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Effect of Polishing Systems on Surface Roughness and Topography of Monolithic Zirconia

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Clinical Relevance

Porcelain polishers are generally not as effective as zirconia polishing systems for smoothing ground monolithic zirconia.

SUMMARY

This study evaluated the effect of different chairside polishing systems on the surface roughness and topography of monolithic zirconia. Thirty-five monolithic zirconia specimens (Lava PLUS, 3M ESPE) were fabricated and divided into five groups of seven and polished with the following: Group 1 (WZ)—Dura white stone followed by Shofu zirconia polishing kit; Group 2 (SZ)—Shofu zirconia polishing kit; Group 3 (CE)—Ceramiste porcelain polishers; Group 4 (CM)—Ceramaster porcelain polishers; and Group 5 (KZ)—Komet ZR zirconia polishers. All specimens were ground with a fine-grit diamond bur prior to polishing procedures to simulate clinical finishing. Baseline and post-polishing profilometric readings were recorded and delta Ra values (difference in mean surface roughness before and after polishing) were computed and analyzed using one-way analysis of variance and Scheffe post hoc test ($p<0.05$). Representative scanning electron microscopy (SEM) images of the ground but unpolished and polished specimens were acquired. Delta Ra values ranged from 0.146 for CE to 0.400 for KZ. Delta Ra values for KZ, WZ, and SZ were significantly greater than for CE. Significant differences in delta Ra values were also observed between KZ and CM. The SEM images obtained were consistent with the profilometric findings. Diamond-impregnated polishing systems were more effective than silica carbide–impregnated ones in reducing the surface roughness of ground monolithic zirconia.

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INTRODUCTION

Zirconia has gained popularity as an alternative to cast metal for the fabrication of crowns and bridges as a result of its better esthetics, comparable strength, and ease of fabrication using CAD/CAM technology.[1] Yttria-containing tetragonal zirconia polycrystalline (Y-TZP) is the most widely used zirconia in dentistry. Zirconia prostheses can be fabricated by either soft or hard milling techniques.[2] In soft milling, partially sintered blocks are machined in enlarged frameworks and sintered to full strength. Sintering is accompanied by approximately 25% shrinkage of the milled framework.[2] In hard milling, robust grinding systems are used to mill frameworks from fully sintered zirconia blocks. As zirconia is relatively opaque, porcelain is often veneered onto zirconia frameworks to improve esthetics. Clinical studies[3-5] have, however, reported a high incidence of porcelain chipping with veneered zirconia restorations. The latter has increased interest in full-contour monolithic zirconia prostheses and spurred the development of new zirconia materials with improved translucency.

As a result of the inherent variability of clinical and laboratory procedures, crown and bridge prostheses often require chairside adjustments prior to issue. Occlusal adjustments of dental porcelain may result in roughened surfaces that can rapidly wear the opposing dentition,[6,7] leading to tooth surface loss, dentin hypersensitivity, esthetic impairment, and poor masticatory function. Adjusted prostheses must therefore be polished to reduce surface irregularities. No clear relationship between material hardness and antagonist tooth wear has been established for dental materials. For metals, increased alloy hardness caused more tooth wear via plastic deformation.[8] Dental porcelains are harder than dental alloys but abrade teeth by brittle fractures.[9] As the hardness of zirconia is twice that of porcelain,[10] concerns over antagonist tooth wear opposing adjusted and unpolished full-contour zirconia restorations are reasonable.

Polishing is the process of producing a smooth, shiny surface through the use of abrasives. A particular polishing procedure may be effective for one material but not for another as a result of the relative hardness of the abrasives, abrasive grit size, shape, and particle count as well as inherent surface roughness of the material being treated.[11,12] Studies[13-15] investigating the effects of various polishing techniques on the surface roughness of dental porcelain have yielded contradictory results. Literature pertaining to the polishing of monolithic zirconia is even more limited. Odatsu and others[16] recently reported that diamond paste with felt wheel followed by glazing produced the lowest surface roughness values for zirconia. Polished zirconia has, however, been found to cause less antagonist wear than glazed zirconia.[17,18] The aim of this study was to evaluate the effect of different chairside polishing techniques on the surface roughness and topography of monolithic zirconia.

