Effect of Grinding Inner Surface on Biaxial Flexural Strength, Phase Analysis and Surface Roughness of Translucent Zirconia

Chalisa Wongjirasawad* Vibul Paisankobrit*

Abstract

Objective: Zirconia is generally used in dentistry. Grinding zirconia is difficult because of the high value of its surface hardness. Therefore, specific burs for grinding zirconia were created. To receive proper marginal fit, sometimes grinding a high spot at the inner surface of zirconia fixed partial denture was needed. The objective was to assess the effect of grinding inner surface on biaxial flexural strength (BFS), phase analysis and surface roughness of translucent zirconia.

Materials and Methods: Forty samples, disc-shaped translucent zirconia, were randomly divided into four groups. CT group: no grinding samples; MD group: samples were ground by medium-grit diamond burs; FD group: samples were ground by fine-grit diamond burs; and HS group: samples were ground by heatless stone burs. The burs in MD group were represented as widespread commonly used burs; meanwhile, the burs in FD and HS groups were specifically for grinding zirconia. All samples were ground for a half-minute. The BFS was tested by Universal testing machine and the results were evaluated using one-way analysis of variance Scheffé test were performed to compare BFS among the groups (p-value < 0.05)

Results: The monoclinic phase were existed in all ground zirconia groups and the roughness was raised compared with the CT group. The BFS of FD and HS group were not statistically significant differences from the CT group (p-value > 0.05). However, a significant reduction of BFS was observed in the MD group in comparison with the CT group (p-value < 0.05).

Conclusions: Clinical inner surface adjustment of translucent zirconia fixed partial dentures with specific burs (FD and HS group) had no significant reduction of the BFS. Conversely, the BFS was reduced significantly after translucent zirconia was ground by common diamond burs (MD group).

Keywords: Translucent zirconia, Grinding, Biaxial flexural strength, Surface roughness, Phase analysis

Received Date: Oct 08, 2021

Revised Date: Nov 24, 2021

Accepted Date: Mar 25, 2022

**Department of Conservative Dentistry and Prosthodontics, Faculty of Dentistry, Srinakarinwirot University, 114 Sukhumvit 23 Rd Wattana, Bangkok, 10110, Thailand.*

Introduction

Due to patient's demand for esthetic and tooth-colored dentistry have increased, translucent zirconia became popular (1). It can mimic the optical properties of the natural tooth and also has good mechanical properties (2). Zirconia consists of changeable crystallographic forms and occurs in three different phases: monoclinic phase (M) stable up to 1,170 °C, tetragonal phase (T) between 1,170-2,370 °C and cubic phase (C) at above 2,370 °C (3). Conventional zirconia used in dentistry was added with 3 mol% yttria to stabilize the T-phase at room temperature called 3YTZP (4). The profit of 3Y-TZP is excellent flexural strength at 900-1,200 MPa (5), but its light transmission is limited (6).

To improve the translucency of zirconia, 4-5 mol% of yttria (4,5Y-TZP) were added to increase the quantity of cubic phase called "Translucent Zirconia" (7). The C-phase of zirconia is isotropic in different crystallographic directions, which reduces the dispersion of light that appear at grain boundaries. Consequently, the cubic zirconia presents more translucent (4). On the other hand, the flexural strength of translucent zirconia was decreased to 600-750 MPa (8).

Under the stimuli, for example grinding and airborne-particle abrasion, may create microcracks and trigger T-M phase transformation at the crack tip. The T-M phase transformation results in a local volume increase of approximately 4.4% (9), which reduces crack size and also prevents crack propagation. This mechanism is called "Transformation toughening" that strengthens the zirconia materials.

In zirconia fixed partial denture, the marginal fit should be verified. Even though using a computer-aided design and computer-aided machining (CAD-CAM) technology (10), high spots at the inner surface of restoration may occur in some cases. Grinding inner surface of zirconia restoration was needed to achieve a proper marginal fit between restoration and tooth abutment (11). Grinding exhibits a counteracting effect on the flexural strength of translucent zirconia. Either it produces a compressive stress layer on ground surface that can increase flexural strength by transformation toughening (9) or creates surface flaws that can weakening the zirconia (12).

