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Microtensile Bond Strength of Lithium Disilicate to Zirconia with the CAD-on Technique

Maj James Renda

Abstract

Purpose: Recently, a novel technique was introduced to combine lithium disilicate and zirconia into one restoration. The purpose of this study was to compare the microtensile bond strength of veneering ceramic to a zirconia core in two different techniques: the e.max® CAD-on technique and the Press-on technique (Ivoclar Vivadent). **Materials and Methods:** Group A was prepared by veneering sintered zirconia blocks (e.max® ZirCAD, Ivoclar Vivadent) with lithium disilicate blocks (e.max® CAD, Ivoclar Vivadent) using the CAD-on technique according to manufacturer's instructions. Group B was prepared by taking sintered e.max® ZirCAD blocks and veneering them with fluorapatite glass-ceramic (e.max® ZirPress, Ivoclar Vivadent) using the Press-on technique according to manufacturer's instructions. Each block was loaded in a dynamic cyclic loading machine. The blocks were then sectioned into 1mm x 1mm beams (n=43) using a precision saw, thermocycled, and loaded in tension until failure on a universal testing machine (Instron). A mean and standard deviation were determined per group. Data were analyzed using an unpaired t-test ($\alpha=0.05$). **Results:** The mean microtensile bond strengths were 44.0 ± 13.8 MPa for the CAD-on technique and 14.9 ± 8.8 MPa for the Press-on technique. Significant differences were found between the two groups ($p<0.05$). **Conclusions:** The CAD-on technique (lithium disilicate / zirconia) resulted in greater microtensile bond strength than the Press-on technique (fluorapatite glass-ceramic / zirconia).

Keywords: All-ceramic; zirconia framework; CAD-on; Press-on; microtensile bond strength

Introduction

All-ceramic crowns and fixed dental prostheses (FDPs) are increasingly being used in clinical dentistry due to their optimal esthetics and ease of use. In regards to esthetics, all-ceramic crowns may be more esthetic than metal-ceramic restorations specifically due to their lack of metal substructure which allows them to blend with natural teeth.[1] When CEREC®2 (Sirona Dental Systems, Charlotte, NC) was introduced in 1994, its capability of milling single unit crowns forever changed the landscape of all-ceramic restorations. Companies began to develop all-ceramic systems that not only attempted to meet esthetic demands, but also incorporated computer aided design/computer aided manufacturing (CAD/CAM) technology for chair-side and laboratory uses. The benefits of milling indirect restorations using CAD/CAM include: ability to provide a definitive restoration for a patient the same day as tooth preparation, elimination of porosities inherent in hand-applied porcelain, elimination of casting errors by precise milling of frameworks, and compensation of volumetric shrinkage of core ceramics such as yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP).[2,3] It has been reported that marginal adaptations as low as 9-15µm have been achieved in milled restorations.[4] Also, it has been shown that in the right applications, these CAD/CAM all-ceramic restorations can have good durability with the survival rate of all-ceramic FDPs with zirconia frameworks after 5 years being comparable to that of conventional metal-ceramic FDPs at 8 years.[5, 6]

Some of the success of all-ceramic crowns and FDPs could be attributed to the strength of the core materials. Today, Y-TZP is considered the core material of choice for all-ceramic posterior restorations, particularly FDPs, due to its superior flexural strength and fracture toughness compared to other core materials.[7,8] One study reported that the fracture load of 3-unit FDPs with a Y-TZP framework was significantly higher than frameworks made of glass-infiltrated alumina and glass-infiltrated alumina strengthened with zirconia.[9] Recently, it has been shown that ceramic restorations with zirconia cores have greater flexural strength than other ceramic cores including lithium disilicate regardless of zirconia veneering techniques.[10] However, despite the superior flexural strength of Y-TZP, chipping of the veneering porcelain is the problem that has plagued restorations with zirconia cores. Aboushelib et al. concluded, “The core-veneer bond strength is one of the weakest links of layered all-ceramic restorations and has a significant role in their success.”[11] One study reported after 3 years, 13% of FDPs with zirconia frameworks had chipping of veneering porcelain which was “veneered using conventional veneering techniques” and their follow up study at 5 years showed chipping of the veneering ceramic in 25% of the FDPs.[8,12]