METHODS AND MATERIALS

Thirty-five LAVA PLUS High Translucency Zirconia (3M ESPE, St Paul, MN, USA) specimens (7 mm long × 7 mm wide × 2 mm thick) were obtained by sectioning the zirconia blocks in the green stage. The sectioned specimens were subsequently sintered at 1450°C by an authorized LAVA dental laboratory. The sintered specimens were secured onto a metal jig and ground using a fine grit (30 μm) diamond bur (F105R, Shofu Corporation, Kyoto, Japan) under standardized conditions (20 unidirectional strokes, high speed at 200,000 rpm, with continuous water coolant) to simulate clinical finishing (ie, gross reduction of restorations to obtain desired contours). The baseline surface roughness (Ra) values of the ground and unpolished specimens were determined using a profilometer (Mitutoyo Surftest SV-400, Mitutoyo Corporation, Tokyo, Japan) with a probe diameter of 2 μm and a cut-off wavelength of 0.8 mm. Ra measurements were taken centrally along all four directions of each square specimen as well as diagonally at a speed of 1 mm/s. The five Ra values were averaged to give a mean Ra value for each specimen. The ground and unpolished zirconia specimens were then ranked and sequentially divided into five groups of seven and treated as follows:

1) Group 1 (WZ): White stone (Dura White—200,000 rpm, 40 strokes over 60 seconds, with water coolant) followed by two-step diamond-impregnated silicone (Shofu Zirconia Polishing Kit—10,000 rpm, 40 strokes over 60 seconds for step 1 and another 40 strokes over 60 seconds for step 2, both under wet slurry conditions).
2) Group 2 (SZ): Two-step diamond-impregnated silicone (Shofu Zirconia Polishing Kit—10,000 rpm, 60 strokes over 90 seconds under wet slurry conditions, for both step 1 and step 2).
3) Group 3 (CE): Three-step silica carbide–impregnated silicone (Ceramiste porcelain polishers—10,000 rpm, 40 strokes over 60 seconds for each step under wet slurry conditions).
4) Group 4 (CM): Two-step diamond-impregnated silicone (Ceramaster porcelain polishers—10,000 rpm, 60 strokes over 90 seconds for each step under wet slurry conditions).
5) Group 5 (KZ): Two-step diamond-impregnated silicone (Komet ZR Zirconia polishers—8000 rpm,

Table 1: *Brand Names, Types, and Manufacturers of Materials Used*			
Brand Name	**Type**	**Manufacturer**	**Manufacturer's Usage Recommendations**
Dura White Stone	Microgrit aluminum oxide	Shofu Dental Corporation, Kyoto, Japan	For fine contouring of porcelain, composite, compomer, enamel, glass ionomer cement
Zirconia Polishing Prototype	Diamond-impregnated silicone	Shofu Dental Corporation,Kyoto, Japan	Zirconia, porcelain
Ceramiste	Silica carbide impregnated	Shofu Dental Corporation, Kyoto, Japan	Porcelain, enamel
Ceramaster	Diamond-impregnated silicone	Shofu Dental Corporation,Kyoto, Japan	Porcelain
ZR Polishers	Diamond-impregnated silicone	Komet Dental, Gebr Brasseler GnbH & Co KG, Lemgo, Germany	Zirconia, porcelain

60 strokes over 90 seconds for each step under wet slurry conditions).