To grind or polish zirconia, having a high grinding efficiency bur is required. Accordingly, specific grinding burs for zirconia, which have more diamond particles imprinted, have been manufactured and are presently in the market. In these burs, diamond grid is imprinted in the silicone stone, so raising the grinding efficiency and decreasing heat generation. High-speed grinding burs for zirconia are often used to grind zirconia fixed partial denture. Iseri (13) stated that when grinding zirconia with the high-speed bur, the value of flexural strength decrease become less, along with less heat production. Recently, low-speed heatless stone burs were introduced for grinding a zirconia, which claimed high grinding efficiency with less heat generation. However, there has been no explicit guideline to choose a suitable bur for grinding inner surface of translucent zirconia restoration, therefore the researcher mimicked the use of grinding inner surface in clinical practice by choosing medium-grit diamond burs, fine-grit diamond burs, and heatless stone burs for grinding translucent zirconia. Fine-grit diamond burs and heatless stone burs represent the dedicated specific zirconia-grinding burs, while medium-grit diamond burs are generally used and accessible in the dental clinic. The aim of this research is to provide a practical guideline on choosing the proper bur for grinding inner surface of translucent zirconia fixed partial denture. The null hypothesis is there are no differences in biaxial flexural strength of translucent zirconia ground with different burs.

Materials and Methods

1. Sample Preparation

The sample size was calculated by two dependent means equation (14) according to prior study(15), total sample size is at least thirty-three samples. Forty disc-shaped samples were manufactured according to ISO 6872 (16). The samples were designed and milled by CAD-CAM (VHF S2, VHF, Germany) using 4Y-TZP Katana^{TM} STML Zirconia block in A3 color (Kuraray Noritake Dental, Japan). The zirconia's properties and components used in this research are listed Table1 After that, the samples were sintered (Sintra Plus, Shenpaz Dental Ltd, Israel) according to the manufacturer's instruction (heat rate 1:10 ^{o}C/min up to 1,550 ^{o}C; hold for 2 hours, followed by slow cooling 1:10 ^{o}C/min down to room temperature).

The dimensions of the samples were 15 ± 0.1 mm in diameter and 1.2 ± 0.1 mm in thickness. The samples were cleaned with ultrasonic cleaner (5210, Bransonic, Germany) for thirty seconds. The diameter and the thickness of the samples were measured using a digital micrometer (Park tool, USA). Forty samples were randomly divided into each of the four groups being three groups for different grinding burs (Fig 1.) and one control group as follows. CT group (control group): no grinding samples; MD group: samples were ground by medium-grit round shaped diamond burs (grit size 90-106 μm, Jota, Switzerland); FD group: samples were ground by fine-grit rugby shaped diamond burs (grit size 38-45 μm, Jota, Switzerland); and HS group: the samples were ground by flame shaped heatless stone burs (grit size 44-74 μm, Jota, Switzerland). The burs in the FD and HS groups were particularly for grinding zirconia while the burs in the MD group were represented as widespread commonly used burs.

Table 1. Properties and components of Katana™ STML zirconia block.

Properties	
Fracture toughness (MPa(m)$^{1/2}$)	3.2
3-point flexural strength (MPa)	784
Modulus of elasticity (GPa)	200-210
Vickers hardness	1,300
Sintering density (g/cm^3)	6.4
CTE (10^{-6}/K)	9.8 ± 0.2
Translucency (%) (Sample thickness 0.5 mm)	38
Components (Wt%)	
Phase composition	Cubic mainly
ZrO_2 + HfO_2	88-93
Y_2O_3 + HfO_2	7-10
Other oxides	0-2

