Original Article

Shear Bond Strength of a Novel Porcelain Repair System for Different Computer-aided Design/Computer-assisted Manufacturing Ceramic Materials

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Abstract

Objectives: The purpose of this study was to compare the shear bond strength of a novel repair system, Nova Compo SF with Ceramic Repair, Ivoclar, to computer-aided design/computer-assisted manufacturing (CAD/CAM) restorative materials (IPS e.max CAD and Empress CAD). **Materials and Methods:** The specimens of each CAD/CAM restorative material were randomly divided into two subgroups of nine specimens, using one of two repair systems. All specimens were etched with hydrofluoric acid and rinsed under a water spray for 10 s, then air-dried for 10 s. Next, repair systems were applied according to the manufacturer's instructions. All specimens were stored in distilled water at 37°C for 24 h and then additionally aged for 5000 thermal cycles. A shear bond strength test was performed using a universal testing machine. Each fracture type was examined under a stereomicroscope at ×12.5 magnification. A two-way ANOVA test was used to detect significant differences between the CAD/CAM restorative materials and the composite repair systems. Subgroup analyses were performed using Tukey's honest significant difference. **Results:** No statistically significant differences were observed between the repair systems ($P = 0.9$). The bond strength values from Empress CAD were statistically higher than those from e.max CAD ($P < 0.05$). **Conclusions:** Within limitations, SuperFlow may be an alternative to the ceramic repair materials we routinely used in the clinic. Empress CAD can be preferable to e.max CAD in terms of esthetically suitable clinical indications.

Keywords: *Bond strength, computer-aided design/computer-assisted manufacturing, porcelain, repair system*

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Introduction

Researchers have been developing alternative dental materials since the esthetic expectations of patients and clinicians have increased. Glass-matrix ceramics such as feldspathic ceramics, as well as leucite reinforced and lithium disilicate reinforced glass ceramics, have been commonly used in dentistry.[1,2] Despite the esthetic appearance, biocompatibility, and color stability, these materials have some disadvantages such as reduced mechanical properties and tendency to break.[3,4] These restorations can be produced in a traditional laboratory.[5,6]

However, traditional methods have some disadvantages such as a long fabrication time, technical sensitivity, and unpredictable errors.[7] Therefore, the computer-aided design/computer-assisted manufacturing (CAD/CAM) technique has become a good alternative for dentists and laboratories because it reduces the fabrication time of dental ceramics.[8] In addition, CAD/CAM blocks are more homogenous and have minimal flaws compared to other restorative options.[9] In particular, high-strength polycrystalline and glass ceramics can become more stable with CAD/CAM technology.[10] These materials can

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be used manufacture inlays, onlays, veneers, crowns, and short-span bridges in posterior load-bearing regions.[6]

Glass ceramics consist of a glassy matrix and crystals. Empress CAD, introduced in 2006, is a leucite-reinforced glass ceramic. The IPS Empress CAD ingots exhibit a dense, homogeneous distribution of leucite crystals. In these materials, the crystal volumes are 35%–45% and the crystal diameters are 1–5 μm. Empress CAD has a flexural strength of approximately 160 MPa;[11] whereas, lithium disilicate reinforced glass ceramics have more flexural strength (between 350 and 450 MPa). IPS e.max CAD ingots have 70% crystal volume (Li_2SiO_3) embedded in a glassy matrix, and the diameter of the crystals is between 0.2 and 1 μm.[7] The distribution and size of these crystals also affect the optical and mechanical properties of materials.[12]

Despite advances in CAD/CAM materials, various factors (fractures, failure on the bonding interface, occlusal and internal stress, and parafunctional habits) may cause failures.[13] Porcelain fracture is reported in the literature approximately 2%–16%, and 75% of these fractures occur in the maxilla.[14,15] Such fractures cause esthetic problems, especially in the anterior region. These fractures are classified as adhesive (between the restorative material and repair system), cohesive (within the restorative material or repair system), and mixed (both adhesive and cohesive).[16]

Currently, different repair systems are available for clinical use and are divided into direct and indirect repair systems. Each system requires specific protocols with different combinations of adhesive systems and resins to repair ceramic fractures. Repair procedures in fixed prosthetic restorations are divided into repair in the mouth (direct method) and repair outside the mouth (indirect method). The indirect procedure is not preferred by clinicians and patients because it causes additional trauma to the restoration and surrounding soft tissue during removal of the fractured restoration to repair the outside of the mouth.[17] Especially when full ceramic restorations are cemented with resin cements, removing restorations from the mouth becomes even more difficult. Thus, intraoral repair is an effective and conventional treatment option.[18]