The polishing systems evaluated and their manufacturers are listed in Table 1. Figure 1 summarizes the procedures carried out and the duration of treatment for the individual steps. The total duration of treatment was standardized at 180 seconds to facilitate comparison among the different polishing systems. All polishing procedures were carried out by a single operator. Mean Ra values of the polished zirconia specimens were obtained with the profilometer, as for the baseline measurements. Delta Ra was computed (mean Ra after grinding and before polishing – mean Ra after polishing) for individual specimens, and the pooled data were subjected to statistical analysis (one-way analysis of variance [ANOVA] and Scheffe post hoc test at a significance level of 0.05) using the IBM SPSS Statistics Software for Windows (Version 22, IBM Corp, Armonk, NY, USA).

Representative specimens of the ground and unpolished as well as the polished zirconia specimens were subjected to scanning electron microscopy (SEM) examination. For SEM characterization, the specimens were sputter-coated for 110 seconds to create a thin layer of gold at about 30 mA under argon gas vacuum (BalTec SCD 005 Sputter Coater, BalTec Maschinenbau AG, Pfäffikon, Switzerland). The SEM machine (Quanta 650FEG, FEI Corporation, Hillsboro, OR, USA) was operated at 10 kV with working distance of 20 mm, and specimens were examined at 1000× magnification.

RESULTS

Mean Ra values after treatment with the various polishing systems ranged from 0.24 to 0.51 μm and are shown in Figure 2. Mean delta Ra representing the decrease in surface roughness ranged from 0.146 to 0.400 for CE and KZ, respectively, as shown in Figure 3. Ranking of mean delta Ra was as follows: KZ > WZ > SZ > CM > CE. One-way ANOVA

