Journal of Dental and Oral Health

Scient Open Access
Exploring the World of Science

ISSN: 2369-4475

Research Article

Strength Degradation of Zirconia Post Air-abrasion of Veneering and Cementation Surfaces

This article was published in the following Scient Open Access Journal:
Journal of Dental and Oral Health
Received August 07, 2017; **Accepted** August 17, 2017; **Published** August 22, 2017

Sheila Butler[1]*, Bernie Linke[2], Narjara C.F. Moreira[3] and John A. Nychka[4]

[1]*Assistant Professor, Schulich School of Medicine & Dentistry, Western University, London, Ontario, Canada*
[2]*Clinical Professor, School of Dentistry, University of Alberta, Edmonton, Alberta, Canada*
[3]*School of Dentistry, University of Alberta, Edmonton, Alberta, Canada*
[4]*Associate Professor, Department of Chemical and Materials Engineering, School of Dentistry, University of Alberta, Edmonton, Alberta, Canada*

Abstract

Purpose: This study evaluated how the flexural strength of a zirconia-based ceramic (Y-TZP) was affected by air abrasion with 30 μm SiO_2 on both zirconia surfaces: the cementation surface, and the veneering surface.

Materials and Methods: Translucent Y-TZP ceramic bars, for four-point bend testing, were prepared and divided considering the compressive (surface treatment for cementation) and tensile surfaces (surface treatment for veneering). Sandblasting was performed or not for each compressive and tensile surfaces. The specimens from all experimental conditions were analysed by SEM. All specimens were tested in four-point bending. Data were statistically analysed using one-way ANOVA and Post Hoc tests ($\alpha = 0.05$). A Weibull analysis was used to analyse the strength reliability.

Results: According to the results of this investigation, the flexural strength was significantly affected by sandblasting on both surfaces: for veneering ($P < 0.001$) and for cementation ($P < 0.001$).

Conclusions: Sandblasting the veneering surface, to improve bonding of the veneer to Y-TZP, negatively impacted strength reliability. Sandblasting the cementation surface decreased the flexural strength while increasing the strength reliability.

Introduction

Dental Y-TZP is been widely used mainly because of its strengthened substructure. For better aesthetic effect, this restorative material may be layered with veneering porcelain. Nevertheless, previous studies have reported a significant incidence of failures such as porcelain cracking (25-50%), chipping (15-62%), fractures (3-33%) and delaminations (less than 10.7%) [1-5]. Therefore, the longevity of this type of restoration is directly related to the bond strength between these two materials. A combination of different factors can affect the dental zirconia–veneer adhesion in a bilayered dental yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) restoration. Such factors are listed as a weak bond at zirconia/porcelain interface [6], Coefficient Of Thermal Expansion (CTE) [7] and elastic modulus mismatches between the porcelain and core, restoration design [8], cooling procedure [7,8], surface defects, and poor porcelain veneer strength [9].

To improve the bonding between zirconia core and porcelain veneer materials, surface treatment such as airborne-particle abrasion using alumina particles or SiC powder has been performed before veneering [9-17]. Airborne-particle abrasion also increases the bond strength between the luting agent and zirconia [18-24]. However, air abrasion procedures develop surface cracks on the zirconia surface, which negatively affect its fracture behaviour [25-28]. Additionally, sandblasting with 150-μm zirconia particles was reported as an alternative to reduce the damage caused to the zirconia material when compared to 150-μm alumina particles [27].

Thus, the present investigation evaluated the effect of airborne-particle abrasion with 30 μm SiO_2 on a translucent Y-TZP ceramic. As external and internal restoration surfaces could be sandblasted to improve veneering and cementation bonding, respectively, the aim of this study was to evaluate the flexural strength of a veneered zirconia system after airborne-particle abrasion before veneering and as a pre-cementation procedure. The null hypotheses are: (1) sandblasting zirconia ceramic surface before veneering would not affect its flexural strength, and (2) sandblasting

***Corresponding Author:** Sheila Butler, Schulich School of Medicine & Dentistry | Western University, Dental Sciences Building. London, ON. Postal Code: N6A 5C1, Tel: +1 780 655 7183, Email: sheila.butler@schulich.uwo.ca

zirconia ceramic surface before cementation would not affect its flexural strength.

