Shear bond strengths of pressed and layered veneering ceramics to high-noble alloy and zirconia cores

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Statement of problem. Heat-pressed ceramics to metal alloys and zirconia have been available for some time. However, information regarding their shear bond strengths is limited.

Purpose. The purpose of this study was to evaluate the shear bond strengths of heat-pressed and layered ceramics with regard to their corresponding high-noble alloy and zirconia cores.

Material and methods. Forty cylinders (approx. 5 mm in diameter) of high-noble alloy (Olympia) were cast and divided into 4 groups (n=10). Metal cylinders were veneered with ceramics to produce shear test specimens: Group PMI with IPS InLine POM; Group LMI with IPS InLine; Group PMC with Pulse press-to-metal; and Group LMC with Authentic Pulse Metal ceramic. Forty cylinders (approx. 5 mm in diameter) of zirconia (Lava) were obtained and divided into 4 groups (n=10). These cylinders were veneered with ceramics to produce shear test specimens: Group PZI with IPS e.max ZirPress; Group LZI with IPS e.max. Ceram; Group PZV with VITA PM9; and Group LZV with VITA VM9. The veneering ceramics, 3 mm in thickness, were either pressed or layered to their corresponding cylinders. Thermal cycling was performed at 5°C and 55°C for 20,000 cycles with a 20 second dwell time. Shear bond strength testing was conducted in a universal testing machine, and the failure strengths were recorded. Fracture surfaces were characterized visually, under a stereomicroscope, and with a scanning electron microscope (SEM). Data were analyzed using rank-based Kruskal-Wallis and Mann-Whitney tests with Bonferroni correction to adjust for multiple comparisons (α=.05).

Results. For metal ceramic specimens, the mean (SD) shear bond strengths ranged from 37.8 (20.6) MPa to 66.4 (22.1) MPa. There were significant differences between Groups PMI and PMC and between Groups LMI and PMC, in which Groups PMI and LMI had significantly higher strength values than Group PMC (P=.041). For zirconia ceramic specimens, the mean (SD) shear bond strengths ranged from 30.03 (9.49) MPa to 47.2 (13.0) MPa, with Group LZV having a significantly higher shear bond strength value than Group LZI (P=.012). Half of the Group PZV specimens failed during thermal cycling, and Group PZV was, therefore, excluded from statistical analysis. For all shear bond strength testing specimens, cohesive failures in the veneering ceramics were observed.

Conclusions. For shear bond strength of veneering ceramics to high-noble alloy, there was no significant difference between pressing and layering with the same manufacturer. For shear bond strength of veneering ceramics to zirconia, there was no significant difference between the pressed and layered groups. (J Prosthet Dent 2011;105:29-37)

Clinical Implications

The results of this in vitro study suggest that, for shear bond strength, clinicians and dental laboratory technicians should consider the use of pressed ceramics to high noble alloy and zirconia as an alternative to traditional layering procedures.

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For complete fixed dental prostheses, metal ceramic restorations, for which there are long-term clinical data, have been a preferred restoration.[1-3] Currently, the clinical data[4-6] suggest that zirconia-based restorations should be considered as an emerging restorative option. Unlike monolithic restorations, such as gold complete crowns and unveneered lithium disilicate-based restorations, these restorations consist of core (coping, framework, or substructure) and veneering ceramic.[7] Traditionally, veneering ceramics are layered on metal or zirconia core materials to establish an optimum esthetic outcome. An alternative technique is to press veneering ceramics to the core materials. Although the pressing technique is not a new technology,[8-10] a process for pressing ceramics to metal and zirconia cores using the lost-wax technique and glass-ceramic ingots has been recently developed.