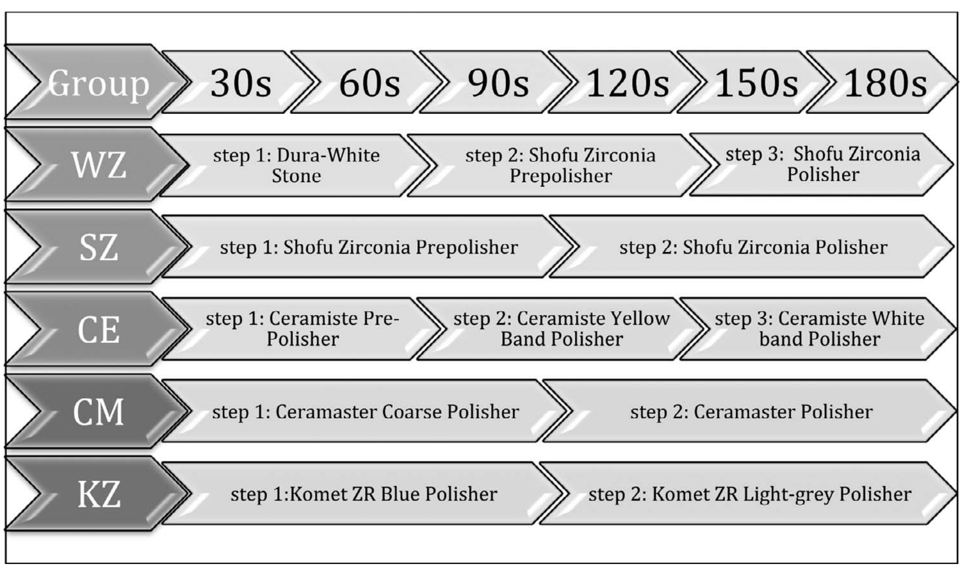

Figure 1. *Schematic outline of the different polishing protocol sequences.*

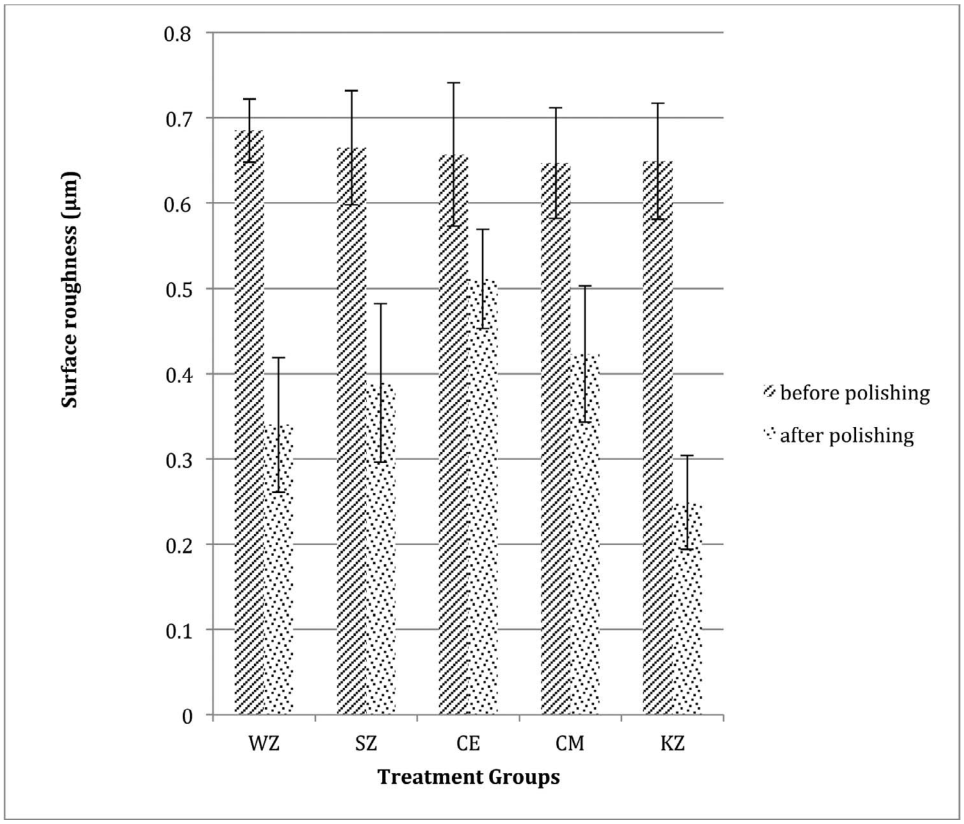

Figure 2. *Comparison of surface roughness before and after polishing with various polishing systems. Error bars indicate standard deviations.*

demonstrated statistically significant differences in delta Ra among the different polishing systems, and the results of the Scheffe post hoc test are reflected in Table 2. Mean delta Ra of KZ, WZ, and SZ were significantly greater than that of CE. A significant difference in mean delta Ra was also observed between KZ and CM. No significant difference was observed among the diamond-impregnated systems KZ, WZ, and SZ.

Representative SEM images of baseline and polished zirconia specimens are reflected in Figure 4. After adjustment with fine diamond burs, successive deep grooves in the direction of the grinding strokes were observed. Following treatment with various polishing systems, the surfaces appeared smoother. Differences in surface topography were, however, apparent among the various polishing systems. Surfaces obtained with zirconia polishing systems (SZ and KZ) were generally smoother than those obtained with porcelain polishers (CM and CE). Sporadic deep flaws resulting from grinding were still visible beneath the polished surfaces of some zirconia specimens.

Table 2: p-*Values for Scheffe Post Hoc Test Between Different Treatment Groups*

Treatment Groups	KZ	WZ	SZ	CM	CE
KZ		0.734	0.061	0.003*	0.000*
WZ	0.734		0.549	0.075	0.001*
SZ	0.061	0.549		0.783	0.047*
CM	0.003*	0.075	0.783		0.425
CE	0.000*	0.001*	0.047*	0.425	

Abbreviations: CE, Ceramiste porcelain polishers; CM, Ceramaster porcelain polishers; KZ, Komet ZR zirconia polishers; SZ, Shofu zirconia polishing kit; WZ, Dura white stone followed by Shofu zirconia polishing kit.
* $p < 0.05$ *indicates statistically significant difference.*

