Original Articles

Shear Bond Strength and Interface Analysis of Different Veneering Ceramic Applications Over 3Y-TZP Substructure

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Abstract

The aim of this study was to compare the shear bond strength (SBS) of different veneering ceramic applications over a 3Y-TZP substructure. The study was performed with a total of 45 3Y-TZP discs. The samples were divided into three groups according to the type of veneering ceramic as followings: base liner group (NobelRondo™ Zirconia, Nobel Biocare, Goteborg, Sweden), conventional layering group (NobelRondo™ Zirconia, Nobel Biocare, Goteborg, Sweden) and pressing group (NobleRondo™ Press Zirconia, Nobel Biocare, Goteborg, Sweden). The SBS was tested with a universal testing machine (Dillon Quantrol TC^2, Fairmont, USA). Then results were analyzed by One-way ANOVA followed by Tukey's post hoc test at significance level α = .05. The surfaces of the samples after testing were examined by a light stereomicroscope in order to determine the fracture mode. One-way ANOVA showed a statistically significant difference among groups, $F_{2,42} = 11.558$, $p < .005$. Tukey tests indicated a statistically significant difference between the base liner group and both conventional layering (p = .02) and pressing ($p < .005$) groups, while there was no significant difference between conventional layering and pressing groups (p = 0.719). Baseliner and conventional layering groups exhibited combined cohesive/adhesive failure while the pressing group failed cohesively. According to the findings of this study, pressable veneering ceramic has comparable SBS to conventional veneering ceramic.

Keywords: Pressing ceramic, Shear bond strength, Veneering ceramic, 3Y-TZP, Zirconia

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Introduction

Zirconia is a crystalline dioxide of zirconium. The mechanical properties of zirconia are very similar to those of metals and its color is similar to tooth color.[1-4] *In vitro* studies of yttrium tetragonal zirconia polycrystals (Y-TZP)-based materials demonstrated flexural strength of 500 to 1200 MPa and compression resistance at about 2000 MPa,[2,4-6] suggesting that zirconia-ceramic fixed denture prostheses (FDPs) can be used in the molar region. Zirconia restorations have been recommended for FDPs supported by teeth or implants. Single tooth restorations and FDPs article in press

with a single pontic element are possible in both anterior and posterior areas because of the reliable mechanical properties of this material.[1,4-9]

Although 3Y-TZP zirconia frameworks have demonstrated relatively higher strength compared to other all-ceramic materials, the opacity of this material results in reduced esthetics. Its color property requires veneering ceramic on the zirconia substructures in order to give natural esthetics. There are two major techniques for veneering ceramic application. The first technique is the conventional layering technique. This technique has been used widely for veneering metal-ceramic restorations and all-ceramic restorations. The feldspathic ceramic powder is mixed with modeling liquid. The crown is then built up 15-18 % oversize to compensate for shrinkage after firing.[10] This technique requires the skill of the laboratory technician to achieve the final all-ceramic crown with excellent esthetic. The other layering technique is pressing technique. Pressable ceramics have the advantage of being technically less challenging by using the lost wax technique. This allows for the convenience of full-contour ceramic wax-up as opposed to the more-technique-sensitive layering method.[11] Pressable ceramics are available in ingots with different shades to match various clinical requirements. During laboratory procedures, these ingots are heat-pressed into a mold by a plunger under pressure within a pneumatic press furnace.[12] Pressable veneering ceramic has a monochromatic color. Therefore, after pressing and divesting, enhanced esthetics can be achieved through an external characterization procedure.

A systematic literature review evaluated the survival rate of all-ceramic restorations in comparison with porcelain fused to metal restorations. A five-year survival rate of all-ceramic restorations was 93.3 %, whereas metal-ceramic restorations had a five-year survival rate of 95.6 %.[13] When comparing zirconia restorations with other all-ceramic systems, zirconia frameworks were the most reliable in the posterior region. Failure of zirconia restorations resulted from chipping or cracking of the veneering ceramic, while other all-ceramic restorations failed mainly from framework fracture.[14]

A five-year clinical study of 3–5 unit zirconia FDP frameworks found a 15.2 % failure rate from chipping of the porcelain veneer layer but no framework failures.[15] Differences in the coefficient of thermal expansion (CTE) between the core and veneering ceramic has become an area of concern.[14,15] Other reports have shown failure rates from 8 to 25 % after 24–38 months in function.[18,19] While zirconia provides strength, clinical failure modes suggest that future development should focus on porcelain veneer materials and resultant bonding mechanisms and stresses.[20,21]

