porcelain (B). All specimens were sandblasted with 50  $\mu$ m aluminum oxide, and etched with 37% phosphoric acid gel. For group A, Metal/Zirconia primer, then Monopaque (Ceramic repair, Vivadent/ Ivoclar, /Liechtenstein) were applied according to manufacturer's instructions, while Monobond-S was applied for group B. Heliobond was applied for all specimens. Each group was divided in to three subgroups of 8 specimens, according to the type of the composite applied as follows: Subgroups A1, B1: Nanohybrid composite (Tetric Evo Ceram, Vivadent /Ivoclar, / Liechtenstein), Subgroups A2, B2: Nanohybrid composite (IPS Empress Direct, Vivadent/Ivoclar / Liechtenstein) ,and Subgroups A3, B3: Microhybrid composite (DFL, Natural look, Brazil). Composites were applied to each specimen according to manufacturer's instruction by the aid of plastic transparent split mold (4mm diameter and 4mm height) especially designed for this purpose, specimens were stored in 37 °C in distilled water for 24 hours before being thermocycled between 5°C and 55 °C for 100 cycles. Shear bond strength was determined by using a universal testing machine (Zwick 1454) at a cross head speed 5 mm/minutes. One way ANOVA test, LSD test, and Paired t-test were used to analyze the shear bond strength values. Results revealed that statistically highly significant differences among the metal and porcelain subgroups respectively. For the metal subgroups DFL (A3) exhibited the highest bond strength values, followed by Tetric Evo Ceram (A1), while IPS Empress direct (A2) exhibited the lowest bond strength values. For the porcelain subgroups IPS Empress Direct (B2) showed the highest bond strength values, and there was no significant difference in bond strength values between Tetric Evo Ceram (B1) and DFL (B3). Composite repair to metal surfaces showed a prevalence of combined failures predominantly adhesive in nature, while most specimens in porcelain groups presented predominantly cohesive fracture within porcelain.

Keywords: Shear bond strength, Composite resins, Metal, Porcelain.

### Introduction

Ceramic materials with excellent biocompatibility are used to achieve highly esthetic characteristics in metal-ceramic restorations. Fractures of the porcelain fused to metal (PFM) restorations do not necessarily mean failure of the restoration, they pose an esthetic and functional dilemma for the patient and dentist (Chung and Hwang, 1997). However, for the repair to withstand functional loads, the bond between the repair material and remaining restoration must be strong and durable. Surface configuration, reactivity of the bonding surfaces, and use of adhesive resins are important for porcelain\metal-resin bond. The quality of this bond is controlled by specific treatments to

promote micromechanical and chemical retention with the substrate (Bona *et al.*, 2000). Mechanical retention can be achieved by airborne particle abrasion (Brosh *et al.*, 1997), roughening with diamond or carbide burs (Crumpler *et al.*, 1989), acid etching with; phosphoric acid (Hummel *et al.*, 1997), acidulated phosphate fluoride (APF) (Swift *et al.*, 1992), or hydrofluoric acid (HF) (Brosh *et al.*, 1997). Air abrasion using 50 $\mu$ m aluminum oxide particles resulted in improved microtopography, better wettability, increased surface energy and bonding surface area (Brosh *et al.*, 1997). Chemical bonding is achieved by using silane. Silane is a coupling agent (methylacrylate) poses the general chemical formula X-(CH<sub>2</sub>)<sub>3</sub> Si (OR)<sub>3</sub>, works as a mediator promoting the adhesion between in

organic and organic matrices through dual reactivity. The treatment with a silane agent contributes to covalent bond formation between the ceramic surface and the composite and it also improves the wetting of the ceramic surface for composite (Sarafianou *et al.*, 2008). When the fracture occurs with metal exposure, the repair is more problematic. Air abraded metal surface have shallow and interconnected furrows, which draw primer and adhesive agent on to the abraded surface via capillary action. Adhesive primers simplify the resin adhesion procedure; these primers contain carboxylic or phosphoric acid functional monomers, which react with oxides on the airborne-particle abraded alloy surface and the resin opaquer of the composite resin (Kim *et al.*, 2003). Opaquer is a resinous material which is placed directly on the metal surface; it must bond to the metal so that the darkness of the metal does not show through the repaired composite resin. The chemical attachment of an opaque layer to the metal surface limited microleakage at the resin-metal interface, which can occur because of polymerization shrinkage and mismatch of coefficient of thermal expansion between the composite and the metal (Rinastiti *et al.*, 2010). In order to achieve long-lasting composite restorations, recent developments in polymer science focus on reducing filler particle sizes and at the same time maximizing particle loading in composites, although there is no consensus on the final target strength is to be reached, sometimes suggested to be around 15–30 MPa (Chung and Hwang, 1997). Therefore, the objectives of this study were to compare the repair bond strengths and failure types of three composite materials, Tetric Evo Ceram (Nanohybrid Composite), IPS Empress Direct (Nanohybrid Composite) and DFL (Microhybrid Composite) bonded to metal and porcelain substrates.