DISCUSSION

Clinical adjustment of full-contour monolithic zirconia prostheses, especially for occlusion, is inevitable. Fine diamond burs were used for the finishing the specimens, as adjustments made using coarse-grit diamond burs have been shown to generate six to eight times the depths of subsurface damage when compared to the use of fine ones.[19] In addition, the use of coarse-grit diamond burs may compromise the strength and reliability of monolithic zirconia.[20] When full-contour zirconia restorations were first introduced, there were concerns about enamel wear on the opposing dentition as zirconia is much harder than porcelain.[21] Wear studies have showed that deterioration of opposing surfaces is linked to the

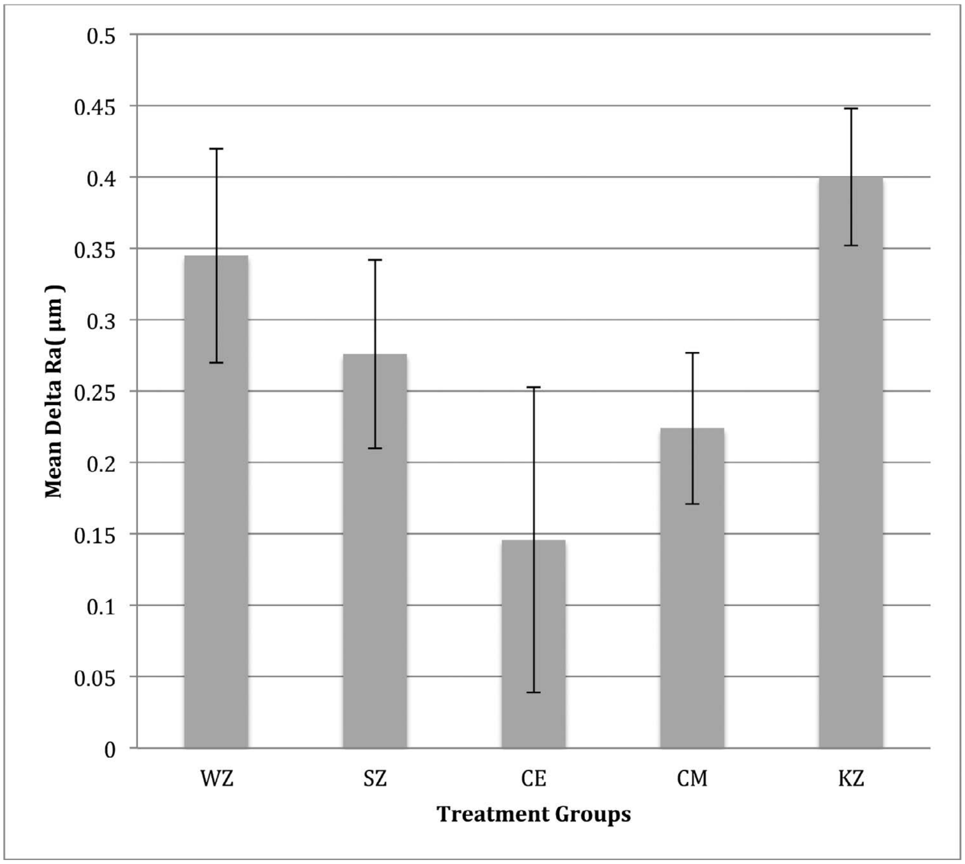

Figure 3. *Mean delta Ra for various polishing systems. Error bars indicate standard deviations.*

frictional coefficient of materials, which in turn is strongly influenced by surface roughness. Two rough opposing surfaces, each with its microscopic irregularities, will have a higher frictional coefficient between them.[8] Rough zirconia was observed to have a higher frictional coefficient against enamel than was polished zirconia. When opposing rough zirconia, fatigue wear was the main mechanism of enamel antagonist loss.[22] Polished zirconia has been reported to be more wear resistant and to cause less wear to enamel antagonists when compared to glazed zirconia and porcelain in recent studies.[17,18,23] Clinical protocols for polishing monolithic zirconia have, however, not been widely researched in spite of the increasing popularity of full-contour zirconia prostheses.