Repair systems can contain various application steps such as etching, silane application, and bonding. These procedures decrease the surface tension and create fine surface roughness, while the dissolute glass matrix causes physical alteration to increase the bonding of the resin to the ceramic surface.[19] Recently, self-adhesive flowable composites have been developed in adhesive dentistry. According to the manufacturer's instructions, these materials do not need any etching, silane application, or bonding protocol.[20]

The shear bond strength is one of the mechanical properties of the materials.[21] It has been utilized for characterization of the bonding of resin-to-resin, resin-to-metal, resin-to-ceramic, ceramic-to-ceramic, ceramic-to-metal, and PMMA-to-metal bondings.[22] In this test, a cylindrical adherent material is adhered to the adherend by adhesives. A tool (shear blade, chisel, metallic tape, or wire loop) attached to the instrument crosshead could provide the load acting on the adherent among the test configuration at shear.[23]

The aim of this study was to analyze and compare the shear bond strength of Ceramic Repair and Nova Compo SF to different CAD/CAM restorative materials (Empress CAD and e.max CAD). The first null hypothesis was that there would be no differences between the shear bond strength of the two repair systems and the various CAD/CAM restorative materials, while the second null hypothesis was that no differences would be found between CAD/CAM ceramic types.

Materials and Methods

A power analysis was performed (G*Power software ver. 3.1.10; Heinrich Heine University, Düsseldorf, Germany) to calculate the sample size required for four groups (Empress CAD-Ceramic Repair, Empress CAD-Nova Compo SF, e.max CAD-Ceramic Repair, and e.max CAD-Nova Compo SF). The results indicated an actual power value of 97 for an effect size of $f = 0.8$, $\alpha = 0.05$, noncentrality parameter of 23, and critical $t = 3.2$. A requirement of nine specimens in each group was determined.

Specimen preparation

All materials are shown in Table 1. Thirty-six 1 mm thick specimens were prepared from blocks ($n = 18$ per CAD/CAM restorative material) using a low-speed diamond saw (IsoMet 1000; Buehler Ltd., Lake Bluff, IL, USD) under water cooling. The specimens were then embedded into a self-cure acrylic resin (Meliodent; Bayer Dental Ltd, Newbury, UK) and polished under water cooling, using 400-, 600-, and 1000-grit silicon carbide abrasive paper to standardize the surfaces. The specimens of each CAD/CAM restorative material were randomly divided into two subgroups of 9 specimens each, according to the repair system used in each condition.

Porcelain repair

All specimens were etched with hydrofluoric acid (5% IPS Ceramic Acid Gel, Ivoclar Vivadent, Schaan, Liechtenstein) to clean the ceramic surface and increase bonding values, according to the manufacturer's instructions (20 s for e.max CAD and 60 s for Empress CAD). Then, specimens were rinsed under a water spray for 10 s and air-dried for 10 s. In the ceramic repair group, the surfaces were treated with Monobond S for 60 s. Then, Heliobond was applied and light-cured for 10 s. No bonding agent was required in the self-adhesive SuperFlow group. To standardize the bonding surface, a Teflon mold with a diameter of 5 mm and a length of 3 mm was placed at the center of each specimen [Figure 1]. Tetric Evoceram composite material was placed into the Teflon mold and polymerized for 10 s using a light-polymerizing unit (Lite Q LD-107; Monitex Industrial Co. Ltd., Taipei, Taiwan, light output: 500 mW/cm^2) for the Ceramic Repair group. In the Nova Compo SuperFlow group, flowable composite material was polymerized for 20 s using the same light-polymerizing unit. After polymerization, the Teflon molds were removed and the specimens were kept in distilled water at 37°C, in a dark place, for 24 h. The specimens were then aged for 5000 thermal cycles between 5°C and 55°C, with dwell and transfer times of 20 s.

Shear bond strength test

Ceramic specimens (n = 9) that were embedded in acrylic resin molds were placed into a universal testing machine (Shimadzu Corporation, Kyoto, Japan). A shear bond strength test was performed at a 0.5 mm/min crosshead speed using a knife edge-shaped indenter, which was 5 mm in diameter and 1 mm away from ceramic-composite interface, placed between the CAD/CAM restorative material and the composite resin [Figure 2]. Shear load was applied until a fracture occurred, and the value was recorded in Newtons (N). MPa values were calculated after the test. Each fracture type was examined under a stereomicroscope (Leica model, Leica QWinV.3 software; Leica Microsystem Imaging Solutions, Cambridge, UK) at 12.5x magnification. These examinations revealed adhesive (between the CAD/CAM restorative material and repair system interface) or cohesive (within the CAD/CAM restorative material or repair system) fracture types.