Methods

Zirconia blocks were provided as “partially sintered” by the manufacturer (Lava™ Plus, 3M ESPE, St. Paul, MN, USA, LOT: 480872). Eighty bar specimens were machined and sintered in a Lava furnace 200 (3M ESPE, St. Paul, MN, USA), according to the manufacturer’s instructions. The final bar dimensions after sintering were 25 mm length x 4 mm width x 0.7 mm thickness. The specimens were cleaned in an ultra-sonic device with distilled water for 10 min and dried. The zirconia bars were divided into four groups (n=20) as shown in Table 1. Air-abrasion with 30 µm SiO_2 particles (RocatecTM Soft, 3M ESPE, Seefeld, Germany, LOT: 450384) was performed making circular movements at a distance of 10 mm with 2.5 bar pressure for 15 s with aid of a custom made jig, as previously reported [25].

To simulate the heat procedure during porcelain sintering, the specimens were submitted to the porcelain veneer VITA VM9 firing cycle (950ºC), according to the manufacturer’s instructions (Vita Zahnfabrik, Bad Säckingen, Germany). The specimens from G3 and G4 were sandblasted on the surface for veneering before heated as mentioned above. The specimens from G2 and G4 were sandblasted on the cementation surface after the firing cycle as described above.

The specimens were investigated by X-ray diffractometry. The relative amount of transformed monoclinic structure (F_M) on the zirconia surfaces was determined as described by Toraya, et al. [29] The Transformed Zone Depth (TZD) was determined on the treated zirconia surface and calculated according to the amount of the monoclinic phase taking into consideration that the grain transformation from tetragonal to monoclinic took place symmetrically along the surface. The TZD was obtained based on the equations described by Kosmac, et al. [30].

The specimens’ edges were chamfered using a custom made jig [24] according to ISO 14704 recommendations. All specimens were submitted to a four-point bending test in a universal testing machine having the veneering surface under tensile stress. The failed tested specimens were examined by stereomicroscopy and SEM. The flexural strength data were statistically analysed using two-way ANOVA. To assess material strength reliability, the flexural strength values were also analysed using Weibull distribution by the equation:

$$P_{(\sigma)} = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right]$$

Where P is the probability of failure, is the fracture strength, is the characteristic strength at the fracture probability of 63.2%, and *m* is the Weibull modulus. The values were ranked using median ranking criteria.

Surface treatment for veneering	Surface treatment for cementation	Groups*
No sandblasting	No sandblasting	G1
	Sandblasting	G2
Sandblasting	No sandblasting	G3
	Sandblasting	G4

*n=20

Table 1: Experimental groups considering the surface treatment on the veneering and cementation surfaces.

Results

The XRD patterns presented monoclinic peaks in the pre-sintered (no air-abrasion treatment) and sandblasted after sintering (Figure 1a). Monoclinic peaks were not detectable after polishing without sandblasting, which reveals that phase transformation (*t-m*) took place as a result of sandblasting. The reverse transformation (*m-t*) was observed after the sandblasted surfaces for veneering were submitted to the porcelain sintering cycle. However, after sandblasting the opposing surface (cementation surface) the phase transformation (*t-m*) took place and was only detected on the cementation side (Figure 1a). In addition, the transformed zone depth is presented in Figure 1b.

The flexural strength was significantly affected by the sandblasting procedure on both surfaces, for veneering ($P < 0.001$)

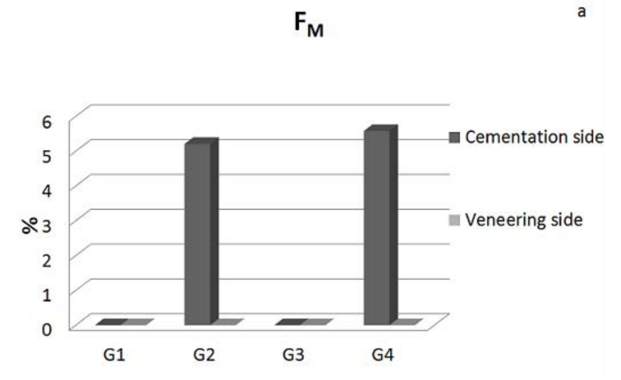

Figure 1a: Relative amount of monoclinic phase (F_M) revealed by XRD on zirconia surface in different stages.