### Materials and Methods

Forty eight disk shaped wax patterns (8mm diameter and 4mm thickness) were fabricated. Each wax pattern was sprued at 45° angle with a 3mm thick and 6mm long round wax sprue with the reservoir. Each 8 wax patterns were sprued together and were painted with a surface tension reducing agent. Size 10X iron casting ring was used for investing the wax patterns. A gypsum free phosphate bonded investment material (Gilvest MG, 0064759660, GmbH, Germany) was used and mixed with the powder \liquid ratio that was recommended by the manufacturer. The material was vacuumed mixed using vacuum mixing machine (Motova, Bego, Germany) and poured in to the

casting ring. After one hour, the casting ring was placed in an electric furnace (MANFREDI ,L7C, ITALY) and heated up to the temperature 300°C and held at that temperature for 30 minutes for burning out procedure, then the heat increased slowly to the temperature 850°C and held at that temperature for another 60 minutes. A multiple orifice oxygen gas torch was used to melt the alloy and the casting procedure was done using a compact manual –driven centrifugal casting machine using Nickel-Chromium alloy (Megapplus Compact, Dentarum, Liechtenstein). The composition of the alloy are listed in Table (1). After casting, the ring was bench cooled for two hours (according to manufacturer's instructions), then divested and the sprues were separated. The castings were cleaned and smoothed with stone bur and rubber bur in a slow speed straight handpiece. Twenty four of the castings were randomly selected for porcelain firing treatments. The specimens were treated according to the manufacturer's recommendation for the conventional feldspathic porcelain application (Ivoclar, Liechtenstein) opaque (Batch no. 247043) and body (Batch no.147092). The alloy surface was blasted with aluminum oxide (50 µm particle size and 3-4 bar pressure), the surface was cleaned by water and brush thoroughly. The specimens subjected to an oxidation cycle in the porcelain furnace (Ivoclar programat X1, Ivoclar, Liechtenstein) at 970° C for 7 minutes. Opaquer layers and dentine porcelain were applied to the sample through a modified syringe tube with 8mm diameter and 6mm height. A thin wash layer of opaquer was applied, followed by a second opaquer layer and two dentine body layers, each of them fired separately according to the manufacturer's instruction. Thickness of porcelain was 2mm (±0.1mm) and the total sample thickness was 6mm (metal, opaquer, and porcelain). All specimens were embedded in acrylic resin blocks except their examined surfaces, then they receive air abrasion treatment using Air flow hand-piece (EMS, Elctromedical system, SA, CH-1260-Nyon, Switzerland), a 5mm distance was maintained between the nozzle of air flow device and the sample surface in all specimens. With 50 µm particle size of aluminum oxide (Brosh *et al.*, 1997), at air pressure 3.5 bar and water pressure of 0.7 bar. The air flow was applied to each specimen for 20 seconds, then thoroughly rinsed for 15 seconds using air water spray and dried for 5 seconds by oil free air (Kern and Thumpson, 1995). The etching treatment for all surfaces was performed with 37% phosphoric acid gel, applied for 15 seconds (Mendoza *et al.*, 1997). All specimens were

thoroughly rinsed with water spray for 15 seconds and dried with air-oil free spray for 5 seconds. For group A (Metal only), Metal/Zirconia primer, then Monopaque (Ceramic repair, Vivadent/ Ivoclar /Liechtenstein) were applied according to manufacturer's instructions. One drop of Monobond-S bottle was dispensed on a plastic dish, with the aid of disposable brush, the solution was applied to the Porcelain surfaces in group B, and allowed to set for 60 seconds. Subsequently a thin layer of Heliobond was applied homogenously to all

specimens with the aid of disposable brush, the excess material was dispersed with oil free and light cured for 20 seconds. Each group was divided in to three subgroups of 8 specimens, according to the type of the composite applied as follows:

A1,B1: Nanohybrid Composite (Tetric Evo Ceram, Vivadent /Ivoclar, / Liechtenstein) .  
A2,B2: Nanohybrid composite (IPS Empress Direct, Vivadent/Ivoclar, / Liechtenstein)  
A3,B3: Microhybrid composite (DFL, Natural look, Brazil).