In vitro studies for bond strength between zirconia core and veneering ceramic have been conducted. Zirconia groups showed statistically significant lower shear bond strength (SBS) than metal groups with corresponding layering veneering ceramics.[22] While another study found that the zirconia group showed comparable SBS to the metal group.[23] It was previously reported that pressable veneer ceramics had a higher zirconia-veneer bond strength than many available layering ceramics.[24] The superior bond could be attributed to many of the attractive properties of the pressing technology, which is performed under controlled conditions, resulting in less incorporation of structural defects, improved wetting of the zirconia surface by the molten pressed ceramics, and less incorporation of air bubbles, which are known to dramatically affect the strength of the veneering ceramic and its bond strength to the underlying framework material.[24] Another study found no significant difference in bond strength between the layering and the pressing veneering applications over the zirconia framework.[25] However, the failure modes of each technique were different. In pressing groups, samples were fractured by the chipping of a small part of veneering ceramic under the impact area, while the zirconia restoration remained structurally intact. In contrast, layered zirconia samples demonstrated delamination of the veneering ceramic, exposing the surface of the underlying zirconia framework.[25]

Although there were studies about veneering ceramic on 3Y-TZP zirconia framework, there were not many studies comparing bond strength between conventional layering and pressing techniques for veneering application over the CAD/CAM zirconia substructure. Therefore, the purpose of this study was to compare SBS of different veneering applications. The null hypothesis was that there was no difference in shear bond strength between conventional and pressing techniques.

Materials and Methods

Preparation of 3Y-TZP discs

A 3Y-TZP framework material (Procera®, Nobel Biocare, Goteborg, Sweden) was milled to disc form (10 mm in diameter, 2 mm in thickness), and sintered by the manufacturer. The discs were polished with 120-grit diamond polishing disc (Metlab Corp., Niagara Falls, USA) under copious water in order to standardize surface roughness. The roughness of the polishing disc was comparable to that of a diamond bur which was recommended by the manufacturer. The surfaces were steam cleaned for two min using a dental laboratory steam cleaner (Lukadent F99504, Germany) prior to the application of the veneering ceramic.

The materials used, and their corresponding lot numbers and manufacturing information are presented in Table 1.

Table 1 Material properties according to manufacturer data

Material	Lot Number	Manufacturer	Build-up Technique
NobelRondo Zirconia Dentin (A3)	#0306	Nobel Biocare, Goteborg, Sweden	Conventional layering
NobelRondo Base liner	#0406	Nobel Biocare, Goteborg, Sweden	Conventional layering
NobelRondo Press	#0207	Nobel Biocare, Goteborg, Sweden	Pressing
NobelRondo Liner Liquid	#2206	Nobel Biocare, Goteborg, Sweden	Conventional layering
Build-up Liquid Quick	#0906	Nobel Biocare, Goteborg, Sweden	Conventional layering

A total of 45 discs was divided into the following groups:

1. Base liner group : Samples were veneered with liner material (NobelRond™ Zirconia Base liner, Nobel Biocare, Goteborg, Sweden) only.
2. Conventional layering group : Samples were veneered with liner material and felspathic veneering ceramic (NobelRondo™ Zirconia Dentine, Nobel Biocare, Goteborg, Sweden).
3. Pressing group : Samples were veneered with pressable veneering ceramic (NobelRondo™ Press Zirconia, Nobel Biocare, Goteborg, Sweden) only.

Veneering procedure for base liner group

The prepared 3Y-TZP discs were placed in an aluminum split-mold (Fig. 1A). Liner material was applied on the 3Y-TZP discs in cylinder form (2.38 mm in diameter, 3 mm in thickness). The samples were fired in a porcelain oven (CeramPressTM Qex, DENTSPLY Ceramco, Pennsylvania, USA), using a linear bake cycle (firing temperature 910 °C). After firing, all samples were measured with an electronic digital caliper (Mitutoyo America Corp., Illinois, USA) with 0.01 mm accuracy, to verify dimensions. Subsequently, a small amount of liner material was added to correct any deficiencies, and these samples were then fired using a liner bake cycle. All samples were examined under the stereomicroscope, and excess liner material was removed using a fine diamond bur with slow-speed handpiece.