Möllers et al. summed up the significance of chipping/delamination of veneering porcelain by stating, “The veneering material plays a significant role for the failure of a FDP and cannot be neglected neither in testing nor in simulation. Thus the loading capacity of dental restorations can only be reasonably evaluated when the whole restoration is taken into account, including framework and veneering.”[13] One author attributed the chipping to residual stresses developed when the core and veneering porcelain are sintered and cooled in the fabrication process. These residual stresses may be the result of differences in coefficients of thermal expansion (CTE) and from the effects of porcelain thickness on the critical cooling rate of the all-ceramic restoration.[14] Another possible reason for the veneer chipping and delaminating from the zirconia core could be attributed to a possible phase transformation at the interface between the veneer and core resulting in stresses.[15] Furthermore, the original technique of fabricating a core with a uniform thickness of about 0.5 mm creates a situation in which there was unsupported veneering porcelain, which is prone to fracture. It is now more common for the laboratory technician to work from the outside in, starting with the final shape of the restoration and virtually reducing the core to create space for a more uniform thickness of veneering porcelain, which results in a stronger restoration.[16] The clinical studies evaluating zirconia-based restorations do not always state whether a modified core design was used, or which method was used to apply the veneering porcelain. The majority of the clinical studies mentioned in the overview of zirconia-based restorations by Denry and Kelly utilized the layering technique.[15] Esthetic considerations might limit the use of monolithic zirconia restorations. Because of the problem with chipping of the veneering porcelain, manufacturers are using different methodologies, such as the Press-on or the CAD-on technique, to adhere porcelains with stronger physical properties to zirconia cores.

Conventional layering differs from the Press-on technique where a molten fluorapatite glass-ceramic (IPS e.max® ZirPress, Ivoclar Vivadent, Amherst, NY) is pressed onto the Y-TZP framework using a lost-wax technique. The Press-on technique requires the application of IPS e.max® Ceram ZirLiner (Ivoclar Vivadent) to the IPS e.max® ZirCAD (Ivoclar Vivadent) core, and then waxing a full contour pattern on the core. The waxed core is invested and the wax is burned out. The fluorapatite glass-ceramic ingots are placed into the investment. The investment is placed into an oven to melt the ingot and a plunger presses the molten ceramic over the zirconia core. After cooling, the restoration is divested, polished, stained, and glazed. Even though Beuer et al. reported no chipping of the veneering porcelain utilizing a Press-on technique after 3 years, it is difficult to state the true clinical performance of the Press-on technique and further clinical studies should be conducted.[17]

In the IPS e.max® CAD-on technique, the veneering ceramic is lithium disilicate (IPS e.max® CAD, Ivoclar Vivadent). Lithium disilicate has become a popular material for all-ceramic restorations both as a core and as a monolithic full contour restoration either milled through CAD/CAM or by using pressed techniques. Although the flexural strength of lithium disilicate restorations is not as strong as zirconia as a core, it has been shown to exhibit "good durability", with only 2.5% of the restorations chipping at 4 years.[10,18] In the CAD-on technique, the Y-TZP core and the lithium disilicate are both milled using CAD/CAM technology. Then, the two milled components are adhered to one another using a fusion glass ceramic (IPS e.max® CAD-Crystall./Connect, Ivoclar Vivadent). The fusion glass ceramic is solid in the quiescent state and liquefied by means of high-frequency vibration (Ivomix, Ivoclar Vivadent). The fusion glass ceramic is then vibrated into the intaglio surface of the milled veneering ceramic, and the Y-TZP core is pressed into the veneer just using finger pressure in combination with the high frequency vibration similar to cementation of a crown. After the excess material is removed, the restoration is put through a crystallization cycle in a ceramic oven, fusing the two components into one restoration. A three-unit fixed-denture prosthesis using the CAD-on technique is demonstrated in Figure 1. The idea of using milled lithium disilicate as a veneering ceramic to a Y-TZP core was studied by Beuer et al. They found greater fracture resistance and superior mechanical stability than conventional layering and pressed techniques on zirconia cores. However, the fusion glass ceramic was described as an "experimental connector material."[19] In 2012, the only study comparing conventional layering technique with the CAD-on technique was published by Schmitter et al. They found that 87.5% of the conventional layering group subjected to *in vitro* aging failed before fracture tests could be carried out, and the CAD-on group not only survived aging, but displayed fracture failure loads up to 1600 N. The investigators concluded that using a CAD/CAM lithium disilicate veneer over a Y-TZP framework was a "promising way to reduce failures originating from material fatigue."[20]