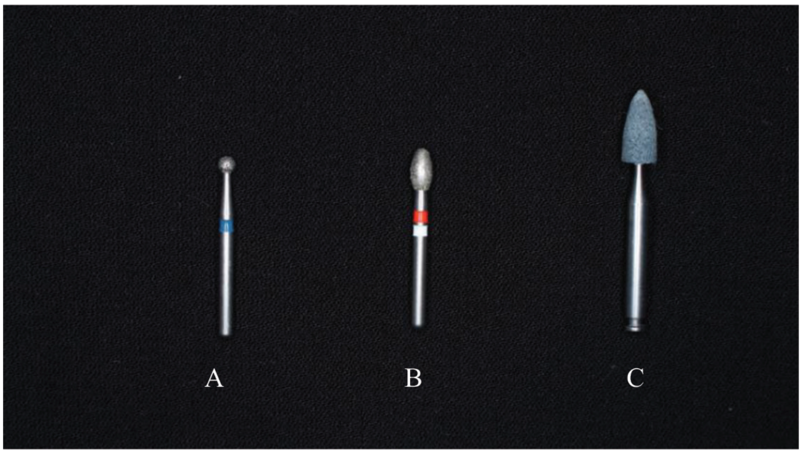

Fig 1. Burs.

(A) Medium-grit diamond bur, (B) Fine-grit diamond bur, (C) Heatless stone bur.

2. Define Grinding Area

A translucent acrylic lid was formed by CAD-CAM in the same size as the specimen with a 7 mm diameter space at the center to pinpoint the grinding area. Using putty silicone as the base to make a specimen stable while in the grinding process. Put the acrylic lid on top of the specimen and mark the grinding area with a pencil then remove the acrylic lid (Fig 2.).

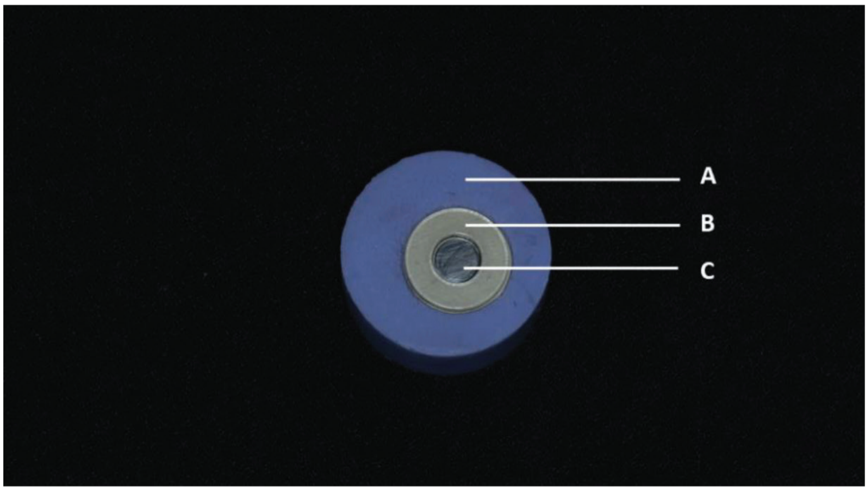

Fig 2. Define Grinding Area.
(A) Putty Silicone, (B) Acrylic Lid, (C) Grinding Area.

3. Grinding

Grinding was achieved by a well-trained operator using a high-speed handpiece (Twin-Power PAR-4HX-O, J.Morita, Japan) at 370,000 rpm under water cooling for MD and FD groups. For HS group, use a low-speed handpiece (J.Morita, Japan) at 42,000 rpm without water cooling. Translucent zirconia discs were ground with side of the bur aligned parallel to the disc surface and the bur moved in same direction for a half-minute under gentle pressure until the pencil mark were eliminated. To secure stability during grinding, the samples were set in a putty silicone and operator's finger rest on it. Replaced the burs after grinding of every fifth samples to preserve a steady amount of grit (17-19). All samples were ultrasonically cleaned for 10 minutes. Randomly pick up one specimen from each group to observe the surface of zirconia under the stereo microscope (SZ 61, Olympus, Japan) at 25x magnification.

4. Surface Roughness Test

The non-contact surface roughness tester (Infinitefocus SL, Alicona, Austria) was used to determine the average surface roughness (Sa) for one specimen of each group at 50x magnification.

5. Phase Analysis Test

Randomly choose another specimen of each group to identify the percentage of crystalline phases of the zirconia, using an X-Ray Diffractometer (XRD; Bruker, D8, Germany). Data was collected in a Bragg-Brentano assembly on 2θ ranges between 10 to 65 degrees with a step size of 0.5 degrees in continuous mode for one minute. The percentage of crystalline phases were calculated using the method established by Garvie and Nicholson (20).