Veneering procedure for conventional layering group

Prior to veneering ceramic application, a thin layer of liner material was applied on the 3Y-TZP discs and fired using a liner bake cycle. The prepared 3Y-TZP discs were placed in a custom-made aluminum split-mold. The samples were veneered with felspathic ceramic (2.38 mm in diameter, 3 mm in thickness). The felspathic ceramic powder was mixed with liquid and applied into the mold. The excess of liquid was blotted by a clean napkin. Then the mold was gently removed. The samples were fired using a first dentin bake cycle (firing temperature 910 °C). After firing, all samples were measured with an electronic digital caliper. Subsequently, a small amount of feldspathic veneering ceramic was added to correct any deficiencies, and these samples were then fired using a second dentin cycle (firing temperature 900 °C). All the samples were examined under the stereomicroscope, and excess liner material was removed using a fine diamond bur with slow-speed handpiece.

Veneering procedure for pressing group

Cylinder patterns (2.38 mm in diameter, 3 mm in thickness) were built with pattern resin (GC Pattern Resin, GC, Tokyo, Japan), attached to Y-TZP discs with positioning wax (ABF-wax, Metalor Dental AG, Oensingen, Switzerland), sprued and invested (Fig.1B). Press ceramic pellets and investment plunger were placed rapidly into the ring and the pressing program was started immediately. The rings were pressed at 1060 oC at 4 bar for ten minutes. Upon completion of the pressing program, the investment rings were cooled to room temperature. The rings were cut and sandblasted with 50-μm aluminum oxide at 2 bar, and a thin diamond disc was used to cut the sprue. The remaining sprue buttons were removed with a diamond point at slow speed with water irrigation. The samples were measured using an electronic digital caliper and polished to achieve a dimension of 2.38 mm in diameter and 3 mm in thickness.

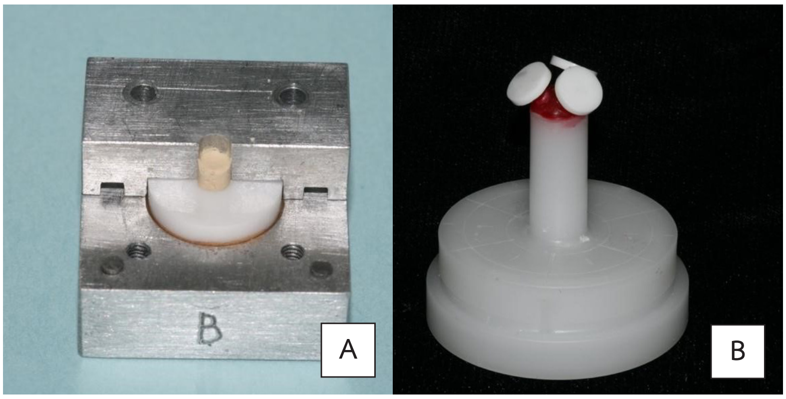

Figure 1 *Build-up Techniques (A) Conventional layering technique: Sample in aluminum split-mold (B) Pressing technique: Samples were sprued before investing*

SBS testing

Samples were embedded in autopolymerizing acrylic resin (Formatray, Kerr Corp, Orange, California, USA). A SBS test was performed using a universal testing machine (Dillon Quantrol TC2, Fairmont, USA), 1000 N at a crosshead speed of 1 mm/ min. The maximum load to failure was recorded.

Light stereomicroscope

The samples were then observed under a light stereomicroscope (X60) to determine the mode of failure. The failure modes were categorized as described in Table 2.

Table 2 *Definitions of different failure modes*

Failure Mode	Definition
Adhesive failure	Complete delamination of veneering ceramic from substructure material
Cohesive failure	Fracture occurs completely and only within veneering ceramic or with in substructure material
Combined adhesive/cohesive failure	Fractured surfaces are within veneering ceramic with areas of substructure material exposed indicating localized adhesive failure

Scanning electron microscopy (SEM)

After examination under the light stereomicroscopy, two samples of each group were randomly selected to be further examined under a SEM to evaluate the fracture surfaces. In order to evaluate the surface structure of the 3Y-TZP discs of three different surface conditions (as-milled from the manufacturer; ground with diamond polishing discs; and ground and heated using a pressing cycle) were examined under a SEM. The samples were sputter-coated with carbon, and then examined with a SEM (Hitachi SU70, Schaumburg, USA). Digital images of these different samples were made at X40, and X250 magnification.