A recently published study by Harding et al. focused on the surface treatments of the core. They concluded that air-abrasion of the Y-TZP framework prior to bonding of veneering porcelain decreased the bond strength, and that the use of IPS e.max® Ceram ZirLiner neither increased nor decreased the bond strength.[21] Another study found no significant difference in the shear bond strength of a nano-fluorapatite glass-ceramic (e.max® Ceram) to a Y-TZP (e.max® ZirCAD) or a lithium disilicate (e.max® CAD) core.[22] Zieghami et al. reported a clinically significant decrease in microtensile bond strength of zirconia core to feldspathic veneering porcelain using the layering technique when the all-ceramic restorations were fired in an oven multiple times.[23] These studies provide valuable information on the strength of various veneering materials to a zirconia core, however, more research is needed investigating the new IPS e.max® CAD-on technique.

The purpose of this study was to compare the bond strength of veneering ceramic to a zirconia core using the IPS e.max® CAD-on and Press-on technique. The null hypotheses tested was that there was no difference in microtensile bond strength of zirconia to lithium-disilicate in the IPS e.max® CAD-on technique or nano-fluorapatite glass-ceramic in the Press-on technique.

Materials and methods

The ceramic restorative materials tested in this study are outlined in Table 1. [24] Four blanks of e.max® ZirCAD (size B40) were sectioned in half using a precision saw (Isomet 5000, Buehler, Lake Bluff, IL) producing eight solid Y-TZP core blocks (14.2 x 15.5 x 20mm). Four of the e.max® ZirCAD blocks were used in each of two sample groups (A and B). Two blanks of e.max® CAD were also sectioned in half. Then, the sectioned blanks were sectioned again into four, 11.4 x 12.4 x 4mm blocks. After sectioning, the veneering surfaces of the blocks of e.max® ZirCAD and e.max® CAD were roughened to simulate a milled surface with a diamond bur (CEREC MC XL Step Bur, Sirona Dental Sytems) in a slow-speed electric handpiece mounted in a custom jig (Sabri Dental Enterprises, Downers Grove, IL). Next, the e.max® ZirCAD blocks were sintered in an oven (Everest Therm 4180, Kavo, Charlotte, NC) according to the recommendations of manufacturer based on the size of the core. Taking into account the volumetric shrinkage of the e.max® ZirCAD after sintering, the new dimensions were approximately 11.4 x 12.4 x 16mm.

Sample group A (CAD-on technique) was prepared by veneering four of the sectioned e.max® ZirCAD blocks with the four sectioned e.max® CAD blocks according to manufacturer's instructions. The core (e.max® ZirCAD) was luted to the veneering ceramic (e.max® CAD) using a pre-dosed fusion glass ceramic (IPS e.max® CAD-Crystall./Connect, Ivoclar Vivadent) that was liquefied in its capsule on the Ivomix unit (Ivoclar Vivadent) by means of vibration. The fusion glass ceramic was applied to the surface of the sectioned e.max® CAD block and the two components (e.max® CAD and e.max® ZirCAD) were pressed together while being vibrated. The excess was removed and the block combination was placed in the ceramic furnace (Programat P500, Ivoclar Vivadent) for fusion/crystallization according to the manufacturer's instructions using the specific parameters developed for the e.max® CAD-on technique.