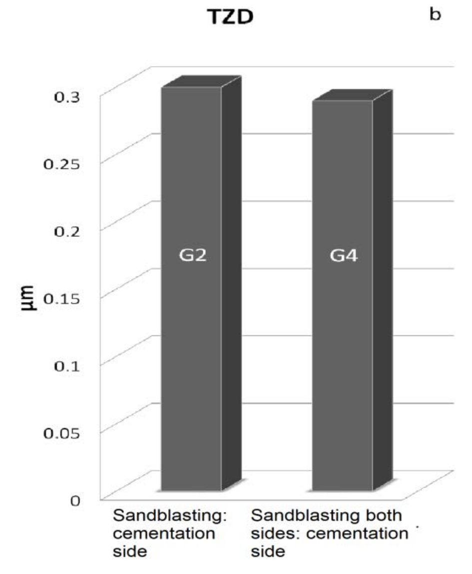

Figure 1b: Transformed zone depth (TZD) on zirconia sandblasted without porcelain sintering cycle. The specimens heated after sandblasting presented no detectable monoclinic phase which is attributed to the reverse phase transformation effect of the heat treatment procedure, from monoclinic to tetragonal. TZD estimates the thickness of the residual compressive stress layer and it is correlated to the zirconia strength.

Group	Flexural strength (MPa)	Characteristic strength ($⍰_{⍰}$) (MPa)	95% Confidence intervals for characteristic strength ($⍰_{⍰}$)	Weibull modulus (*m*)	95% Confidence intervals for Weibull modulus	R^2 (%)
G1	371.3 (99.1)	408	159-1045	4.34	3.65-5.03	90.6
G2	138.3 (29.7)	150	111-203	5.15	4.83-5.46	98.5
G3	443.5 (131.0)	489	162-1477	4.05	3.31-4.79	88.1
G4	296.8 (81.1)	327	165-646	4.11	3.61-4.60	94.4

Table 2: Mean values (MPa) and standard deviations of the flexural strength, and Weibull analytical results obtained for the different experimental conditions.

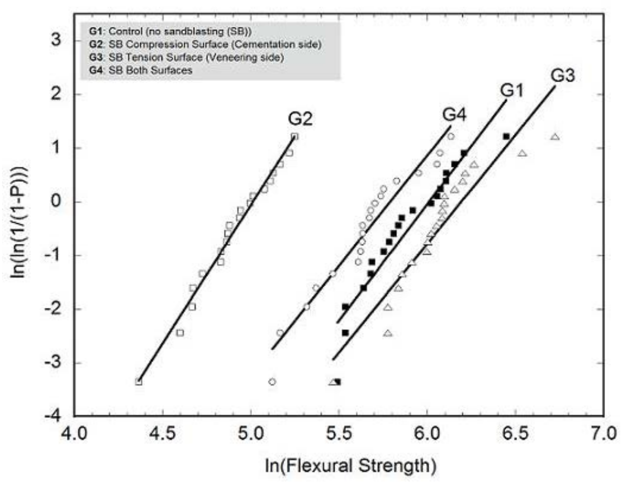

Figure 2: Distribution of the flexural strength data. Notice that G2 is the most even distribution, with the highest Weibull modulus, but with the lowest characteristic strength.

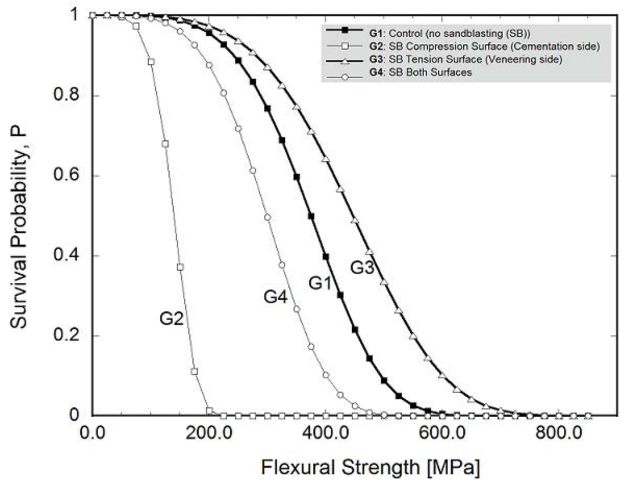

Figure 3: Weibull survivability plot. G3 had the highest flexural strength; G2 the lowest by a factor of ~3. The Weibull modulus of G3 was similar to G1 and G4 (~4), but slightly lower compared to G2 (~5).

and for cementation ($P < 0.001$). The group which had the veneering surface sandblasted combined with no sandblasted cementation surface (G3) presented the highest characteristic flexural strength of 489 MPa (Table 2). The sandblasted surface treatment for cementation combined with no sandblasted surface treatment for veneering (G2) presented the lowest characteristic flexural strength of 150 MPa.