In pursuit of superior esthetics and biocompatibility, the use of ceramic materials has increased in clinical practice and research.[11-14] Esthetic ceramics such as feldspathic porcelain are brittle in nature and weak in tension.[6] Therefore, high strength core materials have been used to reinforce the esthetic, but brittle, veneering ceramics. Such high strength cores not only support the veneering ceramic but also allow clinicians to use a wide range of conventional or adhesive luting protocols during insertion of the restoration.[15,16] It should also be emphasized that adequate tooth preparation and carefully managed laboratory procedures, including maintaining a smooth, uniform thickness of the veneering ceramic on the cores, are also important.[17]

Metal alloys have been extensively used as cores of metal ceramic restorations ranging from single crowns to long-span fixed dental prostheses.[1] Disadvantages of metal alloys are that they do not allow any light transmission and hinder esthetic harmony with the veneering ceramics. Therefore, the masking of metal with opaque porcelain following airborne-particle abrasion and oxidation is required. In contrast, zirconia allows some light transmission,[18] and thus, veneering ceramics can be applied directly to the zirconia cores without masking. In addition, zirconia has better mechanical properties such as flexural strength and fracture toughness compared to other ceramic materials.[19]

The layering technique has been the principal method of applying veneering ceramics to the core material. With this technique, porcelain powder is mixed with modeling liquid, and the mixture is layered on the core using a brush. The layer is usually over built to compensate for condensation and firing shrinkage. Overall, this technique requires skill and multiple applications and firings. With the pressing technique, a complete contour anatomical waxing is performed on a core, and subsequently a sprue is attached to the wax, and the wax-core complex invested. The wax is eliminated in an oven and ceramics are heat-pressed into the mold and to the core, thereby reproducing the anatomy created in the wax and allowing for the creation of the desired tooth anatomy. Moreover, the firing shrinkage experienced with the layering technique is minimized, resulting in a better fit of the porcelain margins to the abutments.[20,21] Distortion of the metal may be reduced during veneering because of support from the investment.[22] However, the heat-pressed method makes development of excellent esthetics more difficult, because the appearance relies on precolored ingots. However, this esthetic limitation can be minimized by a combined technique in which a foundation layer is created on the core with the pressing technique, leaving space for a subsequent and more esthetic ceramic to be applied as a powder.

Both in vivo prospective and retrospective studies evaluating the clinical performance of metal ceramic and zirconia-based restorations have been published.[1-6,23-25] Since metal ceramic restorations have a record of documented outcomes, the performance of ceramic restorations is often compared to that of metal ceramic restorations. Sailer et al[25] reported a similar survival rate for both metal and zirconia-based posterior partial fixed dental prostheses (FDPs) at 3 years of function and with a 100% survival for each. Both types of restorations exhibited minor chipping of the veneering ceramic with more extensive fracture occuring with zirconia-based restorations. When evaluating mechanical complications, chipping and delamination of the veneering ceramic have been more frequently reported than damage to the core.[4,24,25] An understanding of the properties of veneering ceramics and the bonding mechanism at the interface between the core and the veneer material is essential. Interestingly, Beuer et al[26] evaluated posterior zirconia-based 3-unit FDPs that were veneered using pressable glass-ceramic and reported no chipping of the veneering porcelain. However, 2 restorations needed to be replaced due to zirconia framework fracture and loss of retention. This may imply that the application technique of veneering ceramics has the potential to reduce the complication of cohesive fracture. Some authors have used various methods to evaluate the core-veneer bond strengths of veneering ceramic to metal alloy and zirconia cores, and a standard for bond strength has been established for metal ceramics, but not for zirconia.[27-30]

Shear strength is the maximum stress that a material can withstand before failure in a shear mode of loading and is particularly valuable in the study of interfaces between materials.[31] For both metal and zirconia ceramic restorations, studies regarding shear bond strengths have been published.[32-40] According to the International Standards Organization (ISO), the bond between the metal alloy and the veneering ceramics should be a minimum of 25 MPa.[41] However, to the authors' knowledge, a study evaluating shear bond strengths of

both pressed and layered ceramics to the corresponding metal and zirconia cores has yet to be published.

The purpose of this in vitro study was to evaluate the shear bond strengths of pressed and layered ceramics to their corresponding high-noble alloy and zirconia cores. The first null hypothesis was that the shear bond strength of pressed ceramic would not be different from that of layered ceramic to high-noble alloy. The second null hypothesis was that the shear bond strength of pressed ceramic would not be different from that of layered ceramic to zirconia.