Table (1) : Characteristics, composition and manufacturers of the materials selected in this study.

Materials	Characteristics and Composition	Manufacturer
Casting alloy	Ni 61.4 ,Cr 25.7 ,Mo 11.0 ,Si 1.5 ,Mn<1 ,Al<1.0 , C<1.0	Ivoclar/Vivadent Liechtenstein
Total etch	Acid etch gel, phosphoric acid (37wt. %), water, thickening agents and pigments.	Ivoclar/Vivadent Liechtenstein
Metal\Zirconia primer	Phosphoric acid acrylate \ methylacrylate \Cross linking agent	Ivoclar/Vivadent Liechtenstein
Monopaque	Dimethacrylate, Bis GMA, Urethane Dimethacrylate, TEGDMA.	Ivoclar/Vivadent Liechtenstein
Mono Bond-s	3-Meth acryloxypropyl-trimthoxsilane (1.0 wt.%) in a water/ethanol solution.	Ivoclar/Vivadent Liechtenstein
Heliobond	Light curing bonding agent, it contains Bis-GMA and triethylene glycol dimethacrylate (99wt.%) catalysts and stabilizers<1% .	Ivoclar/Vivadent Liechtenstein
Tetric\Evo Ceram	light curing nano hybrid composite, the total content of inorganic fillers( 53-55% vol), particle size ranges from40nm-3.000nm with a mean particle size of 550nm. Fillers :Barium Glass, Ytterbium Tri Fluoride, mixed oxide and Prepolymer (82- 83%wt). Matrix: Dimethacrylates(17-18%wt). Additional contents :additives ,catalysts, stabilizers and pigments	Ivoclar/Vivadent Liechtenstein
IPS Empress Direct	light curing nano hybrid composite, the total content of inorganic fillers 52-59% vol,75-79% wt, particle size ranges from40nm-3.000nm with a mean particle size of 550nm.Fillers Barium Glass, Ytterbium Tri Fluoride, Mixed Oxide, Silicon dioxide and copolymer(77.5-79%wt). Matrix: Dimethacrylates (20-21.5%wt). Additional contents: Additives ,catalysts , stabilizers and pigments.	Ivoclar/Vivadent Liechtenstein
Natural Look	Light curing micro hybrid resin composite, the total content of inorganic fillers 59% vol,78 % wt. Particle size ranges from0.04-2.8µm with a mean particle size of 0.5µm. Fillers : Barium Glass Atomized, Amorphous SilicaHydrophobed,and Canforquinone. Matrix: Bisphenol A Diglycidylmethacrylate, Bisphenol A Diethoxymethacrylate, TEGDMA.	DFL\Brazil

Composites were applied to each specimen according to manufacturer's instruction by the aid of plastic transparent split mold (4mm diameter and 4mm height) especially designed for this purpose. The 1<sup>st</sup> increment of the composite was introduced with a plastic instrument and adapted to avoid air entrapment, the material was light cured using light curing unit (Astralis 5, Vivadent, Austria) for 40 seconds, the 2<sup>nd</sup> layer was added and light cured for another 40 seconds. The tip of light curing unit was intimate contact with the plastic cylinder mold. All specimens were stored in 37 °C distilled water for 24 hours before being thermocycled between 5°C and 55 °C for 100 cycles with a 30 seconds dwell time (Haselton *et al.*, 2001). After thermocycling, specimens were stored in distilled water for additional 8 days before being subjected to a shear load (Kupiec *et al.*, 1996). A universal testing machine (Zwick 1454 ,Germany) with 100kg

load cell, and a 5mm/min cross head speed and a chisel apparatus was used to direct a parallel shearing force as close as possible to the resin/substrate interface (Figure 1). The shear load in Newton at the point of failure was noted, and calculated in mega Pascal's. Fracture sites were examined using stereomicroscope to determined the location and type of failures during deboning (Sun *et al.*, 2000) (Figure 2). Mode of failures were recorded as adhesive (failure at the substrate-resin interface), cohesive (failure within the substrate), or combination (areas of adhesive and cohesive failure). A one-way analysis of variance (ANOVA) was performed to test any statistically significant difference among the tested groups .Comparisons between each pair of the groups were performed by the least significant difference (LSD) test and Paired t-test.