Statistical analysis

The normal distribution of data was examined using the Kolmogorov–Smirnov test. Shear bond strength data of repaired CAD/CAM restorative materials were performed by two-way ANOVA test. Mean bond strength of CAD/CAM restorative materials were analyzed with independent samples t-test. SPSS Statistics V22.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analysis (P = 0.05).

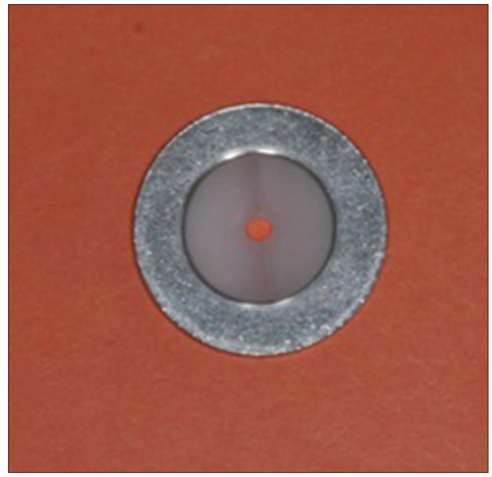

Figure 1: Teflon mold

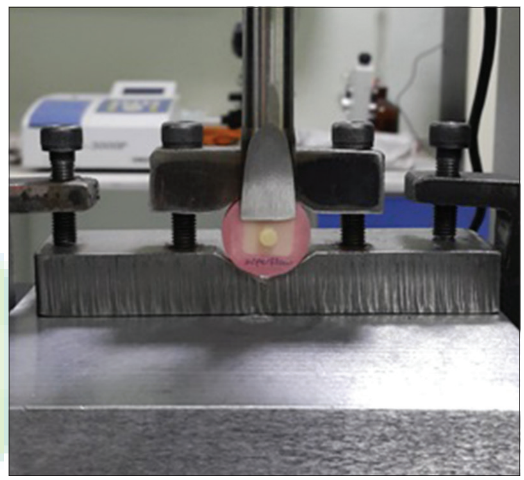

Figure 2: Specimen testing

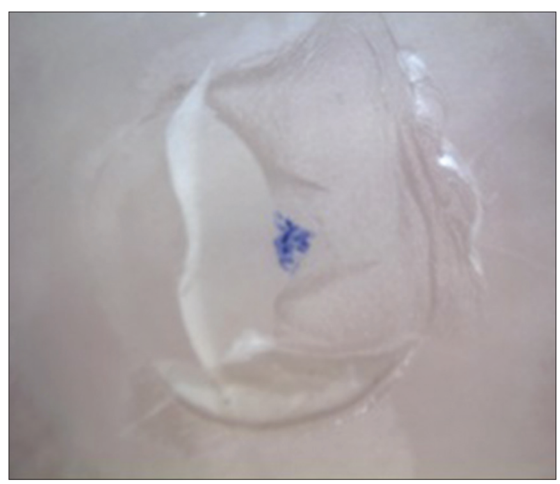

Figure 3: Cohesive fracture (×12.5)

Results

According to Kolmogorov–Smirnov, data showed normal distribution (P = 0.639). According to two-way ANOVA, only material type was found significant (P = 0.000),

Table 1: Used materials

Materials	Chemical composition	Manufacturer
Restorative materials		
IPS empress CAD	60%-65% SiO_2, 16%-20% Al_2O_3, 10%-14% K_2O, 3.5%-6.5% Na_2O	Ivoclar Vivadent AG, Schaan, Liechtenstein
IPS e.max CAD	57%-80% SiO_2, 11%-19% Li_2O	Ivoclar Vivadent AG, Schaan, Liechtenstein
Repair systems		
Ceramic repair		
Monobond-S	3-methacryloxypropyl-trimthoxsilane	Ivoclar Vivadent AG, Schaan, Liechtenstein
Heliobond	Bis-GMA and triethylene glycol dimethacrylate, crystals and stabilizer	
Tetric N Ceram	Dimethacrylates, filler, catalysts, stabilizer and pigment	
Nova Compo SF	10-MDP, 4-META, ULS monomer, dimethacrylates, floroaluminasilicate, initiators and stabilizer	Imıcryl, Konya, Turkey

CAD=Computer-aided design; Bis-GMA=Bisphenol A glycidylmethacrylate; 4-META=4-methacryloxyethyl trimellitate anhydride; ULS=Ultra-low shrinkage; MDP=Methacryloyloxydecyl dihydrogen phosphate