MATERIAL AND METHODS

In this study, pressed ceramics to core materials were defined as the experimental groups, and layered ceramics to the core materials were control groups. Fabrication of specimens and shear bond tests were performed by a single operator.

For the metal ceramic experiment, 40 cylindrical metal specimens were fabricated and ceramics were pressed or layered on one end of the cylinders. The materials used, the corresponding lot number, and the manufacturers' information are presented in Table I. Firing cycles are presented in Table II. To fabricate the metal cylinders, a stainless steel mold, which had holes approximately 5 mm in diameter and depth, was used, and autopolymerizing acrylic resin (Pattern Resin LS; GC America Inc, Alsip, Ill) was injected into the holes and allowed to polymerize. The patterns were evaluated under a stereomicroscope (Inoue Attachment, Tokyo, Japan) using x10 magnification, and the defects were corrected with wax (GEO wax wire medium hard blue 3 mm; Renfert GmbH, Hilzingen, Germany) when needed. Wax sprues (GEO wax wire medium hard blue 3 mm; Renfert GmbH) were attached to the patterns, which were then invested with a carbon-free phosphate investment (Cera-Fina; Whip Mix Corp, Louisville, Ky). The invested patterns were placed in an oven (KaVo Dental GmbH, Biberach, Germany). High-noble metal alloy (Olympia; Jelenko, San Diego, Calif) was melted using an oxygen-gas torch and cast using a non-vacuum centrifugal casting machine (Centrifico; Kerrlab, Orange, Calif). After divesting and removing the sprues, the metal cylinders were divided into 4 groups and coded by veneering process and manufacturer (n=10): Group PMI: IPS InLine POM (Ivoclar Vivadent, Schaan, Liechtenstein), Group LMI: IPS InLine (Ivoclar Vivadent), Group PMC: Pulse press-to-metal (Ceramay, Neu-Ulm, Germany), Group LMC: Authentic Pulse (Ceramay).

The surfaces to be veneered were finished using 240 grit silicon carbide

Table I. Study materials evaluated

Material	Lot Number(s)	Manufacturer
Metal ceramic specimens:		
Olympia metal alloy	3547839, 3302082, 3342076	Jelenko, San Diego, Calif
IPS InLine/IPS InLine PoM Opaquer	L47540 (Pa), L28110 (L)	Ivoclar Vivadent, Schaan, Liechtenstein
IPS InLine PoM Ingots S2	L34080	Ivoclar Vivadent
IPS InLine Dentin A2	L53664 (Po) L39576 (L)	Ivoclar Vivadent
IPS InLine/IPS InLine POM Glaze	L49281 (Pa), L59382 (L)	Ivoclar Vivadent
Pulse Paste Opaque 950°C	3213120947	Ceramay, Neu-Ulm, Germany
Pulse Press to Metal Ingot interface 2	3030130108	Ceramay
Pulse Dentin A2	3200120306 (Po), 1290010108 (L)	Ceramay
Authentic Glaze Paste flour	1110600308, 1100650907	Ceramay
Zirconia ceramic specimens:		
Lava zirconium dioxide		3M ESPE, Seefeld, Germany
IPS e.max Ceram ZirLiner	L32974 (Po), H32800 (L)	Ivoclar Vivadent
IPS e.max ZipPress Ingots A2 HT	K23214	Ivoclar Vivadent
IPS e.max Ceram A2 Dentin	L11240 (Po), L06423 (L)	Ivoclar Vivadent
IPS e.max Ceram Glaze Paste	L60044(Pa) K49036 (L)	Ivoclar Vivadent
PM9 2M2P-T	15800	VITA Zahnfabrik, Bad Säckingen, Germany
VM9 Base Dentin 2M2	28900 (Po), 22080 (L)	VITA Zahnfabrik
AKZENT	16140 (Po) 16000 (L)	VITA Zahnfabrik