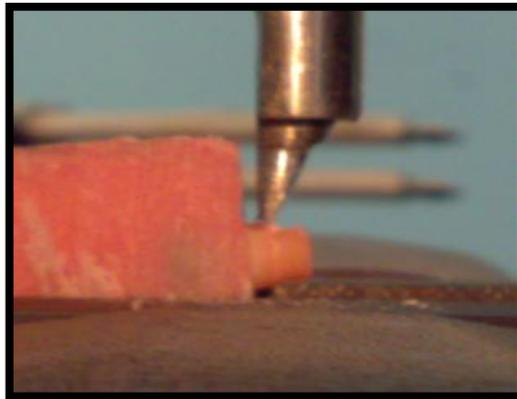


Figure (1): Stainless steel chisel shaped rod delivering the shear force.

### Results and Discussion

Mean shear bond strength values (in MPa), standard deviation, minimum and maximum values for each subgroup are presented in Table (2) and Figure (2).

Effect of type of composite: By using ANOVA test, the results showed statistically highly significant differences among metal and porcelain subgroups respectively ,as shown in Tables (3) and (4). Further analysis was performed using LSD test, the results revealed that for the metal subgroups, DFL (A3) subgroup was statistically significantly higher than Tetric (A1) and IPS (A2) subgroups; and Tetric (A1) subgroup was statistically significantly higher than IPS (A2) subgroup as shown in Table (5). However, for the porcelain subgroups, the results showed that IPS (B2) subgroup was statistically significantly higher than Tetric (B1) and DFL (B3) subgroups; and there was no statistical significant difference between Tetric (B1) and DFL (B3) subgroups, as shown in Table (6).

Effect of type of bonded surface (metal or porcelain): Paired t-test was used, and the results revealed that both Tetric and IPS composites produced statistically higher bond strength to porcelain surfaces than that to metal surfaces. However, no statistical significant difference was found between porcelain and metal groups repaired with DFL composite as shown in Table (7).

Stereomicroscopic examination: Stereomicroscopic examination of the fracture site revealed that there was no pure adhesive failure. For metal subgroups ,all specimens showed combined fractures predominantly adhesive, partially cohesive within opaquer, Figure (3, A, C and E). For the porcelain subgroups, The failure mode vary from predominantly mixed adhesive/cohesive within ceramic to predominantly cohesive within ceramic, Figure (3, B, D and F), no pure adhesive failure, nor composite cohesive failure were seen. Table (8) shows the mode of failure for the different groups.

Table (2): Mean shear bond strength values (in Mpa), standard deviation, minimum and maximum

Groups	N	Mean	Std. Deviation	Minimum	Maximum
A1	8	14.2500	2.76436	10.42	17.56
A2	8	11.1312	1.64782	8.87	13.40
A3	8	19.3188	2.29543	17.06	22.78
B1	8	21.4812	2.24504	18.30	24.10
B2	8	26.0625	2.47740	22.78	29.00
B3	8	21.6588	2.28579	18.35	24.36

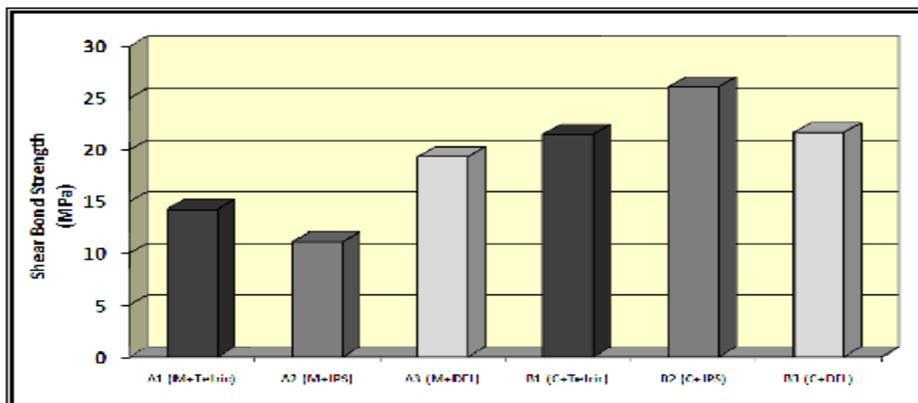


Figure (2): Bar chart shows the difference in mean shear bond strength values (MPa) among subgroups.