6. Biaxial Flexural Strength (BFS) Test

All samples were subjected to a BFS test by the Universal testing machine (Instron 8872, Instron, UK) at a crosshead speed of 0.5 mm/min, the load to failure was recorded for each disc and BFS was computed using the equations according to ISO 6872 (16).

7. Statistical analysis

The statistical analysis of BFS was performed by SPSS statistic 23 (IBM®). Means and standard deviations of BFS were calculated. After that, the normality and the homogeneity of variance were tested. The data of the experiments were statistically analyzed by one-way analysis of variance. The Scheffé test was used to evaluate the statistical significance among groups (p-value ≤ 0.05).

Results

The stereo microscope (Fig 3.) showed that all grinding groups created an irregular surface. MD group; zirconia ground with medium-grit diamond burs; introduced the most obvious deep and irregular scratches (Fig 3.B) followed by FD group; zirconia ground with fine-grit diamond burs which presented shallow scratches (Fig 3.C). In HS group; zirconia ground with heatless stone burs; had no noticeable surface scratch (Fig 3.D). The values of average surface roughness (Sa) were presented in Table 2; MD group had the highest value of Sa (1,635 μm) followed by FD group (807 μm) and HS group (472 μm). The Sa of all the grinding groups was higher than the control group (394 μm). XRD, as follows in Table 2, showed that all the grinding groups presented the M-phase while there was an absence of M-phase in the control group which C-phase was mainly presented.

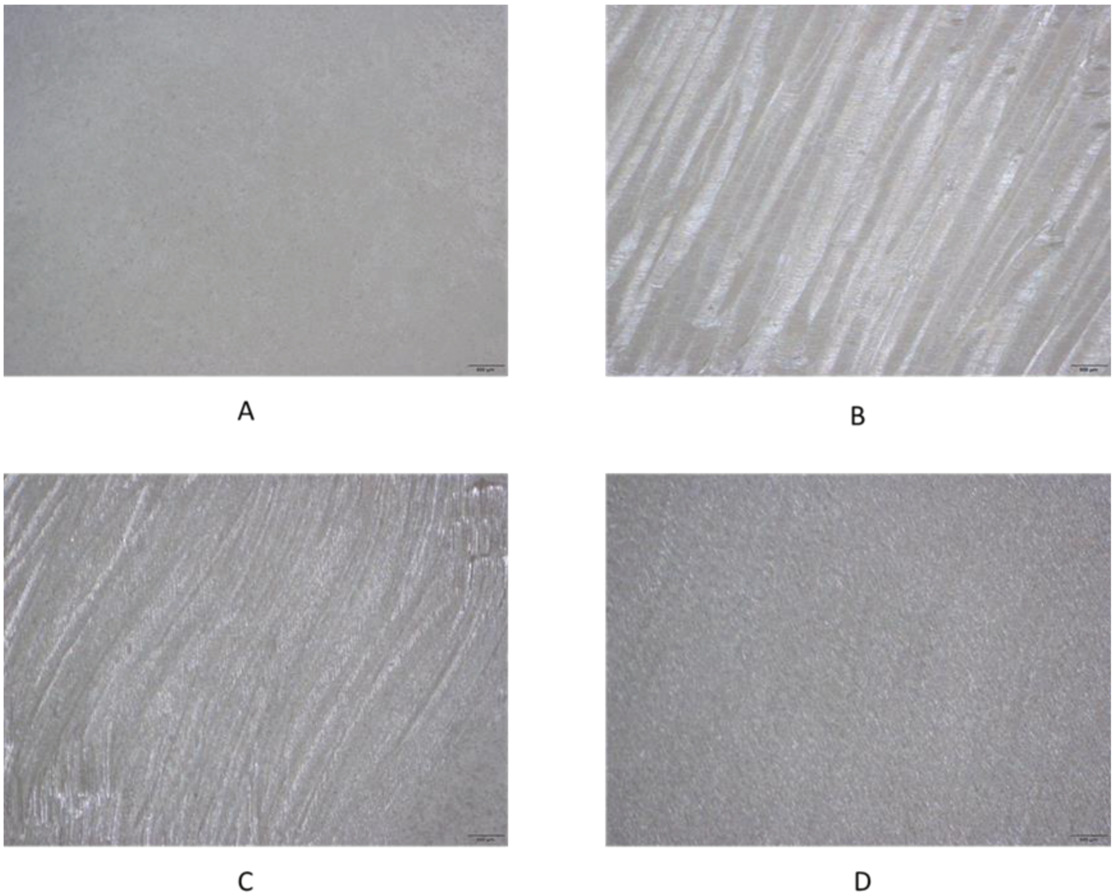

Fig 3. Surface of the samples
(A) CT group, (B) MD group, (C) FD group, (D) HS group.