Po: Powder, Pa: Paste, L: Liquid

TABLE II. Firing and pressing temperatures for veneering ceramics used in study

Materials	Firing Cycle	Final Temperature (°C)	Rate of Temperature Increase (°C/Min)	Holding Time§ (Min)
Olympia	Oxidation	1010	56	0
InLine/InLine POM	Opaque	930	100	2
InLine POM	Press	940	60	20
InLine	1st Dentin	910	60	1
	2nd and 3rd Dentin	900	60	1
InLine/InLine POM	Glaze	800	60	2
Pulse	Opaque	950	55	1 N
Pulse press-to-metal	Press	920	60	20
Pulse	1st Dentin	790	45	1 N
	2nd and 3rd Dentin	780	45	1 N
	Glaze	760	45	1 N
IPS e.max Ceram/ZirPress	ZirLiner	960	40	1
IPS e.max ZirPress	Press	910	60	15
IPS e.max Ceram	Wash firing	750	40	1
	1st and 2nd Dentin	750	40	1
IPS e.max Ceram/ZirPress	Glaze	725	60	1
PM9	Press	1000	50	20
VM9	Wash firing	950	55	1
	1st Dentin	910	55	1
	2nd Dentin	900	55	1
PM9/VM9	Glaze	900	80	1

§N for holding time without vacuum

paper (Allied High Tech Products, Inc, Rancho Dominguez, Calif) and a rotary machine (RotoForce-3, Struers Inc, Cleveland, Ohio) to abrade the surfaces perpendicular to the long axis of the cylinders. Airborne-particle abrasion was performed on the surfaces using 50 μm aluminum oxide particles (Kavo Dental GmbH) for 10 seconds at 0.2 MPa. Subsequently, the cylinders were ultrasonically cleaned for 30 minutes in distilled water, and the surfaces were steam cleaned and dried. Finally, oxidation was performed according to the manufacturers' instructions.

Before pressing and layering of the veneering ceramics, first and second opaque firings for each veneering ceramic were performed using the respective opaque according to the manufacturers' instructions. For the pressed group, cylindrical wax patterns (approx. 4 mm in height) (Prowax; Ivoclar Vivadent) were fabricated on the opaque surfaces; sprues were attached to the top of the wax patterns; and then 5 wax-metal specimens were invested within the same pressing ring. The ring was then placed in the preheated oven (Kavo Dental GmbH), as with the lost wax technique, and ceramic ingots were pressed into the mold according to the manufacturer's instructions in the furnace (EP 5000; Ivoclar Vivadent).

For the layering group, a thin layer of dentin porcelain was applied to cover the opaque surfaces and fired in the pressing furnace (EP 5000; Ivoclar Vivadent). Subsequently, the dentin porcelain was applied and fired twice. To maintain a uniform cylindrical form for both core and veneer, excess ceramic was adjusted using a sintered diamond rotary instrument (Brasseler USA, Savannah, Ga). After finishing the specimens, glaze firing was performed for all specimens.

For the zirconia ceramic group, 40 zirconia (Lava; 3M ESPE, St. Paul, Minn) cylinders were obtained and ceramics were layered or pressed on one end of the cylinders (Table I, Table II).

The cylinders were examined under a stereomicroscope using ×15 magnification for any defects and were then divided into 4 groups, coded by veneering process and manufacturer (n=10); Group PZI: e.max ZirPress (Ivoclar Vivadent), Group LZI: e.max Ceram (Ivoclar Vivadent), Group PZV: VITA PM9 (VITA Zahnfabrik; Bad Säckingen, Germany), Group LZV: VITA VM9 (VITA Zahnfabrik).