A rough surface can be polished (made smooth) by the process of abrasion, in which a series of abrasive particles of increasing fineness are moved over the surface of the object under treatment.[24] To be effective, the abrasive particles must be harder than the surface being abraded. The relative Mohs hardness (qualitative scale that characterizes the scratch resistance of various minerals through the ability of a harder material to scratch a softer material) values for diamond, silica carbide, aluminum oxide, and zirconia are 10, 9, 9, and 8, respectively.[25] In addition to hardness, pressure applied by the abrasives as well as abrasive particle shape, size, rate, and duration of movement may influence the efficiency of a polishing system.[25] To reduce the number of confounding variables, all polishing procedures were performed by a single operator, and the rate (number of strokes per minute) and duration of treatment were standardized. The total duration of treatment was fixed at 180 seconds, as this was the minimum time needed to achieve visual glossiness during our pilot study. Porcelain polishing systems CE and CM were included in the study as these kits are widely available in many dental clinics and laboratories for polishing porcelain crowns after adjustment. Zirconia polishing kits are newer entities, and many dental clinics and dental laboratories have yet to adopt them, despite venturing into zirconia restorations.

Mean delta Ra values indicate the decrease in surface roughness after polishing procedures. The greater the mean delta Ra, the more effective the polishing system is for smoothening finished zirco-