Statistical Analysis

The SBS was statistically analyzed by one-way ANOVA followed by Tukey's post hoc test at significance level $\alpha = 0.05$ using statistical software (SPSS 12.0; SPSS Inc., Chicago, USA)

Results

The mean SBS and standard deviations are summarized in Table 3. The base liner group showed the highest mean SBS (28.50±3.24MPa), followed by conventional layering and pressing groups (23.89±2.91and 22.94±3.93 MPa respectively). One-way ANOVA showed a statistically significant difference among groups, $F_{2,42} = 11.558$, $p < .005$. Tukey tests indicated statistically significant differences between the base liner group and both conventional layering (p=.02) and pressing (p<.005) groups, while there was no significant difference between the conventional layering and the pressing groups (p=0.719).

Table 3 *Mean SBSs and SDs (MPa) and failure modes. (n = 15 per group)*

Group	Mean SBS (SD) (MPa)	Failure Mode
Base liner	28.50 (3.24)[a]	Adhesive 6.67% Cohesive 0% Combination 93.33%
Conventional layering	23.89 (2.91)[b]	Adhesive 0% Cohesive 0% Combination 100%
Pressing	22.94 (3.93)[b]	Adhesive 0% Cohesive 100% Combination 0%

Different lowercase letters within columns denote group differences that are statistically significant (P<.05).

Light stereomicroscopy showed that the failure mode varied among all experimental groups as summarized in Table 3. In the baseliner group, 14 of the 15 samples exhibited combined cohesive/adhesive failures, while one sample demonstrated adhesive failure. The fractured surfaces that showed combined failure demonstrated small remnants of liner material at the contact area with the testing jig, while the majority of the bonded area failed adhesively. All samples in the conventional layering group demonstrated mixed cohesive/adhesive failures. While all samples in the pressing group failed cohesively within the pressable veneering ceramic.

Figure 2A demonstrated the SEM results of a base liner sample at X40 and X250 magnifications. The SEMs showed voids within the liner material. Interestingly, with higher magnification of this area (X250), a thin layer of liner material can be seen embedded with scratches created by grinding with the diamond polishing disc. This sample was categorized as a combination failure. Figure 2B demonstrated a conventional layering sample, showing voids in the veneering ceramic. The size of voids was larger than those found in the base liner group. Remnants of veneering material could also be seen embedded in scratches when the fractured surfaces were examined under high magnification. A pressable sample (Fig. 2C) showed smaller, more uniform circular voids than those found in a conventional layering group. These voids demonstrated crack lines that originated from the testing jig.

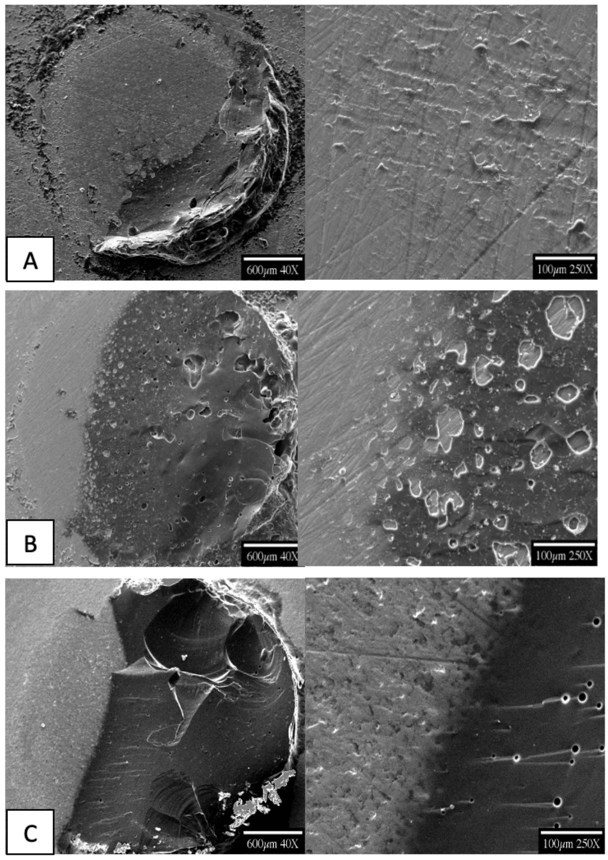

Figure 2 *Fracture surface of each group was evaluated by SEM at X40 and X250 magnification. (A) Base liner group (B) Conventional layering group (C) Pressing group*

Discussion

Zirconia restoration has been widely used in prosthodontic dentistry due to its superior mechanical strength. Although monolithic zirconia became popular due to its translucency, its flexural strength was inferior to 3Y-TZP.[4] Therefore, in some cases, 3Y-TZP zirconia is preferable. In this present study, the SBS between veneering ceramic and 3Y-TZP substructure was investigated. The different techniques of veneering application were compared. The results showed that there was no significant difference between conventional layering and pressing groups. Therefore, the null hypothesis was accepted.