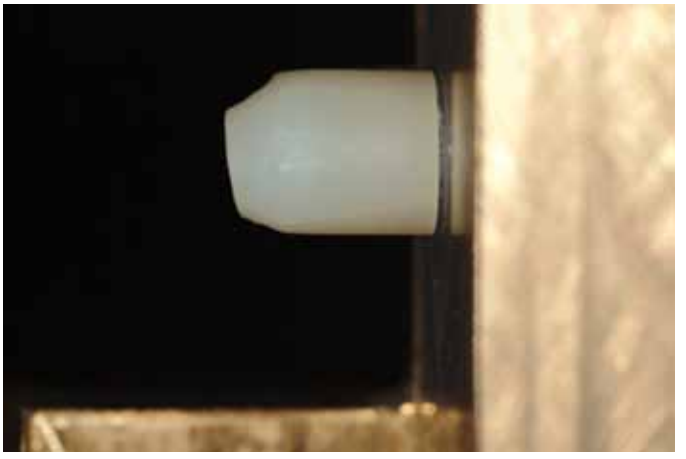
For Group PZI and Group LZI, a liner (ZirLiner; Ivoclar Vivadent) was applied on one end of each zirconia cylinder to be veneered and fired, after which waxing and layering procedures were conducted on the surfaces (Fig. 1). For Group PZV and Group LZV, waxing and layering procedures were conducted directly on the zirconia surface as per manufacturer's instructions. The procedure for pressing and layering was performed in the same manner in the metal ceramic group and following manufacturers' instructions. Oxidation of the metal cylinders and ceramic application for all specimens were performed in a press-firing combination furnace (EP5000; Ivoclar Vivadent).

Thermal cycling was performed on all specimens between water temperatures of 5°C and 55°C with a dwell time of 20 seconds for 20,000 cycles using an automated thermal cycling machine (Proto-tech: Version 2.1a; Portland, Ore). Subsequently, shear bond strength testing was conducted on the specimens in a universal testing machine (Instron model 5500R; Instron Corp, Norwood, Mass) at a crosshead speed of 0.5 mm/min. A diagram of the testing method is presented in Figure 2. The shear stress was calculated by dividing force by interface area in the same manner as in a previous study.[33]

After shear testing, all of the specimens were examined visually and with a stereomicroscope (×15) to determine the mode of failure. Representative fractured specimens from each group were mounted on aluminum blocks via colloidal silver liquid (Electron Microscopy Sciences, Hatfield, Pa). The specimens were sputtered with platinum in an argon gas environment (SPI Module Sputter Coater; Structure Probe, Inc, West Chester, Pa) and examined with a scanning electron microscope (SEM) (JEOL 7000; JEOL Ltd, Tokyo, Japan) with secondary electron imaging and backscattered electron imaging. Digital images of these specimens were recorded at various magnifications to evaluate the fracture surfaces and to verify the mode of failure.

Rank-based Kruskal-Wallis and

1 Example of specimen: zirconia ceramic group (pressed).



2 Example of specimen (metal ceramic group) mounted in shear testing fixture. Load was applied to veneer adjacent to and parallel to interface between veneer and core.

Mann-Whitney tests were used to compare shear bond strengths within the same cores. Within each core group, a Kruskal-Wallis test was used to test the null hypothesis that all groups were the same. If the Kruskal-Wallis test proved significant (α<.05) then Mann-Whitney tests with the Bonferroni correction for multiple comparisons were used to assess all pairwise comparisons between the individual groups. In the metal ceramic group, adjustments were made for the 6 comparisons. In the zirconia ceramic group, adjustments were made for the 3 comparisons. Statistical software (SPSS 16.0; SPSS Inc, Chicago, Ill) was used for all of the calculations.

RESULTS

The mean (SD) shear bond strengths for the metal ceramic groups were obtained. Groups PMI and LMI had values of 66.42 (20.60) MPa and 63.69 (22.08) MPa, and Groups PMC and LMC had values of 37.80 (20.57) MPa and 43.74 (6.64) MPa, respectively. The Kruskal-Wallis test demonstrated that all metal ceramic groups were significantly different (P<.001). The Mann-Whitney tests with the Bonferroni correction for multiple comparisons showed that there were significant differences between Groups PMI and PMC, and between Groups LMI and PMC, in which Groups PMI and LMI had higher strength than Group PMC (P=.041) (Table III). For the zirconia ceramic groups, the mean shear bond strengths and standard deviations of Group PZI and Group LZI were 40.41 (10.28) MPa and 30.03 (9.49) MPa, and Group PZV and Group LZV were 21.34 (24.30) MPa and 47.18 (12.99) MPa, respectively. The Kruskal-Wallis test demonstrated that all zirconia ceramic groups were significantly different (P=.006). The Mann-Whitney tests with the Bonferroni correction for multiple comparisons showed that there was a significant difference between Group LZI and Group LZV (P=.012), in which Group LZV had higher mean shear bond strength. In Group PZV, 5 out of 10 specimens were completely separated during thermal cycling and, as a result, the group was excluded from the statistical analysis (Table IV).