Results of Weibull distribution (63.21% probability of failure) are shown in Table 2 and Figure 3. The G3 group had the highest flexural strength and presented lower Weibull modulus compared to G2 which had a much higher modulus but at reduced strength.

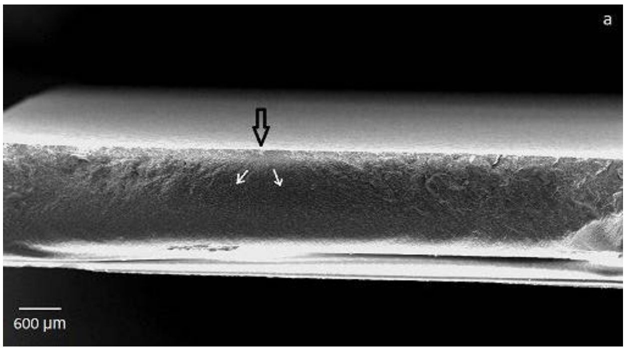

Figure 4a: Representative SEM micrographs of a fractured specimen sandblasted with 30 µm SiO_2 from sandblasted veneering surface (G3) exhibiting the origin of failure (thick black arrow on the sandblasted surface). Thin white arrows follow the hackle lines in the direction of crack propagation surrounding the mirror (a,b). (a) Volume-distributed flaw located at the tensile surface.

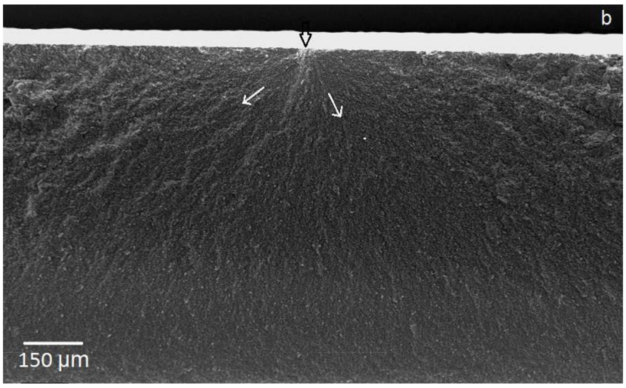

Figure 4b: Higher magnification of the region where failure was generated.

The fractured surfaces were analysed by SEM to identify the origin of failure (Figurer 4a and b).

Discussion

Sandblasting zirconia ceramics is known to induce a surface limited phase transformation (tetragonal → monoclinic) [25,31]. Such a phase transformation was also observed in this study: no monoclinic phase was detected prior to sandblasting. However, a recent study did not observe phase transformation after sandblasting zirconia [32]. This finding could be attribute to the fact that a different zirconia material was evaluated. In the present investigation, the sandblasted veneering surfaces submitted to the porcelain sintering cycle presented no detectable monoclinic phase which confirms the reverse phase transformation generated by the thermal cycling procedure (monoclinic → tetragonal) [25,31].

The first and second hypotheses were rejected. Sandblasting zirconia ceramic surface before veneering increased its flexural strength, and sandblasting zirconia ceramic surface before cementation decreased its flexural strength. Although sandblasting on either the veneering (tension) or cementation (compression) surface of the flexural bars had an effect on the strength, minor effect on the Weibull modulus was observed (Figure 2); the slopes of the lines are similar yet they have been laterally translated based on the particular surface treated. Interestingly, the specimens which had both surfaces sandblasted (G4) had a characteristic flexural strength very close to the average characteristic flexural strength of G2 and G3: 327 MPa vs. 320 MPa respectively. Such a result indicates, speculatively, that the increases or losses in flexural strength due to sandblasting, phase transformations, and any thermal residual stresses might balance each other, suggesting that any gains in strength achieved by sandblasting the veneering surface prior to porcelain sintering will be negatively offset by sandblasting the opposing cementation surface in an attempt to improve bonding.

The greatest flexural strength values exhibited from G3 may be attributed to the formation of compressive residual stresses on the tensile surface (surface for veneering) as evidenced by the presence of the monoclinic phase (XRD analysis) generated by the strain induced phase transformation caused by sandblasting. This finding is in agreement with previous studies [19,33-36]. The tetragonal → monoclinic phase transformation is known to have a positive dilatational volume change, thus creating compressive strains in the lattice when only a thin layer transforms [30]; such strains however, would need to be maintained during the porcelain sintering cycle via the conversion of veneering compound paste to porcelain glaze despite the reverse phase transformation occurring due to heating, which may or may not be possible. Given that the veneer is a powder based paste which densifies and wets the substrate at the porcelain sintering temperature leaving it very accommodating to strain relaxation

For the majority of the sandblasted specimens, volume-distributed flaws were located *at* the surface where the fracture originated (Figure 4a and b). In contrast, volume-distributed flaws were located near the surface for non-sandblasted specimens. The type and location of flaws as a function of surface preparation is consistent with our previous findings [25].