According to the manufacturer's instructions for veneering ceramics used in the present study, the use of liner material is recommended for layering veneering ceramic in order to mask the white color of zirconia and to improve the bond strength between the core and veneer layers. Liner material is not needed for the pressing system due to physical properties of pressable ceramic. In the present study, three groups were tested: liner material only, veneered with a layering system and veneered with a pressing system according to manufacturer recommendations.

The application of liner material over a Y-TZP substructure might not be clinically applicable, since the liner material must be layered with feldspathic ceramic in order to mimic natural translucency. However, this application was included in this study design in order to determine the bonding area between the liner material and Y-TZP. The results of this study indicated that the base liner showed statistically significantly higher SBS than either veneering system.

The majority of base liner samples exhibited combined adhesive/cohesive failure. The character of the tested area showed a thin remnant of liner material at the area where the testing jig contacted the interface, while the rest of the bonded area exhibited adhesive. However, when samples were examined under a SEM with higher magnification, small particles of liner material were found in the grooves created by grinding. This observation was also made by Ashkanani *et al.*[22] The authors suggested that even though a stereomicroscope is a valid tool to evaluate the failure modes of the metal ceramic samples, caution must be used while interpreting the failure mode in zirconia samples due to similar colors of veneering ceramic and core material.

Samples in base liner and conventional layering groups failed dominantly in combination mode. However the patterns of failure of these two groups were different. In the base liner group, small remnants of veneering ceramic failed cohesively at the area in contact with the testing jig. The majority of the bonded area showed mainly adhesive failure, with small liner particles embedded in scratches from grinding. In contrast, conventional layering samples exhibited mainly cohesive failures. This finding was similar to a previous study.[25] This study found that the failure mode for the Nobel Rondo Dentine group was entirely cohesive when the veneering ceramic was directly applied to zirconia. The application of liner material resulted in mixed adhesive and cohesive patterns. They also found that in the pressing group, the failure was entirely cohesive. This finding corresponded with our study. The authors suggested that molten pressing ceramic may improve the wetting of the zirconia surface and create less air bubbles at the interface resulting in improved bond strength between core and veneering ceramics.

Differences in coefficient of thermal expansion (CTE) between the core and veneering ceramic is another important factor for core-veneering debonding.[14,15] A previous study found that pressing veneering ceramic demonstrated higher SBS because it had exactly matched CTE to Zr core.[27] Due to limited information about CTE of veneering ceramics used in this study, this factor could not be discussed. However, in our study, there was no significant difference of SBS between those of conventional and pressing groups.

Al-Dohan *et al.* compared SBS between all-ceramic systems and a metal-ceramic system.[23] The authors concluded that the bond strength of veneering ceramic to a ceramic core for the materials tested is similar to that of metal ceramic control. The SBS in the present study was lower than reported in previous studies.[22-26] This may be a result from differences in several factors, including type of substrate, sample preparation, rate of load application, cross-sectional surface area, and the experience of the researcher.[25, 26]

Conclusion

Within the limitations of this study, the following conclusions could be stated:

1. Pressing technique showed comparable SBS to conventional layering technique.
2. Failure mode was consistent for both conventional layering (combined adhesive/cohesive) and pressing (cohesive) techniques.

Study Limitations

A limitation of this study was that the design of the samples did not replicate a clinical situation. Other limitations of this study included using only a single veneering ceramic for each technique, and that the samples had to be custom fabricated and subjected to grinding, which may have produced some flaws in the samples.

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References

1. Monicone PF, Iommetti, PR, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. ***J Dent*** 2007; 35(11):819-26.

2. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. ***Biomaterials*** 1999;20:1-25

3. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. ***Dent Mater*** 2004;20(5):449-56.

4. Carrabba M, Keeling AJ, Aziz A, Vichi A, Fonar RF, Wood D, *et al.* Translucent zirconia in the ceramic scenario for monolithic restorations: A flexural strength and translucency comparison test. ***J Dent*** 2017;60:70-76.

5. Choo SS, Ko KH, Huh YH, Park CJ, Cho LR. Fatigue resistance of anterior monolithic crowns produced from CAD-CAM materials: An *in vitro* study. ***J Prosthet Dent*** 2021; In Press.