For all specimens, cohesive failure

TABLE III. *P* values from Mann-Whitney statistical analysis after adjustment for multiple comparisons and shear bond strength test mean and SD values for metal ceramic groups

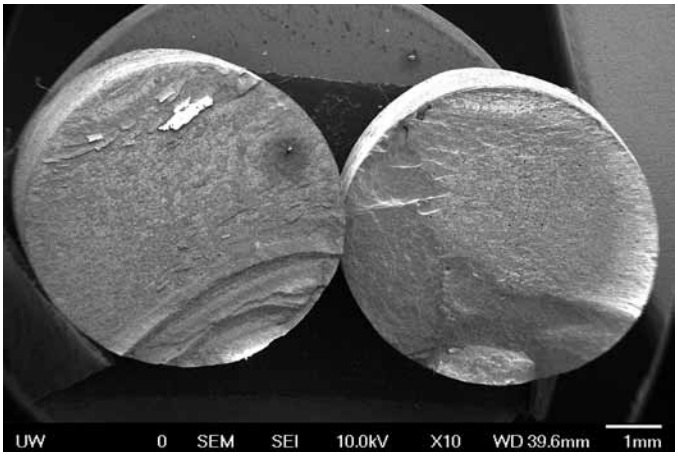
Group	PMI	LMI	PMC	Mean (SD) in MPa
PMI	–	–	–	66.42 (20.60)
LMI	1	–	–	63.69 (22.08)
PMC	.041	.041	–	37.80 (20.57)
LMC	.088	.174	.210	43.74 (6.64)

Results significant for P<.05

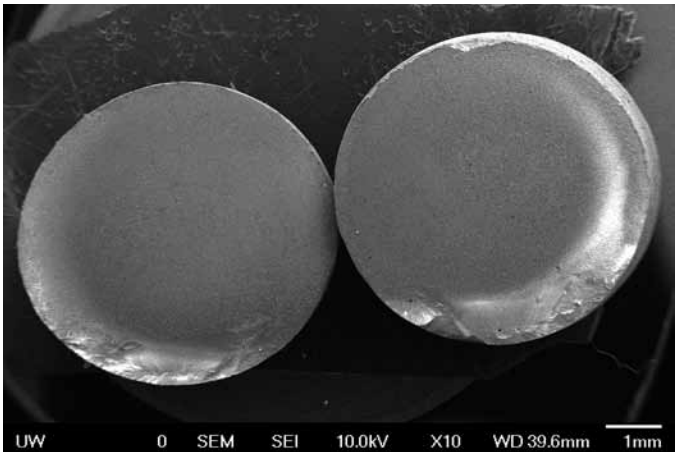
TABLE IV. *P* values from Mann-Whitney statistical analysis after adjustment for multiple comparisons and shear bond strength test mean and SD values for zirconia ceramic groups

Group	PZI	LZI	Mean (SD) in MPa
PZI	–	–	40.41 (10.28)
LZI	.106	–	30.03 (9.49)
PZV	Excluded	Excluded	21.34 (24.30)
LZV	.84	.012	47.18 (12.99)