Table 2: Shear bond strength values (MPa) and fracture types of groups

Restorativematerial	Repair system	Mean bondstrength values (MPa)	Fracture types		*n*
			Adhesive (%)	Cohesive (%)	
IPS empress CAD	Ceramic repair	10.52 (±1)[a]	4 (44.4)	5 (55.6)	9
	SuperFlow	10.95 (±1.06)[a]	4 (44.4)	5 (55.6)	9
IPS e.max CAD	Ceramic repair	8.09 (±1.09)[b]	3 (33.3)	6 (66.6)	9
	SuperFlow	7.53 (±1.05)[b]	3 (33.3)	6 (66.6)	9

[a,b]Demonstrates similar means ($P < 0.05$); CAD=Computer-aided design

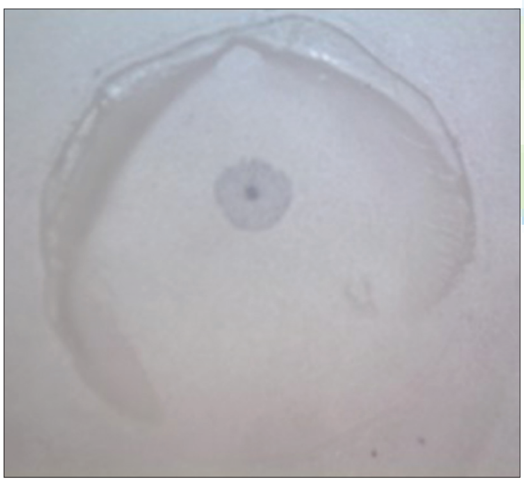

Figure 4: Adhesive fracture (×12.5)

and other factors (repair material type, material type, and repair material type interaction) were found insignificant ($P > 0.05$). Therefore, material type was compared with independent sample's *t*-test. The bond strength values of Empress CAD were statistically higher than e.max CAD ($P < 0.05$) [Table 2].

The numbers of adhesive and cohesive fractures, with their percentages of each group, are shown in Table 2. A stereomicroscopy image of one specimen exhibiting adhesive and cohesive fracture types is shown in Figures 3 and 4. Empress CAD and e.max CAD groups contained both cohesive and adhesive fractures. Adhesive and cohesive fracture rates in the Empress CAD and e.max CAD groups were almost the same.

Discussion

In the present study, we compared the shear bond strength and fracture type between Ceramic Repair (Ivoclar Vivadent) and Nova Compo SF (Imıcryl) and CAD/CAM restorative materials (Empress CAD and e.max CAD). Based on the results, the first null hypothesis was accepted because the bond strength values were not found to be statistically different between the two repair systems ($P > 0.05$); whereas, the second null hypothesis was rejected because the mean shear bond strength values of Empress CAD were higher than those for e.max CAD.

In these two CAD-CAM ceramics, which are preferred for anterior restorations, fractures may occur. Direct (intraoral) repair with composite resin is a suitable alternative to indirect (extraoral) repair[16,24] because of its fast, low-cost solution, and easy use.[12] Repairing restorations require a conditioned surface to increase the adhesion of a resin to a ceramic surface.[25] Different techniques can be used to condition the ceramic surface such as acid etching, sandblasting, and silica coating. Acid etching of the ceramic surface has been the best way to micromechanically enhance the surface roughness of glass ceramics.[26]

Neis *et al.*[27] reported that etching with hydrofluoric acid increases irregularities on the feldspathic, Empress CAD, and e.max CAD ceramics. This method also engenders higher microtensile bond strength compared to tribochemical silica coating and surface wear with diamond bur. Duzyol *et al*.[28] roughened the surface of a feldspathic ceramic, lithium disilicate reinforced ceramic, and resin nanoceramic using a bur, bur and 5% HF, bur and sandblasting, or bur and silica-coating treatment. The highest bond strength values were found in the hydrofluoric acid group for lithium disilicate reinforced ceramics. Furthermore, Sundfeld Neto *et al*.[29] applied different concentrations of hydrofluoric acid (1%, 2.5%, 5%, 7.5%, 10%, and 15%) to IPS Empress esthetic and e.max CAD and found no statistically significant differences between the shear bond strength of the materials. According to these studies, we standardized the surface of our ceramics by etching with 5% hydrofluoric acid.