Table (3): ANOVA test among metal subgroups.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	273.211	2	136.605	26.227	0.000 (HS)
Within Groups	109.382	21	5.209		
Total	382.593	23			

Table (4): ANOVA test among porcelain subgroups.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	107.766	2	53.883	9.855	0.001 (HS)
Within Groups	114.818	21	5.468		
Total	222.584	23			

Table (5): LSD test between the different composites on metal surface.

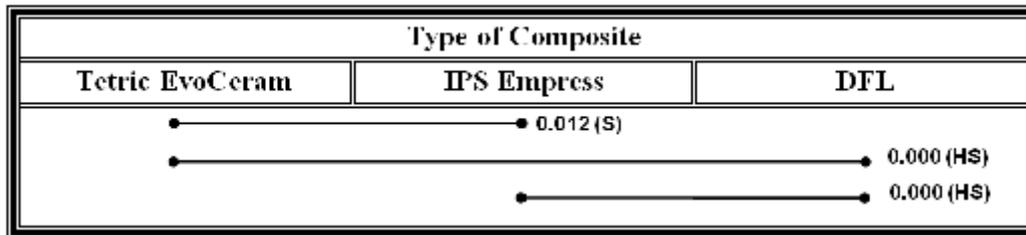


Table (6): LSD test between the different composites on porcelain surface.

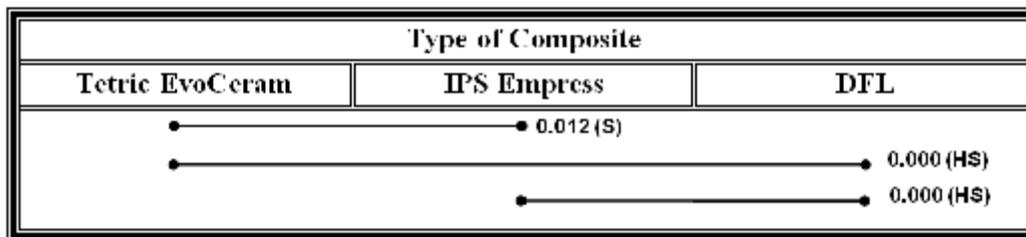


Table (7): Paired t-test between metal and porcelain subgroups.

Type of Composite	Type of the Bonded Surface		
	Metal	Ceramic	
Tetric EvoCeram			0.000 (HS)
IPS Empress			0.000 (HS)
DFL			0.115 (NS)

Table (8): Failure modes of the different subgroups.

Subgroups	Adhesive	Cohesive	Adhesive/cohesive
A1(M+Tetric)		----	100% •
A2(M+IPS )		----	100% •
A3(M+DFL)		----	100% •
B1(C+Tetric )		75% ••	25% •••
B2(C+IPS )		75% ••	25% •••
B3(C+DFL)		75% ••	25% •••

•Combined failure, predominantly adhesive, partially cohesive within opaquer.

••Cohesive within ceramic.

••• Predominantly cohesive within ceramic, partially adhesive.

Stereomicroscopic examination: Stereomicroscopic examination of the fracture site revealed that there was no pure adhesive failure. For metal subgroups ,all specimens showed combined fractures predominantly adhesive, partially cohesive within opaquer, Figure (3, A, C and E). For the porcelain

subgroups, The failure mode vary from predominantly mixed adhesive/cohesive within ceramic to predominantly cohesive within ceramic, Figure (3, B, D and F), no pure adhesive failure, nor composite cohesive failure were seen. Table (8) shows the mode of failure for the different groups.