Conclusions

- In contrast to the control group G1 (no sandblasting), sandblasting reduced the 4-pt. flexural strength of the G2 (sandblasted cementation side) and G4 (sandblasted cementation and veneering sides) specimen groups whilst increased the flexural strength of the G3 specimen group (sandblasted veneering side).
- Regardless of treatment condition the strength reliability of the tested specimen groups was rather similar (Weibull modulus ranged from 4.05-5.15).

References

1. Christensen RP, Ploeger BJ. A clinical comparison of zirconia, metal and alumina fixed-prosthesis frameworks veneered with layered or pressed ceramic: a three-year report. *J Am Dent Assoc.* 2010;141(11):1317-1329.
2. Naenni N, Bindl A, Sax C, Hämmerle C, Sailer I. A randomized controlled clinical trial of 3-unit posterior zirconia-ceramic fixed dental prostheses (FDP) with layered or pressed veneering ceramics: 3-year results. *J Dent.* 2015;43(11):1365-1370.
3. Raigrodski AJ, Yu A, Chiche GJ, Hochstedler JL, Mancl LA, Mohamed SE. Clinical efficacy of veneered zirconium dioxide-based posterior partial fixed dental prostheses: five-year results. *J Prosthet Dent.* 2012;108(4):214-222.
4. Anusavice KJ. Standardizing failure, success, and survival decisions in clinical studies of ceramic and metal-ceramic fixed dental prostheses. *Dent Mater.* 2012;28(1):102-111.
5. Sailer I, Fehér A, Filser F, et al. Prospective clinical study of zirconia posterior fixed partial dentures: 3-year follow-up. *Quintessence Int.* 2006;37(9):685-693.
6. Liu R, Sun T, Zhang Y, et al. The effect of graded glass zirconia structure on the bond between core and veneer in layered zirconia restorations. *J Mech Behav Biomed Mater.* 2015;46:197-204.
7. Fischer J, Stawarzcyk B, Trottmann A, Hämmerle CH. Impact of thermal misfit on shear strength of veneering ceramic/zirconia composites. *Dent Mater.* 2009;25(4):419-423.
8. Benetti P, Della Bona A, Kelly JR.. Evaluation of thermal compatibility between core and veneer dental ceramics using shear bond strength test and contact angle measurement. *Dent Mater.* 2010;26(8):743-750.
9. Aboushelib MN, Wang H. Influence of crystal structure on debonding failure of zirconia veneered restorations. *Dent Mater.* 2013;29(7):e97-e102.
10. Sato H, Yamada K, Pezzotti G, Nawa M, Ban S. Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment. *Dent Mat J.* 2008;27(3):408-414.
11. Kirmali O, Kapdan A, Kustarci A, Er K. Veneer Ceramic to Y-TZP Bonding: Comparison of Different Surface Treatments. *J Prosthodont.* 2016;25(4):324-329.
12. Kim HJ, Lim HP, Park YJ, Vang MS. Effect of zirconia surface treatments on the shear bond strength of veneering ceramic. *J Prosthet Dent.* 2011;105(5):315-322.
13. Liu D, Matinlinna JP, Tsoi JK, et al. A new modified laser pretreatment for porcelain zirconia bonding. *Dent Mater.* 2013;29(5):559-565.
14. Harding AB, Norling BK, Teixeira EC. The effect of surface treatment of the interfacial surface on fatigue-related microtensile bond strength of milled zirconia to veneering porcelain. *J Prosthodont.* 2012;21(5):346-352.
15. Nakamura T, Wakabayashi K, Zaima C, Nishida H, Kinuta S, Yatani H. Tensile bond strength between tooth-colored porcelain and sandblasted zirconia framework. *J Prosthodont Res.* 2009;53(3):116-119.
16. Teng J, Wang H, Liao Y, Liang X. Evaluation of a conditioning method to improve core-veneer bond strength of zirconia restorations. *J Prosthet Dent.* 2012;107(6):380-387.
17. Seiji B , Tohru S , Kentaro Y , et al. Surface properties of dental zirconia after clinical grinding and polishing. *Key Eng Mater.* 2013;24:501-506.
18. Passos SP, May LG, Barca DC, Ozcan M, Bottino MA, Valandro LF. Adhesive quality of self-adhesive and conventional adhesive resin cement to Y-TZP ceramic before and after aging conditions. *Oper Dent.* 2010;35(6):689-696.
19. Kosmac T, Oblak C, Jevnikar P, Funduk N, Marion L. The effect of surface grinding and sandblasting on flexural strength and reliability of Y-TZP zirconia ceramic. *Dent Mater.* 1999;15(6):426-433.
20. Chintapalli RK , Rodriguez AM , Marro FG, Anglada RK. Effect of sandblasting and residual stress on strength of zirconia for restorative dentistry applications. *J Mech Behav Biomed Mater.* 2014;29:126-137.
21. Kern M. Bonding to oxide ceramics- laboratory testing versus clinical outcome. *Dent Mater.* 2015;31(1):8-14.
22. Qeblawi DM, Muñoz CA, Brewer JD, Monaco EA. The effect of zirconia surface treatment on flexural strength and shear bond strength to a resin cement. *J Prosthet Dent.* 2010;103(4):210-220.
23. May LG, Passos SP, Capelli DB, Ozcan M, Bottino MA, Valandro LF. Effect of silica coating combined to a MDP-based primer on the resin bond to Y-TZP ceramic. *J Biomed Res B Appl Biomater.* 2010;95(1):69-74.
24. Druck CC, Pozzobon JL, Callegari GL, Dorneles LS, Valandro LF. Adhesion to Y-TZP ceramic: study of silica nanofilm coating on the surface of Y-TZP. *J Biomed Mater Res B Appl Biomater.* 2015;103(1):143-150.