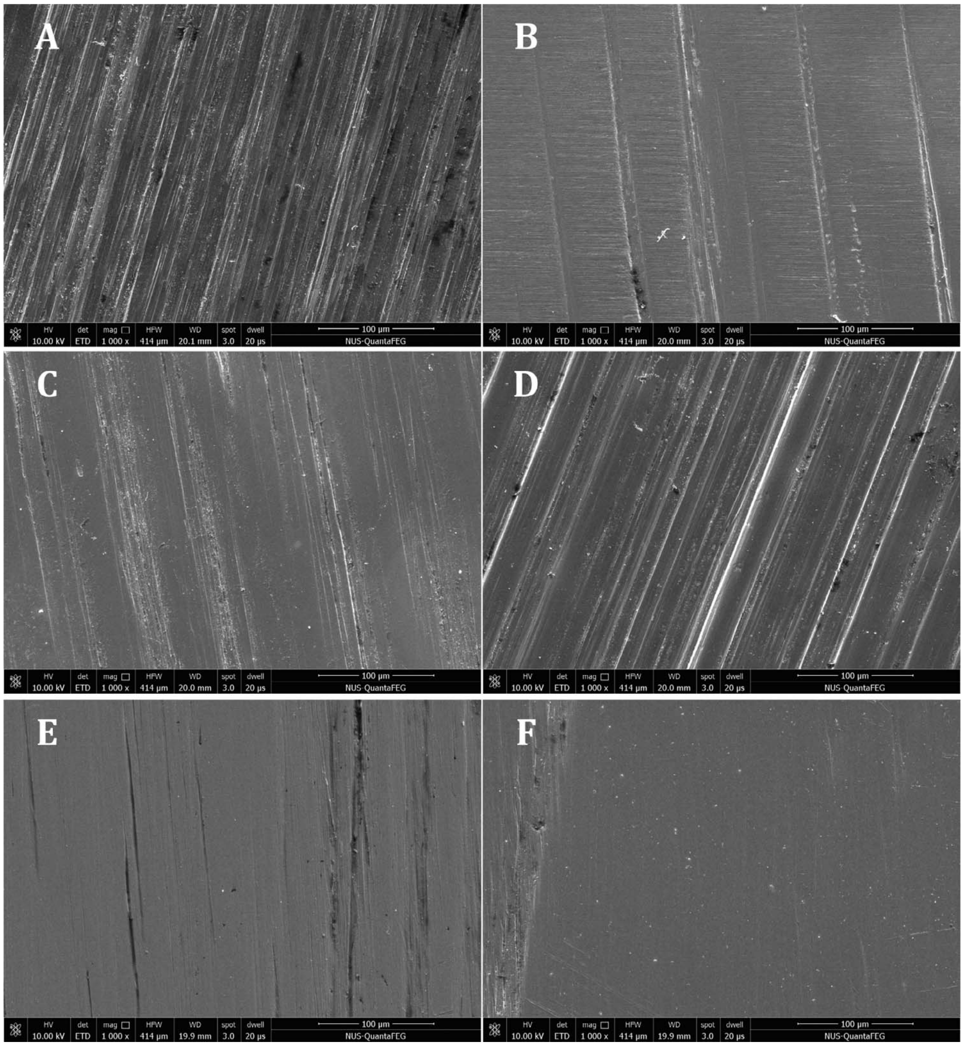

Figure 4. *SEM images of zirconia surfaces under 1000× magnification. A = control group (finished with red band diamond bur, no polishing done), B = group WZ, C = group SZ, D = group CE, E = group CM, and F = group KZ.*

nia. In the present study, significant differences in mean delta Ra were observed between KZ and the porcelain polishing systems CE and CM. No significant difference was observed between the two zirconia systems KZ and SZ. The additional use of aluminum-oxide–based white stones with SZ (ie, group WZ) increased delta Ra by 25%, but mean delta Ra was not statistically significant between groups WZ and SZ. Both KZ and SZ were specifically developed for polishing zirconia and other high-strength ceramics and employ the successive use of two grits of diamond-impregnated silicone (a coarser prepolishing silicone followed by a smoother one for polishing). Although diamond abrasives were also employed in CM, it was not as effective as KZ for polishing zirconia. The varied performance despite the common use of diamond abrasives can be attributed to possible differences in diamond particle type (natural vs synthetic), shape, grit size, density, and binder material. The poorer performance of CE can be explained by the use of softer silica carbide abrasives. Both CM and CE were designed for polishing porcelain and not zirconia.

Clinical protocols for finishing and polishing of monolithic zirconia require further optimization. The effects of finishing and polishing procedures on the physico-mechanical properties, reliability, and clinical longevity of full-contour zirconia prostheses also warrant additional investigation.

CONCLUSIONS

Silica carbide–impregnated polishing kits were not as effective as diamond-impregnated polishers for smoothing ground monolithic zirconia. Not all diamond-impregnated polishing systems work similarly. The performance of zirconia polishers was better than that of diamond-impregnated porcelain polishers. The use of zirconia polishers is thus recommended for polishing zirconia prostheses after clinical and laboratory adjustments.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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REFERENCES