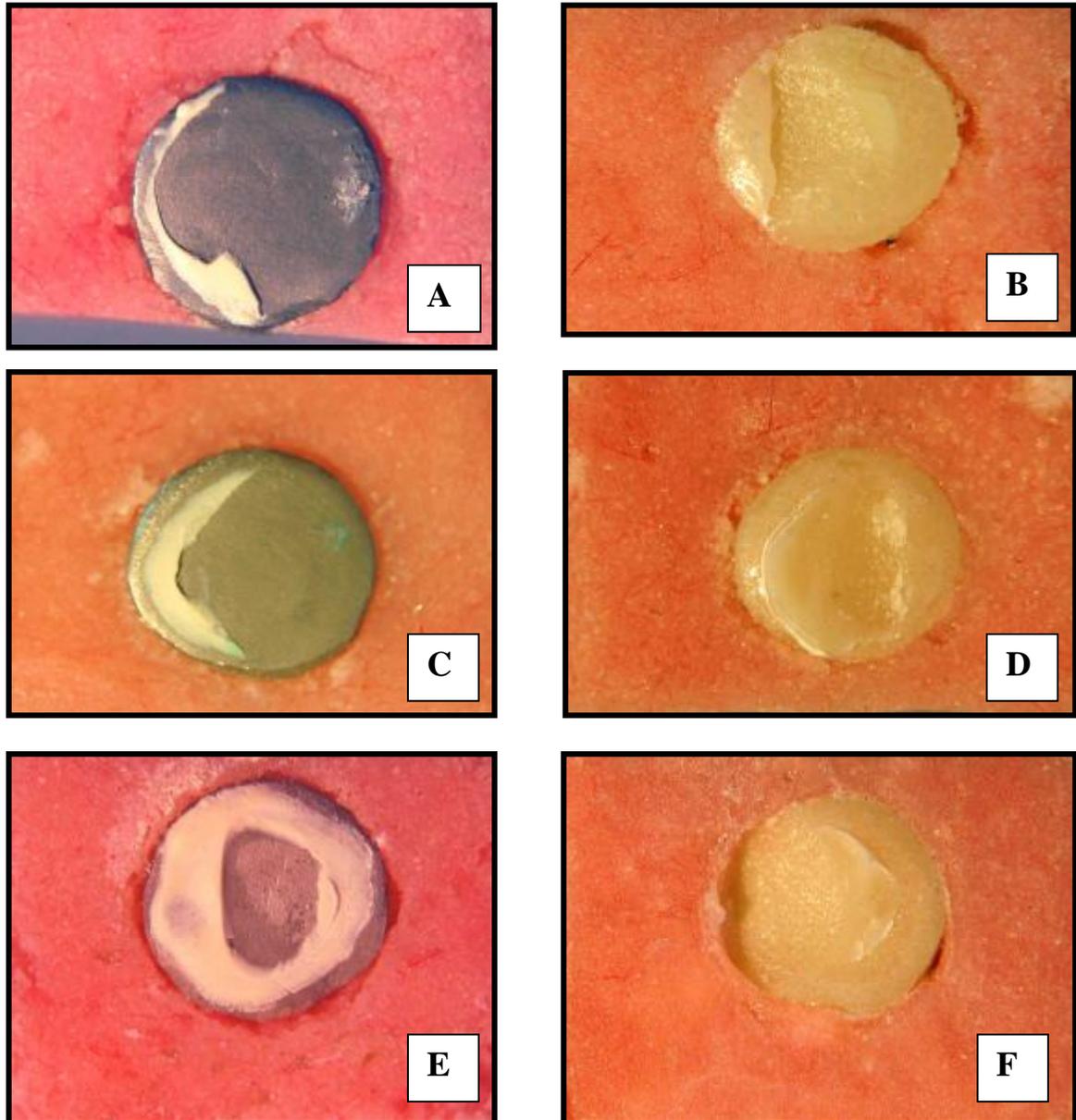


Figure (3): Representative images from a stereomicroscope (x20). A,C,E represent combined predominantly adhesive failure ,while B,D,F represent cohesive failure within porcelain.

The relevance of the present study lies in comparing the interfaces between three types of composite resins, which they were used as a repair material and the original intact metal \ porcelain interfaces. The latter adhesive interface showed significantly higher shear bond strength values than the metal interface, especially for specimens repaired with Tetric Evo Ceram, and IPS Empress (Nano hybrid composites), this result is consistent with previous studies (Matinlinna and Lassila, 2011; Kupiec *et al.* 1996) which have shown that air blasting with aluminum oxide and the use of a

silane coupling agent provide the most reliable method of pretreating porcelain. This finding disagreed with Yesil *et al.* (2012), who found that the highest degree of bonding strength was found in samples with metal substrates, they suggested that the improvements in adhesion of composites to base metals were made by the addition of adhesive monomers to various composite formulations and these composites bond to corundum-blasted base metal surfaces. Achieving a reliable bond between the metal alloy and resin

based composite had traditionally been problematic.