Means and standard deviations of BFS (MPa) of all groups are presented in Table 3. The results from the Shapiro-Wilk test showed that the BFS values were normally distributed ($p > 0.05$). Using Levene's test to examine the homogeneity of variances. One-way analysis of variance showed a significant difference among groups. Scheffé test showed that zirconia in MD group had the lowest mean BFS (392.05 ± 81.87 MPa) with significantly different from the control group (534.50 ± 70.64 MPa) and HS group (503.86 ± 63.55 MPa). Meanwhile, zirconia in FD group (457.49 ± 56.83 MPa) and HS group had no significantly different BFS compared with the control group as follows in Table 3.

Table 2. The results of the average surface roughness (Sa) and phase analysis tests.

Group	Sa (µm)	Phase Analysis (%)		
		C-phase	T-phase	M-phase
CT	394	58.75	41.25	-
MD	1,635	38.36	59.11	2.53
FD	807	35.40	62.31	2.29
HS	472	33.63	63.77	2.61

Table 3. The results of biaxial flexural strength (BFS) test.

Group	BFS		Group	BFS		Mean Difference	*p*-value
	Mean	SD		Mean	SD		
CT	534.50	70.64	MD	392.05	81.87	142.45	0.001*
		FD	457.49	56.83	77.01	0.119	
		HS	503.86	63.55	30.64	0.804	
MD	392.05	81.87	FD	457.49	56.83	65.44	0.230
		HS	503.86	63.55	111.82	0.010*	
FD	457.49	56.83	HS	503.86	63.55	46.38	0.526

Post hoc analysis: Scheffé, * = The mean difference is significant (p-value < 0.05)

Discussion

Grinding translucent zirconia is difficult because of the high value of its hardness. Nowadays, there is no definite instruction of grinding zirconia and choosing the burs even though sometimes grinding inner surface of zirconia restoration was needed to fit in the abutment. Medium-grit diamond burs, fine-grit diamond burs and heatless stone burs were chosen for grinding translucent zirconia because these burs are widely used in the practical dental clinic.

Surface appearance under the stereo microscope showed that grinding translucent zirconia with common diamond burs, medium-grit diamond burs, created deep and sharp scratches. Meanwhile, grinding with specific burs, fine-grit diamond and heatless stone burs, presented shallow scratches. This research showed that all ground zirconia had higher surface roughness than the control group in accordance with previous studies which study in conventional zirconia (3Y-TZP)(15,17,21). Due to the common use of burs for grinding zirconia in dental clinic, the different shape of burs was chosen in this research. According to Nadin, et al. (22) stated that polishing zirconia with different shapes of burs produced statically similar surface roughness values. Specific burs for grinding zirconia show the lower value of roughness; Sa in group FD = 807 μm and HS group = 472 μm, compared to common diamond burs in MD group; Sa = 1,635 μm corroborates with Chavali, et al. (23), which stated that due to the numerous of diamond particles were imprinted in the specific diamond burs for zirconia, grinding or polishing 3Y-TZP with specific diamond burs for zirconia had more efficiently than common diamond burs for ceramics. Surface roughness of ground translucent zirconia might play a crucial role in the strength of materials, Flury, et al. (24) revealed that surface roughness has a significant negative correlation with flexural strength consistent with this research; the higher surface roughness, the lower flexural strength (Table 2 and 3). However, Wang, et al. (25) focused on deep and sharp flaws that effect flexural strength more than the average surface roughness, deep and sharp defects act as areas of stress concentration and can be the weak point of zirconia materials which may lead to catastrophic failure during loading.