25. Passos SP, Linke B, Major PW, Nychka JA. The effect of air-abrasion and heat treatment on the fracture behavior of Y-TZP. *Dent Mater.* 2015;31(9):1011-1021.

26. Hallmann L , Ulmer P , Reusser E, et al. Effect of blasting pressure, abrasive particle size and grade on phase transformation and morphological change of dental zirconia surface. *Surfac Coat Technol.* 2012;206(19):4293-4302.

27. Hallmann L, Ulmer P, Wille S, et al. Effect of surface treatments on the properties and morphological change of dental zirconia. *J Prosthet Dent.* 2016;115(3):341-349.

28. Zhang Y, Lawn BR, Malament KA, Van Thompson P, Rekow ED. Damage accumulation and fatigue life of particle-abraded ceramics. *Int J Prosthodont.* 2006;19(5):442-448.

29. Hideo Toraya, Masahiro Yoshimura, Shigeyuki Somiya. Calibration curve for quantitative analysis of the monoclinic-tetragonal ZrO_2 system by x-ray diffraction. *J Am Ceram Soc.* 1984;67(6):C119-C121.

30. Kosmac T, Wagner R, Claussen N. X-ray determination of transformation depths in ceramics containing tetragonal ZrO_2. *J Am Ceram Soc.* 1981;64(4):C72–C73.

31. Grigore A, Spallek S, Petschelt A, Butz B, Spiecker E, Lohbauer U. Microstructure of veneered zirconia after surface treatments: a TEM study. *Dent Mater.* 2013;29(11):1098-1107.

32. Alao AR, Stoll R, Song XF, et al. Surface quality of yttria-stabilized tetragonal zirconia polycrystal in CAD/CAM milling, sintering, polishing and sandblasting processes. *J Mech Behav Biomed Mater.* 2016;65(20):102-116.

33. Wang H, Aboushelib MN, Feilzer AJ. Strength influencing variables on CAD/CAM zirconia frameworks. *Dent Mater.* 2008;24(5):633-638.

34. Karakoca S, Yilmaz H. Influence of surface treatments on surface roughness, phase transformation, and biaxial flexural strength of Y-TZP ceramics. *J Biomed Mater Res B Appl Biomater.* 2009;91(2):930-937.

35. Aboushelib MN, Wang H. Effect of surface treatment on flexural strength of zirconia bars. *J Prosthet Dent.* 2010;104(2):98-104.

36. Curtis AR, Wright AJ, Fleming GJ. The influence of surface modification techniques on the performance of a Y-TZP dental ceramic. *J Dent.* 2006;34(3):195-206.