In the current study, metal surface treatments with air abrasion, acid etching, followed by the use of metal primer improved the metal - resin adhesion, which might be responsible for the non-significant difference in shear bond strength values between metal and porcelain interfaces when repaired with DFL (Micro hybrid Composite). Metal specimens repaired with DFL (Micro hybrid Composite) recorded significantly higher shear bond strength values than other composite resins tested in this study. The success of the composite to metal adhesion depends on the chemical composition of the surface, its roughness, wettability, and the surface conditioning procedure (Blum *et al.* 2012). The monomer of DFL is composed of TEGDMA, Bis-GMA, and Bis-EMA, while both Tetric Evo Ceram and Empress IPS is composed of Bis-GMA and UDMA. Sideridou *et al.* (2002) found that the maximum polymerization degree of UDMA and Bis-GMA was higher than that of TEGDMA and Bis-EMA. Thus both two composites (Tetric and Empress) might not have sufficient unreacted monomers to create a good adhesion with the monopaque resin. The different composition of the resin matrix as well as the larger filler particle size of DFL (Micro hybrid Composite) affect the wettability, and hydrolytic instability of the primer and adhesive agents, which might contribute to the highly significant bond strength values of DFL Composite group than other tested groups. The results are in agreement with the literature in the fact that different polymer matrices and filler fractions will greatly influence the repair bond strength between composites and metal/porcelain substrates (Chung and Hwang, 1997). In this study, repairs to metal surfaces showed a prevalence of combined failure predominantly adhesive in nature, this type of failure is also reported in the literature (Haselton *et al.* 2001; Santos *et al.* 2006). This behavior indicates that the bonding of these systems to a metal substrate was not as effective as the cohesive strength of the repair materials.

Despite the statistical differences within the porcelain subgroups, the variation between bond strength values of the evaluated composites (21.4, 26.1, and 21.6 MPa) was small, as well as all groups presented predominantly porcelain cohesive fracture, indicating that the bond strength between the repair material and the substrate in all groups was superior to the strength of the substrate itself, this behavior also reported in the literature (Santos *et al.* 2006; Sarafianou *et al.*, 2008; Haselton *et al.* 2001). A change in the size and distribution of the

filler particles, significantly improved the physical and mechanical properties of the composites. Kumbuloglu *et al.* (2003) suggested that the larger particle size hybrid composites at the porcelain interface resulted in higher bond strengths than small sized particle composites. However, it is unlikely that the larger particle size hybrid composite which was used in this study different to the extent that it would have caused such variations in the bond strength. Shear bond strength of composite to porcelain with the use of various composite systems have been reported in the range of 6 to 29.9MPa (Fabianelli *et al.* 2010; Yesil *et al.* 2012; Blum *et al.* 2012). The bond strength of composite resin to porcelain is also affected by the bonding agent, a single type of bond was used to strengthen the bonding. It was found that the composites used showed different degrees of bonding strength. The highest degree of bonding strength was found in IPS Empress Direct composite resin, while there was no significant difference in bond strength values between Tetric Evo Ceram and DFL composite resins. This result is in accordance with the findings of Yesil *et al.* (2012), who found that the composite resins used in their study showed different degrees of bonding strength. The strength and endurance of the resin - metal\porcelain adhesion bond strength varied among the tested specimens, depending on the chemistry of adhesion. However, absolute bond strengths of the efficacy of all bonding methods after water storage and thermocycling should be considered as crucial factors in evaluation. By exposing specimens to temperature variation presumably accelerated diffusion of water in a resin -metal\porcelain interfaces, also created stresses because of different coefficient of thermal expansion of the two materials, which result in marginal gaps and detachments. The efficacy of different systems depends on their ability to resist thermal and mechanical stresses to ensure adhesion of resin on metal\porcelain substructures. (Fabianelli *et al.* 2010; Henriques *et al.* 2012)

Shear bond strength testing ignores the nature of the stresses generated within the adherence zone, which can have a significant effect on the mode of failure. In addition bond tests are associated with stress gradients along the interface region which makes evaluation of a 'true' bond strength value difficult. It has been shown that shear bond strength measurements are very sensitive to the method of application of the adhesive, design of the testing arrangement and differences in elastic modulus of the substrates (Matinlinna and Lassilab, 2011). These factors can lead to false

interpretation of the resultant bond strength data with significant differences in shear bond strengths being obtained for different sample configurations when an identical geometric design and an identical adhesive interface are used.