M-phase was detected in all ground specimen groups whereas it was absent in the control group as same as prior studies that used conventional zirconia (26-28). Kosmac, et al. (29) revealed that M-phase had a direct variation toward the decrease of BFS unlike the result of this research, which showed that the highest M-phase was found in HS group, but it also had the highest BFS as well. This may be since only one specimen was randomly assigned to XRD. Due to irradiating X-rays beam may impact the specimen in the core material, which is deeper than the ground layer. Therefore, the result of M-phase in each group may not represent its value in the ground surface. Nevertheless, Gabriel R. Hatanaka et al. found M-phase in all grinding groups and the quantity of % M-phase had no correlation with decreasing of flexural strength same as this research.

In this research, BFS of grinding translucent zirconia (4Y-TZP) with specific burs (FD and HS group) had no significant differences from the control group (p-value > 0.05). Meanwhile, translucent zirconia ground with common diamond burs, medium-grit diamond burs, had significantly decreased BFS compared to the control group (p-value < 0.05). Accordingly, the null hypothesis was rejected. Grinding can create flaws, as shown in this research, depending on the bur's roughness, grinding force, temperature, rotation speed, and volume of M-phase (30). These flaws or cracks can spread into the bulk of translucent zirconia (31), resulting in decreasing its BFS when the crack level is deeper than the compressive layer of estimate 15 to 20 μm (27,32). Nevertheless, the BFS of zirconia depends on the equilibrium between the increased BFS by transformation toughening mechanism and the decrease in these properties owing to the grinding defections (33). In accordance with Kyung-Rok Lee, et al (28) stated that grinding 3Y-TZP with specific burs for zirconia does not significantly decrease BFS compared with the control group while grinding 3Y-TZP with common burs for ceramics significantly decreased BFS. Also, there is M-phase detected in all grinding groups but it was absent in the control group.

Conclusion

Grinding inner surface of translucent zirconia, 4Y-TZP, with specific burs for zirconia (FD and HS group) did not significantly decrease BFS. However, BFS of translucent zirconia ground by widespread commonly used diamond burs (MD group) was decreased significantly compared to the control group.

Acknowledgments

The authors would like to thank Dental Materials R&D Center, Faculty of Dentistry, Chulalongkorn University for providing the research facilities. This research was supported by Faculty of Dentistry, Srinakharinwirot University fund.

Conflict of interest

The authors claim that there is no conflict of interest in this research.

References

1. Ghodsi S, Jafarian Z. A Review on Translucent Zirconia. Eur J Prosthodont Restor Dent. 2018;26(2):62-74.

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

3. Kisi EH, Howard CJ. Crystal structures of zirconia phases and their inter-relation. Key Eng Marter. 1998;153-154:1-36.

4. Kwon SJ, Lawson NC, McLaren EE, Nejat AH, Burgess JO. Comparison of the mechanical properties of translucent zirconia and lithium disilicate. J Prosthet Dent. 2018; 120(1):132-7.

5. 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 J. 2004;20(5):449-56.

6. Fernández-Fairén M, Sala P, Gil F. Failures of yttria-stabilised tetragonal zirconia: 52 retrieved ceramic femoral heads of total hip prostheses. Biomed Mater Eng. 2006;16(6):415-22.

7. Stawarczyk B, Emslander A, Roos M, Sener B, Noack F, Keul C. Zirconia ceramics, their contrast ratio and grain size depending on sintering parameters. Dent Mater J. 2014;33(5): 591-8.

8. McLaren EA, Lawson N, Choi J, Kang J, Trujillo C. New high-translucent cubic-phase–containing zirconia: Clinical and laboratory considerations and the effect of air abrasion on strength. Compend Contin Educ Dent. 2017;38(6): e13-6.

9. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J. 2011;56(Suppl 1):84-96.

10. Touati B. Innovative dental ceramics: expanding the material alternatives. Pract Proced Aesthet Dent. 2005;17(5):357-8.

11. Kosmač T, Čedomir O, Ljubo M. The effects of dental grinding and sandblasting on ageing and fatigue behavior of dental zirconia (Y-TZP) ceramics. J Eur Ceram Soc. 2008;28(5): 1085-90.