1. Donovan TE (2009) Porcelain-fused-to-metal (PFM) alternatives *Journal of Esthetic Restorative Dentistry* **21(1)** 4-6.
2. Denry I, & Kelly JR (2008) State of the art of zirconia for dental applications *Dental Materials* **24(3)** 299-307.
3. Raigrodski AJ, Chiche GJ, Potiket N, Hochstedler JL, Mohamed SE, Billiot S, & Mercante DE (2006) The efficacy of posterior three-unit zirconium-oxide-based ceramic fixed partial dental prostheses: A prospective clinical pilot study *Journal of Prosthetic Dentistry* **96(4)** 237-244.
4. Larsson C, Vult von Steyern P, Sunzel B, & Nilner K (2006) All-ceramic two- to five-unit implant-supported reconstructions. A randomized, prospective clinical trial *Swedish Dental Journal* **30(2)** 45-53.
5. Sax C, Hämmerle CH, & Sailer I (2011) 10-Year clinical outcomes of fixed dental prostheses with zirconia frameworks *International Journal of Computerized Dentistry* **14(3)** 183-202.
6. Monasky GE, & Taylor DF (1971) Studies on the wear of porcelain, enamel, and gold *Journal of Prosthetic Dentistry* **25(3)** 299-306.
7. Jagger DC, & Harrison A (1994) An in vitro investigation into the wear effects of unglazed, glazed, and polished porcelain on human enamel *Journal of Prosthetic Dentistry* **72(3)** 320-323.
8. Oh WS, DeLong R, & Anusavice KJ (2002) Factors affecting enamel and ceramic wear: A literature review *Journal of Prosthetetic Dentistry* **87(4)** 451-459.
9. DeLong R, Douglas WH, Sakaguchi RL, & Pintado MR (1986) The wear of dental porcelain in an artificial mouth *Dental Materials* **2(5)** 214-219.
10. Raigrodski AJ (2004) Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature *Journal of Prosthetic Dentistry* **92(6)** 557-562.
11. Bollen CM, Lambrechts P, & Quirynen M (1997) Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature *Dental Materials* **13(4)** 258-269.
12. Yin L (2012) Property-process relations in simulated clinical abrasive adjusting of dental ceramics *Journal of the Mechanical Behaviour of Biomedical Materials* **(16)** 55-65.
13. Sulik WD, & Plekavich EJ (1981) Surface finishing of dental porcelain *Journal of Prosthetic Dentistry* **46(2)** 217-221.
14. Scurria MS, & Powers JM (1994) Surface roughness of two polished ceramic materials *Journal of Prosthetic Dentistry* **71(2)** 174-177.
15. Klausner LH, Cartwright CB, & Charbeneau GT (1982) Polished versus autoglazed porcelain surfaces *Journal of Prosthetic Dentistry* **47(2)** 157-162.
16. Odatsu T, Jimbo R, Wennerberg A, Watanabe I, & Sawase T (2013) Effect of polishing and finishing procedures on the surface integrity of restorative ceramics *American Journal of Dentistry* **26(1)** 51-55.
17. Kontos L, Schille C, Schweizer E, & Geis-Gerstorfer J (2013) Influence of surface treatment on the wear of solid zirconia *Acta Odontologica Scandinavica* **71(3-4)** 482-487.
18. Janyavula S, Lawson N, Cakir D, Beck P, Ramp LC, & Burgess JO (2013) The wear of polished and glazed zirconia against enamel *Journal of Prosthetic Dentistry* **109(1)** 22-29.
19. Song XF, & Yin L (2010) The quantitative effect of diamond grit size on the subsurface damage induced in dental adjustment of porcelain surfaces *Proceedings of the Institution of Mechanical Engineers, Part H* **224(10)** 1185-1194.
20. Curtis AR, Wright AJ, & Fleming GJ (2006) The influence of surface modification techniques on the performance of a Y-TZP dental ceramic *Journal of Dentistry* **34(3)** 195-206.
21. Miyazaki T, Nakamura T, Matsumura H, Ban S, & Kobayashi T (2013) Current status of zirconia restoration *Journal of Prosthodontic Research* **57(4)** 236-261.
22. Wang L, Liu Y, Si W, Feng H, Tao Y, & Ma Z (2012) Friction and wear behaviors of dental ceramics against natural tooth enamel *Journal of the European Ceramic Society* **32(11)** 2599-2606.
23. Stawarczyk B, Özcan M, Schmutz F, Trottmann A, Roos M, & Hämmerle CH (2013) Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists *Acta Odontologica Scandinavica* **71(1)** 102-112.
24. Jefferies SR (2007) Abrasive finishing and polishing in restorative dentistry: A state-of-the-art review *Dental Clinics of North America* **51(2)** 379-397, ix.
25. Anusavice KJ, Shen C, & Rawls HR (2012) *Phillip's Science of Dental Materials* **12th edition** Saunders, St Louis, MO, USA.