### References

- Blum, I.R.; Nikolinakos, N.; Lynch, C.D.; Wilson, N.H.; Millar, B.J. and Jagger, D.C. 2012. An *In vitro* comparison of four intra-oral ceramic repair systems. *J. Dent.*, 40: 906-12.
- Bona, A.D.; Anusavice, K.J. and Shen, C. 2000. Microtensile strength of composite bonded to hot-pressed ceramics. *J. Adhesive Dent.*, 2:305-315.
- Brosh, T.; Pilo, R.; Bichacho, N. and Blutstein, R. 1997. Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. *J. Prosthet. Dent.*, 77: 122-6.
- Chung, K.H. and Hwang, Y.C. 1997. Bonding strengths of porcelain repair systems with various surface treatments. *J. Prosthet. Dent.* 78: 267-74.
- Crumpler, D.C.; Bayne, S.C.; Sockwell, S.; Brunson, D. and Roberson, T.M. 1989. Bonding to resurfaced posterior composites. *Dent. Mater.*, 5:417-424.
- Fabianelli, A.; Pollington, S.; Papacchini, F.; Goracci, Cantoro, A.; Ferrari, M. and Van, R. 2010. The effect of different surface treatments on bond strength between leucite reinforced feldspathic ceramic and composite resin. *J. Dent.*, 38: 39 – 43.
- Haselton, D.R.; Diaz-Arnold, A.M. and Dunne, J.T. 2001. Shear bond strengths of 2 intraoral porcelain repair systems to porcelain or metal substrates. *J. Prosthet. Dent.*, 86: 526-31.
- Henriques, B.; Gonc-alves, S.; Soares, D. and Silva, F.S. 2012. Shear bond strength comparison between conventional porcelain fused to metal and new functionally graded dental restorations after thermal-mechanical cycling. *J. Mech. Behav. Biomedical Mater.*, 13: 194-205.
- Hummel, S.K.; Marker, V.; Pace, L. and Goldfogle, M. 1997. Surface treatment of indirect resin composite surfaces before cementation. *J. Prosthet. Dent.*, 77: 568- 572.
- Kern, M. and Thumpson, V.P. 1995. Bonding to a glass infiltrated alumina ceramic: adhesive methods and their durability. *J. Prosthet. Dent.*, 73: 240-249.
- Kim, J.Y.; Pfeiffer, P. and Wilhelm N.W. 2003. Effect of laboratory procedures and thermocycling on the shear bond strength of resin-metal bonding systems. *J. Prosthet. Dent.*, 90: 184-189.
- Kumbuloglu, O.; User, A.; Toksavul, S. and Vallittu, P.K. 2003. Intra-oral adhesive systems for ceramic repairs: a comparison. *Acta Odontol. Scand.*, 61: 268-272.
- Kupiec, K.A.; Wuertz, K.M.; Barakameier, WW. and Wilwerding, T.W. 1996. Evaluation of porcelain surface treatment and agents for composite to porcelain repair. *J. Prosthet. Dent.*, 76: 119-124.
- Matinlinna, J.P. and Lassilab, L.V. 2011. Enhanced resin-composite bonding to zirconia framework after pretreatment with selected silane monomers. *Dent. Mater.*, 27: 273–80.
- Mendoza, D.B.; Eakle, W.S.; Kahl, E.A. and Ho, R. 1997. Root reinforcement with a resin – bonded preformed post. *J. Prosthet. Dent.*, 78: 10-15.
- Rinastiti, M.; Ozcan, M.; Siswomihardjo, W. and Busscher, H. 2010. Immediate repair bond strengths of microhybrid, nanohybrid and nanofilled composites after different surface treatments. *J. Dent.*, 38: 29-38.
- Santos, J.G.; Fonseca, R.G.; Adabo, G.L.; Santos, I. and Cruz C.A. 2006. Shear bond strength of metal-ceramic repair systems. *J. Prosthet. Dent.*, 96: 165-173.
- Sarafianou, A.; Seimenis, I. and Papadopoulos, T. 2008. Effectiveness of different adhesive primers on the bond strength between an indirect composite resin and a base metal alloy. *J. Prosthet. Dent.*, 99: 377-387.
- Sideridou, I.; Tserki, V. and Papanastaiou, G. 2002. Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. *Biomaterials*, 23: 1819–1829.
- Sun, R.; Suansuwan, N.; Kilpatrick, N. and Swain, M. 2000. Characterization of tribochemically assisted bonding of composite resin to porcelain and metal. *J. Dent.*, 28: 441–445.
- Swift, E.J.; LeValley, B.D. and Boyer, D.B. 1992. Evaluation of new methods for composite repairs. *Dent. Mater.*, 8: 362-365.
- Yesil, Z.D.; Karaoglanoglu, S.; Akyil, M.S. and Seven, N. 2007. Evaluation of the bond strength of different composite resins to porcelain and metal alloy. *Int. J. Adhesion Adhesives*, 27: 258–62.