Another important factor in increasing the bond strength of composite resins to ceramics is a bonding agent. Various adhesive systems are available such as the self-etch and total-etch (etch and rinse) adhesive systems.[30] The total-etch system needs two separate steps of rinsing and drying and has a higher technical sensitivity. Due to its acidic monomer, the self-etch adhesive does not need an etching phase, rinsing, or drying. The bonding of the total-etch and self-etch adhesives to enamel, dentine, and porcelain surfaces can be compared. Mohammadi *et al*.[31] found no statistical differences between the bond strength of the self-etch and total-etch adhesives and feldspathic porcelain, as we have found in our study. Conversely, dos Santos *et al*.[32] applied a total-etch and self-etch adhesive repair systems to feldspathic porcelain. The authors found that the self-etch adhesive repair system (Bistite II) showed higher shear bond strength values than the total-etch adhesive repair system (Clearfil SE Bond).

The ceramic repair (Ivoclar) system also requires silane (Monobond S) and bond (Heliobond) applications. Monobond S contains silane, which is a dually functional monomer with a silanol group that reacts with porcelain's surface. Silane includes a methacrylate group that copolymerizes with a composite resin matrix.[26] In addition, silane increases both wettability of a glass matrix as well as mechanical and chemical bonding of a composite resin to porcelain.[33]

Nova Compo SF is a self-adhering, flowable dental composite that can be used as pit and fissure sealant; direct composite material in Class I, III, and V restorations; base/liner for all restorations; and porcelain repair materials, according to the manufacturer's instructions. Therefore, we compared the shear bond strength of a novel porcelain repair system (Nova Compo SF) with that of a porcelain repair system (Ceramic Repair System Kit) and different CAD/CAM ceramics used routinely in our clinic.

Nova Compo SF has some advantages such as its two functional monomers (methacryloyloxydecyl dihydrogen phosphate [MDP] and 4-methacryloyloxyethyl trimellitic acid anhydride [4-META]) that form a better double-chemical adhesion, reduce potential sensitivity, bond without a separate bonding agent, and improve restorative procedures by reducing the time, steps, and materials needed.[34] MDP (diphosphate monomer) optimizes self-etch performance and provides durability in adhesion. This monomer, which has a phosphate group for bonding to metal oxides, has a higher bond strength than base metal alloy or polycrystalline ceramics (aluminum oxide and zirconium oxide).[35] Because these materials do not have glass, etching with hydrofluoric acid is not recommended. Instead, previous studies have recommended using a bonding agent that contains 10-MDP after sandblasting.[36] While there are many studies demonstrating that MDP monomer improves the bond strength between metal-composites and polycrystalline ceramics composites, there is no evidence that this monomer improves the bond strength between leucite and lithium disilicate reinforced ceramic composite. 4-META monomer has been shown to have good bonding properties to base metal alloys such as MDP.[37]

In our study, shear bond strength values of Empress CAD were found to be higher than those for e.max CAD. Whereas Empress CAD contains 60%–65% SiO_2 and 16%–20% Al_2O_3,[38] e.max CAD contains 57%–80% SiO_2, but does not contain Al_2O_3.[39] This difference can affect the effectiveness of MDP in SuperFlow and may explain the higher Empress CAD bonding values in our study. In addition, the manufacturer's instructions indicate that Nova Compo SF contains a high molecular weight ultra-low shrinkage (ULS) monomer, which has a high molecular weight and a small amount of C=C double bonds, which limits polymerization shrinkage. Moreover, the ULS monomer exhibits a higher monomer-to-polymer conversion than that of conventional urethane dimethacrylate, bis-glycidyl methacrylate monomers. The ULS monomer has good elongation and toughness, which is why Nova Compo SF can be used for highly durable restorations.[34] This information can explain why the self-adhesive system, SuperFlow, is as successful as total-etch repair systems (Ceramic Repair, Ivoclar).

The fractures observed can be classified as adhesive, cohesive, or mixed according to the region where the fracture occurs.[16] Ustun *et al*.[40] evaluated the shear bond strength of different repair systems (Ceramic Repair and Clearfil repair) to CAD-CAM restorative materials (IPS e.max CAD, Vita Suprinity, Vita Enamic, and Lava Ultimate) and found complete adhesive failure in the e.max CAD group. In our study, we found the same rates for the fracture types of restorative materials.

On the other hand, one of the limitations of our work was that the defect size could influence the bond strength of the repair material. When the defect area was larger, or a face of the restoration was completely fractured, the success of the repair material may have been changed. *In vitro* findings cannot directly represent the *in vivo* conditions. Further, *in vitro* and *in vivo* studies are required to confirm the results of our study.

Conclusions

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

1. SuperFlow may be an alternative to ceramic repair materials we routinely use in the clinic
2. Higher shear bond strength values were found in Empress CAD specimens. Empress CAD can be preferred to e.max CAD in esthetically suitable clinical indications.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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