6. Raigrodski AJ. Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature. ***J Prosthet Dent*** 2004;92(6):557-62.

7. Potiket N, Chiche G, Finger IM. *In vitro* fracture strength of teeth restored with different all-ceramic crown systems. ***J Prosthet*** Dent 2004;92:491-95.

8. Powers JM, Sakaguchi RL. Craig's Restorative Dental Materials. 12th ed. 2006 Mosby Elsevier. St. Louis, USA. p. 455.

9. Beuer F, Schweiger J, Eichberger M, Kappert HF, Gernet W, Edelhoff D. High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings-A new fabrication mode for all-ceramic restorations. ***Dent Mater*** 2009;25:121-128.

10. McLean JW. The science and Art of Dental Ceramics. Volume II: Bridge Design and Laboratory Procedures in Dental Ceramics. 1980 Quentessence. Tokyo, Japan. p. 45.

11. Schweitzer DM, Goldstein GR, Ricci JL, Silva NRFA, Hittelman EL. Comparison of bond strength of a pressed ceramic fused to metal versus feldspathic porcelain fused to metal. ***J Prosthodont*** 2005;14(4):239-47.

12. Chung KH, Liao JH, Duh JG, Chan DCN. The effects of repeated heat-pressing on properties of pressable glass-ceramics. ***J Oral Rehabil*** 2009;36:132-141.

13. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CHF. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. ***Clin Oral Impl Res*** 2007;18:73-85.

14. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CHF. A systematic review of the survival and complication rates of all-ceramic and metal ceramic reconstructions after an observation period of at least 3 years. Part II: fixed dental prostheses. ***Clin Oral Impl Res*** 2007;18(3):86-96.

15. Sailer I, Feher A, Filser F, Gauckler LJ, Luthy H, Hammerle CH. Five-year clinical results of zirconia frameworks for posterior fixed partial dentures. ***Int J Prosthodont*** 2007;20(4):383-388.

16. Coelho PG, Silva NR, Bonfante EA, Guess PC, Rekow ED, Thompson VP. Fatigue testing of two porcelain-zirconia all-ceramic crown systems. ***Dent Mater*** 2009;25:1122-7.

17. Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S, Mercante DE. The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: a prospective clinical pilot study. ***J Prosthet Dent*** 2006;96(4):237-44.

18. Raigrodski AJ. Materials for all-ceramic restorations. ***J Esthet Restor Dent*** 2006;18:117-118.
19. Tinchert J, Schulze KA, Natt G, Latzke P, Heussen N, Spiekermann H. Clinical behavior of zirconia-based fixed partial dentures made of DC-Zirkon: 3-year results. ***Int J Prosthodont*** 2008;21(3):217-22.
20. Tinschert J, Natt G, Hassenpflug S, Spiekermann H. Status of current CAD/CAM technology in dental medicine. ***Int J Comput Dent*** 2004;7(1):25-45.
21. Strub JR, Stiffler S, Scharer P. Causes of failure following oral rehabilitation: biological versus technical factors. ***Quintessence Int*** 1988;19(3):215-22.
22. Ashkanani HM, Raigrodski AJ, Flinn BD, Heindl H, Mancl LA. Flexural and shear strengths of ZrO2 and a high-noble alloy bonded to their corresponding porcelains. ***J Prosthet Dent*** 2008;100:274-84.
23. Al-Dohan HM, Yaman P, Dennison JB, Razzoog ME, Lang BR. Shear strength of core-veneer interface in bi-layered ceramics. ***J Prosthet Dent*** 2004;91:349-55.
24. Aboushelib MN, Kleverlaan CJ, Feilzer AJ. Microtensile bond strength of different components of core veneered all-ceramic restorations. Part II: Zirconia veneering ceramics. ***Dent Mater*** 2006;22(9):857-63.
25. Aboushelib MN, Kler MD, Zel JMVD, Feilzer AJ. Microtensile bond strength and impact energy of fracture of CAD-veneered zirconia restorations. ***J Prosthodont*** 2009;18(3):211-6.
26. Guazzato M, Albakry M, Quach L, Swain M. Influence of surface and heat treatments on the fractural strength of a glass-infiltrated alumina/zirconia-reinforced dental ceramic. ***Dent Mater*** 2005;21(5):454-63.
27. Isgro G, Kleverlaan CJ, Wang H, Feilzer AJ. Thermal dimensional behavior of dental ceramics. ***Biomaterials*** 2004;25:2447-245.