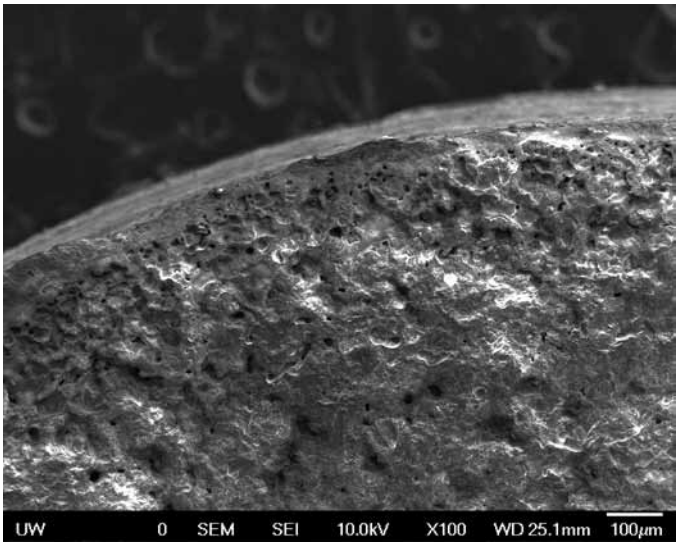
Results significant for P<.05



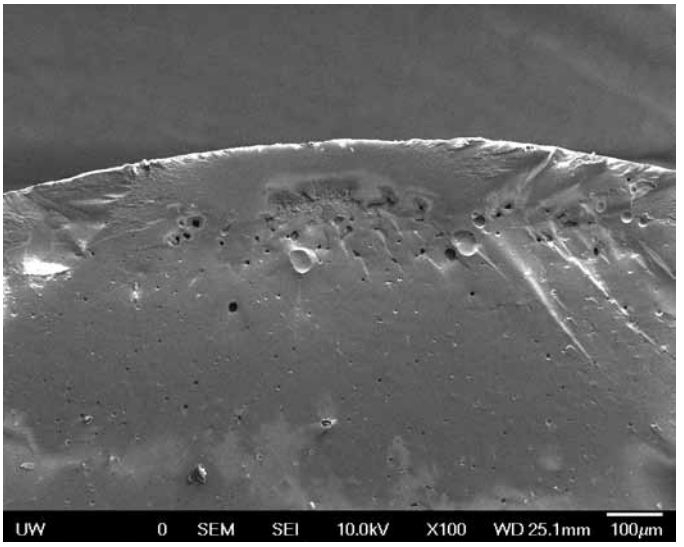
3 SEM image of LMI specimen (metal ceramic group) after shear testing: cohesive failure in veneering ceramic (original magnification ×10).



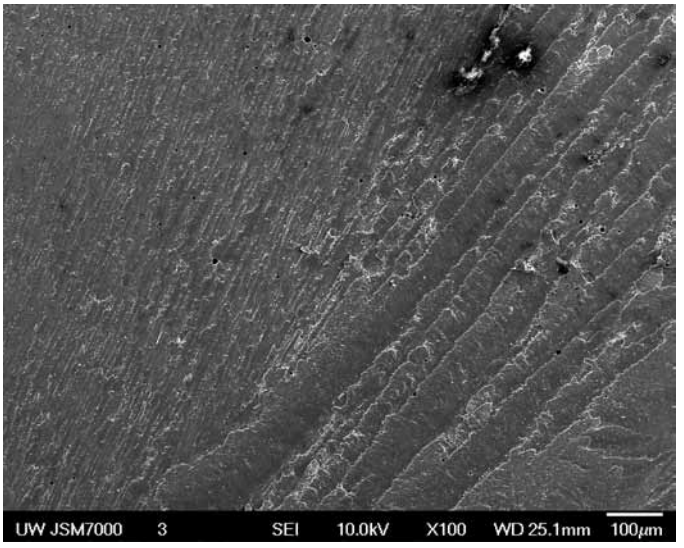
4 SEM image of LZI specimen (zirconia ceramic group) after shear testing: cohesive failure in veneering ceramics (original magnification ×10).



5 SEM image of PMC (metal ceramic group): fractures initiated at small inherent processing defects such as porosity (core side, original magnification ×100).



6 SEM image of PZI (zirconia ceramic group): Typically fracture initiated at small inherent defects such as porosity (core side, original magnification ×10).