12. Guazzato M, Quach L, Albakry M, Swain MV. Influence of surface and heat treatments on the flexural strength of Y-TZP dental ceramic. J Dent. 2005;33(1):9-18.

13. İşeri U, Ozkurt Z, Yalnız A, Kazazoğlu E. Comparison of different grinding procedures on the flexural strength of zirconia. J Prosthet Dent. 2012;107(5):309-15.

14. Lemeshow S, Hosmer DW, Klar J, Lwanga SK. Adequacy of sample size in health studies. Chichester: Wiley; 1990.

15. Khayat W, Chebib N, Finkelman M, Khayat S, Ali A. Effect of grinding and polishing on roughness and strength of zirconia. J Prosthet Dent. 2018;119(4):626-31.

16. International Organization for Standardization, Technical Committee ISO/TC 106, Dentistry. Dentistry: Ceramic Materials (ISO 6872:2015). European Committee for Standardization; 2015.

17. 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.

18. Karakoca S, Yılmaz 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):930-7.

19. Botelho MG, Dangay S, Shih K, Lam WY. The effect of surface treatments on dental zirconia: An analysis of biaxial flexural strength, surface roughness and phase transformation. J Dent. 2018;75:65-73.

20. Garvie RC, Nicholson PS. Phase analysis in zirconia systems. J Am Ceram Soc. 1972;55(6):303-5.

21. Preis V, Schmalzbauer M, Bougeard D, Schneider-Feyrer S, Rosentritt M. Surface properties of monolithic zirconia after dental adjustment treatments and in vitro wear simulation. J Dent. 2015;43(1):133-9.

22. Al-Haj Husain N, Özcan M. A study on topographical properties and surface wettability of monolithic zirconia after use of diverse polishing instruments with different surface coatings. J Prosthodont. 2018;27(5):429-42.

23. Chavali R, Lin CP, Lawson NC. Evaluation of different polishing systems and speeds for dental zirconia. J Prosthodont. 2017;26(5):410-8.

24. Flury S, Peutzfeldt A, Lussi A. Influence of surface roughness on mechanical properties of two computer-aided design/computer-aided manufacturing (CAD/CAM) ceramic materials. Oper Dent. 2012;37(6):617-24.

25. Wang H, Aboushelib MN, Feilzer AJ. Strength influencing variables on CAD/CAM zirconia frameworks. Dent Mater J. 2008;24(5):633-8.

26. Sato H, Yamada K, Pezzotti G, Nawa M, Ban S. Mechanical properties of dental zirconia ceramics changed with sandblasting and heat treatment. Dent Mater J. 2008;27(3):408-14.

27. Hatanaka GR, Polli GS, Fais LMG, Reis JMDSN, Pinelli LAP. Zirconia changes after grinding and regeneration firing. J Prosthet Dent. 2017;118(1):61-8.

28. Lee KR, Choe HC, Heo YR, Lee JJ, Son MK. Effect of different grinding burs on the physical properties of zirconia. J Adv Prosthodont. 2016;8(2):137-43.

29. 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):426-33.

30. Hjerppe J, Närhi TO, Vallittu PK, Lassila LV. Surface roughness and the flexural and bend strength of zirconia after different surface treatments. J Prosthet Dent. 2016;116(4):577-83.

31. Luthardt R, Holzhüter M, Sandkuhl O, Herold V, Schnapp J, Kuhlisch E, et al. Reliability and properties of ground Y-TZP-zirconia ceramics. J Dent Res. 2002;81(7):487-91.

32. İşerı U, Özkurt Z, Kazazoğlu E, Küçükoğlu D. Influence of grinding procedures on the flexural strength of zirconia ceramics. Braz Dent J. 2010;21(6):528-32.

33. Denry I, Holloway J. Microstructural and crystallographic surface changes after grinding zirconia-based dental ceramics. J Biomed Mater Res B Appl Biomater. 2006;76(2):440-8.

Corresponding author:
Dr.Vibul Paisankobrit
Department of Conservative Dentistry and Prosthodontics, Faculty of Dentistry, Srinakarinwirot University, 114 Sukhumvit 23 Rd Wattana, Bangkok, 10110, Thailand.
Tel: (662) 649 5000 # 15112
E-mail: vibul@g.swu.ac.th