Sample group B (Press-on technique) was prepared by veneering four of the sectioned e.max® ZirCAD blocks with e.max® ZirPress according to the manufacturer's instructions. The e.max® ZirCAD blocks had e.max® Ceram ZirLiner brushed onto the roughened surface of the block. The blocks were fired using the parameters recommended by the manufacturer's instructions. A standardized 11.4 x 12.4 x 6mm sprued wax pattern was luted to the e.max® Ceram ZirLiner coated surface of the e.max® ZirCAD block with sticky wax. The resulting assembly was invested in IPS PressVEST® (Ivoclar Vivadent) and placed in the furnace for the pressing of the veneering ceramic, e.max® ZirPress onto the e.max® ZirCAD block (i.e., lost-wax technique for pressed ceramics). The specimens were divested and trimmed with diamond burs.

All eight specimens were put into a dynamic cyclic-loading machine (Sabri Dental Enterprises) and subjected to a loading cycle of 50,000 cycles under a load of 150 N at 1 Hz in distilled water at room temperature. Then, each specimen was embedded in acrylic resin (Frick International, Streamwood, IL) and sectioned using the precision saw. The embedded specimens were sectioned with five parallel slices of the diamond blade. Light body vinyl polysiloxane impression material (Extrude, Kerr, Orange, CA) was injected into the slices to absorb the vibration energy produced by the cutting blade. Five more slices were made perpendicular to the original cuts to create a grid of 16 beams. A final slice was made in a third plane to separate the specimens to create a total of 64 (8x1x1mm) beams for each sample group.

The beams were inspected for defects and unacceptable beams were discarded for reasons such as premature fracture during sectioning or chipping of the ceramic. The remaining beams per sample group (n=43) were subjected to 5,000 cycles of thermal cycling at 5ºC and 55ºC with a 30-second dwell time (Sabri Dental Enterprises). The cross-sectional area of each beam was recorded using a digital caliper. Each beam was luted to a fixture mount using a cyanoacrylate adhesive (Zap-It, DVA, Corona, CA) then loaded in tension until failure at a cross-head speed of 1mm/min on a universal testing machine (Model 5943, Instron, Norwood, MA). The maximum force at failure was recorded in Newtons and converted to megapascals (MPa = force/cross-sectional area). The mean and standard deviation was calculated per group and the data were analyzed by an unpaired t-test (α=0.05).

The specimens were observed under light microscopy to determine whether failure modes were cohesive, adhesive, or mixed. Cohesive failures occurred within the veneering ceramic, while adhesive failures occurred at the interface between the Y-TZP core and the veneering ceramic. Mixed failures included failures that were not completely adhesive or cohesive. The data was analyzed with a Fisher's Exact Test (α=0.05). See table 2.

Results

The mean microtensile bond strengths were 44.0 ± 13.8 MPa for the CAD-on technique (sample group A) and 14.9 ± 8.8 MPa for the Press-on technique (sample group B). A significant difference was found between the two groups (p=2.7E-19). Sample group A had no cohesive failures, 20 adhesive failures (47%), and 23 mixed failures (53%). Sample group B had 22 cohesive failures (51%), no adhesive failures, and 21 mixed failures (49%). A significant difference was found between the two groups (p=2.3E-12).

Discussion

The null hypothesis was rejected; the microtensile bond strength of the CAD-on technique (sample group A) was significantly higher than the Press-on technique (sample group B). By executing this research *in vitro*, the design of this study eliminated the many clinical variables of crown and FDP fabrication including preparation design, cementation, and underlying tooth or core structures. Also, the materials and techniques were all from the same manufacturer and the same Y-TZP core material was utilized in both groups.