7 SEM image of LZV (zirconia ceramic group): Thin layer of veneering ceramics covered zirconia surface (core side, original magnification ×1000).

was observed (Figs. 3, 4). For both metal ceramic groups and zirconia ceramic groups, fracture initiated at small defects such as porosities (Figs. 5, 6). Cohesive failure within the veneering ceramic was confirmed by a thin layer of veneering ceramic covering the zirconia surface (Fig. 7).

DISCUSSION

This study evaluated the shear bond strengths of pressed and layered veneering ceramics to their corresponding high-noble alloy or zirconia cores. For the metal ceramic groups, there were significant differences between Groups PMI and PMC and between Groups LMI and PMC, in which Groups PMI and LMI had higher strength than Group PMC (P=.041). Therefore, the first null hypothesis was rejected. For the zirconia ceramic groups, the results demonstrated that there was no significant difference between the pressed and layered groups. Thus, the second null hypothesis was not rejected.

To reduce the variables in the study, pairs of pressable and layering ceramics from the same manufacturer were selected. Thus, the metal ceramic specimens in Groups PMI and LMI or Groups PMC and LMC had similar procedures performed in terms of the process of opaque application. However, application of veneering ceramics was done either via pressing or layering. In addition, when comparing group PZI and Group LZI or Group PZV and Group LZV in the zirconia ceramic specimens, veneering ceramics were either pressed or layered, with Group PZI and Group LZI having a liner applied prior to the ceramic application.

For pressed specimens, the desired shape of the specimens was achieved with a single pressing procedure. However, the layering specimens required 3 applications and firings, and subsequently, adjustments were needed to acquire the definitive shape for shear testing. This was due to the firing shrinkage of the layering proce-

dure, but this adequately represents clinical practice for fabricating the restorations. Finally, glaze firing was performed on all specimens to simulate the situation in the dental laboratory and to enhance the surface quality. A variety of factors, such as material composition and properties, firing temperatures, cooling rates, operator's skill, porosities, and fabrication process, may affect the quality and strength of the bond between the core and the veneering materials. In this study, 5 out of 10 specimens of the Group PZV (Vita PM9) experienced complete separation during thermal cycling. Exact reasons for the separations are uncertain, although porosities were observed at the interface. As a result, the group was excluded from the study.

Various testing methods have been used to evaluate shear bond strengths between veneering ceramics and the cores of metal alloy and zirconia.[27] Some of the studies compared the effect of application of veneering technique, pressed and layered, and found similar bond strengths between pressed ceramics and layered ceramics.[29,30] In this study, shear bond strengths were evaluated by a method used in a study by Ashkanani et al,[33] which is similar to a circular interface test described in a prior study and in a review.[36, 38]

Limitations of this study include the fact that the design of the specimens does not represent the clinical situation, the sample size was limited, and the fabrication of the specimens was performed by a single operator. For the layered groups, only a single category of porcelain (dentin) was used.

After aging, shear bond strength for both the metal ceramic and zirconia ceramic groups analyzed, pressed and layered, exceeded the value required by ISO 9693.[41] In the future, studies evaluating shear bond strengths with different combinations of cores and veneering materials, the effect of surface treatments such as airborne-particle abrasion on core materials, and the effect of different thermal cycling protocols should be conducted. In addition, different methodologies to evaluate shear bond strengths might be considered. Additional studies may evaluate the mechanical properties of the different veneering ceramics, such as flexural strengths and fracture toughness, and the effect of application methods. A quantitative evaluation of the residual stresses in zirconia and veneering ceramics for the pressing technique, as compared to the layering technique, and the effect of veneering application procedures and the cooling rate might also be conducted.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions may be drawn:

1. In terms of the shear bond strength of veneering ceramics to high-noble alloy, there were significant differences between Group PMI (IPS InLine POM) and Group PMC (Pulse press-to-metal) and between Group LMI (IPS InLine) and Group PMC, in which Group PMI and Group LMI had a higher value.

2. In terms of the shear bond strength of veneering ceramics to zirconia, there were no significant differences between the pressed and the layered groups. Within the layered groups, Group LZV (VITA VM9) had a significantly higher value than Group LZI (IPS e.max. Ceram).

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