As previously mentioned, the majority of the studies evaluating the clinical performance of zirconia-based restorations have focused on conventional layering techniques where feldspathic porcelain was stacked onto the Y-TZP core and fired in increments. It should be noted that this layering technique was piloted for this study, but there were complications with bonding to the flat surface of the Y-TZP block and the amount of firing cycles needed to layer the porcelain to a thickness of 4mm required for creating beams for microtensile bond strength testing. The layering method repeatedly failed and no specimens were fabricated. In addition, approximately 1/3 of the specimens from both the CAD-on and Press-on technique were discarded due to premature fracture or chipping of the ceramic during fabrication of the beams. The actual microtensile bond strength of the discarded beams was not determined in this study and limits the ability to include lower failure loads.

Over the last decade, the Press-on technique has been another popular method for fabrication of all-ceramic restorations that utilize a Y-TZP core. In this study, the mean microtensile bond strength value of the Press-on group (14.9 MPa) was similar to the values previously reported by Harding et al. in 2012 (13.55-18.11 MPa) and lower than the values reported by Aboushelib et al. in 2008 (16.8-49.8 MPa).[21,25] However, as Harding et al. suggested, the lower values could be due to the thickness of the zirconia block causing a relative decrease in cooling rate leading to more residual stresses within the veneering ceramic.[21] Even though the manufacturer (Ivoclar Vivadent) recommends the use of e.max® ZirLiner before pressing e.max® ZirPress over e.max® ZirCAD, it has been reported that the use of a liner weakens the bond strength.[26,27] Harding et al. also proposed that the inherent porosities in e.max® ZirLiner in his testing specimens may be present because the liner is brushed on and fired similar to layered ceramics, possibly weakening the resultant bond strength.[21] Porosities within the e.max® ZirLiner were also noted microscopically in this study as well, supporting this theory. In contrast, the fusion glass ceramic in the CAD-on technique has no liquid added to it, providing a uniform thickness when vibrated into place between the core and veneer during the crystallization cycle. During microscopic examination following failure, no porosities were noted in the CAD-on group. The modes of failure in this study could be attributed to the relative strengths of the veneering materials. It has been reported that the flexural strength of lithium disilicate (e.max® CAD) is 360 MPa, whereas the flexural strength of the fluorapatite glass-ceramic ingot (e.max® ZirPress) is 110 MPa.[19] These differences in flexural strengths may explain the failure modes of the Press-on group which were 51% cohesive and 49% mixed. The CAD-on group had no cohesive failures with only 47% adhesive and 53% mixed failures.

As previously mentioned, the CAD-on technique offers an alternative method to utilize a Y-TZP core. With the historical problem of delamination/chipping of the veneering porcelain over a zirconia framework, there have been two areas of focus: the strength of the veneering materials and the bond between zirconia and the veneering porcelain.[11,13] The results of this study show that that bonding lithium disilicate to Y-TZP will produce a better bond than the bond between fluorapatite glass-ceramic and the Y-TZP core.

Since the introduction of the CAD-on technique, another technique has been marketed which uses resin cement instead of a fusion glass ceramic to adhere veneering porcelain to a zirconia framework. The concept of milling the zirconia framework and the veneering porcelain and luting the layers together was studied most recently by Schmitter et al.[28] In their study, the investigators made crowns with zirconia cores and subjected two groups to *in vitro* chewing simulation. One group was veneered using conventional layering of feldspathic porcelain and the other group was fabricated by cementing a CAD/CAM-milled feldspathic porcelain (CEREC bloc, Sirona) to the zirconia core with Panavia 2.0 (Kuraray, New York, NY). They found that 87.5% of the crowns veneered with layered feldspathic porcelain failed, while none of the CAD/CAM-veneered crowns failed chewing simulation.[28] Future studies evaluating zirconia-based restorations should continue to focus on comparing mechanical properties and clinical performance between the four veneering techniques: layered porcelain, Press-on, and cemented or fused CAD/CAM-veneering of zirconia core materials.

Conclusion

Within the parameters of this study, it can be concluded:

1. The CAD-on technique, with lithium disilicate bonded to zirconia, resulted in greater microtensile bond strength than the Press-on technique with fluorapatite glass-ceramic bonded to zirconia.
2. The failure of the CAD-on technique is less likely to be within the veneering ceramic (cohesive failure).

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